RESNA '93

Engineering the ADA

From Vision to Reality with Technology

PROCEEDINGS

LAS VEGAS

Experience the Excitement of Technology in Las Vegas

16th Annual Conference
June 12-17, 1993
Mirage Hotel
Las Vegas, Nevada

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of the
RESNA '93
Annual Conference

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Mary Binion
Editor

Donny Loux
John Chambers
Conference Co-Chairs

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Foreword

RESNA, a long time leader in empowerment of people with disabilities through technology, is widely recognized for its role in passage of the Americans with Disabilities Act in 1990. In 1993 RESNA members remain vigilant in the realization that full implementation of ADA precepts has been measured in steps rather than leaps and continues to face major challenges every day. Many of these continuing challenges are systemic, some are attitudinal, but key to overcoming the major barriers to the full inclusion for people with disabilities envisioned by the ADA is access to appropriate, affordable, accessible technology.

How does technology become appropriate? By building partnerships between its envisioners and its consumers. How to make it affordable? By adding more partners from manufacturing, from medicine, from business, government, education, rehabilitation and the non-profit sector. And what about accessible? How about combining these growing partnerships with the Logic Model developed by consultant Michael Morris.

• If Assistive Technology is of high quality, thoughtfully designed and faithfully backed by its manufacturer, and

• If individuals with disabilities, and the professionals who serve them, are knowledgeable about the benefits and availability of Assistive Technology, and

•If financing is available to help make Assistive Technology affordable, and

•If that funding is well financed, consistent and flexible,

•THEN individuals with disabilities will enjoy increased independence and self-sufficiency, full community participation, and greater quality of life.

RESNA '93 celebrates these partnerships and precepts by bringing together the nations most prominent visionaries. Some have disabilities, some do not. All share a critical role in making inclusion and choice by words of the future. One of those great visionaries, Justin Dart, is this year's E&J Distinguished Lecturer. During the past eight years he assumed a leadership role in the development and advocacy for national disability policy, particularly the Americans with Disabilities Act (ADA). During the formulation of the ADA legislation Justin made seven major national trips to solicit input and urge united advocacy for its passage, visiting each of the 50 states at least three times. As Chairperson of the Congressional Task Force on the Rights and Empowerment of Americans with Disabilities, he again traveled throughout the nation holding public forums and meeting with more than 30,000 members of the disability community. In 1990, appearing on the dais with President Bush at the signing of the ADA, he received the national award for leadership essential to the Enactment of the Americans with Disabilities Act.

There is perhaps no single American who more personifies the spirit of the ADA and its tie to the opportunities created by advancing technology. A wheelchair user since 1948, Justin has utilized and advocated a combination of technology and independent living to establish a permanent disability presence in the U.S. and throughout the international community.

On behalf of Justin, the organizers of this year's conference, the RESNA Board of Directors, and the many Nevadans with disabilities who plan to participate in RESNA '93, we welcome you to Las Vegas! You represent the progress of the present and the hope of tomorrow, we are truly honored to act as your hosts and to share in your work and in your commitment.

John Chambers and Donny Loux
RESNA '93 Conference Co-Chairs

Gregg C. Vanderheiden
RESNA President

Preface

Welcome to RESNA '93 **Engineering the ADA--From Vision to Reality with Technology.** This conference is not only about the progress and potential of assistive and rehabilitation technology, but about the ways that we as RESNA members can make the ideas be realized.

This conference is about change. The format of the conference continues to evolve to reflect the ways information can be shared. Following the implementation of a standardized paper review process, the author kit was revised to clarify the paper submission process. This year, the scientific program includes not only platform paper presentations, but a great emphasizes on interactive sessions and computer demonstrations. There is also time during the conference to gather informally without the hectic pace that usually seems to drive this conference.

Change is also found in the Special Interest Groups (SIGs) and others as they collaborate to jointly sponsor special sessions. Meeting participants will benefit from the cross fertilization of ideas, concepts, and believes. We are also joined at this year's conference by the United States Society for Augmentative and Alternative Communication, USSAAC members, the RESNA Technical Assistance Project, and representatives from the Tech Act states. We welcome the addition of the Drooling SIG to the Conference this year, as well as active participation from RESNA's international members from Canada, Mexico, South Africa, Australia, the Far East, and Europe.

RESNA as an organization is changing. "The most important single process involved in effective change is the process of learning while doing. The complexity of change demands that feedback and replanning make up the essential core of change management." Richard Beckhard and Wendy Pritchard in <u>Changing the Essence: The Art of Creating and Leading Fundamental Change in Organizations</u>.

The RESNA Town Meeting is a call to all RESNA members to join with the Executive Committee, Board of Directors, and Committee Chairpersons to discuss the changes in and future of RESNA. This interactive meeting will provide an opportunity for focussed discussion on RESNA's goals, objectives, and future activities. RESNA's future is certainly a time for learning while doing. Plan on attending this session to help make RESNA what you want it to be.

Congratulations to the Local Conference Chairpersons, Donny Loux and John Chambers, the Local Committee, the Meetings Committee, the SIG Chairpersons, and the RESNA staff for assembling a conference of exceptional quality. This is a conference that I would gamble on to be a winner!

Mary Binion
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and Special Interest Groups Program

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Rancho Los Amigos Medical Center
Shepherd Spinal Center
South Carolina Vocational Rehabilitation Department
United Cerebral Palsy of Nevada
University of Nevada, Las Vegas
University of Washington, Seattle
Woodrow Wilson Rehabilitation Center

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AN INTERNSHIP PROGRAM FOR THE TRAINING OF REHABILITATION ENGINEERS

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ABSTRACT

This paper describes an internship program for training engineers to become rehabilitation engineers. The program provides an intensive practical experience in the field of wheeled mobility and seated positioning. Anatomy, biomechanics and medical aspects of disabilities are taught as supplements to the experience working with clients.

INTRODUCTION

Rehabilitation Engineering is a new discipline still struggling to define the role and training for a Rehabilitation Engineer. We have received inquiries from engineers who had or were about to receive a bachelor's degree in traditional engineering disciplines such as mechanical, electrical or industrial engineering, regarding how they could enter the field of Rehabilitation Engineering. They expressed an interest in working more closely with people rather than with "things"; and felt that Rehabilitation Engineering offered a way to combine their technical skills with their interest in people. A common problem mentioned by engineers was that they had been rejected for jobs due to lack of Rehabilitation experience, but had difficulty obtaining experience without a job. As a response to requests for assistance, we decided to develop a program that would train engineers to work in Rehabilitation Engineering.

EXISTING PROGRAMS

Most existing programs for training Rehabilitation Engineers are masters degree programs [1,2,3,4,5]. A common feature of these programs is that they combine class room learning and experience working with clients.

There are probably many programs that offer on-the-job training [6], but these programs are seldom reported in the professional literature. This form of staff development is probably more out of the necessity of training new staff members, who are expected to remain with the program rather than developing individuals who are expected to leave for other programs.

UNIVERSITY OF WISCONSIN INTERNSHIP PROGRAM

In 1986, we decided to develop an internship program that would provide engineers with the experience, skills and background knowledge to obtain jobs in Rehabilitation Engineering. We decided to use an internship model rather than an academic one for several reasons. We felt that an internship model would allow us to shorten the time required to develop Rehabilitation Engineers and reduce the cost.

Our basic approach was to hire an engineer who lacked rehabilitation experience at a reduced salary for one year. We were able to provide extensive experience working with clients since our wheeled mobility and seated positioning programs averages ≈1,600 client visits annually. The intern was able to work with the Physical Therapists, Occupational Therapists, Special Educator and Rehabilitation Engineer who provide direct client services. Anatomy, kinesiology, biomechanics and medical aspects of disabilities were taught as supplements to the work experience by one of the Department's Physical Therapists.

Our Department strives to be self-supporting from charges for client services. In order to offset the cost of training, we decided to hire the intern at a salary of ≈50% that of a permanent staff member. Interns required extensive supervision during their first few months, but much less during their last few months. In our experience, the 50% level is roughly the value of an inexperienced staff member for the first year.

RESULTS

Two individuals have completed the internship program. Both are employed as Rehabilitation Engineers. Both felt that the internship prepared them for work in the field of wheeled mobility and seated positioning. The experience working with clients in a fee for service setting was felt to be advantageous in obtaining a job.

DISCUSSION

One consideration in developing a training program is choosing between an internship and a graduate student model. An internship program is likely to be supported from fee for services revenues rather than grant funds. However, graduate students provide the sponsoring institution with higher income from grant support and tuition fees. An internship model may provide more financial support for the trainee. Participants in an internship program receive a salary and do not have tuition expenses. Graduate students may or may not receive salary and tuition assistance.

Interns are likely to see a greater number of clients than graduate students. In our program, interns participated in ≈400 client visits.

Another consideration is breadth vs. depth of training. Is it better to produce trainees with an in depth exposure to one area of Rehab. Technology or a more limited exposure to many areas of Rehab. Technology?

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ASSISTIVE TECHNOLOGY CAREER DEVELOPMENT PROJECT

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ABSTRACT

Although human services professionals are skilled in their respective service areas, many are not aware of the potential benefits of and, in some cases legal requirements for, assistive technologies. At the same time, the number and variety of AT devices, techniques, and services is expanding rapidly. This paper briefly describes a set of instructional materials that introduces the pre-service student to the field of assistive technology.

BACKGROUND

It is estimated that between 25 and 45 million Americans with disabilities could benefit from the use of some type of assistive technology (5). In most instances appropriate AT can modify or circumvent a disability, thus improving independence, productivity, and participation in the benefits of society. Often, however, people with disabilities and/or service providers are not aware of the availability of AT or the benefits technology can provide (3), (10), (13).

The need for AT training for professionals was emphasized repeatedly in hearings that preceded the passing of the Technology-Related Assistance for Individuals with Disabilities Act of 1988 (P.L. 100-407). Title II of the act specifically addressed awareness and training needs. It was recognized that human services cannot be better than those who provide the services. Fifield (7) points out that, over the past twenty years, several federal initiatives to expand services to provide model programs for individuals with disabilities have been passed by Congress. Examples include supported work, independent living, early intervention, and technology-related assistance. None of these federal initiatives gave sufficient attention to the training of professionals needed to provide the services. Without such training professionals must learn by trial and error, on the job. Sophisticated and effective technology, well financed and provided by a comprehensive interdisciplinary service system, but delivered by untrained providers, to consumers who were not trained to use it properly, are doomed to a very pale success (6). The current passivity and resistance from service systems and human service providers, felt by the assistive technology state programs, reflect the lack of awareness and training.

Most human service professionals are interested in people rather than equipment or how things work; many are virtually technology illiterate--some have "technophobia." The promise and potential of technology as an intervention is often seen by such persons as a threat. Technology requires a new jargon, coordination with new disciplines, and new relationships with consumers in determining needs and making decisions. These requirements often place today's professionals in uncharted areas requiring a paradigm shift in thinking and practice (2). Furthermore, the rapid growth and changing nature of technology has made it difficult for professionals to keep abreast of new products and effective methods for their selection and use (12).

All of the initial nine states funded for assistive technology programs under Title I included training as one of their objectives. To date the training provided has been directed at the awareness level, focused on consumers and the general public. Little training material has been developed and virtually none of this has been validated or field-tested (personal correspondence with the directors of the pioneer funded states).

The need for better professional training in assistive technology is evidenced at both the local and national levels. The call for increased professional training in assistive technology has been made not only by providers who recognize their lack of expertise with assistive technology, but also by consumers who often find that they are better informed about available technology, resources, and the benefits from technology than the providers from which they seek service (9).

OBJECTIVE

Assistive Technology Career Development Project staff are developing instructional materials designed to motivate and prepare university students, who will be practicing in human services fields, to provide assistive technology to consumers of their professional services.

APPROACH

Instruction about assistive technologies is provided in a set of modules. The modules address two separate levels of learner mastery. Level I instructional modules focus on the familiarity and knowledge needed by first-contact, human service professionals. Level I modules are designed to [1] increase the pre-professional's awareness and familiarity with sources of information about assistive technology, its benefits, and its rapid evolution and development and [2] to encourage these pre-professionals to pursue further specialization in assistive technology careers. The Level I modules will also provide general awareness and familiarity about assistive technology for consumers and staff members in advocacy organizations.

Level II modules focus on skill acquisition through clinical application. Level II modules provide specific assistive technology skills training to Vocational Rehabilitation Counselors and Speech Therapists (modules for other essential disciplines will be developed at a later time). Level II Modules contain material in simulated and real problem-solving situations focusing on in-home and community settings.

The topics covered in the modules include an overview of assistive technology, AT-related legislation, shared decision making, information and referral services, assistive technology devices, assessments for AT, funding for AT, job accommodations, AT for persons who have impaired hearing, AT for persons who have impaired vision. The first four form a basic set of Level I modules. The remaining module topics, and others, will be addressed in both Level I and Level II instruction. Knowledge and skills gained in all of the Level I modules will also be synthesized and applied in the more advanced modules. Each module includes [1] videodisc-based information, and [2] a manual, containing print materials, readings, home and community application exercises, and pre- and post-tests.

In addition to, and in support of, the module material, a second set of videodiscs contains "vignettes." Each vignette shows examples of assistive technology devices of a particular type being used to facilitate independence and employment in home and community settings. In one vignette, for example, mid- and low-tech "page turners" are shown in action and their characteristics are described. The ABLEDATA categories are being used as a classification scheme. A pilot version of this disc has been produced which shows about 30 devices from about 6 categories. When the initial set of discs is complete about 120 categories of devices will be represented by, perhaps, five times that many devices. This will represent only the initial coverage of the categories.

A ten-step research and development process is being used to guide the development of the modules. The ten steps include three field tests: preliminary, main, and operational. As a part of the preliminary field test, modules are being developed, reviewed and revised to meet the recommendations of professionals in the field and consumers participating on the Training Advisory Committee. The materials are currently being field tested and revised. They will be reviewed again, before proceeding to the main field testing. Operational field testing of the modules will include their independent utilization in pre-service and (for a number of the modules) in in-service settings. Following final revision, the modules will be ready for dissemination, nation-wide, near the end of 1994.

DISCUSSION

Taken together, the modules will provide an introductory course at the university level in assistive technology, appropriate for a number of disciplines, including Vocational Rehabilitation, Communicative Disorders, Special Education, Physical Therapy, and Nursing. A number of the modules will be usable by in-service as well as pre-service individuals. In this role, the materials will provide the in-service professional initial instruction and ways to continue upgrading his/her AT-relevant knowledge and skills. In addition, to pre-service and in-service instruction, the materials provide a valuable resource for state assistive technology programs and consumer organizations.

The videodisc format (with a modular design for the instruction) was selected because of its sound and color video capability and its flexibility and adaptability for pre-service instruction, in-service instruction, and on-the-job, ready-reference utilization. The videodisc format also allows for individual and group instruction, locally or via telecommunication-based distance learning.

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A TRAINING PROGRAM IN REHABILITATION ENGINEERING: A STUDENT'S PERSPECTIVE

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ABSTRACT

This paper describes a particular training program for rehabilitation engineers from the perspective of a student who has participated in the program. The author proposes key components which should be a part of any rehabilitation engineering training program. Issues are raised about the quality and composition of training programs in general.

INTRODUCTION

It is becoming increasingly important to further develop and refine training programs for rehabilitation engineers as the demand for qualified professionals in the field of rehabilitation engineering increases. If we wish to pass on a guarantee of quality assurance to our customers we must first begin by emphasizing the importance of quality in our training programs. Training programs will also play a critical role in satisfying the proposed requirements of a forthcoming credentialing process for rehabilitation engineers (1).

I would like to provide some insight on what I believe a comprehensive rehabilitation engineering service delivery training program should encompass. My perspective and opinions are based on personal experience as a participant in a rehabilitation engineering training program offered at a major medical center. I am currently in my last term of the program and plan to graduate in May.

THE CENTER'S TRAINING PROGRAM

Objective
The objective of the program is to provide trainees with an adequate foundation of knowledge in the area of rehabilitation engineering and assistive technology service delivery in order to prepare them for careers in service delivery, industry, or research. This is done by integrating hands-on-experience with formal educational training. Students are expected to become independent in all areas of service delivery by constantly interacting with clients to perform evaluations, recommend appropriate devices, set up systems, and provide maintenance and follow up as needed.

Program Content
The training program is composed of two basic components; a clinical internship and course work leading to an M.S. in Bioengineering. In the past, most students have met these requirements concurrently over a two year period.

Clinical Internship
Between one and three students are selected each year to participate in the internship. Past interns have had undergraduate backgrounds in bioengineering, mechanical engineering, and computer science. Students who have previously obtained a Master's degree may also be considered for the internship. Interns are required to work a minimum of 20 hours per week at the university medical center for 4-6 terms (one term constitutes a 4 month period). Two full time rehabilitation engineers on staff at the medical center and the Rehabilitation Engineering Program Director serve as mentors to the students.

The initial term of training allows new interns to be exposed to all aspects of the Rehabilitation Engineering Service Delivery Program by observing staff and senior interns. Beginning in the first term and continuing throughout the internship they participate in weekly department rounds where both staff and interns review ongoing inpatient and outpatient cases. Students gradually take on more responsibilities, including setting up environmental control systems for inpatients, participating in the computer literacy program, and addressing related computer access issues. By their last term senior interns are expected to function relatively independently by assuming primary responsibility for a number of inpatients and outpatients. They write recommendations for assistive technology equipment, perform solo home visits to set up adaptive devices and environmental control systems, and conduct follow up visits as needed.

A five week period of time is also spent off-site at the seating service affiliated with the Rehabilitation Engineering Program. During this time students observe the processes involved with wheelchair prescription including initial evaluation, wheelchair selection, and fabrication and customization of the seating system. Students interact with physical therapists, occupational therapists, and seating specialists to gain a better understanding of techniques used in seating and positioning. They also become familiar with various types of wheelchairs and hardware components used for postural supports and positioning.

Academic Component
In addition to meeting the requirements of the internship, students simultaneously complete course work towards an M.S. degree in Bioengineering. A Rehabilitation Engineering Option exists within the Bioengineering Graduate Program which requires students to choose electives in the following areas: neuroanatomy/neurophysiology, biomechanics, ergonomics, and human factors. Students may select additional electives from a variety of other areas depending on their specific goals and interests. Although 30 semester credit hours are necessary to fulfill the requirements of the Bioengineering Masters Program, students choosing the Rehabilitation Engineering Option often take an additional 4-10 hours to satisfy the requirements of the Rehabilitation Engineering Training Program.

During the first term of the internship, students participate in a course entitled "Rehabilitation Engineering and Assistive Technology". This course consists of lectures, interactive discussion sessions, lab time, and product demonstrations. Over ten different guest speakers, most from the Department of Physical Medicine and Rehabilitation (PM&R), cover topics in the areas of mobility, seating and positioning, augmentative communication, computer access, computer literacy and training, environmental control, and sensory aids. In conjunction with several of the lectures, students are required to conduct thorough literature reviews and investigate existing products/technologies in a particular area. Devices and methods in the areas of mobility, augmentative communication, environmental control, and computer access are further subdivided into categories, and students are each assigned a category. They are given a week to interact with devices available to them in the rehabilitation engineering department and use literature and other resources to gain knowledge about those not available. At the end of the week a 20-30 minute presentation is given by each student along with a demonstration of some of the hardware and/or software in their assigned category. Presentations serve not only as a demonstration of knowledge, but also allow the interns to educate one another. At the culmination of the semester, students use the knowledge they have acquired about the rehabilitation process to present a case study involving a particular patient.

In the summer following the first year of the internship, students typically take the course "Disability and Rehabilitation Methods." This course is offered through the medical school and covers disability, rehabilitation methods, etiology of disability, psychosocial aspects of rehabilitation, and functional outcomes including daily living activities, education and vocation. Reading assignments are taken from the "Handbook of Severe Disability" (2) and elsewhere. The course is taught by individuals from a variety of disciplines within the Department of PM&R. Among the topics discussed are issues such as ventilator dependency, sexuality and disability, independent living, cognitive rehabilitation, prosthetics, and disability awareness.

EVALUATION OF THE CENTER'S PROGRAM

Overall I feel the internship has provided me with outstanding preparation for a career in rehabilitation engineering. Extensive clinical experience is the heart of the program. Trainees are treated as employees of the rehabilitation engineering department, instead of additional distractions or burdens for staff members. They are expected to participate in productive, meaningful projects that make a difference in the lives of the clients they are working for. After seventeen months of on-the-job experience I feel as if I have been exposed to a large number of the problems which I may eventually face in the working world. The program has given me confidence in my ability to solve these problems independently.

The environment of a major medical center with a well known rehabilitation program has offered me the added advantage of being exposed to a variety of neurological impairments, as well as highly skilled doctors and staff who use the latest techniques in dealing with these cases.

The one-on-one guidance from devoted mentors promoted greater interaction and was highly conducive to learning. This individual attention saved me hours of frustration and discouragement.

In retrospect, the program has potential for improvement in some areas both in terms of student experience and program efficiency. It would be advantageous to students and more efficient for staff if training was more formalized in certain situations. For example, basic skills such as technical shop activities, writing chart notes, and other standard procedures could be taught to trainees as a group. Presently, interns usually learn each skill or procedure as the need arises. Increased options for accommodating the variable skill levels of interns would also be helpful.

Although two courses are presently being offered which consist of subject matter specifically related to rehabilitation engineering, there is a need for additional courses. I felt that a number of the courses I took in the Bioengineering Graduate Program had only indirect application to my work in rehabilitation engineering.

The Rehabilitation Engineering and Assisitive Technology course offered in the first semester of the internship was an excellent way to familiarize new interns with assistive devices, but this type of formal product research should be continued throughout the duration of the internship.

In addition, trainees would benefit if they were provided with a more complete picture of the overall rehabilitation process, including different models of assistive technology service delivery programs. By understanding what goes on in other rehabilitation settings trainees will gain a better understanding of their role as rehabilitation engineers. They will also be less naive when approaching the job market and be more likely to apply their skills with confidence in a variety of environments.

IMPLICATIONS FOR PROGRAMS IN GENERAL

Defining standards for training programs is not a straightforward matter. In order to assess the quality of a training program it is important to not only identify the necessary components, but also the relative amount of time which is devoted to each area. An ideal program would take into consideration the unique interests of each of its participants, but in general should contain at least some exposure to certain key areas. The following categorization is used to analyze the structure of rehabilitation engineering training programs in general.

Client Interaction
Client interaction includes contact with clients or patients from a variety of settings in all areas of rehabilitation engineering/ assistive technology service delivery. Specific tasks in this category include conducting client evaluations and training sessions, educating the public through demonstrations/ presentations, recommending and installing equipment, and assessing work, school, or home environments for the application of technologies.

Basic Skills
Trainees should learn a number of basic technical skills at the outset of the training program. These include operation of hand and power tools, knowledge of commonly used materials and hardware components, techniques in the areas of fabrication and mounting of devices, and simple electronic skills such as soldering. In addition, trainees should be familiar with both IBM PC compatibles and Macintosh systems including knowledge of computer communications, peripheral devices, operating systems and system configurations.

Technical Projects
Technical projects allow trainees to apply the skills they have learned by designing, fabricating, modifying, and customizing devices for specific applications. When possible, trainees should undertake projects corresponding to a particular client's case. In this way they will become aware of the factors

involved with matching an assistive technology device to an individual person.

Product Investigation
Throughout the training program trainees should be responsible for investigating available assistive technology devices. They must acquire a thorough understanding of a broad range of devices to enable them to integrate the most appropriate device in a particular situation.

Coursework
Academics is a necessary component of any training program. Suggested areas of study include medical courses in disability and rehabilitation, and medical terminology; courses in other rehabilitation disciplines such as physical therapy, occupational therapy, and speech; and courses covering assistive devices/ technologies, human factors, ergonomics, and industrial design. Typically universities offer few, if any, courses specific to rehabilitation engineers. Consequently, training program coordinators must make a special effort to formulate such courses. Rehabilitation professionals from various disciplines should be called on to speak about a broad range of rehabilitation issues. This is critical in exposing trainees to the entire process of service delivery.

Research
All trainees should participate in research in some way, either by actively taking part in ongoing studies or reviewing literature in research journals. The purpose of these activities is to develop insight on product development and awareness of important issues in rehabilitation. This will enable trainees to critically assess new assistive technologies.

Documentation
This category includes documenting and monitoring patient progress in the form of chart notes, writing evaluations regarding products and devices, billing customers for services and equipment, and writing formal recommendations or prescriptions to obtain funding for clients. Exposure to these areas plays an important role in perceiving the big picture of the rehabilitation process.

Flexibility
A program should not be so structured as to prevent an individual from pursuing their specific area of interest whether it be in research and development, consulting, pediatrics, geriatrics, rural rehabilitation, vocational rehabilitation or any other area. Time should also be set aside to allow trainees to strengthen areas in which they feel they have a weaker background. Participants enter the program at a variety of skill levels and from different backgrounds. By incorporating flexibility into the program the needs of all students can be accommodated.

DISCUSSION

Considering the components outlined above, a training program at least eighteen months long should be required before participants achieve a level at which they are capable of assuming a position as a full-time rehabilitation engineer with only minimal supervision. From personal experience I feel that programs any shorter than this would have difficulty covering the key areas adequately, especially interaction with clients.

The importance of practical hands-on experience cannot be emphasized enough. Students must be allowed to put into practice what they have learned through observation and reading. By interacting with as many clients as possible students will be able to draw from their training experiences, combine knowledge from several clinical cases and apply it to situations they may find themselves challenged with during their careers.

A significant amount of time should also be devoted to product investigation. Becoming familiar with assistive technologies on today's market, old and new, can be overwhelming. Even as I near the end of my training, I feel as if I have hardly scratched the surface of this task. Considering that this is one of our primary obligations as rehabilitation engineers, I feel that training programs should devote more time to this area. With this in mind, training programs should also ensure that participants have access to a wide range of resources including products, literature, and people. Staff members must be willing to spend a significant amount of time as mentors. The staff to trainee ratio should remain very small to allow staff to be available to answer questions and provide guidance.

The relative importance of academics vs. training is a critical issue in evaluating any rehabilitation engineering training program. I do not feel that a Master's Degree needs to be an essential component of a training program, unless it is tailored specifically for rehabilitation engineers. Trainees should not be required to fulfill restrictive requirements set forth in the curriculum of a broader area of engineering. Time would be more wisely spent in other areas of training.

CONCLUSIONS

I feel that the training program I participated in has given me an excellent foundation from which to build my future career, however, only after being employed as a rehabilitation engineer will I truly be able to test my level of preparation. Hopefully at that time I will be in a position to provide further feedback regarding areas which can be improved upon. By providing feedback to rehabilitation training programs we are sending a message about the acceptable level of skill for entry level employees. As we strive to maintain quality in rehabilitation service delivery we must ensure that tomorrow's rehabilitation professionals are given the quality of training necessary to perform successfully in their careers.

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ASSISTIVE TECHNOLOGY TRAINING AT NORTHERN ARIZONA UNIVERSITY

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ABSTRACT

Assistive technology training programs in US are few in number and are now just beginning to appear in four year institutions of higher learning. Additionally, there are few assistive technology interdisciplinary training models in place. Under grant funding from the federal government the Arizona University Affiliated Program is proceeding with the implementation of an interdisciplinary undergraduate and graduate training program in Assistive Technology. Training in assistive technology increases the provider's ability to assess and evaluate the functional capability and independence of persons with disabilities. The program is the first ever in the State of Arizona and emphasizes an interdisciplinary team model approach to include Allied Health, Engineering, and Technology trainees. This paper provides background and then describes the grant, objectives, faculty involvement, course preparation and status to date of the Assistive Technology program.

BACKGROUND

Assistive technology devices and provision of assistive technology services is the latest method of increasing functional capability and independence for persons with disabilities. Increasing functional capability can mean the difference of being employed, educated, or performing activities of daily living. Increasing independence for persons with disabilities is strengthened through the knowledge gained by professionals, paraprofessionals, families, caregivers, and consumers in assistive technology. There is a great need for training in all facets of assistive technology for the delivery of devices and services. However, assistive technology training programs in US are few in number and are now just beginning to appear in four year institutions of higher learning. Additionally, there are few assistive technology interdisciplinary training models in place. The Arizona University Affiliated Program is proceeding with the implementation of an interdisciplinary undergraduate and graduate training program in Assistive Technology. The program is the first ever in the State of Arizona and emphasizes an interdisciplinary team model approach to include Allied Health, Engineering, and Technology trainees.

GRANT

In April of 1992, a grant proposed a new interdisciplinary training program in assistive technology for undergraduate and graduate students in Allied Health, Engineering, and Technology professions. The program was developed to meet local, state, and national needs in training professionals and paraprofessionals to understand the multifaceted role assistive technology can perform in the lives of persons with disabilities. Additionally, training in assistive technology principles and applications will foster interagency cooperation state wide, as well as expand the interdisciplinary efforts of all three Arizona universities.

The program was developed through interagency collaboration between this agency and local/state service providers, state agency directors, consumer groups, faculty at all three State universities, local educational agencies, and individuals from private industry.

OBJECTIVES

The program includes five objectives: (1) to conduct a systematic, state-wide needs assessment for training in assistive technology (AT), (2) to develop a core of faculty expertise in AT, (3) to develop and implement an interdisciplinary preservice training program, (4) to develop and implement an interdisciplinary inservice awareness of AT, and (5) to develop and establish an AT dissemination center for interdisciplinary training material.

The objectives are interrelated to the extent that the activities for each objective build upon one another. Data from the needs assessment will determine, in part the training expertise and knowledge base of AT in Arizona. The information will facilitate interagency collaboration and assist agencies in identifying areas of service need, models for service delivery, and accountable and responsible programs. Faculty training and development activities will develop expertise in a cadre of trainers in AT applications and foster an atmosphere of interdisciplinary cooperation in diverse academic areas. Students from each of the interdisciplinary disciplines will achieve a working knowledge of the interdisciplinary team model necessary in the delivery of AT devices and services. Additionally, the modules and materials in the seven content and nine functional areas of AT under development for faculty, students, providers, and consumers, by staff and program personnel will be available for state-wide dissemination. Dissemination activities will also be developed as a result of the needs assessment and will complement the implementation of training for each population of trainees.

FACULTY INVOLVEMENT

The prospect of participating in the AT interdisciplinary program of training has generated considerable interest in faculty at this institution. At the present time there are faculty from engineering, technology, and allied health fields that have shown interest in cross training in AT. However, since very few faculty are trained in both technology and disabilities, faculty will receive training through hands-on experience in their areas of interest and involvement in AT. Cross-training of the faculty will include two survey courses in the format of workshops. The first course will target the Engineering and Technology faculty unfamiliar with the field of developmental disabilities, and will provide information concerning disabilities and the need for assistive devices and services. The second course offering will target those Allied Health faculty with interests in applying engineering and technology principles and practices in the area of disabilities.

COURSE PREPARATION

In addition to the standard coursework offered through each department, two survey courses, several workshops, independent study, and project design courses will be developed and offered to students. Additionally, practica experiences will be available during the duration of the grant. Similar to the training developed for faculty, an initial emphasis will be placed on providing general knowledge in technology and disabilities to the students of Allied Health, Engineering, and Technology fields.

The survey courses will cover introductory information, and will cffered in a seminar format during the fall and spring semesters for both undergraduate/graduate students. The first survey course will focus on information about disabilities and issues regarding individual's need in AT while the second course will focus on the more technological aspects of AT and its application in different social, educational, and vocational environments.

Seminar content will include awareness and general applications of AT in the student's specific discipline; the role and contribution of other disciplines in the evaluation, design, and adaptation of assistive devices and services; and the AT team model of approach in the delivery of services for intervention, planning, and integration of persons with disabilities in education, vocation, and socially.

Students will choose additional workshops and one independent study in AT. The purpose of the workshop and independent study is to provide in-depth information in topics directly related to the student's interests and program of study. Every effort will be made to accommodate student's needs to receive training in an area of AT that best suits their academic program.

A practicum of forty-five hours in AT will be required of each student. Students will work with service professionals to evaluate the need for assistive devices/services, determine the selection of devices/services best suited for an individual, implementation of devices/services, consultation with parents, teachers, employers, and consumers on the need for assistive devices/services by these individuals.

Finally, one project will be completed by each team of students. The team of students will be based on the AT interdisciplinary team model approach where several disciplines are represented from engineering, technology, and allied health.

STATUS TO DATE

Approval of the grant occurred in August and is now in the first year of implementation with objectives 1: Needs Assessment, 2: Faculty Training, and 3: Course preparation underway.

The professional provider survey has been prepared and is ready for mailing to six groups of professionals identified as possible service providers in AT. The identified groups include educational and rehabilitation personnel as well as physical therapists, occupational therapists, and speech pathologists in the State of Arizona. The survey includes questions to describe the current assistive technology service delivery system and to determine the training requirements of the provider population. Survey data, available for conference presentation, will be analyzed and used to prepare and expand student course content areas.

SUMMARY

The Assistive Technology Training Initiative Grant is the first funding program that emphasizes an interdisciplinary training model approach in the delivery of devices and services for persons with disabilities in the State of Arizona. A needs assessment survey is prepared, faculty training is commencing, and student course material preparation is underway.

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COLLABORATION OF OCCUPATIONAL THERAPISTS AND VOCATIONAL REHABILITATION COUNSELORS IN THE APPLICATION OF ASSISTIVE TECHNOLOGY

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ABSTRACT

Service delivery in rehabilitation is aimed at restoration of function in the person with a disability to enhance independence. An important part of independence for many people is work. To achieve this, it is necessary to perform tasks in various environments. For persons with disabilities, assistive technology is sometimes the only way to accomplish this. This requires a level of expertise in so many areas that a team approach is essential. It has therefore become imperative that all professions, each with its unique skills and expertise, collaborate to enhance the effectiveness and efficiency of the rehabilitation process. This is in accordance with professional practice and also to meet the requirements of the Assistive Technology Act of 1988, the Americans with Disabilities Act of 1990, and the Rehabilitation Act of 1973 as amended (especially the 1992 amendments).

BACKGROUND

Ideally the people on the rehabilitation team work well together. However, in reality members often focus on their own fields without effective communication as to the consumer's needs and the context in which the solution will be applied. The VRC without expertise in technology may be expecting a magical fix by putting in a piece of equipment which is not in fact assistive; the OT may marvel at the physical improvement in functioning without recognition of its significance, or lack of significance, in the workplace. Each team member contributes his/her piece, but without effective communication and coordination the pieces do not fit together into a meaningful whole. Consequently the consumer of these professional services does not receive optimal benefit from application of technology to assist in meeting the demands of work in the real world.

PROBLEM STATEMENT

How to improve the provision of assistive technology through the facilitation of effective communication among members of the interdisciplinary team.

ILLUSTRATION

In order to improve her productivity, a secretary who typed using a mouthstick was provided with a computer without team consultation. It sat unused for 6 months because she was unable to hold down two keys simultaneously. When she conferred with an OTR (other than the one who taught her to type), an inexpensive (under $15) latch device was provided which enabled her to perform the function and use her equipment.

A woman with multiple sclerosis had multiple limitations including a visual impairment and ability to read longer than 15 minutes at her best, a hearing impairment, and a hand tremor. An effective team was not in place. She was referred for an evaluation for computer technology prior to obtaining a visual examination and no hearing evaluation was performed. A system was recommended at an estimated cost totalling more than $16,000 and included a large print system, talking software, a Kurzweil Personal Reader and a keyguard. Because there was no adequate interdisciplinary assessment and plan, there was no basis to expect that this system would be usable by her to accomplish her work tasks. Questions included, the following: could she understand synthesized speech? If the hearing loss is progressive, will she be able to understand it next year? Will the large print system enable her to read for a longer period of time? If the visual impairment is progressive (as subsequent evaluation revealed it was), will the usefulness of the large print system also be lost in the near future? Does she have keyboarding skills, and the stamina to key in her own work? At risk here is not simply $16,000 in resource, but the potential loss of this woman's vocational future through the application of perhaps inappropriate technology rather than the discovery of technology that would work for her.

APPROACH

In 1992 an agreement was reached between the Occupational Therapy Department of a major university with an established interdisciplinary program on assistive technology and a State VR agency to include a group of VRCs in intensive training courses on assistive technology together with a group of occupational therapists.

RESULTS

1) Team members learned a systems approach to assistive technology: a system whose components include the consumer, the tasks to be performed, the environment(s) of use, and the devices; 2) trained VRCs became more aware of the focus of OT and the OT approach to assistive technology; 3) trained OTs became more aware of the role of the VRC in the Vocational Rehabilitation process and the VRCs focus and approach to the utilization of assistive technology; 4) the university faculty now serves as consultants on technological issues; 5) additional resources were identified and utilized; 6) the trained VRCs are now being utilized by other VRCs for technology consultations and provision of in-service training; 7) the trained VRCs became members of an existing statewide technology task force that is addressing and supporting the uses of assistive technology (it is now planned that this training be made available to all members of the task force); 8) the trained OTRs learned of the need to consider realistic vocational information when evaluating the consumer and planning for discharge; 9) the trained OTRs learned to work more effectively with the VRC toward the goal of employment: 10) consumers are receiving more effective and economical services.

ILLUSTRATION

As the result of a diving accident Paul had only functional use of his wrists, elbows, and shoulders and used a manual wheelchair for mobility. While his VRC was arranging for him to enroll in a computer training program, the counselor conferred with Paul's OTR to determine if he needed a voice activated software program to access the computer. After the OT evaluated Paul, she the counselor and Paul meet to discuss what would be best for Paul. The consensus of the group was that the OTR would supply Paul with a set of special hand splints and back-up set which would enable him to access any computer without additional special software or hardware modifications. The OTR also recommended that he could conserve his energy by using a power wheelchair. Results: Paul completed his computer training program, has been successfully employed for three years using any computer in the office where he works, has bought his own powered wheelchair and has an excellent work record. The special hand splints cost less than $20.00 in comparison to a $2,000 voice activated software program which would have required a special computer.

A woman with M.S. worked as a professor and an audiologist at a college. She was unable to stand or walk, and used a 3-wheeled scooter which did not fit into the audiology lab. She had difficulty accessing and using her computer from the scooter seat and because of upper extremity weakness. Her home was not accessible, she was not independent in most ADLs, her husband drove her between home and work, and at home she used a manual wheelchair which left her exhausted. her only professional assistance was from her neurologist who treated the M.S. When she applied for vocational rehabilitation services, the VRC first met with her to review her needs and priorities, then obtained medical information from the neurologist, and then assembled a team which included the Consumer, an OTR, an architectural consultant, a rehabilitation engineer, and a vehicle modification specialist. The outcome included home and van modifications, adaptive equipment for ADLs, a new 4-wheeled scooter which would fit in the audiology lab and which was equipped with a power seat lift, assessment and redesign of her workspace and change in computer hardware and software. The success of this plan depended on the common understanding by each consultant of the desired goals and the role of each of the other consultants. The VRC made sure that each team member understood the consumer's goals and the role of each consultant, coordinated the provision of services, kept each team member and the Consumer advised of each step in the process and secured the employer's cooperation for the workplace modifications.

DISCUSSION

The benefits of coordinated efforts and communication among members of the rehabilitation team in the provision of assistive technology are apparent in both quality and the cost effectiveness of the services and devices provided, as has been illustrated.

These joint training courses took several approaches to assisting each group of professional learn more about the other. Frequently a team was created to solve a particular problem through technology. One of the most beneficial exercises was the presentation of a case study with each specialty group identifying for the other how they would undertake the task. This not only pointed out the similarities between both, but also clearly identified the priorities each specialty had and what they would do to work toward a solution to the stated problem. A free exchange of ideas took place which enhanced both the technical knowledge and the understanding and appreciation of the other discipline. While it is recognized that established interdisciplinary training programs on assistive technology are not universally available, joint in-service training, workshops, conferences and seminars could also be useful in facilitating improved teamwork. This approach should be readily transferable to other settings.

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Continuous Quality Improvement in Assistive Technology - Establishing, Maintaining, Measuring

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ABSTRACT

Continuous Quality Improvement (CQI) strategies have begun to take root in American industry as an outgrowth of the quality assurance movement prevalent in the 1970's and 1980's. The impetus for this movement has come about in part due to complacency and subsequent loss of market share of American products and services.

CQI has as its basis a customer oriented approach in which all employees of an organization are empowered to make decisions towards improving its products and services. Human service organizations in general and assistive technology programs specifically are beginning to make a shift from the previously held assumptions that quality can be determined by meeting performance thresholds. CQI initiatives shift the focus to customer orientation, definition of service strategy, and performance measurement.

BACKGROUND

As assistive technology continues to evolve from research and development laboratories into the clinical service delivery environment, successful programs will study and learn from the Continuous Quality Improvement (CQI) revolution currently underway in American business and industry. During the past two decades, the provision of medical rehabilitation services has undergone a paradigm shift; moving the field from a social service framework to one of accountability associated with running a business. Assistive technology programs must begin to make this transition if providers expect third party payers to recognize assistive technology as a viable and cost effective tool in the rehabilitation process. The Continuous Quality Improvement approach has a short but rich history in American business and industry; assistive technology programs can benefit in an increasingly unstable reimbursement environment by learning from other service industries which have implemented CQI to compete and even survive in difficult times.

Continuous Quality Improvement is not another program to be added to already overburdened managers and staff but rather a way of thinking and operating in order to establish long term success. (1) The following principles have been identified as critical to the success of any service industry; assistive technology programs notwithstanding.

I. CUSTOMER FOCUS

The Technical Assistance Research Program (TARP) found that at any given moment one in four customers of the average American organization is upset enough to stop doing business with it if they can find a reasonable alternative. Yet of those upset customers, only five percent will actually register a complaint. Assistive technology programs seeking to create a consumer oriented approach should ask and respond to these questions: (2)

How well do we understand our customers and their expectations of us?

Have we defined our strategy - our mission or goal - in terms of customer expectations?

Have we established a clear vision of what superior service is and communicated that vision to employees at every level?

Are our delivery systems accessible and approachable? Have we minimized the "hoops" our customers must jump through to access our services?

Are our people selected, trained, empowered, and rewarded for providing exceptional service to the customer?

Assistive technology is first and foremost a service business, and the priority of any service industry must be to listen and respond to what customers are saying. This may be even more critical in assistive technology programs given the unique and individualized needs of the consumer.

II. DEFINE SERVICE STRATEGY

Most assistive technology programs have neither the resources nor the expertise to be all things to all people. It is imperative that a clearly defined service strategy is identified and communicated. The service strategy should differentiate the program from others, have value in the eyes of the customer, and be deliverable to its customers. The service strategy is the organization's way of keeping its focus on its mission and meeting the expectation of its customers. An assistive technology program with a clearly defined strategy of service knows what it can and cannot do for its customers and when to refer to other programs or agencies. The service strategy defines the organization's direction both internally (staff) and externally (customers) in order to achieve its clinical, financial, and programmatic goals.

The service strategy within the framework of quality improvement always has a customer oriented, not a product oriented, focus. If the assistive technology service providers within the staff understand and are trained in this approach, the service strategy will become one with long term focus, prevention of errors, lowered costs, and higher quality.

III. MEASURING PERFORMANCE

Outstanding organizations have as one of their characteristics a dedication to measuring their performance in order to quantify their results and to improve their delivery of service. (3) Measurement tools specifically for assistive technology programs are unavailable to date; but, nevertheless, several types of measurement systems will give the feedback necessary to determine if goals are being achieved. One of the most common and effective measurement tools is the customer survey. Properly devised, it can yield diverse information about an organization. Guiding principles of a useful survey include:

1. Design it around the organization's service strategy. If the mission of the organization is to provide high quality assistive technology services, ensure that the questions pertain directly to the quality of services provided.

2. Be specific. Questions such as, "Do you think we did a good job?" do not provide information which can be used in any meaningful way. The customers' personal experience and feelings about their experience can be better elicited in questions such as, "How would you rate the technical skill of the staff?"

3. Collect data useful to individuals as well as work groups.

4. Make sure all staff people see the results by posting them.

5. Collect both quantitative data (numerical ratings) and qualitative data (customer comments).

6. Ensure the results are used to improve performance, quality, and customer satisfaction.

Continuous Quality Improvement

Another type of measurement which is important is benchmarking. Benchmarking compares the performance of one organization against another. It enables a business or program to recognize superior performance, to identify what needs to be changed, and to determine targets or goals to achieve that change.

The use of quality indicators are needed to give the organization the data it needs to make adjustments to its service delivery and to eliminate guess work when evaluating the organization's performance and the customer's needs. Implementation of quality indicators requires a four step process:

1. Identify those elements of the program which require data examination to determine whether or not the program is meeting customer expectations and is operating as efficiently as possible.

2. Establish a baseline for each indicator.

3. Identify goals or targets.

4. Decide measurement techniques and methods.

5. Share data, receive input, make adjustments.

Continuous Quality Improvement should not be confused with its predecessor often referred to as quality assurance. CQI is a top down, everyone involved, customer focus approach to doing business. (4) Some of the old quality assurance programs were authoritative, punitive, and had more emphasis on cost, schedule, and volume. Continuous Quality Improvement, on the other hand, means fixing problems as they occur, preventing problems before they happen, and improving capabilities to meet new and existing customer requirements. Managers must create an environment which fosters innovation and trust among the staff. For assistive technology programs to survive in the marketplace, these basic yet profound principals must begin to take root.

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IMPROVING SERVICE DELIVERY OF ASSISTIVE TECHNOLOGY: FROM SPECIALISTS TO CONSULTANTS

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ABSTRACT
The use of complex technology in rehabilitation requires novel approaches to ensure efficient, high quality service. Generally, a specialist team accepts a limited number of referrals and follows a client through the assessment-provision sequence. Intensive, specialized service means that only a small number of clients can be seen. One option to improve productivity is to involve a wider base of field clinicians. However, as technology has advanced, the knowledge of average field clinicians has not kept pace. A shift from an `expert' team to a consultative approach enables field clinicians to integrate professional development with work practice.

ORGANIZATIONAL ENVIRONMENT

The British Columbia Rehabilitation Society (BCRS) is the major rehabilitation organization serving adults with neurological and physical disabilities in the province of British Columbia (1991 pop. 3,280,000). BCRS operates from 2 sites located in Vancouver, BC. and employs over 200 trained clinicians. In the past, when a client potentially needed to use technology, the client was referred to the technology specialist team of the Assistive Technology Program (ATP).

THE ASSISTIVE TECHNOLOGY PROGRAM

The members of the ATP consist of: 4 rehabilitation technology consultants, 1 S-LP AAC specialist, 1 PT equipment specialist, and 1 OT assistive technology/seating specialist. The program has about $500,000.00 of assistive technology for assessment and loan purposes and each site has an assistive technology centre. At present the following technologies and applications are supported by ATP:

- electronic augmentative communication
- environmental control
- vocational and educational technology
- access to technology (switches, mounting, etc.)
- leisure activities (games, writing, music, art, etc.)
- integration of technology (making components work together).

THE EXPERT TEAM MODEL

Under the expert model the ATP team received referrals from clinical teams requesting a technology assessment for a client. Assessment and decisions concerning assistive technology and the client were made primarily by the expert team. The process included: the identification of client goals, assessment and prescription, contact with funding sources, purchase and provision, training and follow-up. The team was cohesive and provided high quality service; however, the intensive nature of the service meant that only a small percentage of total requests were served (low productivity). The sharing of specialized knowledge through peer professional education was viewed as a separate activity.

On the other side, field teams found it expedient to deal with clients requiring technology by sending them to the ATP team. Field teams were so separated from the application of technology as a rehabilitation tool that the technology became an end in itself (rather than a means to an end). A notable symptom of this viewpoint was the large number of clients referred to ATP because: `Mr. X needs a computer,' or `Ms. Y wants to learn about computers'.

WHY A CONSULTATIVE MODEL?

The motivation to move to a consultative model arose from: frustration with low productivity; pressure from society to respond to rehabilitation needs on an integrated community level; and the need for peer professional education.

In a consultative model, the field team and the client set general goals for desired outcomes. If technology is potentially involved in realizing these goals, the field clinician and the client arrange an appointment with the appropriate ATP specialist. Assessments are conducted jointly to produce options. The field clinician takes responsibility for training and follow-up. The ATP specialist is available to assist, inform or demonstrate at any point in the process.

The theory is that initially, productivity is lower; however, the superior on-the-job training of field clinicians should eventually result in higher productivity with more clients seen and served. Peer professional education is integrated with daily work and high quality service remains the top priority.

TECHNOLOGY AS A TOOL
When clinicians graduate from training programs they have a general knowledge base that allows them to practice in a variety of environments. As they work in a given environment, clinicians need to learn to use the tools specific to a particular process and population. At BCRS this process is goal-driven rehabilitation of adults. Clinicians must learn to use the technological tools as they apply to the rehabilitation process.

Learning about technological tools implies developing a basic understanding of methodology and principles of these tools. A basic understanding allows clinicians along with their clients to make informed decisions about technological options and improved knowledge to determine the effectiveness of a particular tool in the realization of goals. Detailed information is available from specialists on a `need to know' basis. Technology is not the answer, it only supports the answer.

MAKING THE TRANSITION
Field clinicians often report that they are overwhelmed, `I don't have enough time, I don't know what to do.' For field clinicians motivators towards acceptance of a consultative model are: job enhancement and improved personal marketability; superior client service in the future; improved ability to assess success/failure of interventions; and ownership of the process and outcomes. Specialists fear the loss of security and uniqueness, the change from a leader to a consultant. Motivators for specialists are: maintenance of specialist status but a shift in focus from pure service delivery to gathering/disseminating knowledge; superior client service through greater productivity; and maintenance of clinical skills through consultative clinical activities.

Consulting specialists must change their focus from a principal to a supporting role. Some of these supporting activities include:

- organizing equipment and information so that it is accessible to clinicians;
- purchasing a representative stock of assistive technology;
- providing clinicians with technological tool options;
- in conjunction with clinicians: instructing, demonstrating and trouble-shooting the application of technology;
- critical evaluation of equipment and software;
- researching new developments and information;
- preparing instructional materials about technology for community use;

Infrastructure at BCRS has been modified to promote the transition to a consultative model. An efficient method of information organization and retrieval is crucial, ie. a well constructed, computerized data base. Another aspect is a consistent policy that specialists will only see clients if the appropriate field clinician is present.

EXPANDING TO THE LARGER COMMUNITY
The shift from an expert to consultative model has been in progress at BCRS for only 3 months and it is too early to measure the results. The trend in service delivery in North America is towards community integration. The shift in

service delivery at BCRS is taking place within a single large organization which enjoys close geographic proximity, established teams and generous resources (both human and material). The transition to a consultative model in the context of the province of BC with communities spread across its 947,000 square kilometres of mountainous terrain will pose unique challenges.

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A MODEL OF REHABILITATION ENGINEERING SERVICES IN AN ACUTE REHABILITATION SETTING

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ABSTRACT

A model of rehabilitation engineering and assistive technology service delivery in the acute rehabilitation setting is presented as it is implemented at our Center. Potential methods of evaluating program effectiveness are explored in order to facilitate quality assurance. The goal of this paper is to support the development of standards for assessing and improving assistive technology service delivery.

BACKGROUND

Rehabilitation engineering and assistive technology services are provided in many centers during or after the acute rehabilitation phase in inpatient, outpatient, vocational rehabilitation, and other settings. It is in these settings that the individual with a newly acquired disability learns about, utilizes, and often relies upon assistive technology. Major questions exist about the effectiveness of such services and how they help individuals with newly acquired disabilities meet their rehabilitation goals.

The rehabilitation engineering program described in this paper is part of a university-based regional medical center. The Center often provides services to patients with complex and unique diagnoses with an emphasis on providing a continuum of care from the intensive care unit to home. The Center's rehabilitation engineering program provides services to these patients throughout their hospital stay and continues to follow them after they have been discharged. It is not atypical for a patient to receive assistive technology service delivery in the intensive care unit, be followed throughout their hospital stay, and have services provided once they have been discharged home. This service has been provided for patients since the early 1970's. Since that time the program has continued to progress in caseload, services provided, student and professional training, and the array of assistive technologies utilized.

OBJECTIVES

One objective of this paper is to describe the Center's rehabilitation engineering services in the acute rehabilitation setting as a specific model of assistive technology service delivery. The goals of this model include providing services which optimize function and facilitate independence in communication, mobility, activities of daily living, and educational and vocational pursuits. At our Center, rehabilitation engineers take a primary role in providing assistive technologies and play an integral role in the comprehensive rehabilitation management from very early in the hospitalization through the post discharge period. The goals of this program also include a commitment to the growth of the profession of rehabilitation engineering through student education, training of rehabilitation engineering interns, and research.

Given the Center's hospital based rehabilitation engineering service delivery program, this paper emphasizes inpatient services which are coupled with the medical model. While other outpatient services (including educational and vocational services) are also provided, they are not be covered to the same degree in this paper, since they are not as unique to a hospital service delivery model and have been more frequently described.

As members of a developing profession, rehabilitation engineers have an obligation to evaluate the effectiveness of the service that they provide (1-6). Not only is this critical for the provision of quality client care, but also for justification of services to third party payers. By obtaining feedback through formal assessment we can determine the efficacy of the program in terms of outcomes, cost effectiveness, and other factors. Towards this end a second objective of this paper is to explore the concept of how we can develop methods of program evaluation and assessments of program effectiveness. The issues and potential methods of assessment are vast, and it is a difficult task to identify those strategies that would be most useful in program evaluation without actual implementation and comparison. However, by examining these issues it is our intention to facilitate development of standards for optimization in service delivery.

THE REHABILITATION ENGINEERING AND ASSISTIVE TECHNOLOGY SERVICE DELIVERY PROGRAM

Acute Care

The Center's rehabilitation engineers provide services in a multitude of situations within this tertiary care facility. Initiation of services occurs when a consult is made by a physician to the rehabilitation engineering program. Within the context of this paper, reference to "acute" patients includes patients with acute onset of illness who have been admitted to the medical intensive care units or medical units, patients with new traumatic injuries who have been admitted to the neurological, surgical, burn, or pediatric intensive care unit and patients with previous congenital problems or traumatic injuries who have been admitted for medical management of an acute problem.

Patients admitted to the intensive care units with either an acute illness or traumatic injury share some specific needs. The goals of the rehabilitation engineer in this environment are to introduce these patients to the assistive technology service available, to promote success in independence, and to begin the education process regarding assistive technology. The most generally provided service for these patients is the establishment of an effective nurse-call system to allow the patient to summon help. Usually the provided system involves switches interfaced with the standard hospital systems that also allow control over the television, telephone, and hospital bed. If the patient is non-verbal the rehabilitation engineer works with speech-language pathology to establish a communication strategy. Augmentative and alternative communication methods employed in this environment range from spell boards to commercially available AAC devices to switch-activated talking tracheostomy systems. If the patient is post-operation and in need of an accessible device for delivery of pain medication, the rehabilitation engineer works with the physician and nurse to provide a patient controlled anesthesia system that can be independently operated.

Inpatient Rehabilitation

When the patient has suffered a traumatic injury requiring inpatient rehabilitation, these early interventions by a rehabilitation engineer may be the patient's initial exposure to rehabilitation. As the patient progresses towards rehabilitation, many other professionals will become involved. However, the early intervention by the rehabilitation engineer may provide an introduction to the complete rehabilitation process as well as specific rehabilitation engineering services. If so, the engineer may educate the patient about the rehabilitation process and the integral role of rehabilitation engineering and assistive technology in optimizing the patient's function. It is important that the engineer be appropriately educated and trained in regards to psychosocial issues and be sensitive to the patient's emotional adjustment to disability when presenting this new information. Early establishment of good rapport between the patient and the rehabilitation engineer can provide some consistency in the transition from intensive care unit or medical unit to the rehabilitation unit. The rehabilitation engineer may be one of the few professionals who remains consistent throughout the admission working with the patient as he/she progresses from the intensive care unit, medical, or surgical unit into a rehabilitation program and beyond.

Once the patient is transferred to the rehabilitation unit, the rehabilitation engineer is involved in providing the following services in coordination with professionals from other disciplines: AAC and computer access/literacy with occupational therapy and speech-language pathology; environmental control, powered mobility, and wheelchair seating with occupational therapy and physical therapy; and recreational therapy with the rehabilitation team. This multidisciplinary approach facilitates the provision of comprehensive services and recommendations by incorporating the expertise of all those involved in developing the therapeutic plan. As part of this approach, the rehabilitation engineer participates in the patient's initial staffings, chart rounds, goal setting meetings, family meetings and discharge meetings, as well as administrative meetings and rehabilitation retreats. All of these involve representatives from other services which may include medicine, physical therapy, occupational therapy, speech-language pathology, nursing, dietary, rehabilitation psychology, continuing care, social work and others appropriate to the specific meeting. A number of the meetings also include the family, insurance representatives and other professionals who will be involved with the patient once he leaves the facility. A multidisciplinary approach is critical to the success of all of these communication forums.

When the inpatient goals have been met and the patient is discharged, the rehabilitation engineer continues to provide service and support as needed to appropriate individuals in their homes. This continuum of assistive technology service delivery provides valuable continuity of care from admission to home as well as school or work.

"Outpatient" Rehabilitation

Although it is not a primary focus of this paper, rehabilitation engineering and assistive technology services are also provided to "outpatients". These clients can range from those who are recently discharged from an inpatient rehabilitation program, to those who are receiving other medical rehabilitation services, to those who have no link with medical rehabilitation at all.

If the client has assistive technology needs from an existing condition, but will not be admitted to the rehabilitation unit, the progression of service provision is somewhat different. These clients may have long standing disabilities and may need assistance in determining the best technological solutions to their rehabilitation needs. In this situation the engineer may provide evaluation, recommendations, training, and/or technical services. Of utmost importance is the continued availability of the rehabilitation engineer to provide a link between the client and advances in technology and services available.

DISCUSSION

A major question relating to rehabilitation engineering and assistive technology services is how they relate to functional outcomes (mobility, communication, environmental control, etc.) as well as more general considerations such as success in independent living efforts or educational and vocational endeavors. The value of such services can readily be demonstrated on an anecdotal basis. For example, an environmental control system and sip-and-puff controlled electric wheelchair has allowed independent living for a 28-year-old client with a C-3 spinal cord injury with quadriplegia. Without this technology, it would be necessary for him to have much more consistent nursing assistance or possibly be placed in a long term care facility. As a second example, a client with a C-1 spinal cord injury and quadriplegia who is ventilator dependent is able to keep up with his 7th grade class with the use of a computer, modem and fax even when he is unable to physically attend school due to medical issues. From a bedroom in his home he receives and submits classroom work in tandem with his classmates.

Anecdotal reports, however, are not sufficient. Outcome studies are sorely needed to establish the extent of assistive technology service effectiveness. These studies need to include measurement of outcomes related to functional abilities as well as quality of life issues.

Both of the clients described above received assistive technology services in the acute care hospital setting early after their injuries. It would be valuable to determine whether the point at which the rehabilitation engineering intervention occurred influenced the subsequent success of the clients with the assistive technologies provided. Recognition of the most appropriate time for intervention could potentially influence the success of assistive technology services.

In considering the effectiveness of early provision of assistive technology services, the potential advantages and disadvantages must be weighed. A number of potential advantages can be hypothesized in support of early intervention. It would seem that early provision of assistive technology could enhance the independence of a patient thus helping to improve self-esteem and motivation earlier. It must also be considered, however, that offering these services too early following a traumatic event might force the recognition of limitations before a person is ready to do so. With properly trained service providers it is our belief that the advantages of improved functional level generally outweigh the possible disadvantages.

Investigation of this issue could be pursued in a number of ways, such as a survey of patients and their families regarding their perceptions of the appropriateness and timing of assistive technology interventions. Additionally, standardized assessments of motivation, self-esteem, and other psychological factors, as well as functional outcomes, could be compared for different groups of patients who began receiving services at varying times in their rehabilitation programs.

Another factor related to early intervention is whether it is cost effective. Potentially, it can reduce the time and effort required for communication between the client, their family, and other rehabilitation professionals. Additionally, having the client immediately available can save travel time and expense which would otherwise be incurred if services were provided after a client has been discharged. Of course, any cost efficiency of early intervention must be weighed against the possible compromise of numerous other goals related to an inpatient rehabilitation program.

The question of who should provide assistive technology services is another consideration. At our Center rehabilitation engineers take a primary role in assistive technology service delivery. However, a number of options exist for provision of these services within the hospital setting. Major questions about such options remain. For example, can technicians in collaboration with allied health professionals with assistive technology expertise achieve similar goals or outcomes for patients within this environment?

More important than the title of the individual providing service is the qualification of the individual or team involved in the provision of assistive technology. This refers not only to academic qualification but also to clinical experience and expertise in regards to product availability, design, and modification. Provision of service by an unqualified individual or team can result in disappointing functional outcomes, expense incurred due to incompetence, unsafe practices, and poor representation of the profession and its benefits. Qualification requirements for rehabilitation engineers and other rehabilitation professionals involved in assistive technology service delivery are currently being identified (7,8) and should be used to the greatest extent possible. Not only should these criteria be applied for new positions, but centers which currently employ individuals in this capacity should also examine the qualification standards and seek to supplement the background of their service delivery team to meet these guidelines as they develop. Reports from centers which implement these types of guidelines regarding how their assistive technology service delivery models have been effected by following these criteria should be encouraged.

SUMMARY

There is strong motivation to evaluate the effectiveness of rehabilitation engineering and assistive technology services in a wide variety of settings. Such evaluation, as applied to assistive technology services in the acute rehabilitation setting, is critical to determining the effectiveness of early intervention with assistive technologies. It is our goal to stimulate the development of evaluation methods which will improve the quality of services provided and enhance reimbursement based on the demonstration of service cost-effectiveness.

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Automation of an Assistive Technology Center

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Abstract
Automation of an assistive technology center via a PC based database is described. The automated system addresses the needs of both assistive technology service and device delivery. The system was found to be effective in an evaluation by both clinical and administrative personnel.

Background
Automation of health care facilities has proven to be beneficial for both clinical and administrative managers, and studies have shown that automation is both cost effective and time-saving[1]. Assistive technology centers which provide both services and technology cannot make use of automation software designed for rehabilitation technology suppliers because it does not include service provision. Likewise software for clinical service programs does not include devices. This paper describes a hybrid automation system developed to meet these multiple needs.

Statement of Problem
The purpose of this project was to develop an automated system for the client service delivery program at an assistive technology center. This center provides client services, and assistive devices in the fields of augmentative communication, computer access, seating, and mobility. The clinical staff includes speech pathology, rehabilitation engineering and occupational therapy. The center did not have a management information system of any kind, and all scheduling, generating purchase orders for client devices, tracking, billing and computing annual statistics was done on paper forms, involving a considerable amount of time and effort.

Rationale
Each of the steps in the manual system was reviewed for possible automation. The rationale for selection was (1) the amount of paper work involved, (2) relative importance of data to be stored, and (3) use of the information in multiple modules. The goal was to reduce time and effort to record and maintain client information quickly and effectively.

Design
The following steps were included in the manual system between the time of referral through follow-up for a client: (1)INTAKE : required information is obtained and recorded on a form which includes client demographics, referral information, clinical diagnosis, funding sources and reason for referral; (2)FUNDING: Based on the gathered information a cost estimate and funding authorization is initiated, the funding source is contacted and a written authorization for payment is received; (3) PRE-ASSESSMENT REVIEW: The client's needs are determined, a case manager is assigned, and the assessment session is scheduled; (4) EVALUATION: the client is evaluated by the assessment team, a report is generated and sent to the client and the person or agency paying for the assessment; (5)BILLING: the funding agency is billed based on the time spent by each professional in the assessment; (6)IMPLEMENTATION: arrangements for funding are made, and a written authorization obtained; (7)ORDERING EQUIPMENT: an equipment request form is filled out with information on the device including any discount, and shipping charges, the request is then sent to purchasing where a Purchase Order is generated; (8)RECEIVING EQUIPMENT: equipment is delivered, and a check-in form is completed, and an operational check is performed; (9) DELIVERY: equipment is assembled and adaptations are made if necessary, device is delivered to the client, billing for the equipment; (10)TRAINING:needs training in the use of a device may be recommended, billing takes place at the completion of training; (11) FOLLOW-UP: follow-up is provided for the first year after delivery; (12)

ANNUAL REPORT: client statistics are computed at the end of each year for a required annual report.

The structure of the database includes several modules. The INTAKE is used as the primary or main form which has all the basic important information about a client and is made use of in several other forms. The assessment information module utilizes the product database to capture recommended devices and services in the client report. This information can be transferred directly into a word processor file. Equipment ordering, in-coming inspection and set-up are recorded in the EQUIPMENT UTILIZATION module. The TRACKING module keeps track of the client's status from referral through follow-up. This includes training hours authorized and completed; equipment ordered, received and delivered; referrals pending assessment; and recommendations pending authorization. The PRODUCTS database contains current information on all devices recommended by the center. The user enters the name of the product, and all relevant information is immediately displayed. This can be used to generate recommendations in assessment report, prepare a purchase order or to develop a client invoice.

Development

Software is the most important component of a information system. Before selecting the software, many factors were considered and the needs of the organization were identified and narrowed down as follows: (1) flexibility for future modification, (2) LAN compatibility (3) capability to easily display and print out forms and reports, and (4) compatibility with commonly used programs such as spreadsheets and word processors. DataEase met all the above requirements, and it was preferred since it programming design applications is easy. It is very user friendly, and it is menu driven which assists the user at every step. Displaying and printing out forms is a simple process. Complex operations on data files can be performed with simple commands.

The hardware requirements for this system are: IBM PC, XT, AT, PS/2, DOS 3.1 or higher and 640 K RAM (recommended). The system specifications are: Extended memory support, dynamic program swapping, up to 2000 files per database, two billion records per file, 4000 characters per record, 255 fields per record, 255 characters per field, 16 screens per form, and 2000 reports. A modular approach was used in which each portion of the data base was developed and linked to other basic modules.

Evaluation

The semantic differential technique(SD), a seven step scale with bipolar adjectives (e.g., easy, hard) at each end, was employed to measure user reactions toward the system. This measurement has been used in a wide range of research areas such as linguistics, psychology, communication, and personality [2]. Its validity, reliability, and comparability have been well-established. Good [4] used the SD to measure user attitudes toward a computer text editor. Evaluators of our system were the future users (clinical and the administrative staff).

The evaluation included an introduction to the system, familiarization with terminology, and a demonstration system use followed by entry of data by the evaluators. Finally, the SD form was completed. An instruction manual consisting of guidelines to operate the system was given to each of the subjects. A list of ideas and suggestions for improving the system was compiled by the evaluators.

The SD evaluation had three areas: functional system performance, interaction with the system, and overall impression.

The results of the functional evaluation showed that the areas of <u>useful</u> and <u>accurate</u> received maximum scores 7 out of 7), with <u>efficient</u> and <u>useful</u> at the next lower level (6 out of 7). <u>Reliability</u> received a score of 5. In the interaction category, <u>friendly, encouraging, easy, nice</u> were all rated at 6, and <u>simple</u> was rated 5. The overall impression of the system rated <u>meaningful, useful, worthwhile and</u>

positive at 7 and complete at 6. Written comments were generally very favorable as well.

Discussion

The development of an automated system incorporating both assistive technology service and device delivery implemented. The majority of the steps in the service delivery process have been automated. The system is user friendly and simple to use, and it eliminates the problems encountered by the manual system. The system also assists in easy tracking of the client's status.

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FCC PART 15 CERTIFICATION: A NECESSARY STEP IN DEVELOPMENT OF ASSISTIVE DEVICES

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Abstract

This paper discusses Certification associated with Part 15 of the Federal Communications Commission (FCC) Rules, which must be considered when designing assistive devices incorporating digital techniques. This topic appears to not have been addressed by very many manufacturers in the Rehabilitation field; very few devices in this field are FCC Certified.

The FCC Part 15 Rules apply to almost all digital devices, "defining standards and operational requirements for all devices capable of emitting RF energy within the range 450 kHz to 1 GHz."[1] The relevant sections of Part 15 referenced for this paper have been Subparts A and B; Subpart A provides a general overview of the rules for radio frequency devices, while Subpart B deals specifically with unintentional radiators (to be defined later).

Background

The FCC Part 15 Certification has been established for equipment designed to be operated without an individual license, and is intended to regulate Electromagnetic Interference (EMI) generated by electronic equipment and systems to be used in the United States. Except for certain subclasses of digital devices that are exempt, compliance with the technical requirements associated with conducted and radiated emission limits, as defined in the appropriate sections of the FCC Part 15 Rules, is mandatory to market or sell digital devices in the United States.

The Certification is issued by the FCC, based on representations and test data submitted by the applicant, or laboratory on behalf of the applicant.

Statement of the Problem

Digital devices can generate a multiplicity of periodic binary electronic waveforms which can unintentionally generate RF energy. This RF energy can be conducted along power lines, or radiated directly into space, or a combination of both, causing unwanted interference to radio communications.

Definitions

The FCC defines a digital device as an "unintentional radiator (device or system) that generates and uses timing pulses at a rate in excess of 9000 pulses (cycles) per second and uses digital techniques... Note: Computer terminals and peripherals that are intended to be connected to a computer are digital devices."[2]

Further, the FCC defines an unintentional radiator as a "device that intentionally generates radio frequency energy for use within the device, or that sends radio frequency signals by conduction to associated equipment via connecting wiring, but which is not intended to emit RF energy by radiation or induction."[3]

1. Motorola Semiconductor App. Note AN1050, p.2
2. FCC Part 15, Subpart A, 15.3, (k)
3. FCC Part 15, Subpart A, 15.3, (z)

The FCC has defined two Certification Classifications for digital devices, Class A and Class B.

A Class A digital device is a "digital device that is marketed for use in a commercial, industrial or business environment, exclusive of a device which is marketed for use by the general public or is intended to be used in the home."[4]

A Class B digital device is a "digital device that is marketed for use in a residential environment notwithstanding use in commercial, business and industrial environments. Examples of such devices include, but are not limited to, personal computers, calculators, and similar electronic devices that are marketed for use by the general public."[5]

Approach

Many of the assistive devices developed for use by people with physical disabilities, such as adapted keyboards and alternate computer input devices, incorporate digital techniques and require Certification as Class B digital devices. Particularly, as previously indicated, Class B Certification is applicable for equipment that is to be marketed for use in residential environments, even if it can be used in a commercial, industrial, or business environment. Class B Certification is also definitely applicable if the equipment is to be available through catalogs.

Specialized medical devices are one exemption from the specific technical standards and other requirements described in the FCC Part 15 Rules. But, the medical exemption is only applicable for circumstances where equipment is always being used by, or under the direct guidance of, a qualified practitioner; products intended for personal use by individuals in residences must comply with the provisions identified for Class B digital devices.

The following excerpt identifies the criteria to be considered when determining applicability of the specialized medical device exemption:

The exemption is applicable for "Specialized medical devices (generally used at the direction of or under the supervision of a licensed health care practitioner) whether used in a patient's home or a health care facility. Non-specialized medical devices, i.e., devices marketed through retail channels for use by the general public, are not exempted. [Further,] this exemption does not apply to digital devices used for record keeping or any purpose not directly connected with medical treatment."[6]

Another exemption pertains to home-built devices. "Equipment authorization is not required for devices that are not marketed, are not constructed from a kit, and are built in quantities of five or less for personal use."[7]

FCC Part 15 Class B Certification

The process required for FCC Part 15 Class B

4. FCC Part 15, Subpart A, 15.3, (h)
5. FCC Part 15, Subpart A, 15.3, (i)
6. FCC Part 15, Subpart B, 15.103, (e)
7. FCC Part 15, Subpart A, 15.23, (a)

Certification is well established and reasonably straightforward. Certification requires AC power line conducted measurements, which are normally performed in an RF anechoic chamber, and open air radiated emissions measurements, which are normally performed at an open field test site.

AC power line conducted measurements are applicable for equipment designed to be connected to the public utility power line. For Class B Certification, the "radio frequency voltage that is conducted back onto the AC power line on any frequency or frequencies within the band 450 kHz to 30 MHz shall not exceed 250 microvolts."[8]

For radiated emission measurements, "the field strength of radiated emissions from unintentional radiators at a distance of 3 meters shall not exceed the following values:

Frequency of emission (MHz)	Field strength (microvolts/meter)
30 - 88	100
88 - 216	150
216 - 960	200
Above 960	500

The measurement frequency range for radiated emissions is from 30 MHz to 1 GHz.

If the equipment for which Certification is being sought is to be normally connected to, or installed with, peripheral or accessory devices, then the entire system must be tested; the entire system must meet the Certification requirements. Test requirements for Certification of an individual computing device (i.e. computer peripheral) requires that the device be tested while operating in a manner and configuration representative of typical usage for that equipment. For example, a personal computer, keyboard, monitor, external serial device such as a modem, and external parallel device such as a printer, collectively constitute a minimum test configuration for a personal computer peripheral; this is a typical configuration required for Certification of 3rd party manufactured computer input devices such as alternate input devices.

The one-time testing and report preparation fee for FCC, Class B Certification is normally less than $4000.00 U.S., provided good engineering practices are employed during the design phase, to meet the specified technical standards to the greatest extent practicable. A separate Certification processing fee of $735.00 U.S. is also required by the FCC when the final test report is submitted.

It is the manufacturer's responsibility to select an FCC Part 15 accredited laboratory for measuring and evaluating equipment compliance. A recent listing is available, via modem, from the FCC's Public Access Link at 301-725-1072.

Implications

Compliance is a precondition for both placing equipment on the market and putting equipment into service. "Marketing of equipment in the United States requiring a grant of equipment authorization to be issued by the Commission, prior to issuance of required authorization, is prohibited under Section 2.803 of the FCC Rules and Regulations."[9]

Willful violation of equipment authorization, importation, or marketing rules, can result in a fine of $10,000 U.S. per violation, per day. Also, individuals or organizations may be subject to further penalties of up to $100,000 U.S. and/or a criminal fine totaling twice the gross gain obtained from sales of the non-compliant equipment. Also, FCC field personnel, working in conjunction with U.S. Marshals, may confiscate illegal equipment.

Non-compliant equipment can be reported by filing a complaint with the local FCC office or laboratory. The complaint can be submitted in a letter explaining the situation

Discussion

Thus, FCC Part 15 Certification is a necessary step in development of assistive devices. Most people with disabilities depend on electronic equipment, and many electronic devices incorporate digital techniques, therefore this Certification is particularly imortant for the proper functioning and safety of the equipment being used by people with disabilities.

Two devices designed by Madenta Communications Inc. have been FCC Part 15 Class B Certified. The process was reasonably painless, particularly for the second certification, once the process was learned.

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SOURCES OF FUNDING FOR RESEARCH AND DEVELOPMENT IN ASSISTIVE TECHNOLOGY

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ABSTRACT

This article identifies sources of funding for research and development (R&D) of assistive technologies.

INTRODUCTION

In general, the goal of R&D is to develop new and improved assistive technologies for use by persons with disabilities. People usually think the sole objective of R&D is to develop a new product or technique that can be made available to others in the field. There are other benefits of conducting R&D. Even if no new products or techniques emerge, conducting R&D helps keep an organization's staff on the cutting edge of technology, makes it easier to introduce new technology as it comes along, and allows the staff to keep learning and expanding its knowledge.

R&D can be funded from within an organization or from sources outside of the organization. Many large companies allocate 5-10% of their profits to support R&D to keep improving technology and market competitiveness. However, most small companies cannot afford to do this, and must seek outside sources of funding to conduct any substantial amount of R&D activity.

In the field of assistive technology, hospitals, universities and some enterprising practitioners have acquired R&D support from outside sources, conducted the developmental work, and then sought out small companies (who otherwise could not afford to conduct R&D) to make the products or techniques commercially available. In this way, everyone wins, especially the clients who benefit from the improved technology.

OVERVIEW OF SOURCES OF OUTSIDE FUNDING

Private funding: Of all the money raised every year in the United States for non-profit institutions, 90% of the total is donated by individuals, mostly through mail appeals. The remaining 10% is donated by foundations and institutions in roughly equal proportion. One such source of private funding is the Spinal Cord Research Foundation at the Paralyzed Veterans of America (PVA). This foundation had a FY 92 budget of $1.2 million. It funds development of assistive technologies for persons with spinal cord injuries and other spinal cord diseases. Contact Larry Johnston, Director of Research and Education at PVA for further information at Spinal Cord Research Foundation, Paralyzed Veterans of America, 801 18th Street NW, Washington, DC 20006, (202)416-7652.

Public funding: The government provides large amounts of funding every year. Most is provided by the Federal Government. Very little R&D money is provided by state or local governments

SOURCES OF FEDERAL FUNDING

There are **four Federal agencies** that are possible sources of funding for R&D in assistive technology.

a. US Department of Education: Within this Federal department are three programs of special interest.

National Institute on Disability and Rehabilitation Research (NIDRR). The annual budget for NIDRR in Fiscal Year 1993 (FY 93) is $101.3 million. Approximately $34 million is allocated toward technology assistance grants. The remaining $67 million is NIDRR money available for R&D purposes. Information can be obtained through RESNA at (202) 205-5666.

Rehabilitation Services Administration (RSA): The FY 93 budget of RSA is approximately $2.2 billion. It funds training, service and research projects in a number of categories, such as Rehabilitation Short Term Training Grants, Rehabilitation Long Term Training Grants, Special Projects and Demonstrations, Projects with Industry, and Experimental and Innovative Training. RSA is known in the assistive technology field because it is the "Federal parent" of the state departments of rehabilitation in the country. Information can be obtained directly from RSA at US Dept. of Education, 400 Maryland Avenue, SW, Washington, DC, 20202-2575, (202) 205-5482.

Office of Special Education Programs (OSEP): The FY 93 budget for OSEP is about $2.96 billion. It funds projects relating to education of people with disabilities. This includes the training of parents, teachers and other professionals involved in education and in technology used in the education of children. Projects include Field Initiated Research, Experimental Projects, Special Projects, and Preparation of Personnel Grants. The Media and Technology Project has a budget of $10.8 million and funds research and demonstration projects to develop and improve technology for the education of children and youths with disabilities. Information can be obtained directly from OSEP at US Dept. of Education, 400 Maryland Ave., SW, 20202, (202) 205-5507.

b. Department of Veterans Affairs (VA)

Within the VA is the Rehabilitation R&D Service, which has an FY 93 budget of about $26.8 million. It provides funding for projects in the broad area of assistive technology. Within the VA Rehabilitation R&D Service Program, research and development activity is funded in the categories of prosthetics, amputation and orthotics; spinal cord injury and related neurological disorders; communication, sensory and cognitive aids; and aging. The VA provides funding only through VA hospitals, of which there are 172 in the country. People outside the VA organization can participate in VA projects by way of a subcontract or a staff working relationship with a VA hospital. Information can be obtained directly from the VA at Rehabilitation R&D Service, Department of Veterans Affairs, 103 S. Gay Street, Baltimore, MD 21202, (301) 962-2563.

c. US Department of Health and Human Services (DHHS)

The National Institute of Health (NIH) is part of the DHHS. Within NIH there are many institutes which fund basic research related to specific injuries and diseases. Other institutes and centers within NIH that fund development of assistive technology include: The National Center for Nursing Research, Dr. Laura James, (301) 402-3290; The National Institute of Neurological Disease and Stroke, Dr. Patricia Grady, (301) 496-3167; The National Institute on Arthritis and Musculoskeletal and Skin Diseases, Dr. Steve Gordon, (301) 496-7326; `The National Institute on Deafness and other Communicative Disorders, Dr. Judith Cooper, (301) 496-5061.

Within the National Institute of Child Health and Human Development (NICHD), a new program has been legislated, the National Center for Medical Rehabilitation Research (NCMRR). The FY 93 budget for NCMRR is approximately $9 million. The new program has recently completed its research plan which identifies priority areas for funding. The new NCMRR program will focus on the treatment and prevention of impairments, functional limitations, and disabilities, within the limiting process. The report and plan for the center identifies seven priority areas: mobility; behavioral adaptation; whole body system response; assistive technology; measurement, assessment, and epidemiology; treatment effectiveness; and training of scientists for medical rehabilitation research. Information can be obtained directly from the National Center for Medical Rehabilitation Research—NICHD—NIH, second floor, 6100 Executive Boulevard, Bethesda, MD, 20852, (301) 402-2242.

Also within DHHS is the Center for Disease Control, which funds research and development in the field of assistive technologies. Contact Larry Burt, (404) 488-7080.

d. National Science Foundation (NSF)

NSF has a program on Biomedical Engineering and Research to Aid Persons with Disabilities which funds R&D in the broad area of assistive technology. The program is within the Engineering Directorate of the National Science Foundation. Specific projects should focus on the development of engineering technology. The program's FY 92 budget was approximately $3.9 million and included funding for individual investigator research and undergraduate and graduate engineering design projects. The FY 93 budget was not available as of January 1993. Additional information can be obtained directly from Research to Aid Persons with Disabilities, National Science Foundation, 1800 G Street, NW, Room 1132, Washington, DC, 20550, (202) 357-7955.

ACCESS TO FEDERAL, FOUNDATION, AND CORPORATION FUNDING

These sources of funding outside your own organizations can be acquired by submitting grant applications in response to advertised announcements on the availability of funds.

SOURCES OF INFORMATION AND ASSISTANCE

The *Federal Register* is a publication put out by the federal government which announces grant funding opportunities. It is issued daily and is a thick document covering many federal programs. Likewise, the *Commerce Business Daily* is a publication which announces contracts available from the federal government. It, too, covers many federal programs and is not convenient to read every day.

There are "clipping services" which are published covering opportunities announced in the *Federal Register* and the *Commerce Business Daily*. For instance, the "Health Grants and Contracts Weekly" is a weekly newsletter listing grant and contract announcements for funds available. It is published by Capitol Publications, P.O. Box 1453, Alexandria, VA 22313-2053, (703) 683-4100. Annual subscription cost is $292.

There are community foundation centers around the country which are excellent resources of information on funding sources, writing grant proposals, and providing assistance in acquiring support for worthwhile causes. The granddaddy is the Foundation Center in New York City (79 Fifth Avenue, New York, NY 10003-3076, (212) 620-4230). There is a network of cooperative foundation centers all over the country. Information on the one closest to you can be obtained from the Foundation Center in New York.

SOURCES OF FUNDING

AUTHORS

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Resisting Assistants with Assistive Assitance

Center for Rehabilitation Technology,
Georgia Institute of Technology

Cabell Heyward, Industrial Designer
Alan Harp, Industrial Designer
Riley Hawkins, Rehabilitation Engineer
A. N. Elder, Industrial Designer

As opportunities for employment increase for the disabled population, the problem of accessing documents or printed materials has also increased.

This past year at the Center for Rehabilitation Technology, efforts in the design and development of devices have been pointed towards devices which are able to manipulate different types of printed material instead of depending on the assistance of an assistant.

Product solutions to handling various types of documents in different employment situations opens doors for more people and the purpose of this paper is to disseminate the possibilities of a few different assistive devices.

Background
The Center for Rehabilitation Technology designs and fabricates specialized products which facilitate certain functions performed in various work environments. The center works in conjunction with the Georgia Department of Rehabilitation Services in providing technology in answer to our clients' needs for maximum work efficiency.

This past year, we were presented with four different problems related to the access of printed material critical in performing a job. We have designed and fabricated products or modified an existing product in answer to these problems. The printed materials included topographical maps, architectural drawings, books and unbound stacks of paper.

Problem Statements
The problem addressing the accessiblity of topographical maps was the need for our client to be able to read and access up to 6 maps while working on the computer. The size of the maps varied, with the maximum dimension being 22" x 20". The client who would be reading the maps and creating other maps on the computer utilizes a mouthstick and a powered wheelchair.

The problem addressing the accessibility of architectural drawings was the need for our client to access E size drawings (34" x 44") and being able to get close to every detail in the drawing. The client who would be reading the drawings to do cost analysis is an incomplete quadriplegic and uses a powered wheelchair.

The problem addressed in accessing books was the need for clients to read manuals, text books and any printed material needed to perform their job. In addition, the solution needed to make accessible more than several books, because maximum independence plays a major part in solving the clients' needs.

The problem addressed in accessing unbound sheets of paper, was the need for a stack of paper to be readable by the client while typing information from the top sheet into a computer, and after the client had completed typing the information from that sheet of paper then it needed to be removed to reveal the next sheet of paper in the stack. The client who would be performing this job utilized a respirator and a powered wheelchair.

Research
Existing products on the market today which addressed our problems did not offer quick solutions in solving the problems of disability but rather rely heavily on the ability of the user.

As in the case of handling large drawings such as maps and architectural drawings, the ability to place the paper on a large surface and manually manipulate it, in order to perform a job, is inherent to the design of any product which aids the user. An example would be a drafting table which holds large drawings. Research did reveal the microfilming of architectural drawings which could then be accessed through a microfilm reader.

Another product, which relies heavily on the ability of the user, is the book holder. There are many different solutions for supporting books on a table but again the user must be able to retrieve and place one book at a time on the product. This product does not solve the problem of a severely disabled person accessing several books without the aid of an attendant. There exists a product which will hold up to three books at a time but in our clients case there was a need for access to at least 6 books in a minimum amount of space.

Several products have been developed which manipulate paper in the form of pages in a book or in loose stacks. A number of page turners are on the market but most are complex machines which have proven to only work sporadically and also have high price tags attached to them. A device currently on the market which manipulates loose sheets of paper requires an able bodied person to insert the sheets into a vinyl housing which is then rolled around a cylinder. The user then scrolls through the sheets until they reach the end and then more sheets need to be inserted to replace the old sheets. This device seemed valuable if used to access magazines and the pages would remain in the product for a long period of time. But in the case of our clients' need to access several hundred sheets per day, this device seemed tedious and required a fair amount of assistance.

Design Solutions

Our clients' job of creating composite land use maps from five or six separate geological subject maps such as topography, soil type, hydrology, etc., created the need for a product which aids in the handling of the maps. This work is done via computer on a large color monitor interfaced by voice and mouthstick, but, because the subject maps are digitized, the originals must be referred to continually to insure accuracy, legibility, etc. Needed was a system by which our client could conveniently view all six maps, preferrably two at a time. Access by the client to the loading and unloading of each set of maps was not considered since the maps only need changing at each new job, which occurs only once a month. The solution took advantage of designs already developed for the AbleOffice workstation system's reference carousel, which were simply inverted and suspended on the underside of overhead shelves. A counterweighted clear cover for each of the six surfaces (three on each of the two carousels) was built allowing the user to lay the map face down to load it. Broad spectrum lighting was added and control is by means of mouthstick accessible momentary push buttons mounted in front of the keyboard platform.

The inverted carousels are located on both sides of the monitor, creating a visually accessible mise en scene

A decision was made to approach the problem of accessing architectural drawings by the venue of microfilm. This solution offered easy access to many drawings in a small amount of space because all the drawings for one construction job could be put on a roll of film and projected and enlarged on an accessible surface. All the while, most architectural firms are in the practice of having their drawings microfilmed for storage purposes.

An extensive search was done to locate a microfilm reader which could be operated independently by our client. It did not exist in pure form, so we decided on one which incorporated the best means of zooming in on any part of the drawing for detailed work, and also offered the most leeway for adapting the controls for our clients use.

In adapting the microfilm reader for usability, several problems were addressed. First , we changed the hand crank to a motorized scrolling mechanism. Slide pots control the variable speeds for moving through the roll of film forward and reverse at a selected pace.

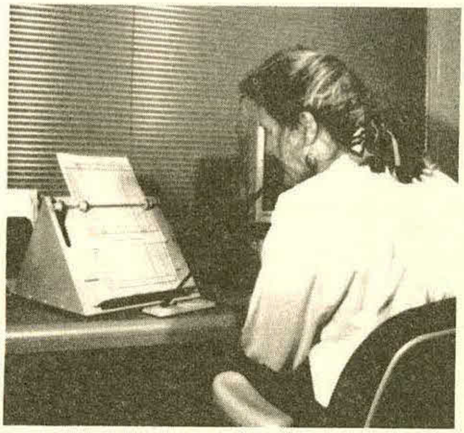
Secondly, three other features of the roll film reader were modified for use by the client: focus, zoom and scan. Two sliding bars were mounted horizontally next to the focus and zoom rings of the lens. These bars were connected via stainless steel straps to the rings. These bars were also connected via cable to actuating levers located next to the slide pot used to control the advance/rewind motor. The scan feature was made usable to the client by extending the overhead lever down to within the clients grasp. Again, the client is unable to load or unload the micro-film, but this is of little consequence since it is necessary only infrequently, and help is readily available for this task.

The design solution for handling heavy documents, such as in the case of books, takes advantage of vertical travel as opposed to horizontal or circular travel. This approach allowed minimal space requirements, and was an accessible solution since the books would be travelling to the client instead of the books needing to be within reach of the client.

The heavy document lift has 6 shelves (28" x 11") which are attached by drawer slides to an outer shell. The outer shell raises and lowers to the desired shelf with the push of a button.
The lift is designed to be durable yet inexpensive by using analog controls, custom linear glides and stock roller chain components. Once the shelf is selected it can be brought in front of the reader automatically or manually depending on the needs of the client. Each shelf can support 2 large books.

The design solution for solving the problem of handling unbound sheets of paper for data processing was developed by an engineering student and is a project in the student design competition. The designers at CRT produced a production model from the prototype built by the student. The page slide is an A-framed structure comprising of a 13"L x 16 1/2" W x 10"H styrene housing which holds a 30 rpm instrument motor, a series of pulleys, a belt, and electronics for switch control. The belt drives a pulley that is attached to a stainless steel rod. The rod holds 4 friction drive wheels which are kept in compression to the paper with internal springs. When the friction wheels are activated, they roll the top piece of paper up and over the housing, revealing the next page in the stack.

The page slide will hold up to 200 sheets of paper at a time and an adjustable shelf was designed to accomodate several sizes of paper, the maximum sheet size being 11" x 11".



The page slide allows data processors to work through a stack of paper with the press of a button.

Evaluation
The four products discussed are currently being used by clients in various work environments and have definitely progressed viable solutions to job performance accomodations. If you would like more information about these products please contact the Design Department at the Center for Rehabilitation Technology, Georgia Institute of Technology, Atlanta, GA.

Vocational Orthotics for "Reasonable Accommodation"

Center for Rehabilitation Technology,
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Riley Hawkins, Rehabilitation Engineer
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Cabell Heyward, Industrial Designer
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Americans With Disabilities Act of 1990, title I, sec. 101. (9)(B): Reasonable accomodation may include- job restructuring, part-time or modified work scheduling, reassignment to a vacant position, acquisition or modification of equipment or devices,...

This paper is meant as a discussion of the terms "equipment and devices" as used in title 1, sec.101. (9)(B) of the ADA. Designing and delivering specific equipment and devices for disabled clients in Georgia has been one of the main functions of the Center for Rehabilitation Technology (CRT) since its inception at the Georgia Institute of Technology in 1980. The majority of these projects have been funded by the state's Department of Rehabilitation Services(DRS) in conjunction with CRT. However; the intentions of the ADA are clearly that employers will provide equipment and devices for their employees. It is unlawful for a covered entity not to make reasonable accommodations.[1] Our projects and others completed at rehab centers and/or orthotic facilities across the country are done solely for vocational function. These projects meet the criteria of equipment and devices as defined in the ADA and it is for these projects that the future holds a new funding source.

Some vocational orthotics are already being provided by employers. One of the more common is the wrap-around back support seen on UPS drivers, movers, warehouse employees, etc. This orthosis is being provided to employees with pre-existing disabling back conditions and also prophylactically for those without back problems. Other examples of currently provided vocational orthotics are ergonomic seating and foot rests, forearm typing supports, and carpal tunnel syndrome wrist supports. Historically, employers have probably been nudged into the provision of these devices out of the fear of Workers Compensation claims and lawsuits (of course when your boss bought it for you she said it was out of the kindness of her heart) but nonetheless section 101(9)(B) reinforces the argument in favor of their purchase.

This year CRT completed a project for a client employed as a back hoe operator who is in the early stages of Rheumatoid Arthritis. Rheumatoid Arthritis complies with the ADA definition of "disability". Our clients difficulty was only with hand pain during power grip of the back hoe control knobs. An off-the-shelf carpal tunnel wrist support was purchased and modified with a rubber coated metal hook which made it easy for him to push and pull his controls. This orthosis was provided along with plenty of nudity (just seeing if you are awake). The entire expense included the cost of the splint plus roughly four hours of orthotist labor (custom design, fabrication, client visits, etc.). Reasonable accommodation cannot merely represent the base cost of an off-the-shelf orthosis since it is the nature of disability to require customization.
CRT asserts that this vocational orthosis is a "Reasonable Accomodation". In this case, however, the project was paid for by DRS and CRT.

More examples of vocational orthotics completed at CRT include:

<u>Body Tray</u> - An employee at a large administration building in Atlanta has hemiplegia due to TBI and is working in the central mail room. Sorting mail with the use of only one limb was required. An orthosis was designed and fabricated so the client could rest a small bundle of mail on a tray suspended from a shoulder harness. Her speed was increased to that comparable of a sorter using one limb to hold mail and one to sort.

<u>Scrub Brush Forceps</u>- A nursing student with a congenital defect in her upper limbs has resultant range of motion limitations in her elbows that prohibit her from reaching either arm with the opposite hand. She was able to perform nearly all of her vocational functions but had particular difficulty scrubbing down for OR because she couldn't sterilize her arms. An orthosis was designed and con-

structed that consisted of a pair of custom sterilizable 10" forceps that she could clamp around a scrub brush effectively extending her reach to include all of each arm and forearm.

Insurance Computer- An individual with a left above elbow amputation worked as an auto insurance claims adjuster. With just one hand he had difficulty operating the key pad on the hand held computer while at the same time holding it . An ingenious flip-up support that suspended the computer from the hip was constructed by my grandmother, in her garage, in less than 3 hours (again, checking to see if you're awake). The support was constructed to allow an ergonomic position for data entry and flipped down to a storage position. This project is one of the good precedents for the ADA since it was funded by the insurance company that employed our client.

Screwthosis[2]- An incomplete quadriplegic who worked as a TV/VCR repairman could not hold his battery powered screwdriver while at the same time operating the switch. An orthosis was fabricated that allowed him to concentrate on supporting the screwdriver while it automatically turned on and off due to pressure at the tip.

All of these projects were provided by CRT's design group. As a particular example, the screwthosis was an expensive project. If it was sold on a custom basis, it could be expected to cost in the $500 range . What is too expensive? The Equal Employment Opportunity Commission and the U.S. Department of Justice state that automatic page turners may be considered reasonable accommodation. These devices can cost up to $3500.00.[3]

In closing this discussion, be aware that CRT will continue to provide vocational orthotics to individual clients to the best of our ability regardless of where we get the funding. This paper is not meant to represent or define CRT policy. Also be aware that the ADA has specific definitions for the terms employer, employee, disability, undue burden,etc.. Questions concerning the interpretation of the law will only be decided in court. Maybe DRS will take the lead in demanding that employers increase their purchases of equipment. Maybe rehabilitation suppliers like CRT and orthotic facilities will start sending employers the bill just to see what will happen. Maybe an employee will demand in court that his employer provide a $5000.00 piece of equipment. When the courts say no, we'll all have to wait for the next court ruling but when they say yes, it will start the change.

(You can go to sleep now.)

If you would like more information about these projects please contact the design department at the Center for Rehabilitation Technology, 490 Tenth St. Atlanta, GA 30318 (404)894-4960

References

1. Americans With Disabilities Act Handbook; Equal Employment Opportunity Commission and the U.S. Dept. of Justice. Oct 1991

2. TV-Repair Workstation: Paraplegia News, 46(10), October 1992, pp 28,29

3. Medical Equipment Distributers Catalog (MED) AI-1032 page turner,p7, 1992

PIANO "PEDAL ACTUATOR"
A switch activated device to depress the piano pedal

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ABSTRACT

Professional piano players use piano pedals to acquire a sustained sound for particular notes while playing the piano. These pedals are typically depressed using the right foot. People who have lost the function of their lower extremities are unable to depress the piano pedal in the typical manner. A device, called the piano "pedal actuator", has been developed to allow wheelchair users with the loss of lower extremity function, specifically with above knee amputations, to use the piano pedals. This device can also be used with other appliances that require a pedal to be depressed.

BACKGROUND

The Center for Applied Rehabilitation Engineering designs and develops custom assistive devices for persons with disabilities to aid these individuals in performing work, school and daily life activities. A client who has bilateral lower extremity amputations was referred to the Center for evaluation with an assistive device that would allow him to return to the profession of piano playing. The above knee bilateral amputations preclude him from activating the pedals of the piano, therefore, preventing him from properly playing the piano. After conducting a thorough search of assistive devices through ABLEDATA (1), Job Accommodation Network (2) and several local piano vendors, it was determined that no commercially available device existed which would depress the pedal of the piano.

Based on the above mentioned information, the objective of the project was to design and develop a device that would allow a person with above knee bilateral amputations who uses a wheelchair to independently depress the right pedal of any piano.

DESIGN AND DEVELOPMENT

Preliminary Characteristics

Preliminary characteristics for the piano "pedal actuator" included the following:

1) The device would need to be activated by the user from the wheelchair for ease of operation.
2) The device would need to be height adjustable to all floor pianos, because some pianos rest on dollies, increasing the height of the pedals.
3) The device would need to be portable because it needs to be transported by the client.
4) The device should operate quietly so as not to distract from the music.
5) The device should be cosmetically appealing so as not to draw negative attention from the piano player.
6) The device must be powered by a DC power supply to eliminate the need for an AC cord or outlet.

Measurements

A dynamometer was used to measure the amount of force the client was able to exert in hip abduction with his lower extremities. With a cord around his right residual lower extremity, the client pulled in the direction of the right armrest. The client was then asked to perform the same test with the left residual lower extremity in a similar manner. After several measurements were taken, it was determined that the right residual limb was stronger and more natural for the client: pulling approximately two pounds of force in the direction of the right armrest.

A linear measurement was used to

measure the distance the client could move the right residual lower extremity while seated in a wheelchair. The client was able to move his right residual limb two inches in hip abduction/external rotation.

A dynamometer was also used on five pianos to measure the force needed to depress the piano pedals. The amount of force varied from 12 pounds to 15 pounds. The travel distance of the piano pedals was measured to be one inch. The speed that the pedal needed to be depressed, based on a sampling of "able bodied" pianists, was approximately two hertz, which translates into 3 in/sec of travel speed of the actuator. Because of delays experienced in the electronic circuit and the mechanical inertia of the actuator, it was necessary to specify an actuator that had a travel speed of 9 in/sec.

Because the piano pedal needed between 12 and 15 pounds of force, and the client was only able to exert 2 pounds of force, it was necessary to use a powered device. Mechanical methods were explored but were not successful due to the limited strength and mobility of the clients residual lower extremity compared to the force and displacement needed to depress the piano pedal.

Given the above characteristics, an electromechanical device was designed to be voluntarily activated by the user through a single pole switch. The switch was located between his right residual lower extremity and the armrest of the wheelchair.

To push the piano pedal, a custom ball drive actuator with a speed of 9 in/sec, 12 VDC, travel stroke of one inch, and a push force of fifty pounds was selected. This actuator was mounted on an adjustable height platform secured to a wooden base. The battery was also positioned on this wooden base. When the switch was activated, the device pushed down the pedal of the piano. By releasing the switch, the piano pedal returned to its original position. (Figure 1)

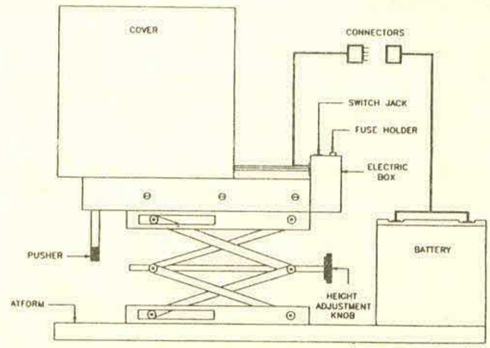

Figure 1
Piano "Pedal Actuator"

EVALUATION

The piano "pedal actuator" was given to the client for an initial trial. To set up the device the client needed to perform the following steps: 1) adjust the height of the piano "pedal actuator" to the piano pedal, 2) connect the battery to the actuator, and 3) connect the switch to the control box. The client activated the switch using his right lower extremity. The device complied with the desired characteristics and satisfied the concerns that were discussed above.

RESULTS

The client was able to return to piano playing in hopes of resuming his profession. The piano "pedal actuator" enabled the client to activate the piano pedal with proper timing for professional performances.

Although this device was custom designed for a client in a wheelchair with above knee bilateral amputations, this device can be used by anyone who has limited lower extremity function which prohibits pushing of the piano pedal or a pedal activated appliance.

ACKNOWLEDGEMENTS

Funding for the development of the piano "pedal actuator" has been provided by the Office of Vocational Rehabilitation, Allentown, PA 18103.

REFERENCES

(1) ABLEDATA, 8455 Colesville Road, Silver Spring, Maryland, 20910. (800) 346-2742.

(2) Job Accommodation Network, West Virginia University, 809 Allen Hall, P.O. Box 6122, Morgantown, West Virginia, 26506. (800) 526-7234.

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ABSTRACT

Consumers involved in design development and the evaluation process of assistive technology generally have a commitment to use it. The need for a device to overcome a functional limitation in a job and/or in independent living functions must be initiated and accepted by the consumer. The consumer must be a member of the rehabilitation engineering team to achieve the optimum solution.

INTRODUCTION

The importance of assistive technology has been gaining acceptance, especially due to: 1) The Technology Related Assistance to Persons with Disabilities Act of 1988, 2) Americans with Disabilities Act of 1990 and 3) The Rehabilitation Reauthorization Act of 1992. But the acceptance of assistive technology depends on: needs, user friendliness, aesthetic value, affordability (who pays for it), reliability, simplicity, repair (quick responsiveness and cost), safety, etc. The acceptance of the technology is eminent when the consumer is involved in the selection, modification, design, development, and evaluation process. The "consumers choice and empowerment" are the basic issues of the 1990's and needs to be well integrated in the Rehabilitative Engineering problem solving process.

The following case studies indicate persons with severe limitations can gain their functional independence upon communicating their choices to the rehabilitation engineering staff.

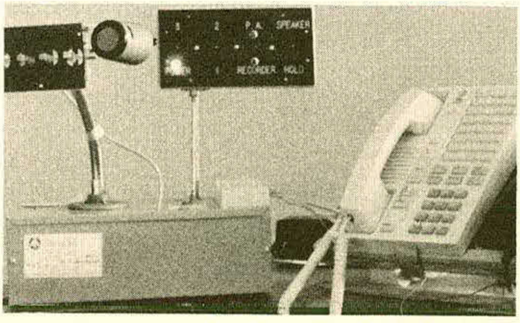
CASE STUDY #1

<u>CHOICE</u>: Sister J., 61 years old, always wanted to be a telephone operator in spite of her Multiple Sclerosis which prevents movement below her neck. She operates a powered wheelchair with chin and tongue control switches and her head position is limited to a usable radius of six inches. Using her voice causes fatigue after prolong use, so she is more comfortable using her tongue.

<u>OBJECTIVE</u>: The switchboard operator job at Villa Julie Infirmary was identified for Sister J. Sixteen different switch functions are required to: operate the switchboard with three lines, use the public address system and record messages on a tape recorder.

<u>SOLUTION</u>: A duplicate phone set was purchased and the Telephone Pioneer's rewired the phone so that the necessary functions could be done by an electrical contact closure. Eight miniature micro switches were mounted in a special housing unit. One tongue paddle operates two switches (up and down positions). The control system was designed so that the first and second upward motions of the paddle turned on and off the 12 volt system respectively. This provided 4 electrical functions for each paddle and with 4 paddles, the need for 16 contact closures were met.

<u>RESULTS</u>: After a prolonged evaluation, Sister J. could handle the three incoming lines, put calls on hold, page people over the public address system and record messages on the tape recorder as needed. This system has been in daily use for over 1 1/2 yrs.



COSTS: Materials ($1,000) and labor costs were paid by Maryland Division of Rehabilitation Services, Villa Julie Infirmary and Alliance, Inc.

CASE STUDY #2

CHOICE: Mr. X., a 54 year old male, with cerebral palsy uses a wheelchair for mobility needs to access food and drink from the refrigerator, especially when he is unattended for a long period of time.

OBJECTIVE: Due to the constraints of space and limited use of his hands, Mr. X. is unable to reach into a refrigerator or get close enough to the door shelves to retrieve food.

SOLUTION: An inclined plastic shelf mounted on door slides was installed without modification to the refrigerator. Opening the door allows the shelf to slide out for easy access to food and drink. The shelf slides back in when the door is closed.

RESULTS: The caregiver loads the sliding tray each morning with food and drink. This has been successfully operational for over a year. Both the husband and wife, with a similar disability, have benefitted from this device.

COST: Materials ($45) and labor costs were paid by the State Developmental Disabilities Administration.

CASE STUDY #3

CHOICE: A foster home caregiver, Mr. F. who has limited lifting capacity due to a back injury, needed a transfer device for Ms. B., a 23 year old who has severe mental retardation, physical disabilities, and a seizure disorder.

OBJECTIVE: A mobile adjustable height platform for transporting and transferring Ms. B. to accomplish such everyday functions as bathing, toileting, getting in and out of bed. The numerous swing-type lifts available are not suitable to meet this need, due to problems in lifting, space, and width of doors and hallways.

SOLUTION: A mobile hydraulic operated scissor platform was modified to meet the need. The platform (23" X 35") has an adjustable height ranging from 11 to 38 inches. The platform is raised by a foot operated lever and lowered by a hand operated valve that controls the rate of descent. The fixed front casters were replaced by swivel casters with a wheel lock. A back rest and an auto type seat belt were installed on the platform in order to increase her safety.

RESULT: The modified platform has been in use for six months. This device allows the caregiver to perform all of the daily functions without straining his back.

COST: Material ($1,108) and labor costs were paid by the State Developmental Disabilities Administration.

SUMMARY: An evaluation of a device along with many changes are performed with the help of a consumer before it's given for routine use. There are times the device may require further modification depending on change of environmental needs or advancement of disease or disability. But the consumer choices must be the focal point of any services.

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A Study in Accessibility of a College Campus

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ABSTRACT

With the passage and implementation of the Americans with Disabilities Act (ADA), many businesses are taking a close look at the issues addressed by the new law. Among these issues is that of building accessibility. An inaccessible building can communicate a negative image of a company, portraying a lack of concern for people in general. Failure to correct, adapt or accommodate accessibility problems can affect customers, visitors and employees of a company. Increasingly, companies are turning to people who are knowledgeable and skilled in performing building assessments, asking for assistance to identify problems and offer suggestions and solutions for correction of non-complying situations. One study is described.

BACKGROUND

Over a period of several years, the Georgia Institute of Technology approached the problem of accessibility on a case-by-case basis. Faculty and students encountering difficulties could request assistance in correcting problems through one of several campus services, including Student Services, Architectural Services, and Plant Operations. Personnel at these offices would assess individual situations, then recommend and implement solutions.

While this approach for correcting accessibility problems provided generally successful short-term solutions, the long range results were often inadequate. Solutions were not always implemented in an appropriate, coordinated or consistent manner, and on occasion, a correction in one area could lead to problems in another. For example, temporary handicapped parking was created to serve a building where a disabled student attended class, then moved as a student changed classes and buildings. A curb cut at one corner of an intersection might not have a corresponding cut at an opposite corner. Or, each of four curb cuts at a single intersection might be built in a different style, with only one of the four complying with accessibility specifications.

The tightening of regulations for agencies receiving Federal funding required those areas of campus where the funded activities were located to be in compliance with the Uniform Federal Accessibility Specifications (UFAS). Georgia Tech's extensive research activities are carried out over much of the campus.

The awarding of the 1996 Olympic Games to the city of Atlanta also impacted Georgia Tech. The campus will serve as the site of the Olympic Village, and all athletes will be housed in existing or newly built dormitory space. There are stringent requirements for the athletes living spaces which will necessitate renovation of existing buildings to bring them into compliance. Additional new housing will also be needed. All construction planned for the Olympics will also be required to comply with current accessibility specifications.

OBJECTIVE

To assist Georgia Tech in identifying and correcting accessibility problems on campus, the Center for Rehabilitation Technology offered its services in directing a coordinated and comprehensive accessibility study of the campus. A proposal was submitted to the Office of Strategic Planning to evaluate the approximate 150 buildings controlled by Georgia Tech, identify non-compliance areas, and offer suggestions on correcting the problems. The proposal was accepted and funded.

METHOD/APPROACH

The Center for Rehabilitation Technology worked closely with Architectural Services for the duration of the project. A listing of all campus buildings was compiled. Those buildings which were privately owned, as fraternity housing or leased buildings, were eliminated from the list. Buildings housing mechanical equipment, structures planned for demolition, and storage facilities were also among those eliminated. 119 buildings were ultimately identified for survey.

Floor plans for all identified buildings were obtained from Architectural Services and duplicated.

Five Georgia Tech students were hired to assist in the survey of the campus. All worked 40 hours a week during the summer months. Two students were retained after the beginning of the academic quarter in the fall to assist in reviewing uncompleted reports, rechecking incomplete or incorrect data and, in general, bringing the project to a close. All students were trained by 1) Viewing a 3-part video conference on the ADA, 2) Viewing a slide series developed at CRT for identifying accessibility problems, 3) Reading accessibility guidelines, specifically the ADAAG (ADA Accessibility Guidelines), UFAS and ANSI A117.1-1986 (American National Standards Institute Standard for Buildings and Facilities - Providing Accessibility and Usability for Physically Handicapped People) documents, 4) Familiarization and use of survey equipment, 5) Performing a supervised practice survey using a checklist data collection form, 6) Performing actual surveys under supervision until such a time that it was clear each understood the survey concept and procedures.

Equipment used included a standard 16- foot tape measure, a magnetic polycast protractor, and a fish scale. A surveyors wheel was available to measure long distances, but not used regularly. Also available were a light meter and a sound meter.

Students performed all surveys in teams of two.

In general, a building was surveyed first for availability of accessible parking, then approach to, entrance into and circulation within the building were evaluated. Individual components were then addressed, including stairs, elevators, restrooms, doors, signage, telephones, water fountains and other building features.

RESULTS

Upon completion of each survey, students were expected to write a draft report on the building(s) surveyed. Draft reports underwent rigorous revision, then were each reviewed by two separate readers. Since it was possible in some situations to combine similar buildings into a single report, 100 Final Reports were written on buildings and submitted to the Office of Strategic Planning. Three additional reports were also written and submitted, one covering Parking, one on Emergency Phones, and one on General Campus Access.

The survey took approximately 6 months to complete.

At the time of this paper, Georgia Tech intends to use the Final Report in development of an ADA Compliance Plan, a Master Plan for correction of existing accessibility problems campus-wide, and to assist with future campus planning efforts.

ACKNOWLEDGEMENTS

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Thanks to Architectural Services for their assistance in obtaining building plans and information that was essential for the completion of this project.

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A MODEL FOR THE EVALUATION AND SELECTION OF ADAPTIVE COMPUTER INTERFACES

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ABSTRACT

A vocationally-motivated procedure for selection and design of alternative computer interfaces is presented. Novel features of this approach include collection of data representing motor performance, mathematical modeling of the functional relationship between motor performance and device features; quantitative estimation of productivity with candidate interfaces; and summary of performance predictions to client, vocational counselor, and other service providers.

BACKGROUND

Assistive technology has the potential to significantly improve vocational prospects for people with disabilities without requiring substantial financial resources for equipment and training. Our model, which is an extension of earlier work in selection of augmentative communication devices[2], offers predictive information to support the user's selection of an alternative computer interface. This information is derived from mathematical estimation of the user's productivity with a variety of interfaces.

Our focus on efficient evaluation of devices through a systematic comparison involving predictions of productivity is particularly relevant in the context of the Americans with Disabilities act (ADA).

OBJECTIVE

Our goal is to improve the vocational prospects of people with disabilities through the custom design and/or selection of alternative computer interfaces to increase productivity in specific computer-use activities. This is meant to include both introducing individuals to vocationally-oriented computing, and improving access for individuals who are already using computers.

The selection process favors the use of mass-market hardware and software whenever possible. This helps minimize the higher cost typically associated with adaptive or custom-built equipment.

METHOD/APPROACH

The current project is aimed at the development of a systematic, generalizable technique for the design and development of alternative computer interfaces for persons with neuromotor disabilities, including speech impairments[1]. Our technique proceeds according to the flowchart given in Figure 1:

Interview.
An interview is conducted in order to identify the individual's vocational goals, including currently used computer interfaces, if any. Ideally, the user will be working with a vocational counselor who would provide professional evaluation of the user's goals. This information serves to give direction to the subsequent phases of the individual's involvement, along with establishing the end goals of the design.

Evaluate current technique
If the participant is currently using a computer, his/her input rate is measured, in order to provide a baseline against which performance predictions for proposed designs can be compared. In addition, a visual record is generated, consisting of photographs and videotapes. This record provides qualitative information to augment the rate measurements.

Select "control sites" and potential interface types
The project team, with substantial input from the user, identifies appropriate control sites on the user's body. This

identification is guided by consideration of the user's motor control and personal preferences, and by characteristics of devices might be appropriate for the user.

Collect Data
The user performs a series of tasks designed to measure motor performance for operation of potential input devices. These tasks include reciprocal target-tapping, alternating switch closure, and reaction time tests, involving all potential control sites. These tasks are designed to measure motor performance independent of any mental load imposed by the need to learn actual devices. For example, two round, unlabeled switches stand in for keys on a keyboard, allowing the user to concentrate on the physical aspects of the task. This is mentally less demanding than standard computer keyboards, which require the user to learn the layout of the keys. As a result, practiced familiarity with an interface is approximated[2].

Model and predict productivity
The data is then used to generate mathematical models of the individual's performance. These models relate movement time to the physical characteristics of interfaces, and are used to predict the practiced functional rates that the individual would be able to achieve using the input devices under consideration. Comparison of these predicted rates to the user's measured rate of input using his/her current device provides a measure of predicted potential improvement.

Provide user with information on his/her predicted performance
The implications of these models are discussed with the user, in terms of predicted input rates and other advantages and disadvantages of the various alternatives. These issues are particularly relevant for the use of devices that are noticeably unusual, such as speech recognition devices.

User and team select an interface
Based on the results of the predictions and discussion with the user, a selection is made. This selection is based on factors such as predicted productivity, user preference and cost.

Implement interface and train user
At this point, the interface is designed and assembled. Although mass-market devices are used whenever possible, custom hardware and/or software is built if suitable commercial components are unavailable. The system is installed and the user trained in its use.

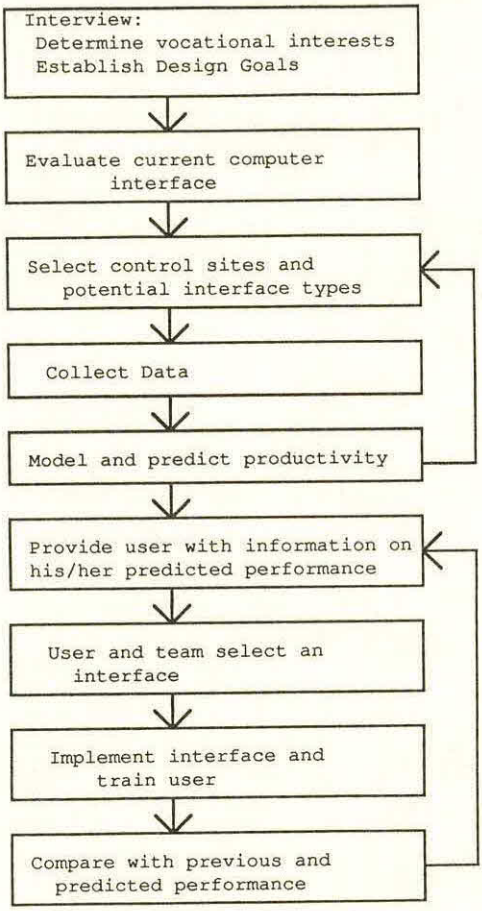

Figure 1

Compare with previous and predicted performance
The new interface is evaluated, in terms of rate of use and the degree to which

vocational and personal needs have been met. Data on rate is compared to the measured rate with the previously-used interface, and to the predicted rate for the new interface. This provides both a measurement of improvement and an experimental test of the validity of predictions.

It is expected that the client's functional use of the new interface will frequently expose the need to revise the interface and possibly rethink vocational goals. Greater experience with the interface may identify shortcomings and areas for potential improvement. Eventually, as the user discovers enhanced possibilities, (s)he might also update his/her vocational goals, which could lead in turn to specifications for further interface modification. Vocational counseling can provide professional assessments of these new goals.

RESULTS

Several individuals have participated in our project according to the model described above, and earlier versions of this approach.

DISCUSSION

By summarizing the results of the modeling for the user and including him/her in discussion of potential designs, we hope to arrive at designs that are both objectively superior and well-suited to the user's needs as (s)he perceives them. There are several benefits for the user:

Insights concerning appropriate solutions: Data collection and model-based evaluation of interfaces lead to a more thorough understanding of combinations of device characteristics that are desirable for the user.

The opportunity to compare alternatives before investing large amounts of time and money. Evaluation of devices through mathematical modeling is much easier and less expensive than experimenting with possible interfaces. In addition, it can eliminate devices that are clearly inappropriate for the user, and narrow the field of superior candidates.

Education about previously unknown alternatives. Many users are uninformed about the possible alternative devices that they might find useful. Our evaluation can include devices that turn out to be very effective, but would not otherwise have been tried because they were unknown to the user.

Informed basis for making decisions. Numeric ratings of alternatives, in the form of performance speed predictions for benchmark computing tasks, provide a direct means of comparisons among candidate interfaces.

Control over his/her own destiny. Perhaps most importantly, involving the user in discussion of the modeling process allows full consideration of user input and allows the user to assert preferences, voice concerns, and ask questions.

Our initial use of this approach has proven encouraging, in the context of an academic research project. As our research continues, we hope to gain further experience with the model, including an evaluation of vocational benefits.

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THE REHABILITATION TECHNOLOGY RESOURCE CENTER THREE YEARS LATER...

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ABSTRACT

This paper will provide an update on the services provided by the Rehabilitation Technology Resource Center (RTRC). Background on the initial development of the RTRC will be presented. Recently expanded services of the resource center and future plans will be described.

BACKGROUND

The Rehabilitation Technology Resource Center was founded in 1989 in order to respond to the need to have a central location where individuals could have access to various forms of assistive technology. The RTRC was designed to compliment an existing rehabilitation technology mobile services component of the agency. Initial services of the RTRC included:

* Hands on experience with various types of assistive technology devices;

* Information and referral about available technology;

* Guidance regarding equipment purchases;

* Information on funding alternatives;

* Assistance in adapting devices to meet individual needs;

* Training and demonstration sessions of assistive technology;

* Short term loans of assistive technology devices for consumers and rehabilitation professionals;

* Training sessions by various manufacturers.

The RTRC's physical structure was designed to provide space to clearly display various assistive technology devices in addition to providing ample room for a large demonstration and seminar area.

THE REHABILITATION TECHNOLOGY RESOURCE CENTER TODAY

Over the past three years, the RTRC has continued to grow in size, services and staff. The resource center currently houses approximately 1,100 pieces of assistive technology including augmentative communication; adapted daily living aids; vocational adaptations; mobility and seating systems; environmental control units; alternative computer input devices; adapted toys; and switches.

RTRC THREE YEARS LATER...

In response to increasing advances in assistive technology and growing consumer requests, the RTRC has expanded it's services to include: access to technology databases such as Abledata and AppleLink, computer input assessments, technical consultations for trouble shooting, and assessments and guidance on technology options via the telephone or picture phone.

In addition, the resource center has provided over 15 half-day conferences on specific areas of assistive technology such as seating and positioning, environmental controls, voice recognition, adapting toys and fabricating switches, as well as our annual augmentative communication and mobility conferences.

Finally, the growing number of students with disabilities being served in supported, inclusive education environments has enabled the resource center to provide it's services to a growing number of public school systems throughout New Jersey. School districts are requesting an array of services ranging from general overviews of assistive technology to in-depth, student specific, technical assistance on assistive technology.

Most recently, the RTRC has initiated a mobile education and referral satellite, The Southern Technology Assistive Resource (STAR) Center. The STAR Center is part of the New Jersey "Tech Act" program (PL 100-407) and will provide mobile presentations on assistive technology throughout southern New Jersey.

Funding and support for the resource center has come from many, various sources. To offset the cost of maintaining items loaned through the center, an annual membership fee is charged. The expense for an individual with a disability or a family member is $25.00 per year. The cost for a facility, organization or professional is $75.00 per year. In addition to membership fees, funds to staff the resource center and cover overhead costs come from contracts with the New Jersey Division of Vocational Rehabilitation Services (DVRS) and a grant from the Office of Special Education and Rehabilitation Services to provide assistive technology assessments to DVRS clients statewide. Finally, much of the assistive technology which is displayed or loaned within the center comes from equipment manufacturers and local vendors through purchases or long term loans.

PLANS FOR THE FUTURE

The Rehabilitation Technology Resource Center continues to expand it's services to further enhance the lives of persons with disabilities through assistive technology in New Jersey. Current expansion efforts include the addition of speech pathologists who specialize in augmentative communication to serve as "on-call" consultants to provide augmentative communication assessments to children and adults with disabilities in the school, home, and workplace. In addition, plans to provide facilitated communication assessments are being developed. Finally, the resource center will continue to expand it's services within public school settings to serve students with disabilities who are integrated in regular classroom settings.

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ACKNOWLEDGEMENTS

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ASSESSING OUTCOMES OF AT USE: THE REVISED CONSUMER FORM OF THE "ASSISTIVE TECHNOLOGY DEVICE PREDISPOSITION ASSESSMENT (ATD PA)"

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ABSTRACT

In response to user feedback and new emphases in recently passed legislation, the consumer version of the **Assistive Technology Device Predisposition Assessment** (ATD PA) has been modified. It now incorporates items addressing *outcome achievement* by inquiring into consumers' subjective sense of "disability" and the role of assistive technologies in eliminating "disability." The revised form of the ATD PA remains a research instrument undergoing pilot evaluation and, as such, is available at no cost to persons who wish to participate in its pilot testing.

BACKGROUND

Two earlier RESNA presentations described the development and validation of a **Matching Person and Technology (MPT)** model. The model is person-focused and addresses three separate areas of influence on a person's technology use or non-use:

1. The characteristics of the Milieu (environment and psychosocial setting) in which the technology is used,

2. Pertinent features of the individual's Personality and temperament, and

3. The salient characteristics of the Technology itself.

As part of the **MPT** model, assessment/ screening instruments were developed to flag possible mismatches between a proposed technology and a potential user: The **Assistive Technology Device Predisposition Assessment (ATD PA), Educational Technology Predisposition Assessment (ET PA), Workplace Technology Predisposition Assessment (WT PA), Health Care Technology Predisposition Assessment (HCT PA) and Technology Overload Assessment (TOA).**

The **Assistive Technology Device Predisposition Assessment (ATD PA)** consumer form and the **Assistive Technology Device Predisposition Assessment (ATD PA)** professional form and summary sheet are the focus of this presentation. The two forms of the **ATD PA** were designed to be used as a set in order to assure:

a) Consumer input drives the **Matching Person and Technology (MPT)** process,

b) the degree of match between consumer and professional perspectives is assessed, and

c) professionals are guided into considering all relevant influences on technology use while focusing primarily on the consumer's quality of life.

Each form is on a single two-sided sheet and requires about 15 minutes to complete. The items are of varied format, including 5-point Likert scales and checklists. There are subscales to separately assess characteristics of the technology, the individual's temperament, the environment in which the technology will be used, and the influence of disability on the individual's technology use and quality of life.

While the forms are still in the pilot phase, and are undergoing further refinement as information about their usefulness is collected across the U.S. and abroad, preliminary analyses indicate they have good inter-rater reliability and criterion-related validity. Since the items emerged from the actual experiences of technology users and non-users, they have content validity.

RECENT DEVELOPMENTS AND REQUESTED ADDITIONS

As part of the pilot testing process, consumers and professionals were asked to complete an evaluation of the ATD PA forms. Feedback from users indicated a desire for additional items that would be useful in assessing outcome achievement over time. Additionally, several new laws have enhanced the emphasis on outcome driven assessment (e.g. the Rehabilitation Act Amendments of 1992 (P.L. 102-569) and Individuals with Disabilities Education Act).

APPROACH

Based on user feedback and legislative intent, new items were added to the consumer version that inquire into the individual's subjective sense of "disability" and satisfaction with various quality of life domains -- domains where the match of person and assistive technology has been determined to be important to quality of life attainment. The new items also necessitated a change in the response format and number of items used in scoring. The new items and response options are listed in Table 1. The content of the prior version of the ATD PA-C is in Table 2.

DISCUSSION AND IMPLICATIONS

The most useful assessments are ones tested in a variety of settings and refined over time. Thus, the author welcomes hearing from individuals interested in pilot testing the revised forms of the ATD PA and will provide at no cost all current instruments and a manual for scoring and administration. The purpose of the ATD PA remains that of flagging potential mismatches between person and technology in the hopes that early identification of mismatches will:

a) reduce technology non-use or inappropriate use
b) identify needed technology modifications, and
c) eliminate frustration that occurs with a poor match.

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Table 1 Revised ATD PA Consumer Form Item 4

How satisfied are you with what you have achieved in the following areas? Please circle the best response for each:

	Not Satisfied	Satisfied	Very Satisfied
Independent living skills	1	2 3 4	5
Communication skills	1	2 3 4	5
Emotional well-being	1	2 3 4	5
Physical comfort and well-being	1	2 3 4	5
Social and recreational involvement	1	2 3 4	5
Ability to go where desired	1	2 3 4	5
Educational attainment	1	2 3 4	5
Employment status/potential	1	2 3 4	5
Overall health	1	2 3 4	5

Put a [+] beside the one(s) you want to improve over time

Table 2 Former ATD PA Consumer Form Item 4

Please rate your present capabilities in the following areas by circling the best response for each:

	Poor	Average	Good
Learning speed*	1	2 3 4	5
Educational attainment	1	2 3 4	5
Employment status/potential	1	2 3 4	5

Put a [+] beside the one(s) you believe will improve over time

* "Learning speed" has been moved to Item 3 in the revised version.

SURVEY OF ASSISTIVE TECHNOLOGY SERVICE DELIVERY IN CARF ACCREDITED COMPREHENSIVE INPATIENT REHABILITATION PROGRAMS

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ABSTRACT

There are 496 CARF accredited Comprehensive Inpatient Rehabilitation Programs or facilities in the United States as of December 31, 1992.[1] Clients who are disabled by disease or a traumatic event participate in the rehab process with the intent of maximizing their function. When a client is properly seated, in a mobility device suited to his individual need, and able to access other assistive technologies, his rehabilitation potential improves. It is imperative that an effective model or models of rehabilitation technology service delivery be established for use by these programs as it is an integral component of the rehabilitation process.

BACKGROUND

Rehabilitation technology is a rapidly growing profession comprised of individuals from many different disciplines who have come to understand that it is an integral component of the rehabilitation process. In 1987 RESNA, the Interdisciplinary Association for the Advancement of Rehabilitation and Assistive Technologies published a practical guide for rehabilitation technology service delivery which gives a brief overview, advantages, and disadvantages of seven different rehabilitation technology service delivery models.[2] There are no guidelines or strategies on how to effectively implement a service delivery system in any of the different models.

INTRODUCTION

Rehabilitation facilities across the country are beginning to embark on the delivery of rehabilitation technology services in an effort to provide comprehensive care and to maximize the functional outcome of their clients. These facilities are left to devise their own method of providing these services with limited information available on effectively pursuing this venture. If a facility is unable to devise an efficient and cost effective manner in which to provide this service, the patients who receive care at the facility may not reach their full rehabilitation potential.

CURRENT INFORMATION

A survey of healthcare administrators conducted by Gaster and Gaster in 1991 regarding the acceptance of rehabilitation engineering found the ability to enhance the functional outcome of existing chargeable activities and the ability to generate additional chargeable activities (revenue) were the reasons most often given for purchasing equipment and employing rehab engineers. The survey also found that fewer than 17% of the respondents employed rehabilitation engineers. From the comments they received many respondents indicated that services such as seating, mobility, augmentative communication and environmental control were being provided by existing therapy staff, not designated rehabilitation technology staff.[3] This leads one to question the effectiveness of the evaluation, fitting, training, assessment, and justification process that is involved in procuring appropriate equipment. Staff productivity, the amount of therapy time lost, and the ability of the individual therapists to keep current with rapidly advancing and changing technologies is also questioned.

At the RESNA International '92 meeting, an educational round table chaired by Jean Minkle, P.T., was held to discuss the delineation of roles for the user, family, caregiver, clinician, rehabilitation technology supplier, engineer/designer, and technician as they pertain to the acquisition of seating and wheeled mobility devices.[4] The information presented is quite thorough. It leads one to question whether this is the most effective method of service delivery, how many facilities provide services in this manner, and whether it can be proven effective and implemented in facilities that provide services in an alternative manner.

C. Gerald Warren has drafted a number of position papers regarding Quality Assurance in assistive technology which have included information on RESNA certification of assistive technology providers.[5] This is a commendable effort. However, if a large portion of assistive technology service delivery is being provided by therapy staff who may or may not belong to RESNA will this certification process have an impact?

STATEMENT OF THE PROBLEM

The efforts of the individuals attempting to establish criteria for developing appropriate and effective delivery of assistive technology services is exemplary. However, with 496 comprehensive inpatient rehabilitation programs and facilities in the United States there is a potential for a large number of service delivery models within the rehabilitation settings. Of these different models there will be some that will succeed and some that will fail thus it is imperative that we understand what criteria establish an effective and financially viable rehabilitation technology service delivery system before we can attempt to define roles and implement certification.

OBJECTIVE

In an attempt to who is providing rehabilitation technology service delivery and how a survey has been developed. It is in response to the questions raised in the survey conducted by Gaster and Gaster, the preliminary guidelines for role deliniation established by the Educational round table discussion, and the information relating to RESNA certification presented by Gerry Warren and the RESNA QA committee. The survey will attempt to answer the following questions:

1. What percentage of CARF accredited comprehensive inpatient rehabilitation facilities provide rehab technology services?

2. What age groups and diagnostic categories are served by rehabilitation technology services? Is there a correlation between the age groups served and the assistive technology services provided? Is there a correlation between the diagnostic categories served and the assistive technology services provided?

3. What percentage of each assistive technology service is provided within comprehensive inpatient rehabilitation facilities?

4. Who are the primary individuals responsible for implementing assistive technology service delivery?

5. What role does each team member play in the process for advocating the procurement of appropriate seating and wheeled mobility devices? Is there a correlation between how services are rendered and how they are reimbursed?

6. How is the Rehabilitation Technology Supplier selected? What is the correlation between how the RTS is selected and what role the RTS plays in the delivery of service.

7. What percentage of comprehensive inpatient rehabilitation facilities have trial / evaluation assistive technology equipment available to their patients, regardless of whether they provide formal rehabilitation technology service delivery or not.

METHOD

A pilot of the survey was sent to 9 active members within the Seating and Wheeled Mobility Special Interest Group (SIG-09) of RESNA from all regions of the US for feedback on accuracy in content and wording.

A pilot of the survey was then sent to local / regional CARF accredited comprehensive inpatient rehab settings to determine whether the survey could be filled out easily, accurately, and within a reasonable amount of time.

A cover letter, survey, and return reply envelope were then sent to all 496 subjects with a request to return the survey, in the return reply envelope, within one month.

PLAN

When a response is received the data will be collected and entered into a computer for analysis.

If a response is not received within the given time, a second survey, and another reply envelope will be sent with a new due date.

The data will be analyzed 2 weeks after the second due date has passed.

CONCLUSION

The survey has been reviewed by the members of the SIG-09 Clinical Service Delivery Sub-Committee and has been revised. It has also been reviewed by local and regional CARF accredited comprehensive inpatient rehabilitation programs and was found to be clear, concise, and able to be answered without difficulty. Results of the survey will be available at RESNA 93.

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ACKNOWLEDGEMENTS

Marianjoy Rehabilitation Hospital and Clinics (MRHC), in Wheaton, IL. provides a variety of levels of rehabilitative care to inpatient and outpatient clients of all ages and disabilities. The Department of Applied Rehabilitation Technology at MRHC is an interdisciplinary team which provides evaluation for, fitting of, and training with a variety of rehabilitation technologies.

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THE REHABILITATION ENGINEERING TRAINING PROGRAM AT WRIGHT STATE UNIVERSITY

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ABSTRACT

This paper describes a masters level training program which is directly responsive to an Ohio manpower needs survey. The curriculum is presented with an emphasis on the cap stone three month internship.

BACKGROUND

This program is directly responsive to a 1990 study of manpower needs conducted by the Ohio Rehabilitation Services Commission which identified Rehabilitation Engineering as the number two preservice training need in the state. Further, this regional personnel training need is reflective of deficits on the national level. In a national survey of rehabilitation engineering services providers, Langton, Coker & Smith (1989), reported that, due to the lack of appropriately trained personnel, rehabilitation engineers and technologists are not yet used in significant numbers in state vocational rehabilitation agencies. Based on results of a recent survey of RESNA's Rehabilitation Engineering Professional Specialty Group, it has been estimated that there are fewer than 185 practicing rehabilitation engineers nationwide (Trachtmen, 1991). Although there have been recent increases in the number of training programs in rehabilitation engineering/technology (e.g., Hale, Schweitzer & Puckett, 1991), the need for additional preprofessional training programs has been acknowledged to be critically high (Dolan, 1992).

This training program has been developed in consultation with the state and local rehabilitation service provider community and involves representatives from those agencies and organizations in academic and clinical instruction roles.

THE TRAINING PROGRAM

Recruitment efforts are conducted nationally among undergraduate training programs such as Biomedical, Human Factors, Electrical and Mechanical Engineering. Candidates must meet university and departmental requirements for admission to the master's program including evidence of appropriate undergraduate background. In addition, for this program, motivation and potential to pursue study in rehabilitation engineering is assessed through a personal interview and a letter written by the candidate. The candidates must show that they are people oriented.

Degree requirements require include the completion of 42 quarter hours of academic coursework and 12 quarter hours of internship during their last quarter of study. The curricular sequence is as follows:

<u>Quarter 1</u>	
Bioinstrumentation	4 hrs
Intro to Rehab. Egr.	3 hrs
Neuromuscular Rehab.	3 hrs
Applied Statistics I	4 hrs
<u>Quarter 2</u>	
Rehab Assistive Systems	3 hrs
Rehab Egr Computers I	4 hrs
Rehab Egr Design I	3 hrs
Applied Statistics II	4 hrs
<u>Quarter 3</u>	
Biomedical Computers II	4 hrs
Human Fct Egr in Rehab	3 hrs
Intro Clinical Prac	4 hrs
Rehab Egr Design II	3 hrs
<u>Quarter 4</u>	
Rehab Egr Internship	12 hrs

Academic course work establishes the knowledge base to prepare students to work in a comprehensive service delivery program; to provide assistance with respect to the adequacy of design parameters and materials of rehabilitation technology; to address factors related to the safety, reliability, and maintenance procedures of technological devices; to assist in modifying commercially available technology to meet individual client needs; and to analyze and design new devices.

The internship is a capstone course. This field work course is provided at a rehabilitation center and requires one full quarter for completion. It is designed to provide students with practical experience as a rehabilitation engineer who works within rehabilitation teams. Other team members include a physician, nurse, psychologist, physical, occupational, speech and recreational therapists, and a social worker. Under the direct supervision of a professional engineer experienced in rehabilitation engineering, the trainees practice engineering approaches to management of head injury, stroke, amputation, and spinal cord injury in out-patient and in-patient rehabilitation. In addition, they are involved in the evaluation and recommendation of driving systems, home and workplace modifications, and programs in industrial and in-home rehabilitation. Students are expected to design and build or, depending upon the complexity, supervise the building of a number of devices meeting rehabilitation needs.

Grades in the internship are based on attendance, completion of clinic tasks, and designs. Written and oral feedback is received on student progress several times during the course from the professionals involved with the students, and feedback from the students is sought twice. Students meet weekly with the supervising professional engineer. Students are provided with a list of tasks to complete which guarantees a minimum experience level. These tasks involve different areas of rehabilitation, include are:

Assistive technology services;
Driving evaluations;
Home visits;
In-home rehabilitation;
Industrial rehabilitation;
Occupational therapy;
Pediatric observations;
Physical therapy;
Psychological testing;
Recreation therapy;
Rotations with rehab teams (4);
Social services;
Special clinics i.e. MD & MS;
Speech therapy; and
Vocational rehabilitation.

A task is considered to be completed when one of the site-based rehabilitation team members signs off on it. The design requirements are assigned within the different rehabilitation areas. Grades on design projects are based upon the overall completeness involving an engineering notebook, engineering analysis, and implementation of the design.

The following are examples of the task lists:

<u>Physical Therapy</u>

1. Body Mechanics
   A. Lifting & Posture Training
   B. Transfers
2. Design Case Assigned
3. Design Case Completed
4. Exercise Training
5. Gait Training
   A. Weight Shifting
   B. Balance Activities
      1. Sitting
      2. Standing
6. Home Health Visit #1
7. Home Health Visit #2
8. Modalities
   A. Cold Treatment
   B. Continuous Passive Motion
   C. Electrical Stimulation
   D. Heat Treatment
   E. Electrophoresis Treatment
   F. Paraffin Treatment
   G. Ultrasound Treatment
9 Visit BME service

<u>Assistive Technology Services</u>

1. ACCP Evaluation #1
2. ACCP Evaluation #2
3. Driving Evaluation #1
4. Driving Evaluation #2
5. Design Case Assignment
6. Design Case Completed
7. Wheelchair Clinic #1
8. Wheelchair Clinic #2

<u>Psychology</u>

1. Cognitive Evaluation
2. Psychometrics
3. Bio-feedback

Speech

1. Swallowing Evaluation
2. Cognitive Evaluation

Occupational Therapy

1. ADL Disabled Simulation
   A. Dressing
   B. Homemaking
2. Cognitive/Perception Training
3. Cognitive/Perception Evaluation
4. Design Case Assigned
5. Design Case Completed
6. Home Modification Visit #1
7. Home Modification Visit #2
8. Mobility
   A. Wheelchair Mobility Train.
   B. Wheelchair Seating Eval.
9. Splinting
   A. Static
   B. Dynamic
10. Upper Extremity Evaluation

RESULTS

This program has attracted trainees primarily from Ohio. Five came from industry and 7 from BS programs. One graduate started a rehabilitation engineering company, one went to work in a rehabilitation center, one became an industrial rehabilitation engineer, and one went on to medical school.

The response of the rehabilitation center staff to the summer internship was very positive. They willingly participated in the design of the task lists, provided supervised hands on training, and continuously came up with challenging design needs. At the end of the summer the students formally presented all of their designs to the physicians and service managers of the center.

DISCUSSION

One of the challenges in mounting this program was assuring that the students receive a practical training experience which would serve their needs upon graduation. The academic courses are a mix of rigorous and applied engineering. During the year, field trips are taken to show the students how the knowledge they are gaining is applied. The internship is a good experience. It brings to focus all the students have learned into an applied setting. They have been well accepted as members of the rehabilitation teams.

Mounting the internship within a rehabilitation center environment has at least two advantages: one, it is a controlled environment and appropriate checks and balances can be applied to assure that the quality and quantity of the training experience is measurable; and two, the students are exposed to a large number of individuals with varying degrees of disabilities.

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ASSISTIVE TECHNOLOGY SERVICES AT SHEPHERD SPINAL CENTER, INC.

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ABSTRACT

Shepherd Spinal Center, Inc. (SSC) is a 100 bed rehab. facility for persons with spinal cord injury, spinal related diseases, and various neuromuscular diseases. SSC is one of only 13 hospitals nationally to be designated a Model Spinal Cord Injury Program by the U.S. Department of Education. This presentation illustrates the delivery of assistive technology services at SSC.

DISCUSSION

The center's assistive technology services are delivered by a team consisting of several departments. The departments include Physical Therapy, Occupational Therapy, Rehabilitation Technology, and Rehabilitation Equipment.

The Physical Therapy Department manages prescriptions (RX's), letters of medical necessity (LOMN's) for wheelchairs, seating, home durable medical equipment (DME), and bathroom equipment. The Occupational Therapy Department is in charge of RX's, LOMN's for environmental control units (ECU's), computer equipment, driving evaluations, and equipment for activities of daily living (ADL).

The Rehab. Technology Department operates on a consultation basis. Areas of expertise include ECU's, computer equipment, switches, electronic adaptations, call light systems, backup ventilator alarms, and recreational equipment. The Rehab. Equipment Department is in charge of the set-up and maintenance of all SSC wheelchairs, in-house DME, and the fabrication of custom wheelchair and seating items.

Upon admission, a patient enters the acute stage of rehab.: Phase 1. At this time, the patient is unable to tolerate 3 hours of therapy per day. Initial evaluations are conducted during this phase. The patient is assigned a Physical Therapist (PT) and an Occupational Therapist (OT). A Rehab. Technology Engineer sets up equipment to provide access to the call light, TV and phone. The OT screens the room technology and consults the Rehab. Engineer (RE) if different access is needed.

As soon as possible, an assistive technology team arranges a Seating Clinic meeting. The PT completes an initial wheelchair request form and submits it to the Rehab. Equipment department. Rehab. Equipment then sets up a wheelchair to be used in the initial Seating Clinic. The PT, OT, Rehab. Equipment Technician, and Seating Clinic Staff are present at the first and each following seating clinic. This collective input reduces continual wheelchair modification by providing a more comprehensive prescription.

Phase 2 begins when a patient can withstand 3 or more hours in therapy. Within two weeks, the OT completes a technology screening checklist. The OT makes an appointment with a RE to evaluate the patient for appropriate technology. The OT and the RE meet at a minimum of bi-monthly to clarify and update the patient's technology needs.

During this time, the PT evaluates wheelchair and seating needs for the patient. Follow-up seating clinics are scheduled as necessary. In the clinics, staff members consider how technology such as ECU's will be interfaced with the wheelchair. Custom items such as wedges or backs can be fitted. Rehab. Equipment makes the changes as soon as possible so the patient can be placed in the optimal position for learning functional and ADL skills.

Final prescriptions for all assistive technology are completed during Phase 3. The OT makes sure the RE has the final prescriptions and consultation reports for custom equipment and training. The PT schedules a seating clinic for final wheelchair and seating prescriptions. If equipment is delivered during Phase 3, the assistive technology team provides training to the patient. The patient's family is trained on all equipment during Family Training Sessions.

ACKNOWLEDGMENTS

Special thanks to the Physical Therapy, Occupational Therapy, and Rehab. Technology Departments at Shepherd Spinal Center.

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TEAMWORK
AN INTERDISCIPLINARY APPROACH

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ABSTRACT

Teamwork is the key component in solving unique problems. The following case study illustrates the interdisciplinary approach utilized with a Guillian Barre client. The purpose of this case study is to exemplify the effects of two professionals and a client working together to achieve a simple goal of eating independently within community settings. The primary team member is Bryan, the client. Additional members include the primary occupational therapist and rehabilitation technology specialist.

BACKGROUND

Bryan was initially hospitalized August 10, 1992 with Guillian Barre Syndrome. He was admitted to an acute care facility for three months and was then transferred to an acute care facility with multi-levels of care to participate in intense therapy. Bryan was evaluated and functional goals were established by the individual team members. A comprehensive treatment plan was designed to address the identified goals. Near the conclusion of his inpatient stay, his functional needs and specific durable medical equipment items were identified.

OBJECTIVE

The objective of this case study is to display the integrated approach used with Bryan. Utilizing the team approach is important when working with an individual with multiple needs. If we had neglected to collaborate, we would have limited Bryan's chances to obtain the necessary and appropriate equipment to function independently at home.

METHOD

The client was evaluated, goals were determined, and a treatment plan was completed. A need for durable medical equipment was evident.

To begin the durable medical equipment process, the primary occupational therapist and primary physical therapist obtained a physician's order. After receiving the physician's order, the referral form was completed and the specific items were recommended to assist in goal achievement. Primarily, Bryan was in need of a lightweight wheelchair, a rolling walker, a left balance forearm orthosis, and bathroom equipment items. To obtain these medically necessary items, the rehab technology specialist formulated a letter of medical necessity and prescription for procurement of the above mentioned equipment.

APPROACH

Following a period of intensive therapy, Bryan achieved many of the goals initially established and a discharge plan was established. By the time Bryan was discharged home, he was able to ambulate with a rolling walker but still needed assistance with self-care tasks. This was due to limited upper extremity strength and endurance. He continued to utilize the balance forearm orthosis mounted to his lightweight wheelchair to feed himself.

During the rehabilitation process, Bryan showed increasing lower extremity strength, and improved function. His upper extremity strength however was still not adequate to feed himself. Bryan no longer required the lightweight wheelchair for mobility yet needed the wheelchair to continue using the balance forearm orthosis for feeding.

After his discharge from the acute rehabilitation program, Bryan returned for a day rehabilitation program. One day during his occupational therapy session, Bryan asked his primary occupational therapist if it was possible to mount his balance forearm orthosis to his rolling walker. He stated that this would enable him to dine in the community without having to transport his wheelchair. The occupational therapist contacted the rehabilitation technology specialist with the question and they worked together to conclude that the task was feasible.

The following week, a standard balance forearm orthosis bracket was securely mounted to the upper portion of the right rear of the walker. To begin, Bryan sat in a chair with his walker positioned behind at his left side. Following the set up of the balance forearm orthosis, the device was tested for the first time. Subtle changes were made as Bryan attempted to eat his lunch. It appeared that the weight of the client's arm in conjunction with the balance forearm orthoses weight set the rolling walker off balance. To stabilize the walker, additional readjustments were required. The occupational therapist positioned the walker's left rear leg against the chair's right rear leg. This allowed enough stability for Bryan to independently feed himself.

RESULTS

Shortly after these modifications, Bryan reported that he was able to successfully dine out with his wife and three children.

DISCUSSION

This experience clearly exemplifies the importance of working as a unified team. If each discipline had functioned independently, the overall effectiveness would not have been the same. Without hesitation, the team considered the client's idea, believing that the opportunity to have him participate in creating solutions to a task would be beneficial. Without difficulty, he utilized the simple technology of mounting a balance forearm orthosis to a rolling walker.

Frequently, the most beneficial ideas are formulated by our clients. This example should encourage healthcare professionals to incorporate their clients in decision making and design processes, and to value an interdisciplinary team approach. This way, everyone has the opportunity to play an integral part in the rehabilitation process.

ACKNOWLEDGMENTS

Special appreciation is extended to Bryan and his family for allowing us to share their experiences. Thanks also to Carol Sargent for her engineering efforts. The authors acknowledge the Marianjoy Administration and the Departments of Applied Rehabilitation Technology and Occupational Therapy for their support.

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ADAPTIVE EQUIPMENT SERVICES VIA MOBILE SERVICE DELIVERY IN NORTH DAKOTA

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ABSTRACT

This paper describes the planning and implementation of a Mobile Service Project that provides adaptive equipment services for persons who have developmental disabilities in the State of North Dakota. The purpose of the project is to overcome geographic barriers to service delivery that exist in this large and sparsely populated state.

DEMOGRAPHICS

North Dakota is the most rural of all the states, with a population of only 635,000 and a total land area that ranks 17th in the nation. Forty-five percent of the state's residents live in larger cities such as Fargo, Grand Forks (eastern border), and Bismarck (south central). The remaining 55% live in rural farm communities that cover more than 90% of the land area.

HISTORICAL BACKGROUND

Since 1982, there has been a gradual movement of persons who have developmental disabilities from institutional based programs to community based programs in the state. Near its peak in 1972, the Developmental Center at Grafton was home to over 1000 persons with developmental disabilities. Presently, fewer than 190 people live at the Developmental Center.

During the same period, the state has supported the development of adaptive equipment services to assist people remaining at Grafton, and in communities throughout North Dakota. Services such as seating and positioning, vocational adaptations, mobility, communication support, environmental control, and classroom adaptations are available to individuals statewide.

Despite the "availability" of these services, Grafton's location at the extreme eastern part of the state has been a barrier to people living in the western part of North Dakota. People needing services often traveled six hours one way for appointments.

PROGRAM RATIONALE

Many individuals who have moved to the community from Grafton have severe cognitive, sensory, and physical disabilities. These people require access to adaptive equipment, along with a wide range of support services, in order to a be part of their communities.

The North Dakota State Council on Developmental Disabilities, made up of individuals who have a developmental disability, parents, and state officials, identified the need to improve access to adaptive equipment services in their 1990 Policy Analysis Report.

Given the geography and demographics of the state, and long travel distances to established services, the State Council began supporting the idea of providing these services through a mobile service delivery model.

A needs assessment survey of twenty-seven providers of residential and day programs was conducted. Nearly all programs surveyed perceived the need for greater access to adaptive equipment of all types. Although the survey did not include school age children at home, or adults living in family homes, their needs were expressed by members of the State Council familiar with individuals in these situations.

In May of 1991, the Developmental Center submitted a $50,000 two year grant proposal to the State Council for the purpose of developing and implementing a Mobile Service Project for adaptive equipment. The proposal was accepted and work began during the summer of 1991.

EQUIPMENT

The mobile service vehicle (MSV), designed to transport equipment and staff to clinic sites, consists of a Ford F-350 one ton trunk chassis with duel rear wheels and a 14 foot cargo box. The rear of the box is equipped with an overhead type door and an end gate lift (figure 1).

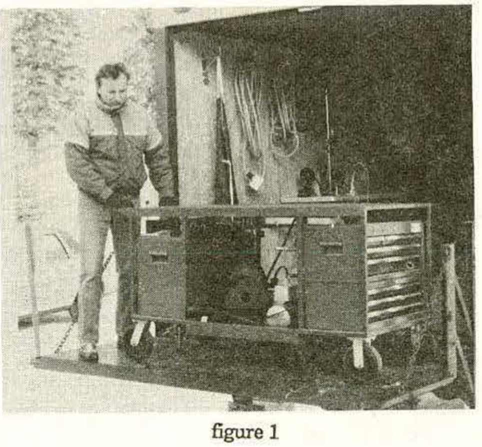

figure 1

The MSV is equipped with two custom 6x3 steel workbenches (figure 2). These benches were built around tool boxes containing all necessary electric and non-electric hand tools, parts, fasteners, and other materials. A smaller, wheelchair accessible workbench contains a drill press, bench grinder, and vise. In addition, the vehicle carries an industrial quality sewing machine, portable wire feed welder, and a portable metal cutting band saw. Materials such as foams, plastics, and upholstery stay in the vehicle and are obtained as needed.

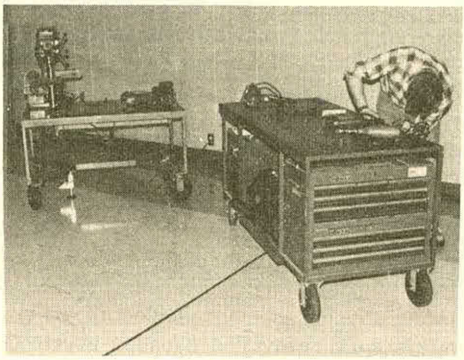

figure 2

The vehicle carries equipment and supplies necessary for fitting custom or commercial seating systems. A power chair simulator is available to clients who require assessment using alternative controls, such as modified joystick, multiple switch, single switch scanning, or head controls. All equipment is completely portable and is moved indoors at the clinic site.

SERVICE DELIVERY

Coordination

The key to this program is coordination at the local level. This is accomplished through the Regional Human Service Center network throughout the state. Staff at these centers take responsibility for advertising upcoming project visits, screening referrals, scheduling appointments, and coordinating with project staff prior to clinics.

The project also works to coordinate with local private suppliers of equipment. In many cases, the client is best served through the combined efforts of public and private providers of adaptive equipment services.

Staffing

Staffing for a clinic visit usually consists of the project director (a physical therapist), an adaptive equipment specialist, and, an adaptive equipment technician.

The project director coordinates with local personnel at the clinic site, and provides clinical support during assessments and fittings. The director maintains client documentation, works with funding agencies, and makes changes to the delivery system based on feedback from clients and local agencies. The adaptive equipment specialist provides fabrication services on-site if possible, or brings projects back to Grafton if needed. project staff try to complete as much fabrication work as possible during the clinic visit.

Areas Served

This is a new project and has yet to become truly "state-wide". The project currently holds clinics in Minot, a larger community in the north central part of the state. The project draws clients to Minot from smaller communities within one hundred miles. Other stopping off points have developed en route to Minot. Recently, the project expanded its services to the Bismarck community, located in the south central part of the state. A similar system of stopping off points and nearby community referrals seems likely to develop. Future expansion will depend on the success of the program and funding.

RESULTS

The Mobile Service Project has improved access to custom adaptive equipment services for persons living throughout North Dakota. In many cases, people are receiving services in their home communities. Those who must travel to clinic sites can do so comfortably within 1-2 hours. The project is a resource for local programs that are supporting people using adaptive devices. For example, custom mounting of devices and switches has helped to improve the effectiveness of existing technology.

Project staff have been effective advocates for persons seeking funding for assistive devices, especially state Medicaid funding. Overall, the project has been extremely rewarding for clients, staff, and families who have participated.

ACKNOWLEDGMENTS

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Utah Assistive Technology Foundation to Facilitate Funding for Assistive Technology

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ABSTRACT

To address the problems of funding the purchase of assistive technology, Utah has established a private funding foundation whose purpose it is to solicit funds from corporations, service clubs, individuals, and other foundations to be used to assist in the purchase of assistive technology for persons with disabilities in Utah.

This interactive display will include the objectives, major procedures, and activities of the Foundation. Brochures, a video, and other assistive technology funding solicitation materials will be available as handouts.

BACKGROUND

In the field of assistive technology there are few issues more pervasive than funding. New innovations, sophisticated delivery systems, expert diagnosis, all mean little if there isn't money to purchase the needed devices and maintain them. The funding maze has been referred to as a colossal bottleneck and in one way or another is the link pin to all of the other problems within our systems.

Virtually every human service program is under funded and must do whatever they can to contain costs. Generally, that means restricting eligibility, eliminating services or complicating the application and approval process. Many social service agencies have found that by not having clear regulations, decisions can be made much more informally and they can restrict, exclude or discourage new costs. As a consequence, most people seeking funding for assistive technology must utilize a variety of skills including persistence, bluff, pressure--almost deceit.

It is estimated that between 25 and 46 percent of the time of the assistive technology professional is spent identifying sources of funding, preparing purchase orders, justifications and getting purchasing approved (1). Because of this professional time investment, the cost of attaining assistive technology is 30-50 percent higher than it needs to be.

The private sector has a long history of providing funding to assistive technology. The Lions Clubs, Shriners, church-sponsored hospitals, and more recently, major funding drives such as Easter Seals and Christmas Seals have helped fund technology for years. We all know that certain assistive devices can be purchased if we go to our local Lions or Kiwanis Club, or a lodge or a church organization. This is one of the few non-public funding options. However, this source of funding does not solve the problem of reducing professional time invested in funding issues. On the contrary, it expands it. Most service clubs have their own agenda and needs and systematic repeat funding through such clubs and service organizations is difficult to maintain.

OBJECTIVES

To circumvent some of the problems identified above, Utah has established the "Utah Assistive Technology Foundation", a Federal 501(c)(3) tax-exempt foundation. The Foundation is a private organization established to assist in the rehabilitation of Utah citizens with disabilities by enhancing their independence, education, employment and quality of life through the use of assistive technology. To accomplish these goals, the Foundation solicits funds from individuals, associations, foundations, service clubs, corporations, and public sources which are then uses to pay for assistive technology devices needed by persons with disabilities.

Working with public and private service agencies in Utah, the Foundation focuses on meeting the needs of persons with disabilities that fall between the gaps of eligibility for other sources or people who need a funding package for more than one device, and/or upgraded devices. Public funding for these situations is usually very difficult to obtain.

OUTCOME

The Utah Assistive Technology Foundation has been operative for approximately a year. The Board members include leading citizens from business, banking, media and industry, as well as political figures in Utah. The Board of Directors guides the funding solicitation efforts of the Executive Director in approaching foundations and corporations for donations to the Foundation.

Solicitation materials including a fact sheet of the need for assistive technology in Utah, a brochure and a short video have been prepared. In addition, model funding proposals have been prepared. These are adapted as appropriate and submitted to potential donors for the Foundation.

The Foundation uses a simplified application form and process. Verification must be provided of the need and the appropriateness of the technology recommended by state service agency or recognized AT assessment team. Procedures to obtain recommendations and assurance of need, as well as availability of other funding, is checked by the Executive Director and members of the Board.

The funds provided to the Foundation are used in a variety of ways including: (1) guarantees for low-interest loans from financial institutions, (2) direct low-interest loans from the Foundation, and (3) direct grants for small components. Wherever possible, the Foundation funds are leveraged, combining them in funding packages from public sources.

The success of the Foundation is measured by the following criteria:

1. The amount of funds obtained.
2. Number of assistive technology devices purchased.
3. Funding from other sources leveraged for technology.
4. Repeat donations to the Foundation by donors.
5. The publicity and recognition provided to donors.

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AMERICANS WITH DISABILITIES ACT: ACCESSIBILITY ON THE "PATH OF TRAVEL"

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ABSTRACT

The object of this paper is to present the available information on assessing and modifying public facilities for physical access on the "path of travel" for persons with disabilities. The Americans with Disabilities Act mandates public and private facilities that offer service to the public be accessible to people with disabilities. Through the use of available checklists, rules, and regulations from included in Americans with Disability Act documents, assessments of "path of travel" in existing and new facilities can successfully be completed. Information is especially useful for individuals who might utilize adaptive devices, such as light switch extensions, lifts, and adaptive door openers, to aid in accessibility.

BACKGROUND

The passing of the Americans with Disabilities Act (ADA) increased awareness about persons with disabilities in this country. Title II of the ADA (Public Services) and Title III (Public Accommodations and Services by Private Entities) make reference to public access to both public and private facilities for everyone, specifically referring to people with disabilities. Title II and III are the sections of the ADA that include references to path of travel accessibility.

Path of travel is the most important part of barrier removal in existing facilities. It covers major access to the facility, as well as areas designated for traveling in and around the facility. The paths are the circulation networks that connect all functional areas of a facility and are critical to accessibility issues.

OBJECTIVE

The objective of this paper is to inform individuals about general requirements for path of travel accessibility as it applies to parking, entrances and doorways, corridors, light switches and outlets, and entrances to the program areas. This paper also will include information about resource and reference materials that are available related to the ADA. Understanding the requirements for each component of path of travel, can provide a knowledge base useful for practical application on existing facilities or for design of a new facilities.

APPROACH

This paper includes information about requirements for barrier removal as it pertains to path of travel. The ADA mandated that all facilities which fall under the jurisdiction of Title II and Title III prepare a plan of action for accessible barrier removal of facilities before July 1992. The plans include a list of barriers for existing facilities and a prioritized schedule for removal of these barriers. The requirement of barrier-removal plans of action made accessibility surveys of existing facilities in high demand. But the law only required that the plans be prepared by July 26, 1992. The actual barrier removal process, however, is completed at the discretion of the owner based on prioritized accessibility.

Path of travel is the progression from arriving at a facility to entering into publicly accessible program areas. Publicly accessible program areas include areas in which goods and services are provided for public use. Some examples include: conference rooms, offices, lobbies, reception areas, and restrooms and elevators. Publicly accessible program areas do not include janitorial, maintenance, or private service areas as these areas are not used by the general public.

DISCUSSION

The ADA defines path of travel as a 36-inch-wide route, with no obstructions greater than 1/2 inch above the floor plane. This route provides a smooth, hard surface with access from parking and walkways to primary building entrances, and then to the interior of the building, including major building program areas and support facilities.

The ADA does make specific reference to each of the particulars of path of travel considerations in the Americans with Disabilities Act Accessible Guidelines (ADAAG). The ADAAG was established to specifically reference the technical information necessary for proper architectural barrier removal, enabling an individual to compose surveys for accessibility barriers themselves.

The path of travel begins in the parking lot. Quantity, size and signage of parking spaces are determined by the ADAAG. Curb cuts are essential for accessing entrance walkways, and ramps for building access are useful only if they meet guidelines determined by the ADAAG. The regulations state guidelines for ramp slope, width, surface friction, handrails, guardrails, and landings, and it offers some suggestions for proper ramp design.

The path of travel entrance sequence is carefully outlined in the ADAAG. Regulations for doorways, types of hardware, floor surfaces at the entrance, signage, and thresholds are detailed for correct access. Information on emergency egress in the form of emergency lighting and signals is specifically mentioned as it pertains to persons with disabilities.

Circulation through the facility, both horizontal and vertical, is discussed in regard to direct access, widths for passing of other persons, and doorways. Vertical circulation is defined through details of accessible stairways and elevator configurations. Also, the requirements for proper access to lighting controls and electrical outlets are detailed in the ADAAG.

Following the requirements stated in the ADA and the ADAAG will help achieve technical accessibility. According to the ADA, this is all that is required. Technical accessibility is different than personal accessibility. Consideration should be given to the different needs of specific users because each individual has his or her own needs that require accommodation in different ways. Assessment of a public facility for accessibility should also include inquiry about any specific requirements users of that facility might require in order to best accommodate them. Convenience also should be taken into consideration. Locations of restrooms and conference rooms in relation to elevators and frequently used program areas is key in improving personal accessibility. A building could technically be accessible but still be inconvenient for persons with disabilities.

The U.S. Department of Justice (the governing body for the ADA) has published a checklist for identifying and resolving path-of-travel barriers. The document is entitled, "The Americans with Disabilities Act Checklist for Readily Achievable Barrier Removal," and is available from each state office of the Department of Justice. This document includes step-by-step instructions for each component of path of travel. Instructions are prioritized, according to the progression on the path of travel.

CONCLUSION

The goal to making barrier assessments and modifications to facilities as mandated by the ADA is to provide access to publicly available goods and services for all people. By understanding the requirements for path of travel accessibility, through visual identification of the problems and resource utilization for verification, the rest of the accessibility requirements, (telecommunications, restrooms, and program areas), will be become much more understandable.

The use of various assistive devices throughout the accommodations phase of accessibility will be imperative as part of alterations. Various kinds of ramping and handrail devices, door-knob adaptive devices, outlet and light-switch extensions are just a few of the possible accommodations. Path of travel is particularly important because the ability for individuals with disabilities to access the inside of a facility is the beginning of complete structure accessibility.

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THE EUROPEAN SINGLE MARKET IN REHABILITATION TECHNOLOGY

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ABSTRACT

An extensive program for facilitating a single market in rehabilitation technology has been launched by the European Community. In the pilot phase, 21 research and development projects are under way. A Europe-wide study of different factors affecting rehabilitation technology development will help to create international harmonization and collaboration.

BACKGROUND

The actions in Europe towards integration, collaboration and harmonization between countries have now reached the field of rehabilitation technology. The aim of the European Community is to create a single rehabilitation technology market. This concept does not only include freedom of trade but also collaboration in research and development, information dissemination, sharing of knowledge and experiences, joint institutions, etc.

STATEMENT OF THE PROBLEM

In studying the rehabilitation technology field from an industrial perspective, the Commission of the European Communities (CEC) has observed that the markets in the individual countries are relatively small and fragmented. This has not allowed the economies of scale that could deliver products incorporating up to date technology at reasonable prices (1).

Meanwhile, it has appeared increasingly evident to actors in the field in Europe, that, given the right support, coordination and resources, technology holds a strong potential to meet the needs of disabled persons (2). But it will take well-organized, joint efforts on a transnational level. And it must include involving new actors, such as major IT&T industry, in the field.

The complexity of the rehabilitation market creates special problems. There are many different actors and factors that impact the market in important ways. Many of them are regulated by national legislation, procedures, organisational structures, tradition and culture and by international endeavors such as standardization and research and development cooperation.

Furthermore, recent legislation in the U.S.A., such as the Americans with Disabilities Act, is seen as a strong stimulation of U.S. industry and a threat against the competivity of European industry in the European market and on a global level.

APPROACH

Some cooperative actions at the European level, such as COST Project 219 "Future Telecommunication and Teleinformatics Facilities for Disabled People" have been initiated earlier. However, these were considered insufficient by the Commission of the European Communities (CEC) to support an efficient single market or a healthy indigenous industry of the future. After a number of studies carried out by industry and academics, the TIDE (Technology Initiative for Disabled and Elderly People) was launched in 1991 (3).

Pilot Action Projects

For the TIDE Pilot Phase, 70 proposals were submitted. 21 projects were selected for funding. The total budget including the national contributions is US$ 25 million. These projects have been grouped into five clusters (4):

- General models and tools
- Manipulation and control
- Personal communication
- Safety and daily support
- Access to information.

Each project is carried out by a consortium made up of partners from several countries, including industry, research institutions and rehabilitation institutes. The projects will run for 18 months through the first half of 1993.

Ten of the 21 projects have been selected for an extension of another 18 months with an additional total budget of US$ 12 million. They are:

CORE - Consensus Creation and Awareness for Research and Development Activities in Technology for Disabled and Elderly People
INSCAD - Development of a CAD/CAM System for Manufacturing Customised Insoles for Shoes
MECCS - Modular Environmental Control and Communications System
SYMBOL - Multilingual and Multiple Lexical Learning on CD-I Environment
MUSA - Multilingual Multimedial Speech Aid for the Hearing and Language Disabilities
STRIDE - Speech-analytic Hearing Aids for the Profoundly Deaf in Europe
FASDE - Future Alarm and Awareness Services for the Disabled and Elderly
CAPS - Communication and Access to Information for Persons with Special Needs
AUDETEL - Audio Description of Television for the Visually Disabled and Elderly.

The projects, as well as all work carried out under the TIDE program, follow the five TIDE principles:

- Market Orientation
- Technology Adaptation and Innovation
- Multidisciplinary Approach
- Technology Verification
- User Focus.

HEART Study
In order to address some important factors impacting rehabilitation technology research and development, TIDE has also initiated a European study, called HEART (Horizontal European Activities in Rehabilitation Technology). It will be carried out by a consortium made up of 21 institutions, organizations and companies under the leadership of The Swedish Handicap Institute.

The objectives of the study are:

- to survey, analyze and assess the current situation
- to spread information about the current situation
- to create communication channels between actors in Europe
- to show routes to facilitate the creation of a single market by proposing directions and priorities.

The study will cover six areas affecting rehabilitation technology including the following activities:

- **Standards, testing and certification/ specification**
  -Survey of testing procedures and test houses; ways to increase cooperation
  -Survey and assessment of current standardization work
  -Proposal of new areas for standardization, both for assistive devices and for the integration of disability requirements in other standardization
  -Pilot work with user influence on standardization and testing requirements
- **Coherence between and among industrial sectors**
  -Existing links
  -New means to establish or improve links
- **Service delivery**
  -Descriptions and analyses of national systems for 15 countries
  -Identification of optimal systems or components
  -User involvement
- **Legal and macroeconomic factors**
  -Listing and assessing legislation and regulations on rehabilitation technology in 11 countries; proposals for future actions
  -Survey of existing socio-economic models; proposals for future actions
- **Training**
  -Survey of existing programs for RT training
  -Identification of training requirements
  -Proposition for components of European curricula
- **Emerging areas of research and development**
  -Identification of new technologies with potential for disabled and elderly people
  -Proposal of ways to achieve synergy between new technologies and rehabilitation technology.

IMPLICATIONS

The TIDE initiative raises the need for a single market in rehabilitation technology to the level of a European political issue and provides a forum bringing together people and organizations with an interest in such a market. The achievement of a single market will make needed equipment and services available to disabled and elderly people at a high quality and a reasonable price. The emphasis will always be on the needs and requirements of the users. In this sense, TIDE is a user-focused program, meaning being responsive to the real needs of users (5).

With the TIDE program, Europe has taken a giant step towards creating a true single market in rehabilitation technology. According to current CEC plans, the program will be given increased resources in the coming years, thus giving a strong contribution to the development of rehabilitation technology in Europe and the world.

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AN ENVIRONMENT FOR CONTROL ASSESSMENT

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ABSTRACT

This paper describes the integration of an environmental control assessment into a home-like apartment located in a hospital. Equipment tables which guide the clinician on matching clients to environmental controllers were developed. Databases for client and device information are used for tracking purposes. An outcome measure which looks at client's rating of importance, performance, and satisfaction with environmental controls is used to measure the effectiveness of service delivery.

BACKGROUND

An Assistive Device Service (ADS) team, located in a rehabilitation hospital, serves clients from Alberta and the North West Territories who are disabled either at birth or through accident or illness. The team evaluates, prescribes and trains clients and clinicians to use technical devices in the areas of computer access, augmentative communication, powered mobility and environmental control systems. The client population includes spinal cord injury, cerebral palsy, muscular dystrophy, multiple sclerosis, and amyotrophic lateral sclerosis. The team helps to develop the client's skills and confidence in a goal-setting program that usually leads to integration into the community. Independent living and maximum personal functioning are desired outcomes.

Environmental control (EC) provides physically handicapped individuals with the opportunity to independently operate electrical appliances in their own home, hospital, extended care facility or workplace setting. The components of an EC system include an access method, controller unit(s), transmitters, receivers and the items to be controlled. Access methods range from speech recognition to single and multiple switch use via scanning displays. Environmental controller units can be simple single-function controllers or they can be complex multiple-function units, using dedicated controllers, computer software or powered wheelchair environmental control boards. Examples of items that can be controlled in this way include household items such as lights, television, stereo, blinds, windows, telephone, door opener and lock, electrical bed, infra-red controlled appliances and power appliances.

For the client, environmental controls may increase safety, productivity, self esteem, quality of life, and decrease attendant care (3). Potential for cost savings is enormous, as a happier productive client may need less medical intervention (1).

Within the hospital there is an Independent Living Suite (ILS), where a client may stay a few days to determine his/her abilities to live in the community. The ILS is a fully equipped apartment. A spouse, significant family member, or residential aide may accompany the client to simulate the home situation. This is an important transition between hospital and home for the client. In the fall of 1992 an Environmental Control Demonstration Centre (ECDC) was established in the ILS. This allowed the ADS team to effectively portray the benefits of an EC system to potential users in a functional setting. Another facility, in Pittsburgh, opened its Environmental Control Room in August, 1992, to provide a similar service (2). This type of integration represents a service not available elsewhere in Alberta or the North West Territories.

Despite its potential, we have not often recommended EC to our clients, partly because it is difficult to demonstrate it effectively. In the past, we used an EC Workstation to demonstrate some EC methods. This was a small cabinet on wheels with electrical outlets, lights, and several kinds of wall switches. It was stocked with EC modules and various appliances to control. While this was fine for showing our clients the control methods available, it did not catch the imagination. People were left with the feeling that EC is only a fancy and expensive way to turn on the lights.

The ECDC allows our clients to explore EC in a living environment. They can see it helping them to do a variety of things - opening doors to admit a visitor, drawing the drapes to increase privacy, turning up the heat, controlling the television and other home entertainment equipment, and, yes, turning on the lights. The home-like atmosphere of the ILS shows that EC is not just hospital equipment or a curiosity. Our clients can practice using the equipment, and decide which items they will use and which they will not. We can model for them some home modifications they may want to make, such as the installation of electric door openers.

The ECDC in the ILS has convenient aspects for us as assessors: the devices to be controlled can remain in place most of the time. Only the controllers will be taken out and put away often, as clients have varying abilities and will use different methods of control.

OBJECTIVE

The purpose of the ECDC is to effectively and efficiently demonstrate ECs to clients, family, clinicians and community. The objective was to develop a protocol to aid clinicians make the best equipment choices, a database to track users and devices, and an outcome measure to rate user satisfaction.

APPROACH

The environmental control system assessment is carried out in the ECDC. All hospital clients regardless of age or disability have access to the ECDC. We encourage high involvement from family members in the rehabilitation process for feedback on the appropriateness of devices and access methods in relation to the client and home.

The ECDC has also been used to train clinicians and educate funding agencies, equipment suppliers and handicapped housing agencies.

Out of town clients send a videotape to the ADS team prior to his/her arrival. The videotape contains footage of the client and the living area, and possible appliances he/she would like to control. After being viewed by the ADS team, EC systems are set up in the ILS that could possibly meet the clients needs.

To help clinicians decide what devices to set up for the EC assessment Environmental Control Equipment Tables have been developed. There is a set of tables for each access method: voice, scanning, or direct. Within each set there is one table for each item to be controlled, the television, for example (Table 1). The clinician looks at the table then assesses the client on each controller listed. If the client is interested in controlling more than one appliance, the clinician compares tables for a common controller. For example, if the client also wanted to access the telephone, one common piece of equipment would be the EZ controller, so the clinician would assess the client on that device. There are many controllers for every appliance: this is a logical way to manage that sometimes overwhelming problem.

Table 1: Television Table

Access Method: Scanning	
Item to control:	Television
Controllers:	Relax[1]
	ACS Controller[2]
	EZ Control[3]

1. TASH, Inc., Markham, Ont.
2. ACS Technologies, Inc., Coraopolis, PA
3. Regenisis, North Vancourver, B.C.

The EC equipment we have available includes: various controllers for telephone, television, appliances, and single switch devices. These controllers use voice, scanning or direct access and they are single or multi-function devices. Items that we can control are as follows: call bell, television, tape recorder, radio, lamps, appliances, Christmas tree lights, telephone, and door opener/lock.

A database is used to monitor the use of the ECDC, tracking information on who it was demonstrated to and what they were interested in. Another database used by the ADS team tracks what has been prescribed to the client. It contains information on: method of access (direct, scan, voice); site of access (head, hand, etc.); location of access (chair, bed, work station); accommodation (house, apartment, hospital); type of device; when it was recommended/ordered/received; service person; and information on integration with other systems.

To measure the effectiveness of the ECDC assessment process the Canadian Occupational Performance Measure (COPM) is used (4). It is based on an explicit model of Occupational Therapy. The COPM is an outcome measure designed to assess the client's perception of his/her occupational performance. The COPM looks at three areas: self care, productivity, and leisure. It incorporates the role and role expectations of the client; considers the importance of performance areas to the client; and considers the client's satisfaction with present performance. This measures client identified problems and incorporates re-assessment of these problems. Depending on client needs, the therapist will ask questions to identify occupational performance problems such as:

1. In the area of self care do you have concerns about calling for help?
2. In the area of productivity do you have difficulties using the computer to complete your school work?
3. In the area of leisure do you have difficulties turning on the television?

The COPM is administered at the beginning of the assessment and the problems are identified. Reassessment on the COPM after a trial of equipment has been completed will assist therapists in determining the effectiveness of the equipment in meeting the identified problems. The COPM will be used to follow up the client to determine if there are occupational performance problems remaining, or if new problems have emerged. It is proposed that follow up occur at 6, 12 and 18 month intervals and on a needs basis after that. The follow up will alert the team to intervene when necessary and monitor the client's progress. This is necessary as a client's function may change, or new improvements and upgrades in the system may develop.

DISCUSSION

This new model of the EC assessment has the advantages of being both more efficient and more effective than our previous model. Because the devices are always in place, there is little set up time required each time the system is used, which makes it easier to use on a day-to-day basis. Because the clients will try out devices in a realistic home environment there will be fewer home visits by staff. Having devices readily available on site eliminates the need to loan out equipment for home trial, leading to greater efficiency.

The use of devices in a functional dynamic setting leads to more appropriate recommendations related to specific individual needs. Early introduction of EC to potential users leads to greater acceptance of EC and an immediate focus on integration of EC into the home environment (1). Having equipment readily available also permits us to train clients and aides in its use prior to the equipment being installed in the client's home. These lead to greater effectiveness.

Clients have given positive feedback on the ECDC, one excitedly remarking about the "cool Star Trek" stuff. Generally, it allows clients to see and use equipment without undue pressure. The ADS team found that families who attend demonstrations in the ILS can better support the client when technological devices are introduced because they were familiar with the purpose and function of the equipment.

The ECDC provides an efficient, effective, and unique method of service delivery. It is the first stage of a long term plan to better demonstrate environmental controls in the home and work place. The next stage will be the development of an environmental control vocational work station. The ECDC maximizes our hospital resources in equipment and staffing. The outcome measure ensures the provision of the right care, to the right client, at the right time, at the right cost.

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A THOROUGH AND SYSTEMATIC APPROACH TO ACCESSIBILITY AUDITING OF EXISTING FACILITIES

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ABSTRACT

The Americans with Disabilities Act (ADA) provides a vehicle for persons with disabilities to bring legal action against an entity which discriminates against the individual by not allowing the individual to fully enjoy the goods and/or services provided by the entity. The ADA requires the immediate removal of all architectural and transportation barriers that are readily achievable and planned removal of barriers requiring more extensive remodeling. This has created a need for thorough accessibility audits of buildings and new construction. The purpose of this paper is to describe an approach to complete a thorough accessibility audit. This approach incorporates an interdisciplinary team with a standardized systematic method that is applicable to any building or facility regardless of purpose or size.

BACKGROUND

The passage and eventual implementation of the ADA created a greater need for professional accessibility consultations. In response to this high demand, individuals with varied backgrounds began offering accessibility consultation services, spurring the growth of the ADA consulting industry. Architectural firms, advocacy groups, occupational therapists, physical therapists, rehabilitation engineers, management consultants, interior designers and many others have provided clients with advice on removing barriers in existing facilities. As with any industry that experiences this type of rapid growth, quality is not a common denominator among all those providing the service. A good reflection of this is the number of derogatory news items about groups offering ADA consultation services. Often missing in these news items is an explanation of what are the necessary qualifications for quality accessibility consultation which leaves the audience still not fully informed.

Many perspectives are necessary for quality accessibility consultation. The following examples highlight a few perspectives and their respective importance. People with disabilities are a tremendous resource of information based on practical experience. Allied health professionals such as occupational and physical therapists, vocational counselors, rehabilitation engineers and rehabilitation technicians are trained in accessibility and work with a variety of people with disabilities thereby giving them experience with barriers and accessibility products in a variety of situations. Architects, engineers and general construction contractors also have an important perspective based on their experience and training in building design and construction.

The provider of the ADA consultation must also be well versed in the ADA. The question then remains: who should be providing accessibility consultations? The answer is that quality accessibility consultation combines input from all of these sources because each perspective is unique and important. This leads to the importance of a standardized process for auditing existing buildings and new construction.

A thorough and systematic method of auditing a building for architectural barriers must be used to insure that all barriers, as defined by the current specifications, are identified and addressed. The standardized audit process should be flexible enough to be used in any type of building or facility regardless of purpose or size. One such method, the ADApt America Accessibility Auditing System, has been developed and is currently used on a wide variety of facilities.

OBJECTIVE

The objective is to provide a complete accessibility auditing service that identifies architectural barriers and provides a barrier removal plan that includes specifications for appropriate renovations in a user-friendly format.

METHOD

The complete accessibility auditing procedure contains three steps: pre-audit preparation, on-site audit, and final report.

Pre-Audit Preparation

The pre-audit preparation involves organizing floor plans and, when available, construction drawings. Time spent preparing for the audit is well spent and has proven to be invaluable in most of the larger facilities. For example, one facility audited using this method is the MetroHealth Medical Center, a hospital facility with more than 1.2 million square feet of finished building space and an additional 200 thousand square feet of exterior parking and grounds. The auditing team reviewed the floor plans of the hospital facility in detail to develop a feel for the buildings. It is very easy to lose any sense of direction in enclosed corridors and winding hallways which is of course extremely detrimental to the completion of the audit. The floor plans also provided a reference used to determine an identification scheme for each element of the facility.

The site plans were also used as a convenient reference for the management of the project. Each building on the site plan was marked identifying the auditing team and showing a timeline for the completion of the building.

All of the specifications addressed in the ADA Accessibility Guidelines (ADAAG) have been organized into groups reflecting common building elements such as hallways, rooms, entrance, elevators, alarms, etc. The audit forms for each element include the specifications in Yes, No or N/A question/answer form. A "No" answer indicates a barrier. For a facility audit the forms are compiled in an easy to follow walk-through format. There is an audit form for each specific element of the facility. The element audit forms are identified for each building element and compiled into a complete set for the building.

On-Site Audit

The auditing team then completes an on-site review of the facility using the prepared auditing forms. Each audit question which is answered "No" indicates a barrier. Each barrier is addressed as it is encountered and barrier removal actions are also noted at that time. Barriers requiring extensive remodeling or a particular expertise are indicated and addressed later by the appropriate professional, usually an engineer or construction expert.

At times it may not be possible to review an entire building. For example, Ohio Bell was awarded the contract to provide a Telecommunication Relay Service (TRS) to the State of Ohio in accordance with Title IV of the ADA and decided to place the TRS in an old telephone equipment building. Due to the high visibility of this project, particularly among advocacy groups, Ohio Bell wanted to make this facility a state-of-the-art barrier free environment. The building was audited but a great deal of the accessibility consultation was done using the construction drawings of the proposed space because the installation of the TRS required extensive remodeling.

Final Report

The final report includes an executive summary, summary table, barrier descriptions, barrier removal actions and information on appropriate accessibility products. The executive summary addresses the most common barriers found and the most involved barriers that should be addressed immediately. The summary table provides a great deal of useful information such as the cost estimates and priority of each barrier removal action in an easy reference format. The cost estimates and priority ratings are important for the client to develop a short term and long term barrier removal plan. The auditing team can identify barriers and suggest solutions but only the client can determine how much money will be spent and when.

A client that operates over two dozen shopping centers nationwide is using the summary table as the barrier removal plan. This enables the client to record progress and effectively and efficiently manage many projects easily.

DISCUSSION

In the past, accessibility was determined by a set of standards that we kept in our head that reflected our training and experience. The ADA has introduced attorneys into this work and this is no longer an acceptable practice. The courts will require documentation. This documentation should address all the barriers represented in the currently accepted accessibility guidelines, the ADAAG. A thorough and systematic approach to this work provides a mechanism for recording the proper documentation. The ADA has left a great deal of work to be decided by the courts; therefore, detail is of the utmost importance.

In the spirit of thoroughness, the team concept has evolved. Rehabilitation professionals and anyone involved with accessibility work should recognize the collective strength of a diverse group. Many perspectives must be considered to provide a client with the very best professional advice.

This ADApt America Accessibility Auditing System has been used extensively and proven very effective. The client response has reaffirmed that this system provides very useful assistance as an early step towards ADA compliance.

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SIG-02
Personal Transportation

PERFORMANCE TESTING OF WHEELCHAIR LIFTS FOR PERSONAL LICENSED VEHICLES

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Introduction

Standards for the design and testing of wheelchair lifts have not changed since 1977 when the Veteran Administration adopted the "VA Standard Design and Test Criteria For Safety and Quality of Automatic Wheelchair Lift Systems for Passenger Motor Vehicles." These standards have become outdated for current lifts in many aspects. In an effort to update and develop new, accepted performance standards for designing and testing wheelchair lifts, the SAE Adaptive Devices Subcommittee developed a Recommended Test Procedure and Practice entitled *Wheelchair Lifting Device for Entry and Exit from a Personally Licensed Vehicle*, October 6, 1990. The SAE subcommittee then requested help from the University of Virginia Transportation Rehabilitation Engineering Center (UVA TREC) to aid in the evaluation phase of the standard through testing of different types of lifts.

This paper presents some of the findings during testing that are of importance to wheelchair users, prescribers and lift manufacturers. The proposed test procedure establishes minimum performance requirements and only lifts satisfying all the tests are considered in compliance. While most lifts manufactured today may not pass all aspects of the proposed standard, most conform to a significant number of the specifications. Some of the requirements of the proposed standard are very stringent and are still in the evaluation process. It is expected that through the acceptance of these standards, the reliability and performance of van lifts will improve and benefit the thousands of disabled people who rely on personal vehicles for transportation.

Background

In order to evaluate the Recommended Test Procedures (RTP), five lifts were identified by the SAE subcommittee and UVA TREC to be representative of the spectrum of lift designs currently available in the market. Four platform lifts, including track and parallelogram lifting frames driven by both hydraulic/electric and electromechanical devices, and one rotary lift were chosen for testing. Four of these were donated by lift manufacturers while one was purchased by the TREC.

The test procedure basically consists of four series of tests which include receiving inspection tests, visual inspections of the installed lift, specification requirements and a series of stress tests. The receiving inspection tests include checking the documentation provided and inspection of all the necessary hardware for installation. The visual inspection of the installed lift is comprised of an inspection of the installation of the lift per manufacturer's instructions and hardware, check for conformance with applicable design standards, in addition to dimensional requirements, inspection for single point failure conditions, electrical hazards, load distribution, vandal protection and maintainability. The following lift characteristics are tested under the specification tests: control switches, electrical current requirements, platform tilt angles, finish coating, maximum platform accelerations, platform openings, and other safety features such as a threshold warning system, wheelchair retaining device and manual backup system. Finally, the stress tests include an accelerated life cycle test, a static proof load test and a static ultimate load test, administered in the order listed.

In addition to the several engineering design requirements that wheelchair lift manufacturers have to meet, the new recommended test procedures propose a series of safety features that need to be integral parts of lifts. These major safety features and their explanations are outlined in table 1.

Methods and Results

As mentioned above, the method used by the UVA TREC to aid the SAE in evaluating the proposed standards involves performing the test procedures on the selected wheelchair lifts in a laboratory environment. One of the requirements of the standards specifies that lifts to be tested must be mounted on a test fixture similar in size and configuration to a van door. A testing fixture was designed (figure 1) for this purpose and was used to test the lifts selected. This testing table consisted of a sheet steel base, steel angle legs and "skeleton" structure, while an aluminum sheet was used for the table top. It was found, however, that being a rigid structure, this table does not simulate the elastic deformation of a typical vehicle's sheet metal structure mounted on a soft suspension. Also, mounting the lifts in accordance to the manufacturer's instructions resulted in not being able to evaluate the mounting brackets in some cases since the testing fixture does not resemble the van door interior. These design problems do not affect most of the tests performed on the lifts, but could compromise the validity of tests such as the accelerations of the lift platform and stress tests, since the appropriate van-lift mounting method may not have been used.

As a result, a new test fixture that conforms to the actual van-lift interaction to a much greater extent is being built as a substitute for the current testing table. The new design (figure 2) is made up of a van section cut out from a 1983 FORD full size van and mounted on a base structure to provide the necessary height and support. This new design will allow for more realistic testing of lift characteristics such as the mounting brackets and instructions. Also, changes will be made from the old test fixture design to make up for its weaknesses such as width (adaptation for space needed) and mounting of additional equipment developed for tests, as in the case of the ultimate strength tests which require the placement of a load on the center of the lift platform.

To this end, testing has been completed for the five lifts chosen. Although none of the lifts were able to fulfill all the necessary requirements and be considered in compliance, some important results were observed. First, the learning process involved in the lift testing raised many questions that

TEST	FEATURE TESTED
Occupant Hazards	Safeguards, sharp edges, projections, unprotected shear and pinch points, dirty and greasy surfaces that the user might come into contact.
Slip Resistance	Slip resistant type of material used on the platform to provide adequate tire-platform traction.
Electrical Hazards	Aspects of design which fail to protect the passenger from short circuits, electrical fires or such incidents.
Wheelchair Retaining Devices	Roll-stop or similar mechanism that prevents wheelchair and occupant from rolling off the lift and keep lift from moving if not properly interlocked.
Platform Angle	Platform deflection under load to prevent rolling-off the platform or unsafe conditions.
Platform Openings	Oversize openings that might prohibit safe use of wheelchairs with thin tires.
Acceleration Test	Smoothness of operation so that occupant does not experience sudden accelerations or decelerations.
Threshold Warning System *	Audible or visual alarm that warns wheelchair occupant if the lift is not in the proper position.
Manual Backup and Emergency Egress	Methods to allow manual operation of the lift by an able-bodied person with minimal effort in case of power loss or malfunction.

* Not currently available in any of the lifts tested or manufactured.

Table 1: Lift Safety Features proposed by the Recommended Test Procedure

enabled the UVA TREC to make recommendations for change and clarifications in the current proposed procedures. It also resulted in a greater interaction between the TREC, lift manufacturers as well as the SAE subcommittee so that problems can be discussed and resolved. Finally, it was possible to identify the major failure modes of current lift designs which can not only help evaluate the proposed standard, but also allow users, prescribers and manufacturers be aware of where present wheelchair lifts are performing poorly. Table 2 outlines the major tests where non-compliance occurred.

Of all the failure modes presented in table 2, the focus is on problems regarding the Accelerations, Accelerated Life Cycle, and Ultimate Load Tests. The Maximum Accelerations test specifies that lift motions must not exceed 0.3 g. in any axial direction. To give the reader a better idea of this requirement, 0.3 g of acceleration might be comparable to the acceleration or deceleration of an elevator as it starts or stops moving. Work is currently on going to find an appropriate method to measure these accelerations

TEST	EXPLANATION OF FAILURE
1. Receiving Inspection	* Poor Documentation - Owner / Installation / Maintenance manual(s) not adequate. * Documentation of compliance with required standards not provided.
2. Wheelchair Retaining Test	* Roll-stop method does not prevent the platform from rising even if not properly deployed. * Roll-stop device not able to withstand applied load.
3. Threshold Warning System Test	* Not available
4. Maximum Accelerations Test	* Excessive jerking, sudden accelerations and decelerations.
5. Accelerated Life Cycle Test	* Problems completing the required number of repetitive cycles successfully. Failures included a broken motor, a weak clutch, and excessive current draws under load.
6. Ultimate Load (Stress) Test	* Failure to withstand the load placed on the center of the platform. * Excessive deflection of the lift platform.
7. Limit Devices Test	* Lack of limit switches to cut the power from the motor once the desired motion is completed, especially on the UP and FOLD modes.

Table 2: Typical Lift Failure Modes observed.

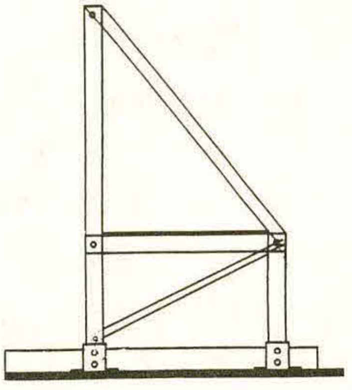

Figure 1: Orginal Test Fixture Design

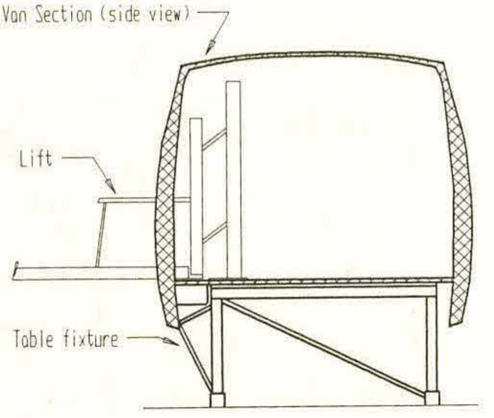

Figure 2: New Fixture Design

while filtering "noise" in the data obtained.

The Accelerated Life Cycle Test is the most time-consuming and perhaps most stringent test that lifts must pass. This test simulates two years of lift use by repetitively cycling the lift through 4400 cycles, alternating 1100 cycles unloaded, and 1100 cycles loaded with the rated load. Clarifications are still needed regarding the delay between cycles and other test conditions such as ambient conditions and maintainability. One of the main questions that arises is that of the validity of the requirements, since lifts never encounter such repetitive cycling in real applications. A compromise between test feasibility and requirements is still to be made. In reference to the Ultimate Load Test, lifts are required to withstand a static load of 2400 lbs. This translates to a factor of safety of 4 since the rated load is set at 600 lbs. The problem that comes up in this case is whether the standard should allow for prorated loads and ultimate load requirements. For instance, what load should be used to test current lifts rated at 400 lbs or new lifts rated at 800 lbs?

Discussion

The new Recommended Test Procedures and Practice proposed by the SAE subcommittee on Adaptive Devices is very rigorous in some of its specifications and will require wheelchair lift manufacturers to redesign some of the mechanical components of their lifts. The main goals of these proposed standards are lift reliability and improved safety features for the wheelchair occupant. The University of Virginia Transportation Rehabilitation Engineering Center's help in the evaluation phase of these procedures is essential in order to test these procedures for feasibility, clarity and rationale of the requirements.

At this point in the research, five different lifts considered to be representative of the existing designs were tested and the main failure conditions were identified. Plans for testing two new different lifts, one using an under-vehicle installation, and one hoist type lift are also under way. Development of a better testing fixture for mounting wheelchair lifts is under way as well as improved testing equipment to validate tests. It is expected that these new standards for designing and testing wheelchair lifts will increase the reliability and safety levels of all wheelchair lifts manufactured in the future.

Acknowledgements

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Testing Procedures for Wheelchair Securement System Standards

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Abstract
The development of wheelchair securement system performance standards requires the development of standard tests to ensure reliable and consistent information. Questions have been raised regarding the significance of variations in the crash pulse, an important test parameter which helps to define the severity of the collision. To investigate the effect of crash pulse variations on securement system loading, a series of dynamic crash tests was conducted. Preliminary results indicated that variations of the pulse produced insignificant changes in securement loading. Additional work is needed to improve test sensitivity.

Background
For many products, performance standards have resulted in significant improvements. For example, auto safety standards have reduced the number of US accident fatalities despite an increase in the number of vehicles. In order to realize similar benefits for wheelchair securement systems, researchers, engineers, and manufacturers have worked since the 1970's to develop performance standards (Hunter-Zaworski, 1990). US standards for wheelchair securement devices for private vehicles are now being developed by the Society for Automotive Engineering's (SAE) Adaptive Devices Standards Committee Wheelchair Restraints Task Group. The development of product performance standards requires the development of standard tests to ensure reliable and consistent information. These tests must simulate real-world conditions, accommodate present and envisioned products, and be compatible with the capabilities of the majority of testing facilities. We are currently working with the SAE Task Group to develop wheelchair securement test procedures which include specifying the crash pulse, severity of the collision, and a reusable surrogate (test) wheelchair. These and the myriad of other testing parameters such as tie-down pre tension, and crash dummy positioning, have not been well documented. We suspect that the resulting lack of standard test procedures may explain cases in which a securement system which passed one facility's test failed another's (Schneider, 1992).

Crash Pulse Investigation
The severity of the collision is specified by the crash pulse. The crash pulse graph maps the sudden stop in "g's", loading in terms of multiples of the force of gravity acting on the decelerated mass (i.e. wheelchair weight), and the time during which the deceleration occurs. Because the proposed crash pulse corridor (Fig. 1) has been drawn to accommodate the rather wide range of pulse variations different test facilities are able to produce, the Task Force is concerned that this pulse variation may produce similarly wide variations in securement loading. Our investigation of this phenomenon has included the fabrication of hardware including an improved wheelchair test platform, a surrogate wheelchair, and reusable wheelchair securement system (Fig. 2). In addition to platform and chair mounted accelerometers, we have developed custom load plates to record chair wheel forces, and integral load instrumentation for the securement system. Preliminary static calibration and 30mph/20g sled crash tests conducted at the University of Virginia's Automobile Safety Laboratory (ASL) have been conducted to determine the quality of the data produced by our test hardware and procedures.

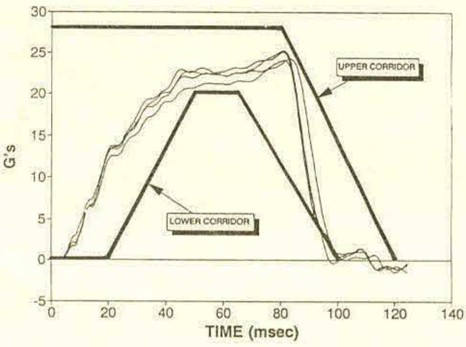

Figure 1. The crash pulse corridor and the four repeatability test crash pulses are presented in terms of deceleration in g's and time in milliseconds.

Repeatability tests: Four identically configured 30mph crash tests, with the surrogate chair and securement system (without a crash dummy), were conducted to assess our ability to duplicate test results. Test-to-test sled crash pulses, which were within the corridor, were very consistent (Fig. 1). The average maximum sled deceleration was 24.74g (24.14g low, 25.32g high) (Table 1). Maximum chair decelerations were also consistent, averaging 27.64g (26.57g low, 28.26g high). Chair deceleration pulses closely matched the sled pulses and lay within the corridor. This suggests good transfer of deceleration loads through the securement system. Left and right side rear tie-down loading, which should have been the same due to the symmetry of the test equipment and nearly identical left and right side chair maximum decelerations, varied unacceptably, with right load bolt readings averaging 8% higher. The maximum difference recorded was 12% or 525 lbf. In test-to-test comparisons of left side load bolt loading, the average variation from the 4364 lbf average was ± 18% (3577 lbf low, 5012 lbf high).

Tests of crash pulse variations: In the next series of tests, we studied the effects of variation in crash pulse on rear tie-down loading (as indicated by the left load bolt). Three different pulses, each of which with a sharper rise than the pulse used in the previous tests, produced an average maximum load of 4416 lbf (3825 lbf low, 5004 lbf high) (Fig. 3). A possible relationship was noted in average test-to-test tie-down loading and average chair deceleration. No such trend was evident in the repeatability test data.

	repeatability tests (105-108)			
maximum values	low	high	ave.	range
sled deceleration g	24.14	25.32	24.74	±2.4%
left chair deceleration g	26.57	28.26	27.64	±3.9%
left rear tie-down lbf	3577	5012	4364	±18%

Table 1. Repeatability test deceleration and loading values. The sled deceleration was recorded by an accelerometer mounted on the centerline of the sled carriage.

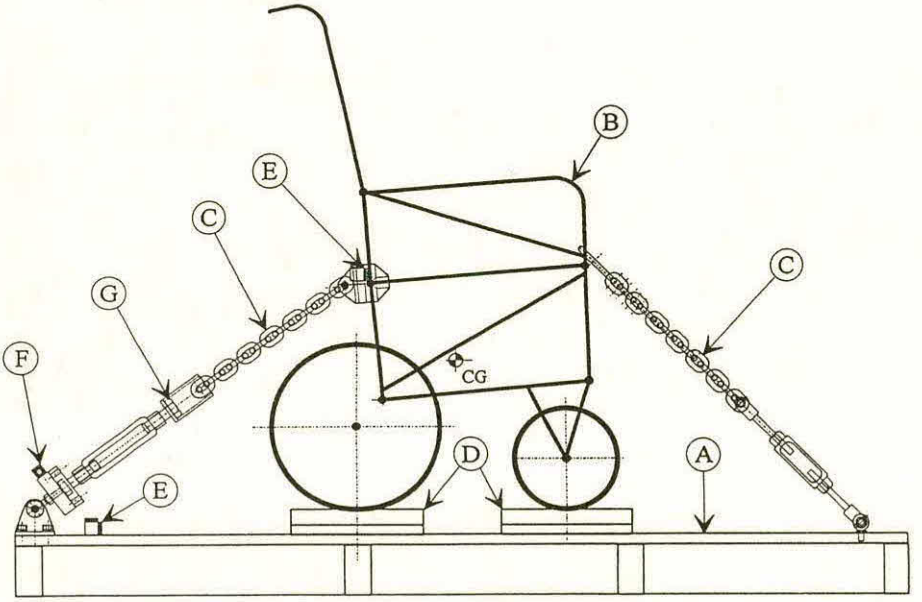

Figure 2. Test hardware including the wheelchair test platform (A), surrogate wheelchair (B), chain and turnbuckle tie-down securement (C), load plates (D), accelerometers (E), pancake load cell (F), and load bolt (G).

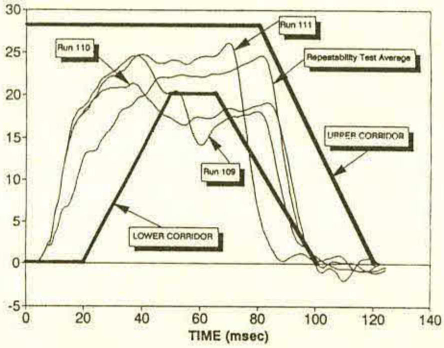

Figure 3. Three crash pulse variations, runs 109, 110, and 111, each rose more sharply than the average pulse of the repeatability test runs. All three pulses violated the lower bound of the corridor.

Discussion

In general, the repeatability tests indicated unacceptably large variations between left and right securement loading and among test-to-test loading. Variations of ± 9%, have been attained for test-to-test dummy lap belt loading in auto tests (Yoganandan et al., 1991). Because the movement of the chair is better controlled than that of a test dummy, a ± 9% variation is a reasonable upper bound for our future tests. Possible reasons for the left-to-right variations, which were also noted in chair deceleration curve shapes, include asymmetrical placement of the chair, uneven pre tensioning of the tie-downs, and asymmetrical deformation of the chair.

Chair deformation may also contribute to test-to-test variation. The amount of deformation diminished as the tests progressed and were imperceptable once the rear axle deformed until the top of the wheel tilted in to contact the chair frame. With the wheel and axle supported, the chair became much more rigid. The effects of this increasing rigidity may explain the downward trend in securement loading and chair deceleration witnessed in the last three repeatability tests. A prototype computer model suggested this response for a more rigid system. The results also indicate that a more rigid chair may more reliably respond to deceleration forces. (due to the reduction of dynamic reactions and deformations acting within the chair/tie-down/platform). We predict that a more rigid chair will significantly improve repeatability.

Despite the fact that the pulses violated the corridor's lower bound, the crash pulse variation tests failed to produce tie-down loadings which fell outside of the (wide) range recorded in the repeatability tests.

Conclusions

Based on this very preliminary data, we conclude that the wide variation in pulse allowed by the proposed corridor may not significantly affect the consistency of securement system test results. Additional tests, with tighter control of parameters, such as chair rigidity, positioning and tie-down pre tensioning, are required to establish narrower, statistically valid tolerance limits.

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FACTORS AFFECTING WHEELCHAIR OCCUPANT INJURY IN CRASH SIMULATION

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ABSTRACT

The kinematic response of the wheelchair seated body to a simulated crash event has been previously described in qualitative terms (1). This paper presents a more detailed analysis that has been performed on data from crash simulations. The relationship between the injury criteria of the occupant and the mechanics of the restraint system was investigated. It was found that when hip flexion was restricted by restraining the torso with a shoulder belt, there was an increase in neck flexion which correlated with an increased level of head injury.

INTRODUCTION

The prevalence of wheelchair users in the community is increasing as barriers are overcome by changing attitudes in society and federally mandated laws (ADA). The independence of wheelchair users and their ability to maintain employment is directly linked with their ability to obtain adequate transportation. Wheelchair securement systems have received considerable attention recently including the acceptance of federal guidelines, design considerations of some wheelchair manufacturers, widespread use of numerous commercial systems, and the funding of many research projects. In this work, however, the safety of the person seated in the wheelchair has not received adequate attention.

The automotive industry has invested considerable effort to research and analyze systems to protect the traveller using an automotive seat. No such effort, however, has been performed for the individuals who must remain seated in a mobility aid during transportation. In the absence of such information, many wheelchair and occupant restraint systems are coming into the market with designs that copy the familiar restraint systems used in automobiles. This paper will present data that indicates the dangers resulting from this design method.

METHODS

Data was collected from sled impact tests performed with a Hyge Impact Simulator (2). A model of the wheelchair bay of a large intra-city bus was mounted on the test sled. For each test, a mobility aid was secured to the model using either commercial or experimental securement systems. A 50th percentile male test dummy was seated in the mobility aid and restrained with lap and shoulder belts. The simulated impact was either a 10 or 20 g half period sine wave with a duration of 100 msec. All tests simulated a frontal collision. The test matrix is shown in Table 1.

Data was collected from on board instrumentation and analysis of high speed films taken during the crash event. The data that was measured directly from the instrumentation is shown in Table 2. The high speed films were analyzed using a motion analysis technique. Using FrameGrabber software, the images of 16 frames at key instances during the crash event were captured and digitally stored. Using customized software key landmarks on the occupant, mobility aid and test frame were digitized. This data was then used to scale the images and calculate the displacement of body segments and joint flexion angles throughout the crash event.

Table 1

Crash Simulation Tests

Test No.	Mobility Aid Type	Mobility Aid Securement	Shoulder Belt Height (in.)	Impact Level (g's)
1	Manual	Commercial Belts	36	20
2	Manual	Commercial Belts	36	20
3	Scooter	Commercial Belts	36	10
4	Scooter	Mod. Commercial Clamp	36	10
5	Scooter	Experimental Clamp	60	20
6	Scooter	Experimental Cables	60	20
7	Power	Experimental Cables	60	20
8	Power	Experimental Clamp	60	20

Table 2

Data Collected from On Board Instrumentation

Occupant
- Head Acceleration (3 axes)
- Chest Acceleration (3 axes)
- Hip Acceleration (3 axes)
- Chest Compression

Occupant Restraints
- Shoulder Belt Force
- Lap Belt Force
- Shoulder Belt Elongation
- Lap Belt Elongation
- Shoulder Belt "Pay-Out"

Mobility Aid
- Acceleration (3 axes)
- Floor Contact Forces (3 axes)
- Mobility Aid Restraints
- Rear Restraint Forces
- Front Restraint Forces
- Front Restraint Elongation

RESULTS

In tests 5-8, the shoulder belts were anchored 60 inches above the floor which is within the specifications being considered by SAE for their guidelines for wheelchair occupant restraints. In these tests, the torso was well controlled and head and chest excursions were limited. In tests 1-4, the shoulder belt was anchored only 36 inches above the floor and it was ineffective in controlling torso movement. The kinematic results and Head Injury Criteria (HIC) for each test are shown in Table 3.

The HIC value is a critical variable because it represents the extent of head injury that would have been incurred by an individual. A HIC of 1000 is the threshold of serious or fatal head injury. A large variation can be seen in the HIC values indicating that for the same simulated impact level, some occupants would have had only minor or no head injury, while others would have suffered significant head injury. Generally, a HIC value approaching 1000 indicates that the head impacted the vehicle interior. Because of the open space around a mobility aid in a large bus, however, in our tests there were no instances where the head struck the modelled bus interior.

Table 3

Maximum kinematic motions of secured occupants

Test #	Neck Flex. (deg.)	Hip Flex. (deg.)	Head Displ. (in.)	Chest Displ. (in.)	Hip Displ. (in.)	Mob. Dev. Displ. (in.)	HIC
1	68	119	20.2	19.1	17.1	4.4	200
2	44	148	25.0	21.7	12.0	4.2	82
3	68	135	28.4	27.4	12.2	4.7	57
4	26	144	24.8	23.5	10.1	2.3	11
5	95	105	19.4	14.4	8.7	1.4	837
6	94	95	15.3	9.4	7.4	.2	594
7	97	122	19.1	15.8	7.4	1.1	1311
8	84	108	15.6	13.6	6.8	1.2	312

The highest HIC values occurred in those tests where the torso was effectively restrained by shoulder belts mounted in the higher position. It was observed that for the cases of high HIC, there was a high degree of neck flexion and the dummy's chin struck its chest, providing the impact that produced the head injury. Analysis of the data shows a correlation (r^2=.86) of neck flexion and HIC values. This relationship is shown in Figure 1. It therefore appears that the head could be protected by controlling the level of neck flexion.

Neck flexion is found to be inversely related to hip flexion (Figure 2). No correlation could be made directly between hip flexion and HIC values. Interestingly, no other factors could be found to correlate with neck flexion or HIC values. It is likely that this is due to the very complex nature of crash dynamics in which many variable interact.

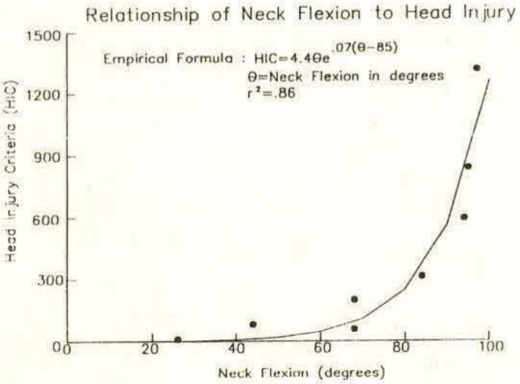

Figure 1

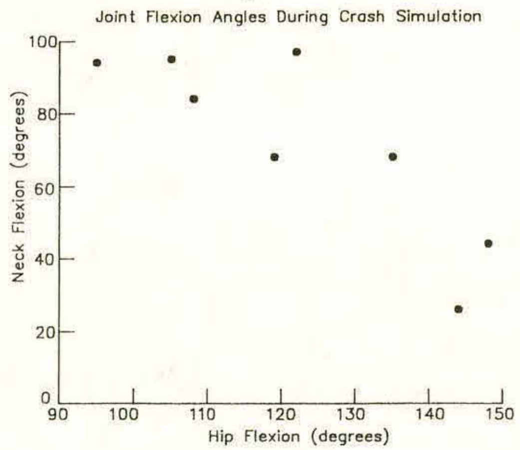

Figure 2

CONCLUSIONS

The increased head injury that occurred when the occupant was restrained in a way that appeared to represent the level of protection offered in an automobile clearly points out the danger in transferring designs from one application to another. If the torso of the individual in a mobility aid is left unrestrained, there is a risk of head impact with the vehicle interior, lumbar fracture from excessive hip flexion, and abdominal injury from higher lap belt forces. Restraining the torso without understanding the dynamics of the crash event can produce head injury as a result of excessive neck flexion. Additional information is needed to understand how to restrain the torso without causing trauma in the head and neck.

The design of a safe restraint system for mobility aid users on public transportation must also take into account that mobility aids will be used with vastly different seat structures and locations within the vehicle. These variables will affect the response of the user with a given restraint system, making this problem even more complex than that faced by the automotive industry in developing the occupant protection system in use today.

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DETERMINING THE TRANSPORTATION SAFETY OF CHEST SUPPORTS AND PELVIC RESTRAINTS

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ABSTRACT

Many wheelchair users require postural supports to insure functional stability. The performance of these supports in dynamic transportation environments is unknown. Postural supports may provide protection or pose a danger to the user. Static testing procedures based on federal testing guidelines were adapted to judge the integrity of postural supports. None of the commercially available supports were able to meet the strength requirements necessary for an occupant restraint, but should withstand the forces experienced during non-impact driving conditions.

INTRODUCTION

The Federal Government regulates the transportation of occupants in a standard vehicle seat. Federal Motor Vehicle Safety Standards (FMVSSs) must be met before a vehicle is marketed. Certain FMVSSs provide for occupant restraint systems to protect occupants during crash situations. These regulations do not, however, apply to the devices or methods used when transporting an individual while sitting in his/her wheelchair.

Many wheelchair users utilize postural supports to achieve a balanced and functional seated posture. Anterior chest supports and pelvic restraints are typically attached to the wheelchair and, when persons wearing postural supports are transported in their wheelchairs, these supports remain secured. These devices may or may not provide support under and/or protect the user from forces resulting from various dynamic conditions, including:

- normal driving
- non-impact, evasive maneuvers
- low-speed impact
- high speed impact

The presence of postural supports in these environments can result in increased safety or unnecessary level of risk.
This project was designed to develop static testing protocols to assess the safety of postural supports in dynamic impact situations. Devices were evaluated by testing procedures modified from FMVSSs which use static test procedures to ensure safety restraints will perform adequately during crash situations. The standards, used as a testing basis, included FMVSS 209- Seat Belt Assemblies, and FMVSS 210- Seat Belt Anchorages.

These standards basically state that:

- a pelvic restraint must withstand a force of 5000 lbs (22.2 kN) and should not extend more than 7 in (18 cm).
- a pelvic/torso restraint must withstand a combined load of 6000 lbs (26.7 kN) or 5000 lbs (22.2 kN) by the pelvic component and 3000 lbs (13.4 kN) by the torso portion. This restraint should not extend more than 10 in (25.4 cm).

METHODS

Several commercially available adaptive seating components were statically tested by applying loads to body blocks restrained by the devices. The test method provided a load-deformation curve for each device. Displacement, points of failure and/or weakness, and breaking strengths were determined and used to assess the ranges of safety the devices provided.

The adaptive seating components consisted of:

- AEL - Hip Belt
  - 1" Side Release
  - 2" Buckle Release
- Dan Mar - Chest Support Harness
- Miller's - Seat Belt
- Otto Bock - Seat Belt
  - 4-Way Chest Strap
  - Butterfly Chest Harness
  - Velcro Straps
  - Side Release Buckle
- Pin Dot - Seat Belt

The pelvic restraints meet a range of user requirements and preferences by providing buckle, padding and size options. The buckle options include side release, push button and lever release. The webbing is available in widths of 1", 1½", and 2" and is constructed of polyester or polypropylene. The torso restraints vary in design, however, the general design includes a pliable foam pad across the chest, anchored to the wheelchair by webbing. The devices may also include buckle and webbing options. The pelvic and torso restraints are anchored to the seating system by various means such as: upholstery screws to the wheelchair frame; clamps around the tubing; wrapping the straps around the frame and threading them through slide buckles; or bolted to rigid seats or seat backs.

A 4208 Instron Universal Testing Instrument was used to apply the tensile load to the body blocks. Two body blocks modeled after the dimensions of a 50th percentile male were used for testing; a pelvic block and a torso block. The pelvic block had the same dimensions as the FMVSS 210 pelvic block and was covered with 1" medium density foam and a lycra cover. The torso block was a half cylinder with a 6.5 inch radius and a 15 inch profile, also covered with 1" medium density foam and a lycra cover. An aluminum plate with two 7/8" tubes attached 15 ½" apart was used to represent the wheelchair back uprights.

The appropriate body block was suspended from the Instron crosshead for the type of restraint tested. The restraint was placed on the body block and attached to the base plate tubing. The restraints were loaded to breaking point or to a maximum of 13.4 kN. Load-deformation information was recorded continuously. Modes of failure were noted as they occurred and permanent damage recorded on film to determine the points of weakness. Two tests were performed on each product for repeatability.

RESULTS

Modes of Failure: Failure was considered to be the point at which the device could no longer support any load bearing. In the tests performed on the pelvic restraints, the hip and seat belts, failure resulted from complete detachment at one of the two wheelchair attachments. The Miller's, Otto Bock, and Pin Dot seat belts attached to the wheelchair frame on either side of the pelvis using upholstery screws through grommets contained in the ends of the webbing. Failure occurred as the grommets pulled through the ends and the webbing broke free, releasing the pelvic block. The AEL hip belts, 1" side-release and 2" buckle release, were secured to the wheelchair by clamps around the tubing. The belt webbing was threaded through slide buckles and end-fittings attached to the clamps. Failure resulted as the webbing slipped out of the slider and end-fitting.

In the tests involving torso restraints, failure occurred in other components, as well as at the wheelchair securement locations. The Dan Mar chest harness failed at one of the plastic pivot mounts that secured the lower webbing strap to the chest pad. Plastic deformation was seen in all four plastic mounts on the support. The top straps were held secure to the seat back throughout the tests. The Otto Bock 4-Way Chest Strap failed as the side release buckle released. The buckle was not damaged and could be refastened. The Otto Bock Butterfly Harness secured by the side release buckle straps failed in both cases, as one of the four wings of the chest pad completely broke free. In one test, a lower wing broke free and the restraint slipped down to the lower torso allowing the upper torso to rotate forward. In the second test an upper wing broke free and the restraint slid up around the neck region. In both cases, the restraint continued to provide securement at these regions until the torso block rotated free of the restraint. The Otto Bock butterfly harness with velcro straps failed at the lowest load of all the torso restraints tested. The release of two of the four velcro wheelchair attachment points fully releases the torso block.

Breaking Strengths: The tables display the average peak and break load and extension values for the two tests performed on each product using the pelvic and torso body block respectively. The breaking loads were lower than the peak loads in each case showing a gradual weakening before the webbing pulls completely free. None of the pelvic restraints were able to reach and maintain a load of 13.4 kN. The torso restraint results show peak load values in the range of 655 N to 2400 N before failure. None of the torso restraints tested, reached or maintained a 13.4 kN load.

CONCLUSIONS & RECOMMENDATIONS

- Failure of the pelvic restraints tested occurred at one of the two wheelchair attachments. By overlapping the webbing ends, the load at which failure occurred tripled.

- None of the positioning devices tested can withstand the forces in a 30 mph/20 g crash. The devices will, however, provide adequate restraint during normal driving and evasive maneuvers.

- Dynamic tests on the products should be performed to further validate use of static procedure for determination of crash performance.

- Design of wheelchair-mounted postural supports that could double as an occupant restraint would provide a nice alternative for wheelchair users that require both.

Clinical Implications & Questions:

• If an approved occupant restraint is available and is being used properly, postural supports should break away in a crash to allow the restraint to function properly. The questions arise when a restraint is not available. How do we instruct wheelchair users and parents of users? Are postural supports that would withstand low impact forces but not high speed impacts advantageous or hazardous? Which supports distribute loads over areas of the body that can accept higher loads? Should testing criteria for restraints used by passengers in buses be different than those for drivers? These questions need to be addressed quickly to assist the many wheelchair users who are transported in their wheelchairs everyday.

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Pelvic Restraint	Peak		Break	
	Load (N)	Extension(cm)	Load (N)	Extension(cm)
AEL 1" Side Release	1270.0	9.20	859.7	25.07
AEL 2" Button Release	1492.5	6.68	1232.4	15.36
Miller's	2021.5	6.47	1971.5	6.51
Otto Bock	4615.0	9.51	3932.0	9.65
Pin Dot	7019.0	9.38	6212.0	9.95

Pelvic Body Block Test Results (Average of Two Tests)

Torso Restraint	Peak		Break	
	Load (N)	Extension(cm)	Load (N)	Extension(cm)
Dan Mar Chest Support Harness	2400.5	8.24	2380	8.33
Otto Bock 4-Way Chest Strap	1853	6.27	Same as Peak	Same as Peak
Otto Bock Butterfly Harness Velcro Straps	655.4	4.35	404.4	6.29
Otto Bock Butterfly Harness Side Release	1552	8.95	Same as Peak	Same as Peak

Torso Body Block Test Results (Average of Two Tests)

STATIC TESTING OF COMMERCIAL HEADRESTS TO EVALUATE TRANSPORTATION SAFETY

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ABSTRACT

Commercially available head rest systems were evaluated to determine their static strength under test conditions similar to motor vehicle tests of head restraints. Certain head rest designs surpass the static strength requirements of vehicle headrests and may be appropriate for transportation use. Dynamic tests should be conducted to validate the static methodology.

INTRODUCTION

Whiplash constitutes the most prevalent form of injury to vehicle occupants struck from the rear. As the trunk is accelerated forward through contact with the backrest, the head snaps back and the neck becomes hyperextended. This hyperextension is often followed by hyperflexion as the head rebounds. This hyperflexion is accentuated if the vehicle hits an object as it is pushed forward. Research in transportation safety clearly identified the effectiveness of head restraints in preventing neck injuries, and the Federal Government responded by requiring head restraints in all vehicles manufactured from 1968. Some vehicle occupants who ride in wheelchairs use headrests as part of their seating system, yet their effectiveness as a head restraint is unclear. Simple static testing was designed and performed as a means to collect information on the performance of commercial headrests in the transportation environment.

Mertz and Patrick (1967) studied the kinematics of actual car-to-car rear-end collisions on a crash simulator to determine the effectiveness of head restraints in preventing whiplash injuries. With the head initially supported by a flat, padded headrest and a rigid seat back, a volunteer withstood an equivalent 44 mph (70.4 km/h) simulation with only slight discomfort. The maximum headrest load seen at a 10g, 23 mph (36.8 km/h) simulation was approximately 150 pounds (667 N). In 1971, Mertz and Patrick studied noninjurious tolerance values for hyperextension and flexion of the neck and recommended that neck extension should be limited to 80 degrees, and preferably 60 degrees to avoid injury.

More current research involving head restraints was carried out by Foret-Bruno et al. (1991) at the Peugeot/Renault Laboratory of Accidentology and Biomechanics. An accidentology study was performed on the frequency and severity of injuries to occupants in rear impact accidents and found that head rests are effective in reducing the risk of cervical injury by 30% for men and women. Foret-Bruno et al. also conducted dynamic tests using Hybrid III dummies to study the influence of horizontal head/headrest distance, head rest stiffness, seat back elasticity, and impact speed on neck load measurements. These tests upheld the observed effectiveness of head rests in road conditions. The tests also indicated that in order for the head rest to be as effective as possible, it should stay in contact with the head and not pivot easily under the force of the head. As the distance between the head rest and the head increases, the shearing force and the rotation of the head in relation to the thorax also increases.

Federal Motor Vehicle Safety Standard 202 Head Restraints

The standard specifies requirements for head restraints to reduce the frequency and severity of neck injuries in rear-end and other collisions. The head restraint may satisfy the regulation with a dynamic or static test procedure. If the static test procedure is used for compliance the restraint must also meet size requirements.

- Dynamic test procedure - The head restraint must limit angular displacement of the head to 45 degrees with respect to the torso under an 8g rearward deceleration applied to the seat supporting structure.

- Static test procedure - A headform is used to apply a rearward load 2.5 inches (6.35 cm) below the top of the head restraint perpendicular to the torso centerline. The load is such that it will produce a 3,300 inch-pound (373 N-m) torque about a seating reference point, corresponding to an approximate headrest load of 132 pounds (587 N). The head restraint must limit horizontal displacement of the headform to four inches (10 cm) from the torso centerline and must withstand increasing this load to 200 lbs (890 N) or until seat failure.

- Size Requirements - The width of the head restraint must be 10 inches (25.4 cm) for a bench seat and 6.75 inches (17 cm) for bucket seats.

METHODS

Eight commercially available wheelchair head restraint systems were statically loaded by displacement of a headform. The test method provided a load-deformation curve for each head restraint system. The energy associated with the deformation of the head restraint was calculated from the load-deformation data and used in determining the ranges of safety of the head restraint for the prevention of neck injury.

The head restraint systems tested are commercially available and included:

- AEL Adjustable Bracket
- Dan Mar - Mini & Sweep
- Millers - Fixed Occipital & Swingaway Occipital
- Otto Bock - Single-Axis Offset & Multi-Axis Offset
- Techni Seat Contoured Assembly

The majority of the restraint systems contained common components of: attachment hardware, vertical adjuster, anterior/posterior (A/P) adjuster, and a head rest pad. The attachment hardware for all the head restraints tested was designed to mount to a solid seat back and usually consisted of a receptacle secured with bolts and T-nuts. The vertical and A/P adjusters permit proper positioning of the headrest pad for different users.

PROCEDURE

The test setup comprised a support structure to which the head restraint/plywood mount unit was clamped. The headform (Figure 6.6) used to load the restraint was a half cylinder with a 6.5 inch diameter and a 6 inch profile made of wood. The headform was mounted by a swivel joint to a load cell on the crosshead of an 1122 Instron Universal Testing Instrument.

The attachment hardware of all the head restraints was mounted to half-inch thick plywood based on the manufacturer's directions and using all provided hardware. The vertical height adjustment range was determined for each head restraint, and two tests were performed at each maximum and minimum height setting. The A/P adjustment, when available, was set such that the anterior surface of the head rest pad was located 1½ inches anterior to the seat back surface. A preload of 5-10 newtons was applied to define surface contact and the zero point. The load was applied to the head restraint through displacement of the headform attached to the Instron crosshead. Load-deformation information was collected continuously as the headform was displaced 14 cm. The restraints were marked prior to the test to determine if any A/P slip occurred during loading. Permanent deformation was recorded on film and the modes of failure were recorded during testing.

Mechanical Properties

A summary of the mechanical properties determined from the testing is presented in Table 6.4. The values are the average of the two tests performed at each height adjustment. *The criteria for pass/fail was for the device to reach a minimum load of 587 newtons and require a minimum energy of 29.8 J for a 8.89 cm displacement of the headform.* The head restraints that met this criteria are:

- Minimum Height -
  - Miller's Fixed
  - Miller's Swingaway
  - Otto Bock Single-Axis
  - Otto Bock Multi-Axis
- Full Range - AEL

The Dan Mar Mini and Sweep restraints met the energy criterion at their minimum height, but failed to reach the critical load within an 8.89 cm displacement. Except for AEL, the restraints did not meet the criteria at their maximum height setting. The Techni Seat restraint failed for its full range of adjustment.

A second criterion was for the head restraints to maintain their functional integrity up to a load of 890 newtons. The restraints that reached this load included:

Minimum Height -
- AEL
- Miller's Fixed
- Miller's Swingaway
- Otto Bock Multi-Axis

These restraints did not fail or lose their integrity until the plywood board yielded and the T-nuts were pulled out at loads from 1000 to 1200 newtons.

RESULTS SUMMARY

1. The minimum height of the vertical adjustment bar of a head restraint will provide greater resistance to loading from the head and limit head excursion more than the maximum height adjustment.

2. The head restraints tested exhibited three modes of deformation:

a) Plastic deformation of the vertical adjuster
b) Plastic deformation and/or failure of the attachment receptacle
c) Yielding of the plywood board

In some cases, combinations of these types of deformation were observed. Based on the observed mode, design improvements can be determined.

3. The majority of the tests resulted in bending of the vertical adjuster of the restraints, this knowledge can be used to determine the required material and dimensions of the adjustment bar necessary to prevent bending at the predicted loads.

4. Head restraints with offsets obtained by a bending or angling of the vertical adjuster failed at the offset point, showing this point to be the weakest.

5. All headrests tested met the size requirements of FMVSS 202.

6. Commercially available head restraints, with a few design improvements, can be effective in preventing neck injury in rear-end collisions.

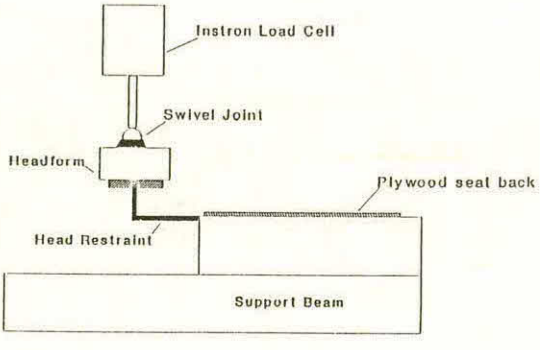
CONCLUSIONS

These tests assume that the vertical backrest members or back upholstery of the wheelchair does not fail upon impact. Wheelchair users who use the headrests studied will typically utilize a full height solid backrest for postural support. The solid back used in this project did not fail until after the strength criteria had been met, but no judgement was made on the integrity of the hardware that attaches the back to the wheelchair or the wheelchair itself.

The effectiveness of a headrest during rear impact is increased if the head is in contact with the pad at impact. This should be the case for many wheelchair users whose headrests are adjusted to support the head in a neutral position.

Headrests were not designed for use in vehicles and the results of this project do not reflect the performance of any restraint under situations for which it was intended (i.e. a headrest or a wheelchair). However, these results do provide useful information about the strength of systems under loading similar to that seen in rear impact. These results should be combined with results from dynamic tests to determine the validity of the static tests in predicting the safety of head rests in the transportation environment.

Instron Mounted Headform w/ Swivel Joint



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Head Restraint Height Setting(cm)	Maximum Load (N)	Disp at Maximum (cm)	Energy (J)
AEL			
Min	1962.08	7.89	117.62
Max	718.66	10.05	37.90
Dan Mar - Mini			
Min	615.24	12.41	30.63
Max	212.55	11.21	10.53
Dan Mar - Sweep			
Min	595.62	11.44	33.95
Max	326.41	10.54	18.78
Miller's - Fixed			
Min	1268.30	11.54	72.49
Max	229.21	11.99	12.08
Miller's - Swingaway			
Min	1601.59	6.26	96.09
Max	354.72	11.98	18.65
Otto Bock - Single			
Min	636.28	3.68	44.13
Max	325.16	11.49	16.89
Otto Bock - Multi			
Min	1038.57	4.81	72.55
Max	277.82	12.03	13.77
Techni Seat			
Min	418.25	10.10	26.72
Max	268.75	9.71	17.78

Table 1 Head Restraint Results

TOWARD UNDERSTANDING CONSUMER CONCERNS ABOUT TRANSPORTING CHILDREN WITH PHYSICAL DISABILITIES IN THE FAMILY CAR

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ABSTRACT

A major issue that concerns parents when preparing for travel in the family car is transferring their disabled school-age child to and from the vehicle. Research is presently underway to develop a transfer system that will assist them by providing a more effective method of ingress and egress.

To determine whether specific issues could be raised that would assist in the development and eventual evaluation of such a device, a focus group of eight parents was organized. In addition to discussing issues of concern, the parents were asked to identify the criteria they would use to evaluate the appropriateness of a transfer device if one was available.

Twenty-three criteria were identified during the meeting. A follow-up survey was conducted to rate the criteria. Participants identified the safety of their children and themselves and cost of the device as being of primary importance. Furthermore, innovative policy schemes for creating a device that was affordable were also proposed. The ability of the consumer to repair the device if it breaks and product versatility were rated to be of lesser importance.

BACKGROUND

Many children with physical disabilities need custom-made seating devices to be comfortable and well-supported while in their wheelchairs. However, this poses a safety problem for parents wanting to transport their child in the family car.

Commercially-available car seats are unsuitable for many children with physical disabilities because these systems have fixed dimensions and offer little in the way of postural support. As a result, parents often use the custom-made seat from their child's wheelchair for this purpose despite being advised by service clinicians that these devices are not roadworthy.

Recently, a unique custom car seat was developed for children weighing between 20 and 40 pounds (1). Parents who evaluated this device indicated that they had few concerns using it for their disabled pre-schooler. However, they were worried about safety in transfers to and from the car as their child becomes heavier with age (2).

Hence, a research project has been undertaken to develop a restraint system for older, heavier children and a device to assist parents in transferring their child into and out of the family vehicle. It is intended that these devices evolve and be evaluated with involvement from parents, children, service providers and industry.

METHOD

Input from parents during the preliminary stages of the project has been obtained through interviews, mail-out surveys, and focus group activities (3). As an example of this, a focus group of parents was organized to determine whether specific issues could be raised that would assist in the development and evaluation of concepts for a transfer device. (A similar methodology was used by other investigators to develop consumer criteria that would aid in the design and evaluation of assistive devices for individuals with visual, hearing and mobility impairments (4).)

Initially, twenty parents were contacted by mail to determine their availability and interest in participating in the focus group. The contacted parents each had a child who was a client of Seating Services at The Hugh MacMillan Rehabilitation Centre, and had expressed concern regarding transporting their child in the family vehicle. Eight of the parents contacted participated in the focus group. One parent was recruited as the facilitator for the meeting. A project team member was present to observe the proceedings and to provide clarification of the project objectives as necessary.

The agenda of the meeting consisted of participants discussing four specific questions:

1. How do you transfer your child into and out of your family vehicle?
2. What issues concern you when handling your child this way?
3. If a device was available to assist you in transferring your child, what criteria would you use for evaluating its appropriateness for you and your child?
4. What is the relative importance of each of these criteria?

RESULTS

Regarding the first two questions, parents reported that they generally "struggle" by lifting their children into and out of the family vehicle. Generally, the restraint is prepared first, then the child is lifted into the seat. Transfers are made in small steps to make the process more manageable (i.e. the child is lifted from the wheelchair onto the floor of the vehicle, onto the edge of the vehicle seat, onto the edge of the car seat, then back into the vehicle seat).

Not only were parents having difficulty in managing the weight, they also had difficulty managing the height of their child due to the space constraints of the vehicle and size of the seating device or car seat. They agreed that taking their child out of the car was more strenuous than putting them into the vehicle. Where to put their child while the restraint was being prepared was also a concern for them. Maintaining safe upper body support during transfers also worried many parents.

All were concerned for their own safety as well as that of their child during transfers. Most agreed that a serious back injury would have a major impact on the family unit. In fact, many reported having back problems which they attributed to lifting their child. All participants agreed that a van with a lift was the ideal solution, yet most felt this was out of reach because of the cost.

Regarding what criteria they would use to evaluate the appropriateness of a transfer device, safety and comfort of their child were identified as primary requirements. Parents would like to transfer their child and seat together to control posture and pathological reflexes.

They reported that if simple repairs are required, then the device should use readily available components and fasteners. However, generally the parents reported that they did not want to make repairs themselves. They appeared to be willing to compromise high reliability for availability of a replacement device.

The cost of the device was identified as a major issue. One parent suggested a rental program and exchange service to make the device developed more affordable to families. Some discussion focused around portability of the transfer device and the need for it to be available at both ends of a trip. Compatibility with vehicles and restraint systems was also identified as an issue to consider. In summary, a list of 23 criteria was created.

Since the focus group was scheduled for two hours, the meeting ended before the criteria could be ranked. However, as a follow-up, letters were sent to all participants. In the letter, the list of criteria was provided and definitions for each criterion was given based upon what was discussed during the meeting. Participants were then asked to rank each criterion from 1 to 23, and return their ratings for interpretation. The ratings received were averaged and criteria were ranked on this basis. Standard deviations of the ratings were used to investigate consensus among participants.

Figures 1 and 2 indicate the top ten criteria identified by participants in the focus group. Figure 1 indicates the average scores and ranking for the top ten criteria. The criteria are listed in order of preference starting from the top of the graph. In Figure 2, the standard deviations of the ratings are shown. Longer horizontal bars indicate more variability in the rating, hence less consensus among parents on the rating assigned.

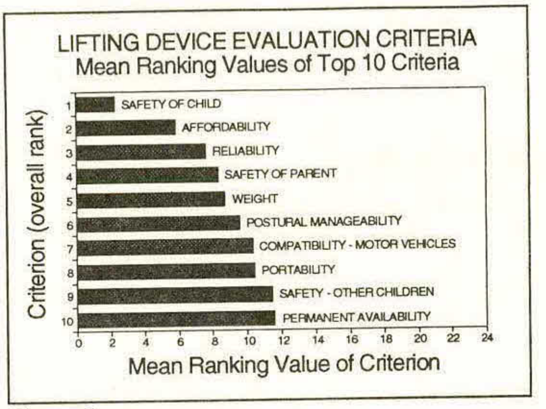

Figure 1

Safety of family members, as well as cost and reliability issues, were identified as being most critical to the success of a transfer device design. It appeared that parents were in agreement that safety of the child being transferred was most important. However, they were more at odds with issues relating to their own safety and the safety of other passengers.

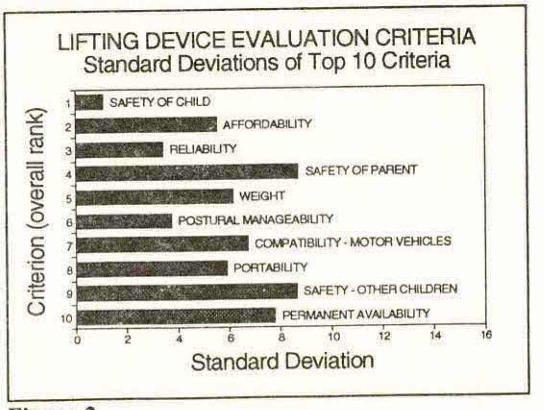

Figure 2

DISCUSSION

In summary, consensus was reached by this parent focus group that features of the transfer device must ensure the safety of the child during its operation. They also indicated that the financial burden on families and functional criteria such as postural manageability and device portability were also important. Reliability of the transfer device was identified in the top ten criteria, however, most parents felt that this requirement could be compromised if the device was readily replaceable. Parents generally agreed that other criteria such as versatility, consumer reparability, and age-appropriateness, were of lesser importance.

While the results of this focus group will assist in screening design options for the transfer device, it also will help in establishing a procedure for obtaining consumer input on other design and evaluation issues.

ACKNOWLEDGEMENTS

The assistance of the parents who participated in the focus group is gratefully acknowledged. Thanks also to Jeff Jutai (HMRC and the Psychosocial Evaluation Team of the Ontario Rehabilitation Technology Consortium) for facilitating this activity. This project was supported by the Rotary Club of Leaside and the Ontario Ministry of Health through the Rehabilitation Technology Consortium.

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WHEELCHAIR AVIATION: CASE STUDIES AND SURVEY OF ADAPTIVE ENGINEERING NEEDS

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ABSTRACT

Although aviation offers significant opportunities for freedom, transportation, employment, and recreation among disabled persons, potential wheelchair pilots often may not be aware of resources within their communities to assist with these goals. The purpose of this paper is to raise awareness within the rehabilitation community of the feasibility of training disabled persons to become licensed airplane pilots and to describe some of the medical and engineering considerations appropriate for patients interested in such an endeavor. Results of a survey of members of the International Wheelchair Aviators suggest potential areas for future engineering design of adapted aircraft to further assist disabled pilots, particularly spinal cord injured pilots.

BACKGROUND

An adapted aircraft can literally and symbolically be a powerful tool to bring independence to appropriate disabled persons. Over the past twenty years at least several hundred disabled pilots whose principal diagnoses most commonly include spinal cord injury and lower extremity amputation have achieved licensure as private or commercial pilots throughout the world. This presentation is designed to survey for the engineering community past accomplishments of wheelchair aviators and to suggest avenues for future innovation.

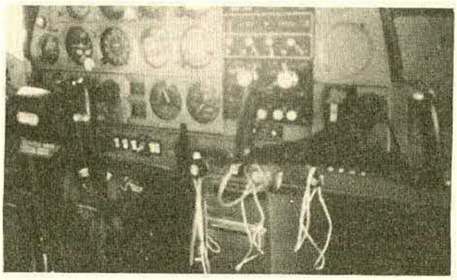
Adapted automobiles are well known to rehabilitation professionals. Adapted aircraft are less well known, perhaps due to the perceived expense of aviation in general and perhaps due to the significantly increased engineering task required to allow a disabled pilot to simultaneously control an aircraft in three dimensions, monitor engine performance, navigate through airspace, and communicate via radio with air traffic controllers. However, a number of organizations have been established over the past 20 years to assist potential wheelchair pilots with the technical, emotional, and legal issues involved in attaining licensure to fly an adapted aircraft. The most popular of these organizations is the International Wheelchair Aviators, located in Escondido, California. At present, this organization has over 200 members, approximately 150 of whom are licensed disabled pilots. The organization estimates there are several hundred additional licensed disabled pilots who are not members of this organization.

ENGINEERING ADAPTATIONS

Piloting a conventional aircraft requires simultaneous operation of three aircraft control surfaces (aileron, elevator, rudder) using a conventional yoke (analogous to an automobile's steering wheel with the addition of forward/backward movement) and foot-operated rudder pedals. The principal difficulty a paraplegic pilot faces in operating such an aircraft is an inability to command the foot-operated rudder and brake mechanisms which are used to control the aircraft in flight and to steer/the aircraft on the ground. A number of engineering designs have been approved by the Federal Aviation Administration for hand control of rudder and brake function; most popular among these is the Blackwood Hand Control which is easily installed in a number of popular training aircraft and consists of a bar which operates via a direct linkage to the combined rudder/brake mechanism on various aircraft.

A quadriplegic pilot faces a number of additional obstacles in adapting an aircraft due to significantly diminished upper extremity dexterity. To date several quadriplegic patients have attained licensure as pilots through modification of the Blackwood hand control with the addition of a ring to further forward/backward translation of yoke movement with limited grip strength. Due to the need for continuous positive control of forward/backward translation of the yoke, all licensed quadriplegic pilots to date have had normal biceps strength and fair to good triceps strength (i.e. highest level of injury C6 incomplete by American Spinal Injury Association classification).

Additional difficulties faced by quadriplegic pilots include the need to manipulate the multitude of knobs, dials, and switches found in a typical aircraft cockpit. In most cases, quadriplegic pilots have adapted this equipment by enlarging controls and/or adding wire loops in order to allow operation through wrist and/or elbow movement alone.



OBJECTIVE AND APPROACH

The objective of this project was to survey currently or previously licensed disabled pilots and other persons knowledgeable of wheelchair aviation in order to ascertain what engineering adaptations they have made to allow them to safely pilot an aircraft and, more importantly, to ascertain what additional modifications they feel might assist potential wheelchair pilots.

A survey was mailed to 224 members of the International Wheelchair Aviators inquiring about the nature of their disability (if any), aviation licensure status, aircraft adaptation currently used, and suggestions for needed aircraft adaptation. Existing adaptations are described above. A number of suggested adaptations were offered, including the following:

* Design and certification of hand controls for tailwheel aircraft
* Design and certification of hand controls for multiengine aircraft
* Design of aircraft control systems for high level quadriplegic pilots, possibly through voice control or through a shoulder harness
* Engineering design to permit a wheelchair ambulator to inspect fuel caps on high-wing aircraft
* Design of aircraft control system to minimize untoward effects of spasticity
* Bladder drainage system easily emptied during extended flight

DISCUSSION

This paper discusses a number of aircraft adaptations made by disabled pilots in order to allow them to safely achieve licensure as pilots. Existing designs allow safe piloting of training aircraft by most lower extremity amputee pilots and paraplegic pilots. Piloting of more complex aircraft, particularly among quadriplegic pilots, still presents a significant obstacle, though from an engineering perspective these barriers should be conquerable. Adaptive aviation allows wheelchair pilots to accomplish something they may not be able to do through any other means: the aircraft gives them the ability to rise up above their wheelchairs under their own control.

Piloting an aircraft is principally an intellectual activity requiring simultaneous interpretation of numerous flight instruments and resultant translation of this data into a discrete number of outputs, most notably control of (1) three axes of movement, (2) engine power, and (3) radio communication. Adapting such systems to the abilities of virtually any cognitively intact patient should be possible through appropriate engineering design.

The authors would be pleased to further discuss with any interested parties ideas regarding appropriate design of adapted aviation controls. Achievement of this goal offers to the disabled pilot what is perhaps the essence of both humanity and rehabilitation: *independence.*

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SIG-03
Augmentative and Alternative Communication

A STUDY OF THE INFORMATION CAPACITY OF HUMAN EYE MOVEMENT FOR AUGMENTATIVE COMMUNICATION

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Abstract

Eye tracking technology offers a potentially revolutionary approach to aiding people with disability by permitting them full use of personal computers. Unfortunately, existing eye tracking applications do not adapt to a user's particular needs and thus exclude many who could thus gain from the technology. The first step toward correcting this problem is the characterization of the individual's ocular control, considering both eye movements and fixations. This paper proposes a preliminary experiment, aimed at this goal, to measure fixational stability and accuracy, as well as movement speed. We present the subject with a sequence of points, recording the point-of-regard during fixation and the movement time in between points. We can analyze the dependence of fixation on position and the dependence of movement on distance and direction. By changing various experimental parameters, we can also investigate the effects of visual feedback, calibration scheme, color, and time on both fixation and movements.

Background

To provide the best opportunities for vocational rehabilitation, an eye tracking package must consider the various idiosyncrasies of the individual's eye gaze. For instance, should the person have difficulty fixating in the bottom left corner of the screen, buttons in that region should be larger or should perform functions rarely needed. Or, if the person fixates poorly but can shift gaze quickly, the interface should employ motion-sensitive activation schemes, as opposed to the usual dwell-time schemes. As motivated by Rosen (4), we must develop an assessment procedure in order to take full advantage of eye tracking's potential as an augmentative communication device. By taking the client's strengths and weaknesses into account, eye tracking technology can make maximum use of his/her capabilities.

Unfortunately, the eye tracking applications that do exist in the rehabilitation literature usually use a *fixed* format. For instance, Hutchinson (3) described ERICA, the Eye-gaze-Response Interface Computer Aid developed at the University of Virginia. The authors used a pupil-corneal reflection eye-tracker, interfaced with a personal computer, using the standard fixation-activated interface. The user interface divided the display into a 3x3 matrix, so that when the user fixated within one area of the grid for approximately two to three seconds, a tone sounded and a mark appeared in the region. The small number of target areas allows users with poor fixational accuracy to still use the system. On the other hand, users with accurate fixations still had to make many selections to indicate just one letter. Even experienced users had to spend 60 minutes entering one page of text.

Foulds (2) innovated the Etran eye movement encoding technique used in computer software developed at Tufts Rehabilitation Engineering Center. The Etran, originally implemented on a clear plastic board, coded 64 characters and important words into sequences of two successive motions (either left, right, up, down, or along the diagonals). Because of its movement-dependent scheme, Etran avoided any potential fixational difficulties. The authors predicted that such a computerized system, using an entire keyboard with a syllabary of 500 or more selections, could yield rates of 60 words per minute. This rate is based upon the assumption of errorless selections at maximum speed. Many of the potential users we studied have difficulty in initiating accurate eye movements, which would imply a lower rate due to errors.

Cleveland (1) discussed potential applications of the better known LC Technologies Eyegaze Eye-tracking system. The paper is mainly a summary of the system and projections about its application but does not provide much detail about the quality of the performance of the system. Several of the problems we found with the LC system include the fact that most of the activation areas (icons) on the display were unnecessarily small. For instance, the communication board only uses half of the available screen, requiring unreasonably precise fixation. In fact, a client with any amount of head movement, leading to small instabilities in fixation, would have little success activating the small icons. Unfortunately, the system does not allow modifications to the size of the keys, nor to the layout of any interface.

The first step in developing an eye-tracking package responsive to the individual's unique capabilities is to characterize the information transfer ability of her/his eye. To do so requires a standard evaluation procedure that will produce an *eye movement and fixation profile* of the individual user. The user will run through a short series of tests, aimed at characterizing his/her fixations and eye movements. With the information contained in the client's eye movement profile, we could design customized interfaces.

Experimental Design

Hardware

Currently, we are using the RK-520PC Auto calibration System of ISCAN, Inc. (Cambridge, MA), running on an IBM-compatible 386 personal computer. An infrared camera, coupled with a light source and infrared filter and run by the ISCAN RK-464 Camera Control Unit, produces the eye images used by the RK-520PC to calculate the center points of the pupil and corneal reflection. The calibration process, during which the user looks at selected (either five or nine) fixed points, results in a mapping between the pupil and corneal reflection locations and the intended point of regard (POR). The user views a 20-inch color monitor of an Apple Macintosh Quadra 950, which receives the POR data through a NB-DIO-96 digital interface board from National Instruments (Austin, TX).

Procedure

To produce this eye movement and fixation profile, we must analyze the user's fixational capabilities, in terms of accuracy, stability, and positional dependence. To do so, we present the user with a target, a small colored dot on the monitor, and define a circular tolerance region around it. The subject has acquired the target when he/she maintains POR within the tolerance region for a certain amount of time, which we define as the minimum fixation period. Then, the system records a fixed number of POR samples. Upon completion of the recording, the target moves to a new location on the screen and the process repeats itself.

We must also analyze the user's eye movement capabilities. The fixation study's experiment allows a suitable framework for understanding movements as well. Once the data collection on one location concludes and the target moves to its new location, we can measure the time for the user's POR to cover the distance in between. We exclude the latency time for the eye to begin its motion by starting the clock when the POR exits the tolerance region about the old target location. We stop the clock on entry to the new tolerance region. If the user's POR should exit the new tolerance region before the minimum fixation period elapses, the clock will continue to run. Therefore, we keep timing through overshoots and any other instabilities before the subject attains the target.

It is important that we decouple the eye-tracking system from perceived eye movements. We expect some displacement between the POR data and the target point, even after the user has attained stable fixation. We must measure this displacement and determine its positional dependence.

To make the data amenable to analysis, we constrain the fixation points to a rectangular grid and construct the sequence of points to guarantee that each point-point transition appears a minimum number of times. This guarantees, in turn, that each point also appears a minimum number of times.

Analysis

After the subject has run through the entire sequence, the application writes the results to disk for future analysis. When viewing the results, the application processes the data, calculating the mean point-of-regard and average distance from the mean for each point, as well as the average movement time for each transition. We can measure fixational accuracy by calculating the bias (the distance between the target and the mean POR for that point). It can also present the data graphically, plotting all the collected data points, as well as the mean point-of-regard and a circle representing the average deviation from the mean.

Parameters

From this data we can analyze the effects of various parameters on fixational and movement capabilities. For instance, by moving the fixation points across the screen, we can analyze the dependence of bias on position and the dependence of movement times on direction and distance. In addition, we can run the experiment with various levels of visual feedback. During the calibration and practice portions of the experiment, the ISCAN output appears as a small inverted rectangle on the Mac window. During data collection, we can turn the cursor off to study the effect of its visibility. The tolerance region's visibility is also optional, to allow analysis of its effect.

We can also investigate various factors at the eye-tracking end of the system. For instance, we will measure the differences between the five- and nine-point calibration techniques. In addition, the tolerance region, grid of test points, and the dimensions and colors of the prompt and POR cursor are all modifiable, permitting analysis of the importance of these parameters.

By varying the time parameters, we can investigate the eye's stability and accuracy. By increasing the number of samples taken per test point, the subject will fixate for longer periods of time, leading to information on fixational stability. We can also vary the number of repetitions and analyze fatigue effects on fixation and movement times.

Results

Results obtained from 10 to 20 subjects will be presented. We will utilize the above protocol, varying the parameters such as visual feedback and calibration scheme to investigate their impact on fixational accuracy and movement time.

Acknowledgments

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Advanced Input Methods for People with Cerebral Palsy: A Vision of the Future

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ABSTRACT

This paper offers a vision of how advanced sensor technologies will influence access methods for people with physical disabilities, in particular cerebral palsy. One aim of the future input system will be to closely match the abilities and natural modes of communication of people with cerebral palsy e.g. gesture, vocalization, movement, manipulation and force. The system could allow the user to interact with people and the environment in multiple modalities. These modes of interaction will be harnessed using advanced sensors supplying data to a computer that uses pattern recognition and signal processing techniques to recognize the user's intention. A system is proposed that could employ multiple sensors to maximize recognition accuracy, offer multimodal interaction, automatically accommodate changes in the user's performance and enhance communication rates. In addition, it could be used for computer-aided assessment.

BACKGROUND

People with severe speech and physical impairment due to cerebral palsy have limited and imprecise motor control. Each member of this population is likely to have an idiosyncratic range of physical abilities.

Frequently, familiar communication partners are able to visually discern intention from imprecise and idiosyncratic gesture. Existing technology fails to harness the multiple communication modalities that are employed in these interactions (1)(2).

Many questions remain from a human factors perspective. What form could a multimodal human-machine interface take? What behaviors are there that are suitable for human-machine interaction? Which bodily functions convey information pertinent to a person's intention?

Although computer recognition of gesture is still in its infancy, research in this area is encouraging. Harwin and Jackson (3)(4) developed a system that recognized head gestures of people with cerebral palsy using a six-dimensional position tracker. The system used the concept of a "virtual head stick" and used hidden Markov models as the recognition method. Rogers (5) successfully recognized the facial gestures of a child with cerebral palsy using an encoded digitized video camera image of the subject's face and then classified the gestures using artificial neural networks.

These authors confirm the feasibility of recognizing human gestures from people with cerebral palsy.

Roy (6) proposed that information from surface electromyograms (EMG) should be available to extract information relating to intention that is not present in movement or force data alone. If antagonist/agonist muscle pairs co-contract inappropriately, the intended movement is prevented, however muscle activity can be detected.

The work of Hiraiwa et al (7) shows that neural networks can be used to recognize readiness potentials (RP) generated the moment before voluntary movement of muscle recorded using electroencephalogram (EEG) topography. If these signals are intact in people with cerebral palsy it may be possible to detect intention directly from the central nervous system.

Considerable effort and determination is required for the target population to operate any assistive device. Fatigue can occur rapidly resulting in a reduced performance. Ideally the device should be able to accommodate changes in performance. Roy (6) suggested that parameters such as pulse rate and galvanic skin resistance might be useful in determining fatigue-state, expected performance, and in identifying the startle reflex.

The authors are working towards the development of input systems that reflect the abilities and the natural modes of communication of the target population. This includes gesture, vocalization, movement, manipulation and force (8).

STATEMENT OF THE PROBLEM

The problem can be viewed from two perspectives. From a user perspective, is it possible to design an input system that enables an assistive device to be operated in modalities that closely match the abilities and natural modes of communication of people with cerebral palsy? From a technological perspective, can sensor technology and computer recognition be used to create a system that predicts intention with an accuracy acceptable to the user?

APPROACH

Observations/Elicitation of Behavior

The researchers have established close links with student collaborators, therapists, teachers and caregivers. This is to assure the quality of data and to identify and elicit repeatable behavior that could be used as an input method. Qualitative observations have been made of students' natural physical ability as they interact with peers, adults and their environment using their existing communication modalities.

The authors have proposed using the technique of mime as a way of eliciting repeatable, intentional gestures. Preliminary studies incorporating the vehicle of a simple charade game and puppet facilitator to elicit mimetic gestures and vocalizations have indicated that many of the student collaborators can produce a range of distinct gestures e.g. eating a hamburger, stroking the fur of cat. Deictic (pointing) gestures will be elicited initially using a pointing board. This will be compared to a pointing strategy which allows pointing in three-dimensional space using the concept of a "virtual" board.

Movement, Manipulation and Force

Observations and preliminary assessments indicate that certain students may be able to execute a distinct set of manipulations while exploring objects by touch. These manipulations will be investigated further using a tactile relief force keyboard that is being developed by the authors. Two prototypes will be evaluated. The user will be able to touch and manipulate either

1) one or more three-dimensional (3D) familiar items and shapes (e.g. plastic animal, toy car) mounted on a board, or

2) an array of 3D projections covered in plastic.

In each case force between the student's hand and the objects along three axes will be monitored using strain gauge sensors.

If it is possible to electronically sense and reliably distinguish gestures, vocalizations, movement, manipulation and force, new modalities of interaction may be possible.

Sensors and Computer Recognition

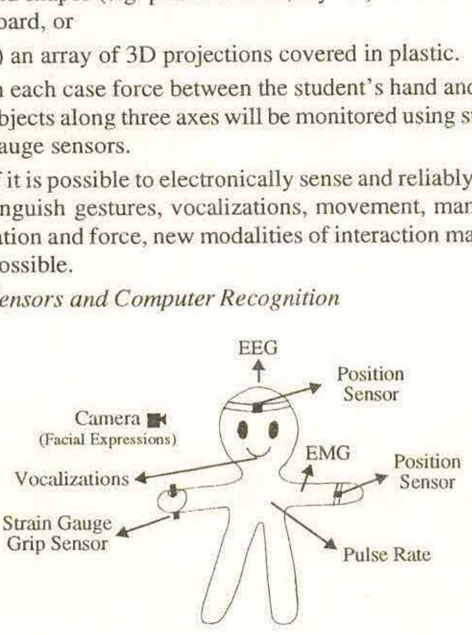

Figure 1

In order to sense movement and force from poorly coordinated muscle action it is necessary to use sensors that output continuous signals. These data contain considerably more information than signals from mechanical switches. A computer is required to recognize intention and to map it to actions. Figure 1 illustrates a possible sensor configuration.

Use of Multiple Sensors

The rationale for using multiple sensors is as follows:

i) It may be possible to increase recognition accuracy if signals that contain information about the user's intention are available from more than one source.

ii) The approach facilitates multimodal access.

iii) A single sensor design is unlikely to be appropriate for all users due to the heterogeneity of the target population.

DESCRIPTION OF PROPOSED SYSTEM

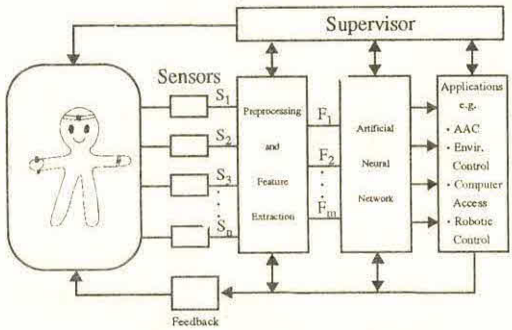

Figure 2

The recognition and mapping process are ultimately similar for all sensors. It is envisaged that a single computer recognition system could accommodate a whole range of sensors employing widely varying technology (see figure 2).

The recognition system will consist of a preprocessor, an artificial neural network and a supervisory level. The preprocessor has a data reduction and signal enhancement function. Extracted features are presented to the artificial neural network classifier. The outputs from the neural network are used as the controlling inputs of the application. The human-machine interface will include visual, auditory and tactile feedback that facilitates user control. Where appropriate this may include a direct representation of physiological parameters. The supervisor will constantly monitor the performance of the user with the device. It will accommodate to the fatigue state of the user and adjust its parameters accordingly. Periodically it will report the recognition rate to the user and recommend that it is retrained to compensate for changes in long-term user-performance. Data recorded during recent use will be used to retrain the recognizer.

The proposed system would operate as follows:

Step 1: Conduct an integrated assessment involving a multi-disciplinary team. Assessment should include elicitation of behavior likely to be successful in human-machine interaction.

Step 2: Identify and locate sensors able to monitor the modalities of interaction.

Step 3: Train the system to recognize the idiosyncratic motor function of the user. If appropriate it is taught to ignore non-volitional motion e.g. startle reflex.

Step 4: At the end of the training process, the system reports to the user/clinician how well it is able to recognize intention and identifies the sensor that are necessary for recognition.

Step 5: The user/clinician decides whether a change in sensors or siting is necessary or whether certain sensors are redundant.

Step 6: The input system is tested in a functional setting.

IMPLICATIONS/DISCUSSION

Although the area of integrated multimodal input devices and gesture recognition is still in its infancy, the proposed input system would have the following benefits for people with cerebral palsy:

i) Facilitation of a new generation of intelligent multimodal augmentative and alternative communication (AAC) devices based on advanced sensor technology and computer recognition.

ii) Multi-modal access that closely matches the user's ability.

iii) Automatic accommodation of changes in the user's performance.

iv) Enhanced communication rates through the integration of the proposed input device with other AAC strategies.

v) Wide-ranging applications including AAC devices, computer access, environmental and robotic control.

vi) Computer aided assessment integrated into the system without additional hardware requirements.

Many of the design issues have yet to be resolved these include portability, practicality of use in daily settings, reliability, social and cosmetic acceptability.

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Predictions of Computer Interface Skills for Children with Mental Retardation

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Abstract
Children with mental retardation with mental age scores ranging from 2.5 - 5.0 years completed a series tasks using five different computer interfaces: mouse, touchscreen, trackball, locking trackball, and keyboard. Children were scored for the level of device mastery achieved for each interface, based upon the relative success, maintenance, and generalization of device control skills with and without specific training. A regression analysis examined the extent to which ten subject skill measurements could predict children's abilities to master the five devices. Of the measurements used in this study, tests of pattern analysis and gross motor skills were among the best predictive variables. While this provides information that may help to focus assessments of cognitive load for users of assistive technology, other factors of individual variation should also affect the extent to which these cognitive factors influence computer interface skill acquisition.

Background
Learning to control computer interfaces involves a variety of motor, perceptual, and cognitive skills. Children without disabilities demonstrate greater computer interface control skills with increasing chronological and mental age (Cress, French, & Tew, 1991). However, it has not been determined whether the ability to operate different interfaces is directly associated with general cognitive development, or whether a combination of skills differentially affect children's abilities to acquire skills in interface control. For children with mental retardation, variation in the development of cognitive and perceptual-motor skills associated with their disability may produce an entirely different pattern of development in interface skill acquisition from that observed in normally developing children. If so, then both the design and training of computer skills need to be adapted to accomodate the specific influence of mental retardation on children's computer skill acquisition and use.

Many resarchers propose that children with mental retardation demonstrate differences in their cognitive processes that are not due solely to slower or less proficient acquisition of developmentally appropriate skills (e.g. Morss, 1983; Baumeister, 1984). Increased variation in skills for children with mental retardation would be predicted because of potential difficulties in specific cognitive skills, including problem solving, memory, and information processing (e.g. Campione, Brown, & Ferrara, 1982; Ferretti & Cavalier, 1991). Greater variation would also be expected because of the higher incidence of motor and sensory processing deficits with certain etiologies of mental retardation, such as Down Syndrome (e.g. Pueschel, 1988). In order to successfully apply standard computer-based technology to assistive purposes for children with mental retardation, it is necessary to examine the extent to which these skill differences influence performance on learning to operate computer devices.

Research Questions
1. To what extent do measurements of cognitive and perceptual-motor skills predict the performance of children with mental retardation on computer interface control tasks?

2. To what extent do these results differ from expectations from similar research with normally developing children?

Method
Subjects
Subjects were 15 children with mental retardation, 11 of whom had diagnoses of Down syndrome and 4 of whom had diagnoses of functional mental retardation. All of the subjects had mental age-equivalence scores from the Bracken School Readiness Composite between 2.5 and 5.0 years (mean 4.2 years MA). Chronological ages ranged between 3.6 and 9.8 years (mean 7.9 years CA). Children received a battery of measures testing cognitive, perceptual-motor, and computer-related skills including the following: Stanford-Binet copying and pattern analysis subtests, Bracken spatial awareness subtest, Miller Assessment for Preschoolers (MAP), motor assessment, task screener, and parent questionnaires addressing computer experience, visual/auditory skills, and Piagetian cognitive skills.

Procedure
The subjects controlled the activity of a series of simple computer movement tasks using each of five computer interfaces: touchscreen, mouse, trackball, locking trackball, and keyboard (cursor keys). In each task, subjects were required to pick up, drag, and drop an object in a target location presented on a MacIntosh Fx computer screen. In baseline tasks, subjects were given two simple demonstrations and asked to deduce the means of operating the interfaces without further assistance. If subjects did not complete this task for a given interface to criterion (7/10 trials correct), training was provided on a similar movement task. Training sessions provided successively more specific cues on interface operation until either the end of maximum training or successful independent

control of the device for 3 trials. Subjects who successfully passed training also completed a repeat of the original task to measure the subject's maintenance of newly acquired control skills. If subjects demonstrated independent skills at using a given interface on initial baseline or maintenance tasks, they completed an additional sorting task with the same interface to see if their control skills would generalize to a task requiring a choice of correct location. All tasks included animation of the screen objects that was contingient upon correct responses, and between-trial feedback regardless of success that was intended to provide reinforcement and encouragement to complete the task.

Data Reduction
A mastery level score was derived for each child's performance on each interface based on the number of experimental tasks passed to criterion and the extent of training required to pass those tasks. Children who passed more complex tasks and who completed tasks independently, without requiring training, received higher mastery scores than children requiring training and/or failing at less complex tasks. The highest mastery score on an interface (a score of 5) indicated that the children were able to deduce the operation of the interfaces with no more than the two simple demonstrations provided in the Baseline task and generalize this ability to the four-part task. The sum of mastery scores for the 5 interfaces was called the total mastery level score (maximum score of 5 X 5 = 25). A summary of the mastery level scale is provided in Table 1.

Table 1: Mastery Level Scoring Summary

Mastery of single interface = 0-5 rating of highest stage passed:

0 = Fail Training - no successful mastery of interface

1 = Pass Training only - did not pass maintenance

2 = Pass Maintenance - maintain but not generalize mastery, with training

3 = Pass Baseline/Maintenance - maintain but not generalize mastery without training

4 = Pass Generalization (Sorting) Task with training

5 = Pass Generalization (Sorting) Task without training

Total interface Mastery (for all five interfaces) = sum of mastery level scores for five interfaces

maximum (adult-like) mastery is 5 X 5 = 25

Results

A set of stepwise regressions was conducted with the mastery scores as dependent variables and the scores of the subject skill measurements as independent predictor variables. The ten predictor variables were: mental age-equivalent scores (Bracken SRC), Bracken spatial test scores, Stanford-Binet pattern analysis and copying scores, gross motor screening scores, and scores on five subtests of the Miller Assessment for Preschoolers (foundations, coordination, verbal, nonverbal, and complex tasks). A modified forward selection procedure was used in which all variables are re-evaluated for inclusion with each new variable entered into a regression model.

Children's average mastery level scores for the five interfaces tested are displayed in Figure 1. Mastery scores for data collected on the same five interfaces with normally developing children aged 2.5 - 5.0 years CA (Cress, French, & Tew, 1991), are reported in Figure 2. While the relative degree of mastery of the various interfaces was similar between groups, the children with mental retardation achieved significantly lower total mastery scores on a nonparametric Wilcoxon test .

For the children with mental retardation, 57% of the variance in their total mastery scores could be predicted by the two measures of pattern analysis and gross motor skills. The verbal subtest of the MAP added 5% to the prediction of variance when forced into the regression equation None of the other factors added more than 3% to the regression model when these factors were included first. Analysis of the results of similar research with normally developing children (Cress, French, & Tew, 1991), revealed that the analysis and motor scores were among the strongest predictors for this population as well, accounting for 53% of the total variance in mastery scores Equivalently strong regression models could be constructed using the spatial awareness scores instead of the analysis measures.

Figure 1: Average Mastery Scores of Children with MR by Interface

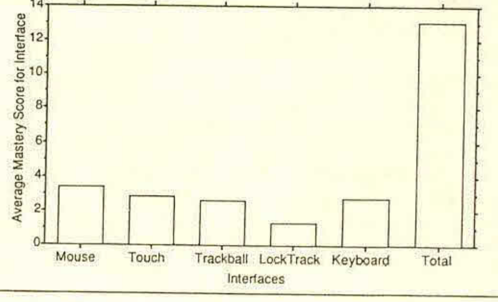
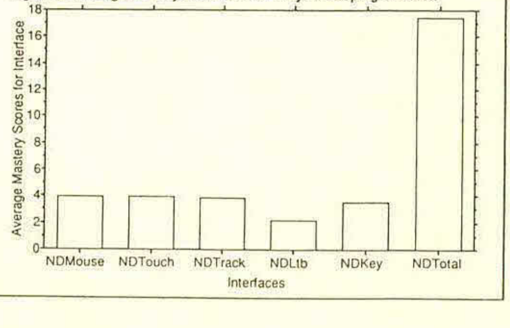


Figure 2: Average Mastery Scores of Normally Developing Children



Discussion
Each of the predictor measures was selected to represent a different type of skill involved in computer interface operation. While deficits in any of these skill areas would be likely to interfere with successful device operation, it is not practically feasible to sample all of these skills to examine potential cognitive accessibility of a given device. For the purposes of assistive technology assessment, it is useful to derive a subset of these measures that may be representative of other relevant skills. If potential device users demonstrate difficulties in these areas, it may then prompt further investigation of more device-specific cognitive and motor skills. A user's functional skills may compensate for the demands of the device operation in some settings but may not be sufficient for more complex tasks.

For instance, the children with mental retardation in this study had analysis scores below the age-equivalent expectations for their mental age scores. This would indicate particular difficulties with pattern analysis relative to the general cognitive skills measured in mental age tests. Also, the children showed MAP scores considerably below the expectations for their mental age. Since the MAP is heavily biased towards sensory-motor integration tasks, it is presumed that some of the motor and sensory difficulties associated with mental retardation, and particularly with Down Syndrome, affected children's performance with the interfaces. It is interesting that the strictly motor subtests of the MAP, namely the foundations and coordination tests, were not as strongly predictive as the verbal subtest, although the difference was small. The verbal subtest was primarily based on articulation and repetitition tasks, which may have reflected subtle differences in fine motor coordination not reflected in the other subtests.

The ordering of relative mastery of the devices by the children with mental retardation in this study was very similar to that observed in earlier results by normally developing children. This suggests that, in general, devices such as the locking trackball may be more difficult to master for a variety of children. However, children's performance with the devices was highly variable, particularly among the children with mental retardation. For instance, some of the children demonstrated much better skill on the locking trackball than the trackball, which tended to be more consistently easy for the normally developing children. Invidivdual variation among children with mental retardation may be related to specific characteristics that have been associated with mental retardation, such as selective diffulty among tasks requiring successive versus simultaneous information processing (e.g. Das, Kirby, & Jarman, 1979). Further research can investigate the role of selective skill deficits on performance differences between different types of computer controls.

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Improving Spoken Communication for Dysarthric Individuals using Voice Analysis and Synthesis

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Abstract

A system, called *Retalk*, is described that improves the spoken communication of speech impaired individuals. To be understood, many such individuals rely on others who are familiar with their speech, listening to and repeating their utterances clearly. We describe a portable computer-based system under development that performs an equivalent function. Speech recognition technology is employed to recognize the individual's pronunciation of basic phonetic components, which are then passed to a speech synthesizer (DEC-talk) for repronunciation. By working at the level of phonetic components rather than words, *all* utterances of the individual can be corrected. To demonstrate *Retalk*, we are employing it to improve the speech of a 45 year old male dysarthric individual whose speech is consistent, but only semi-intelligible.

1 Introduction

Speech is the primary method of communication during many everyday activities, such as traveling on the bus, asking questions at work, talking with friends and conversing on the phone. But for dysarthric individuals, this mode of communication is often frustrating and ineffective because the person with whom they are trying to communicate will often not understand them. Words may be repeated without success, leading the individual to be reluctant to attempt communication.

Although many dysarthric individuals are very difficult to understand for unfamiliar listeners, people who are familiar with their speech patterns can often understand them almost perfectly. This is possible because of two factors: first, the dysarthric individual tends to be consistent in their pronunciation because the speech distortions are caused by a systematic impairment of the organs of speech; second, people familiar with the individual learn to recognize idiosyncratic pronunciations and compensate for them.

People who are familiar with, and understand the dysarthric individual often play an important role in helping them communicate. They often act as intermediaries between new people and the individual—listening to the distorted utterances and repeating the words clearly. This benefits the individual because it facilitates communication with nearly anyone. However, people who are familiar with the the dysarthric speaker are often few in number (such as family members and a speech therapist) and cannot always be available. Hence, this is not a satisfactory solution to their communication problems. What is needed is an intermediary that can be with them everywhere they go, listening to and repeating all their utterances clearly.

This paper describes such an intermediary: a portable computer based system, called *Retalk*, under development. The system employs speech recognition and synthesis technology that is small enough to be portable[1] and available at reasonable cost. Previous approaches to the problem have employed recognition technology that recognizes individual *words* [Schmitt & Tobias, 1986], which are then passed to a speech synthesizer. The principal problem with working at the word level is achieving a sufficient accuracy of recognition, even with speaker dependent systems [Treviranus *et al.*, 1991]. Low recognition rates force a severely limited vocabulary, and thus prevent the computer based system from achieving the same functionality as the human intermediary, who can repeat all of the individual's speech clearly.

The system described here applies a novel method to overcome this problem with limited vocabularies. Rather than working at the word level, *Retalk* works at a much lower level—with *phonemes*, the basic sounds of speech. Since there are only 54 phonemes that, when combined, make up all the words in the English language, the learning problem is much simpler. By learning how the individual pronounces each phoneme, all utterances can be corrected[2].

This paper describes *Retalk* in more detail, but first we introduce our research subject with whom we are initially developing our system. Following the description of *Retalk*, some preliminary results are introduced. The paper con-

[1] For example, a new portable version of DECtalk synthesis system is now available called *MultiVoice*

[2] Assuming that the individual does not use one phoneme to represent more than one sound. This situation is considered later.

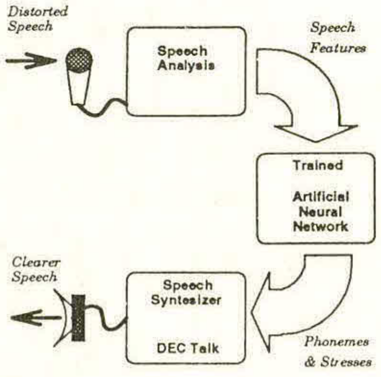

Figure 1: The *Retalk* system in performance mode, clarifying the speech of an individual. Distorted speech is picked up with a microphone and analyzed, producing a stream of time and frequency domain features that is passed to the previously trained artificial neural network. The network recognizes the individual's pronunciation of phonemes and stresses, which are passed to the speech synthesizer for pronunciation.

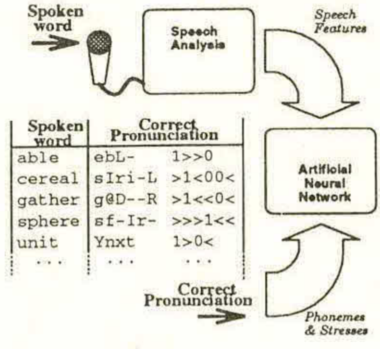

Figure 2: The *Retalk* system in training mode, where the neural network learns to recognize how the individual pronounces phonemes and stresses. The individual provides spoken examples of words whose correct pronunciation is known. For example, when the individual speaks the word `able`, the correct pronunciation (given by the sequence of phonemes `ebL-` and stresses `1>>0`) is provided as the output to the neural network. The network learns an association between its input (a representation of the individual's speech) and its output (the corrected phonemes and stresses).

cludes with a discussion of the potential successes and limitations of our approach.

2 The Client

Duane is a 45 year old male, who as a teenager, had a severe accident that resulted in a head injury. He has been in speech therapy since and can speak consistently, but only semi-intelligibly. Initially we could understand only a few words. Now, following some hours together we can understand perhaps 50% of his speech. He makes an ideal client for this technology because he has a large vocabulary and leads an active life within the community.

3 Design

The components of *Retalk* system, when repronouncing distorted speech, is given in Figure 1. First, the speech is analyzed and features significant for recognition are extracted. These features are presented to the input of an artificial neural network [Lang & Waibel, 90]. Such neural networks have proved successful in many learning applications and, due to advances in computer hardware, are practical devices that can now run on portable computers. The network, once trained, recognizes the phoneme and stress that *should* have been spoken. These are passed on to the speech synthesizer DEC-talk for pronunciation. There are 54 possible phonemes that can be pronounced by DEC-talk and hence recognized by the system. Some examples are given in Figure 2. For example, the phoneme `D` is the sound this, while the phoneme `@` is the sound in bat. More information on the phonemes and stresses can be found in [Sejnowski & Rosenberg, 1987].

Before the system can be used, it must be trained with examples of the individual's speech. This process is illustrated in Figure 2. The neural network must learn to associate patterns of speech features with the correct phoneme that *should* be spoken (not the actual phoneme spoken!). In order to achieve this, samples of words pronounced by Duane are presented to the input of the neural network (after analysis), while the correct pronunciation is presented at the output of the neural network. Correct pronunciations are obtained from the NetTalk directory [Sejnowski & Rosenberg, 1987], which contains standard pronunciations for over 20,000 English words, some of which are given in the table in Figure 2. The network is trained in batch mode, where all the data is presented at one time, so there was no need for Duane to work interactively with *Retalk* during training. Currently, we have obtained from Duane approximately 450 word samples, 3 repeats of 150 different words[3]. These were obtained by using a headset microphone with the words chosen by the computer to best represent the phoneme and stress combinations.

[3] We actually collect 4 repeats, but had to reject the last word sample, as we found Duane consistently changed his pronunciation on the last word.

4 Evaluation

This paper describes work in progress, so our evaluation is limited. Currently, we have trained the network to recognize a few of the 54 phonemes from selected words that are short. Results are encouraging and have demonstrated that phonemes are easier to learn than complete words. In addition, errors at the phoneme level have a much more limited affect on the overall performance, since they usually produce similar sounding phonemes. Results have identified the need to invest significant human and computational resources during the training phase. It is estimated that approximately 1000 sample words will be needed to achieve a reasonable phoneme recognition accuracy and training will take up to 2 weeks of computer time. The number of words is understandable, since the final system will be able to improve *all* utterances of the individual. The large training time required is a product of the neural network approach and is done only once. For this reason, the network is currently being trained on a Sun workstation; however, the trained network requires few resources and will be implemented on a PC.

5 Discussion

The system, once fully functional, will significantly improve the communication ability of dysarthric individuals. Although the current system under development will function on a desk-top PC, a portable version is planned, and will be constructed once the method is fully developed.

There are clear limitations to the method. Most speech disabilities result in a real loss of information, realized by the individual using the same sound to represent distinct phonemes. If this loss of information is too severe, methods will have to exploit additional knowledge in order to recover some of the clarity. With this in mind, we are investigating employing a database of known pronunciations to correct for individual errors in phoneme recognition[4].

The method presented here will be most successful when the errors in pronunciation are systematic and there is little variability in the pronunciation of the same sounds. Determining whether an individual's impairment satisfies these requirements can be achieved relatively quickly by taking speech samples and performing a small trial run of the training procedure. Such studies are in the planning stage for clients with cerebral palsy.

[4]This method is standard in handwriting recognition systems that correct for individual letter errors by using a database of correctly spelled words.

6 Acknowledgements

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Dysarthric Speech Recognition: A Hidden Markov Modelling Approach

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ABSTRACT

An investigation of techniques for the automatic recognition of dysarthric speech has led to the development of a recognition strategy which utilises continuous density hidden Markov models. This paper discusses the implementation of recognition techniques, and presents the results of recognition trials with three cerebral palsied subjects. Results obtained indicate that this recognition approach is capable of capturing much of the reliable statistical information present in dysarthric utterances.

INTRODUCTION

As part of our ongoing project aimed at the development of an effective voice-input communication and control system for severely physically disabled people (Boonzaier and Limon, 1991), we have developed a speech recognition strategy for the recognition of dysarthric speech. In order to test the efficacy of the methods we have used, we have conducted recognition experiments using custom software which we have developed. It is the aim of this stage of the project to investigate techniques for automatic speech recognition, as applied to both normal and deviant speech, and to develop a robust strategy for the automatic recognition of dysarthric speech. Formal techniques developed through this research will be implemented in a communication device. Currently available (commercial) speech recognition systems have not achieved satisfactory results when used by dysarthric speakers, especially athetoid cerebral palsied people.

BACKGROUND

Many individuals whose quality of speech production is so poor as to classify them as functionally non-speaking (or non-verbal), could derive, from whatever residual vocal ability they possess, a set of functional vocal communication *symbols* that would serve as alternate input to a computer-based communication system. Members of this population who are capable of producing reasonably consistent and repeatable utterances, be they verbal or non-verbal, would benefit greatly from a system that could recognise these vocal symbols and translate them into useful information for communication and environmental control purposes.

SPEECH RECOGNITION APPROACH

Due to the presence of considerable articulatory and phonatory variability, automatic recognition of dysarthric speech presents a far greater challenge than does the recognition of normal speech. Deller and Hsu (1987) reported that their testing of dysarthric, cerebral palsied (CP) persons indicated that although their speech was mostly unintelligible, it did contain significant recognizable information, which could be used by an automatic recognition system.

The speech recognition strategy which we have chosen to adopt is that of hidden Markov modelling (HMM). In particular, we have used continuous density HMMs, with multivariate normal distributions. (The reader is referred to the paper by Rabiner et al, 1985, for a thorough treatment of this topic). The rationale for using this method is that the HMM approach uses a statistical characterization of the speech signal, and thus, should capture more information about the signal than do other techniques, such as dynamic time-warping (DTW).

Speech signals were digitized at a sampling rate of 10kHz, using an oversampling analog-to-digital converter. The digitized signal was then pre-emphasized using a simple first-order digital filter, $1-0.95z^{-1}$, and blocked into frames of 30ms, with 50 per cent frame overlap. Each frame was weighted by a Hamming window, before a 12th-order linear predictive coding (LPC) analysis was performed. The LPC vectors were then converted to 15th-order, bandpass-liftered cepstral feature vectors which were used as input vectors to the HMM training and recognition algorithms.

In this work, we have used 6-state hidden Markov models, which have an *ergodic* structure (Deller et al, 1991). Model training is performed using the k-means clustering algorithm, followed by the Viterbi re-estimation procedure (Rabiner, 1989). The Viterbi algorithm is also used in classification.

METHODS AND RESULTS

Speech recognition experiments were conducted with speech samples recorded from three cerebral palsied individuals, SC, NA and JS, aged 15, 21 and 31 years, respectively. In order to obtain an objective grading of the severity of the participants' dysarthria, the single-word intelligibility component of the Frenchay Dysarthria Assessment (Enderby, 1983) was administered to each participant. The assessment results are presented in Table 1 (with scores given as percentages, rather than the prescribed letter indices); as can be seen, these three individuals have severely limited vocal ability.

Subject	Judge 1 (%)	Judge 2 (%)
JS	50	60
NA	40	50
SC	20	20

Table 1. Single-word intelligibility test results.

Two word-corpora were used in the recognition trials: a 10-word corpus comprised of the digits (zero to nine), and an 80-word corpus, adapted from Beukelman et al (1984).

Recordings were made of each of the participants speaking the 10-word corpus ten times. Recording equipment included a Sure SM-10A head-mounted microphone, a custom-built microphone amplifier, and an Aiwa portable DAT recorder (model HD-S1). The isolated utterances were digitized, as described above, hand-edited using Audiomedia™† sound editing software, and then processed using speech processing software which was developed as part of this project. All work was conducted on a Macintosh IIci computer.

The first five repetitions were used in a training phase to create Markov models for each word, and the second five repetitions were used in the recognition trials. Results of the trials are presented in Table 2. The speech recognition software was also tested with speech samples from two individuals with normal speech, yielding recognition scores of 100 and 98 per cent.

Subject	Recog. Rate (%)
JS	95
NA	88
SC	74
Normal 1	100
Normal 2	98

Table 2. 10-word corpus recognition results.

In addition, recordings were made of participant JS speaking the 80-word corpus 10 times. The same training and recognition protocols were followed, as used in the 10-word trials. The recognition rate in this trial was 93 per cent.

DISCUSSION

The results obtained in the trials, indicate that the recognition strategy which we have adopted can yield acceptable recognition rates, in spite of the greater variability present in dysarthric speech. As anticipated, recognition rates for the three dysarthric cerebral palsied speakers were found to correlate with the degree of severity of their dysarthria. Even more encouraging was the fact that recognition performance was found to be only slightly poorer with the larger, 80-word, corpus.

CONCLUSIONS

The approach described in this paper, to the problem of improving automatic recognition of dysarthric speech, has achieved considerable success. As a next step towards our goal of developing a robust, portable, real-time voice-driven communication system, we will incorporate the techniques described in this paper, into an automated on-line speech recognition system, with synthesized speech and/or text output.

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Suppliers
†Audiomedia™: Digidesign Inc., Menlo Park, California.

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Coordinated AAC Delivery Program for Persons with Severe Disabilities

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Abstract
A communication and control enhancement program for individuals with severe disabilities has been implemented through a coordinated effort of an assistive technology center, group home and adult day program. This project has led to enhanced skills on the part of the consumers, greater staff collaboration and the incorporation of assiStive technologies into the daily activities of both programs.

Background

This paper describes a joint program between an assistive technology center, a group home and an adult day program. These individuals have severe developmental disabilities which include lack of fine motor control, inability to speak and unknown cognitive skills. In both programs, the need for greater communication opportunities and for more active participation in program activities had been recognized, and the group home had been cited by a state licensing agency for lack of communication opportunities for its residents. Due to the severity of the consumers' disabilities, consideration of the use of assistive technologies was requested.

Objective

The primary objective of the project was to increase opportunities for interaction, control and communication by the adult consumers in both the day program and group home settings. In order to meet the objective, the needs for assistive technology services characteristic of consumers in both the group home and day programs were determined, and an integrated program was developed to meet these needs.

Method/Approach

The intervention program began with a review of the two programs to identify major needs which might be served by assistive technologies, and to develop an intervention plan to meet these needs. Based on this review and evaluations of two clients from these programs, it was clear that a computer system adapted for a range of motor skills would be of general benefit. A computer system with appropriate adaptations was provided at both the group home and day programs. Software was chosen to develop some basic cognitive skills (e.g, cause/effect, choice making) and to provide limited augmentative communication. Simple appliance control hardware was also used to facilitate interaction and concepts of control. A variety of switches selected to meet the range of needs presented were also obtained for both programs. Equipment chosen is listed in the appendix. This equipment allowed implementation of simple cause and effect, choice making and communication training. Since the same equipment was available at both facilities, there was interaction between the personnel at each location, and this helped with program implementation.

Once the overall needs for equipment were determined, several activities were carried out. The first of these was the screening of individual consumers to determine their motor skills and required control interface and needed reinforcers. By matching the interface and reinforcer (e.g., computer graphics, appliance control) to each individual's needs, we were able to increase interaction and control utilizing assistive technologies such as communication and environmental control systems. The major questions which arise are what type of interface is best given the person's physical skills and what type of reinforcers are most meaningful to that person. For the participants in this program, these questions were answered by conducting a short (1 1/2 hour) evaluation in which basic physical skills were determined, an interface selected, and the interface used with a variety of contingent results (computer, appliance, tape recorder). A brief report identifying the interface, reinforcers and proposed physical/interaction/communication goals was prepared for each consumer and included in a training notebook which was available at both facilities. A list of equipment plus a written, generic training program emphasizing increasing interaction and communication skills[1] was also included in each notebook.

The second activity was the provision of consultation regarding augmentative communication and the development of communication boards. This consultation was provided to both the home and day program staffs, and it was in parallel with the motor screening and motor training. There were communication opportunities in both programs, and the use of language boards allowed the staff to take immediate advantage of them. These included community based activities, group meetings (e.g., resident council) at the group home, and consumer-staff interaction. At the beginning of the project, only three of the 29 consumers in the program were verbal, and the rest relied on gestures, signs and other alternative communication modalities.

In order to address this communication need, a speech pathologist provided consultation on augmentative communication. This included an environmental survey of communication needs completed for each consumer by both the day program and care home staffs. These identified communication opportunities for consumers and resulted in suggestions for specific vocabulary to be included on communication boards.

Consultation was also provided to staff regarding the design and construction of communication boards. Some consumers lacked the physical ability to point to items on a communication board, and additional consultation was provided regarding alternative selection methods such as the use of eye gaze. As physical skills and cognitive abilities improved during motor training, these were applied to enhanced communication opportunities using the computer and software: Step-by-Step w/single switch and Talking word board with up to eight choices using a switch box.

The successful utilization of both the communication boards and the other assistive technologies was dependent on training of both staff and consumers. Our program emphasized staff training, with the staff then training the consumers. Each facility designated a key staff member to lead the assistive technology efforts. Additional staff were trained in the implementation of the program through a series of in-services directed to the various shifts. This training included modeling of intervention with consumers. The training and followup were provided by Center staff in a series monthly trips. Some training sessions were videotaped by group home or day program staff to use with new staff and for review as the program progressed.

As the program was implemented, and consumers developed greater skills, it was necessary to periodically review progress, set new goals and make adjustments based on experiences of staff and consumers. This occurred during the monthly consultation/training sessions held by Center staff. Sessions were held at the group home and day program on alternative months.

Results

The initial screenings identified interfaces and reinforcers for each consumer. Based on these, specific motor training and communication goals were established. These were then implemented by program staff. The progress of each of the consumers was monitored by collecting data regarding speed of response, number of prompts, and communication opportunities. Progress was made for all consumers, but the rate was variable.

The day program and group home staffs were able to extend the screening methods to the remainder of the consumers, and this amplified the time spent by the Center staff.

Both facilities established "activity" rooms equipped with a variety of adaptive devices for both program activities and leisure time. These proved to be valuable for implementing individualized training objectives for each consumer.

An additional result, not initially anticipated, was a new perception of the consumers by staff. As consumers demonstrated the ability to understand communication and control concepts, the staff began to expect more of them. this further enhanced the performance and progress toward more general goals at both facilities.

Discussion

The initial number of consumers included in this project was initially restricted to or approximately one-half of the total number enrolled in the program. This allowed staff to begin to utilize assistive technologies without becoming overwhelmed by large numbers of devices and participants in the program. Second, by observing ADC staff, the program staffs at both facilities were able to apply some of the same methodology to additional consumers. Finally, by starting with a smaller group of consumers, we were able to concentrate our efforts and obtain closure sooner for this group rather than diluting our efforts over a larger number of consumers.

By choosing generally useful technology, the funding agency was able to more easily justify the expenditure than if separate requests had been made for each consumer. As an individual consumer demonstrates communication or control abilities, a specific request for assistive technologies can be more easily justified. This consideration is particularly important under the funding agencies very tight fiscal constraints.

This program was conducted as an adjunct to other technology-based services such as seating and positioning. However, the impact on communication and control provided by an improved positioning system was immediate. Conversely, the need for new positioning was justified and clarified in some cases by the potential for control or communication. In general, this program fit well other services provided to the consumers.

This joint project, funded by normal service sources, provides a useful model for the provision of group-based intervention in assistive technologies. The collaboration between the home, day program and assistive technology center led to important insights and gains which none of the three components would have obtained individually.

Appendix

Equipment utilized- Computer system: Apple IIgs microcomputer, Adaptive Firmware Card w/Switch input box[1], Echo speech synthesizer, color monitor.Software: Motor Training Games[1],Early and Advanced Switch Games[2],Make it in Time[1], Interaction Games I and II[1], Step-by-Step[3], Talking Word Board program[4], Control interfaces: Touch switch[5], Lever switch[5], Wobble switch[6], Big Red Switch[7], Tread Switch[5], Universal switch mounting[7].Simple appliance control: Ablenet Appliance Control Unit, Switch Latch/Timer[1], battery adaptors[7], single switch Ultra-Four transmitter/receiver pairs[8].

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[1]Don Johnston Developmental Equipment

[2]R.J. Cooper & Associates

[3]LSP Children's Hospital at Stanford

[4]Incuded with Adaptive Firmware card

[5]Zygo Industries

[6]Prentke Romich Company

[7]Ablenet Inc.

[8]Tash, Inc.

YOUR EXPRESSIVE SOCIETY (YES)
AN AUGMENTATIVE COMMUNICATION USERS SUPPORT GROUP

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ABSTRACT

An adult consumer based support group for individuals with severe speech impairments has been established to promote the use of voice output communication devices. Adult AAC consumers continue to be underserved. They no longer have the support of a school system and if they attend therapy, it may be on a consultation basis only. Since AAC devices are complex and require regular follow up services, these consumers are in need of technical assistance and/or psychosocial support. The support group consists of AAC consumers from the metropolitan area who have diverse backgrounds and abilities. The following is a summary of how such a group was formed.

BACKGROUND

Individuals using AAC systems, their families, and therapists expressed a need to create a supportive environment where users can practice and learn to be better communicators. It was determined that users were not effectively communicating outside therapy sessions and that they desired communication experience in real life situations. It is recognized that device users need an opportunity for ongoing assistance to further develop their skills beyond the initial assessment and training. They need to develop self-confidence to try newly obtained skills and they need to know they are not alone. As a result of this interest, an AAC users' support group was established and coordinated by a director and assistant director. The first session was held in October, 1990, with eight AAC users in attendance.

OBJECTIVES

- Provide a supportive environment for sharing successes and frustrations with other users of devices.
- Develop users' skills beyond the initial assessment and training.
- Incorporate individual and group goals to facilitate daily use of communication devices.
- Promote self-advocacy.
- Increase public awareness of the capabilities of individuals with speech impairments.
- Encourage participation of family, friends, caregivers and health professionals.

METHOD

The director and assistant director interviewed AAC professionals working in the field. It was apparent from these meetings that there was a vital need for ongoing support for individual users of AAC devices. Eight consumers were identified from throughout the metro area. Personal interviews were conducted within the consumer's home environment to determine individual needs and goals. The next step was to find an accessible location for group sessions. The help of an interested technical advisor was enlisted. As additional consumers expressed a need and desire to join the group, two speech and language pathologists were recruited. The importance of direct and ongoing communication with caregivers cannot be emphasized enough. Meeting notices and follow-up phone calls help staff and caregivers arrange for consistent consumer attendance. Without their support and continued involvement the group would not be able to function. Helping to coordinate transportation for the users to the group meeting place is also required. The group meets on a regular basis in a community facility. The sessions occur bi-monthly for a two hour period. An agenda for each meeting must be prepared specifically to address the needs of the group.

Careful documentation of the meetings is important for the purpose oftracking the progress as well as the changing needs and goals of individual group members.

RESULTS

Group and individual goals were developed. Members were assisted in designing personal goals to meet the needs of their usual daily activities. Members shared ideas and provided feedback to each other as to possible strategies to successfully accomplish these goals. Since the formation of the group, spontaneity of communication has improved. Group members have requested more pre-programmed phrases to be entered into their devices. They have arrived at the group sessions excited and ready to interact with each other. The members have been able to participate in activities which others take for granted such as; initiating conversation, making a telephone call, shopping, singing and "tape recording" a letter, and video-taping a get well greeting to an accident victim. These activities have enabled individuals with severe speech impairments to participate in the mainstream of life. An example of such an activity was singing Christmas carols at a local mall. The group process was exciting as songs were chosen, programmed and practiced in preparation for the "singing event". The "singing debut" was truly a rewarding experience because it allowed users to share the holiday spirit in a unique and fun way. Shoppers, young and old, were given a chance to observe different methods of communication in a non-threatening environment.

DISCUSSION

The group has provided not only an opportunity for the members to learn and grow but also for the public to learn about alternative methods of communication. Overall, the public has responded positively with healthy curiosity.

It is to be noted that technical difficulties are more numerous than expected. The technical advisor has been an integral member of the group, who repairs as well as programs devices. Individual members and the group as a whole have to constantly learn problem solving strategies.

Your Expressive Society (YES) operates on a shoestring budget. No major source of funding is provided. Group members pay no fees. Members do, however, play an active role in fundraising. Over the course of a year, they raised enough money through candy sales to temporarily hire two speech and language pathologists as group facilitators. This also gave members an opportunity to get out in the community and interact with society. Ongoing fund raising projects continue.

Your Expressive Society (YES) is an example of how a support network can enhance one's ability and desire to actively and effectively communicate in society. COMMUNICATION DISABILITIES NEED NOT BE HANDICAPS!!

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A Foot-Controlled VOCA for a Multilingual User

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ABSTRACT

A Voice-Output Communication Aid (VOCA) with English, Russian, and Hebrew language capabilities was designed for a 12-year-old male with cerebral palsy. The VOCA user, bilingual in Russian and English, has used his system to develop literacy in those languages, and also to develop beginning literacy in Hebrew. The device permits display, print-out, and text-to-speech in all three languages. Operated with the same foot control used to steer his powered wheelchair, the system incorporates wireless keyboard emulation for use with desktop computer systems. Through a focused project involving use of all three languages to pursue a highly motivating goal, the VOCA user has achieved a higher expression of personal identity.

BACKGROUND

Born in Kiev, Ukraine, USSR, in 1978, GC has athetoid and spastic cerebral palsy, attributed to anoxia at birth. He emigrated with his parents and grandparents to the United States in 1979 at the age of fifteen months. He received little therapy in the Soviet Union, but was enrolled in various educational and therapeutic programs in the United States as a preschooler and throughout elementary school. He currently attends a residential school for children with cerebral palsy during the week and spends weekends and vacations with his family.

Throughout his life, GC has lacked functional speech and has had no functional hand or finger control. Though his control over his trunk and his lower extremities is extremely limited and does not permit him to stand or walk, he does have considerable control over his left leg and foot. By age five he was able to operate a joystick to play video games with substantial success. GC started receiving speech-language services in a program specializing in augmentative communication when he was three years old. As the state of commercially available communication aids has developed, he has had the chance to try various devices, some of which were purchased for him and mounted on his wheelchair. He operated these devices in row-and-column-scanning mode by activating a momentary-contact single switch with his left foot. He did not respond favorably to any such device for long, indicating that he found them slow and tiring. For a time, he was given a joystick-operated a device, but he was not as accurate with the joystick as he had been with the single-switch approach, so his school staff returned him to the single-switch system.

GC's principal means of communication since early childhood has been facial gesture, looking up for yes and down for no and, where possible, using his eyes to point in the direction of an intended referent. With the help of his parents and therapy staff, he developed a sophisticated word board with a 3-digit encoding system to index about 500 words and phrases and the English alphabet. These vocabulary items were displayed on a tabloid-sized folding board which he carries with him on his wheelchair.

Linguistically, GC has presented a mixed picture. In his receptive competence of spoken English (as determined by his school staff) and Russian (as determined by his family), he has consistently been at or above age level. His mastery of both reading and writing in English, as he approached his thirteenth year, however, lagged considerably. At the time when the intervention described in this paper was initiated, he manifested a number of perceptual problems such as reversals of letters and an occasional loss of place on a page of reading material. He also was prone to a number of syntactic errors in his written expression, at least some of which could be reasonably attributed to interference from Russian, such as omission of articles. GC's teacher's and therapists were concerned about his lack of motivation to use his commercial VOCA. His own explanation for not wanting to use it included its slowness of access and poor voice quality. GC's lack of enthusiasm for his VOCA was seen as but part of a general alienation from the social environment of his residential school.

Two months after he became 12 years old, GC was approached by the social worker at his residential school. She had been particularly concerned in finding ways to interest him in pursuing his academics and in stimulating his communication with others.

One motivating factor seemed to be his self-identity as a Russian. Although his birth city, Kiev, was in the Ukraine, where both Ukrainian and Russian are spoken, GC's family spoke a mixture of Russian and English at home in the U.S.A. His grandparents spoke only Russian with him, and, though he had lived in the U.S.A. since the age of 15 months, he claimed Russian as his "first" language. Around school he liked to be known as "Bad Russian G..."

The school social worker also knew that GC's family was Jewish, but did not know the extent to which he identified as a Jew. Neither of his parents had had any Jewish education or religious affiliation, either in the Soviet Union or in America, and GC himself had not had any exposure to Judaism. Nonetheless, the social worker, noting that GC had just turned twelve, asked him if he wanted to become *bar mitzvah* — that is, to participate in the Jewish coming-of-age ritual for thirteen-year-olds.

She reports that he gestured an immediate and enthusiastic yes. This began a chain of events which led to the program of intervention described in this paper. Although this program is still in progress, it is worth recounting at this time some of the technical and psycho-social factors which figured in the milestones which GC and his team have achieved.

OBJECTIVE and APPROACH

GC's team — consisting of his family and his school staff and, eventually, concerned members of GC's community, sought for him a pathway to enhanced social interaction and better academic performance, especially in linguistic self-expression. Secondarily, and as a stimulus to achieve these primary objectives, they wanted to find a way that he could express his Russian identity in an active way and preserve and develop his Russian linguistic competence. Finally, they wanted to take advantage of his desire to become *bar mitzvah* to direct his energies into literacy- and communication-promoting experiences.

These objectives could not be achieved through assistive technology alone, but it became obvious that such technology did have a role to play. GC's parents had consulted with the authors over the years and now asked if a program of intervention could be designed, incorporating a custom VOCA, which would help GC and his team to achieve their goals. Based on previous work with multilingual users of augmentative systems, the authors joined GC's team in proposing a phased intervention program. GC would, as a result of this program, acquire the tools and training to write, speak, and even sing in all three languages: English, Russian, and Hebrew.

GC had not had any training in Russian literacy at school, but his parents and grandparents had over the years attempted to familiarize him with the Russian alphabet. However, he never had any way to write out Russian words and phrases on his own, much less to have these utterances spoken out. A VOCA with Russian characters and text-to-speech capability was therefore set as one of the tools that GC's program would seek to develop for him.

The requirements of the *bar mitzvah* ritual vary from tradition to tradition, but usually involve the young person demonstrating a reading knowledge of Hebrew by reciting blessings and chanting a portion of the Bible, all in Hebrew and usually in a traditional cantillation melody. The *bar mitzvah* celebrant also is usually expected to deliver a speech related to the Bible portion. This speech is usually delivered in the vernacular of the congregation, which in America is usually English, but in GC's case, with many Russian-speaking family expected to be in attendance, it would properly be both in Russian and English. The English and Russian speech seemed well within GC's linguistic competence, but he had no knowledge of Hebrew or the Bible, not to mention biblical interpretation. GC's was advised that, in view of his physical limitations, he could qualify as *bar mitzvah* just by virtue of being thirteen, without having to demonstrate these substantial intellectual attainments. GC insisted on the more demanding path, which delighted his team, but raised the question: how? Part of the answer would be to provide him with the tools for learning the Hebrew writing system, and then giving him the chance to build a corpus of blessings and Bible verses which he could, in a systematic way, call forth in vocal form in the appropriate order and in the appropriate intonations and melodies.

The goal of the *bar mitzvah* ceremony encompassed the goals of developing literacy and greater social ease in English, as well as helping GC to develop his Russian and Jewish identities through linguistic expression in Russian and Hebrew. From the beginning, it was obvious that, even with volunteer help, this ambitious plan would carry a hefty price tag, especially for the development of GC's VOCA. Although public funds had been available to subsidize the cost of his English-language VOCA, his multilingual system, which needed to be customized, would have to be supported through contributions. GC's team members, however, felt that his story was so compelling that sufficient funds could be raised. There are many reasons to deplore individualized fund raising for assistive technology, but in this case, GC and his team felt such an approach to funding was justified.

METHOD

In the summer of 1991, a wheelchair-portable VOCA was developed which allows GC to write out text strings in any of the three languages. The device, based on a Toshiba 1000 SE laptop with its central processing unit positioned behind the seat and the flat-panel display repositioned on a bracket in fron to GC, provides print-out and text-to-speech in all three languages. A custom interface permits GC to control a cursor on the flat-panel display with the same pedal joystick he uses to steer his powered wheelchair. The system incorporates wireless keyboard emulation for use with desktop computer systems. Voice output is provided by two built-in synthesizers: DECtalk and the Artic 263 chip, the latter used for Hebrew. The operating system of the VOCA was written in Borland C++. The Hebrew and Russian fonts were generated specially for GC's system. The Russian character set contains both upper and lower case. The Hebrew character set contains all the traditional vowel marks and special *trop* diacritics used to indicate Biblical cantillation (chanting) patterns. GC's system presents him with an unlimited number of vocabulary pages, with up to 100 items on a page. One item is always highlighted by a cursor box. GC's foot movement on the joystick causes movement of the cursor box in the corresponding direction. GC can create text strings by spelling them out letter-by-letter and then can save them on any desired page location. Items in different languages can co-exist on a single page. Hebrew text items are printed from right to left, Russian and English, from left to right.

Two rabbis volunteered their time to work with GC for a year to help him to learn the letters of the Hebrew alphabet, Jewish history and belief. His residential school teachers and therapists also learned elementary Hebrew in order to assist him during the week. A student volunteer from a local university also met with him on a weekly basis, as did a professor from another university who specialized in special education. Over a period of about seven months, GC copied letter-by-letter, line-by-line, the various Hebrew blessings and Bible texts. Working with one of the rabbis, he developed his own ideas into a speech. His grandparents and his mother helped him to formulate additional thoughts in grammatical and correctly spelled Russian. A local congregation welcomed him to have his *bar mitzvah* ceremony with them, and to attend services in their sanctuary in the months preceding his own, so he would could become familiar with the order of the service. The congregation also commissioned a ramp to make the raised sanctuary platform wheelchair -accessible.

On May 3, 1992, GC ascended that ramp, steering his wheelchair with his foot-controlled joystick. When his turn came to participate, he used that same joystick to navigate through the "language space" of his VOCA. He chanted in Hebrew, spoke in English and Russian, and, to his satisfaction, claimed his Jewish and Russian and American identities.

GC, with the guidance of one of his rabbis, uses his multilingual VOCA to acquire basic Hebrew literacy

DISCUSSION

GC's intervention program continues. He still is studying Hebrew and the Bible, using his VOCA to print out his homework. He is still working on Russian literacy with his grandparents. He still experiences occasional letter reversals and sometimes loses his place in a text. He uses his English voice output with much greater frequency, and he has made many new friends.

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A COMMUNICATION SYSTEM FOR A NON-VOCAL WOMAN WHO IS BLIND AND QUADRIPLEGIC: A CASE STUDY

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ABSTRACT

Physically disabled people can use computers to pursue educational, vocational, and personal goals in written and spoken communication. This paper examines the special needs of an individual who has severe physical impairments, is non-vocal, and is blind. A custom PC-based communication system in which standard word processing software is used to provide both speech output and written communication is presented through a case study.

BACKGROUND

M.T. is a 42-year-old woman with a 12-year history of multiple sclerosis. As a result, she is quadriplegic with no functional movement in any of her extremities. She has severely dysarthric speech which is almost always unintelligible. In order to communicate verbally, a third party familiar with her speech is required to translate and even this method will not be an option for long due to the deterioration of her condition. She can see shapes and light but she has no functional vision for reading. She has minimal head movement but is able to move her chin laterally and up/down with good control. No cognitive or memory deficits are evident and her hearing is within normal limits. She uses a manual wheelchair for mobility and spends most of her day in the chair. As part of our initial evaluation for augmentative and alternative communication (AAC), M.T. also had her seating and positioning system evaluated. Changes were subsequently made to her seating to improve her comfort and function. She is an avid writer whose main interest is creative writing. Several of her works have been performed by a local theater group.

OBJECTIVE

Prescribing a communication system for M.T. involved the consideration of several options: 1) purchasing a commercially available AAC device; 2) modifying a particular commercially available AAC device; or 3) designing a custom device specific to her requirements. In this case it was decided that assembling a custom device would best meet her needs and maximize her independence in communication. The following case study is intended to present an example of how the success of a custom communication system can be enhanced by the appropriate utilization of technical customization with respect to the user's abilities.

M.T.'s goal was to have a system that would integrate written and spoken communication. She wanted a system that would be easily portable to allow her to communicate using spoken output at any location. In addition, the ability to access an environmental control system (ECS) to enhance her independence was also of importance. Because of her lack of upper extremity function, the system needed to have an input that would allow her access to the system using chin movement. This access method needed to allow for fast and non-disruptive switching between speech output and other tasks. Provisions also had to be made to incorporate audio feedback that she required to enter and review text. It was important to keep costs as low as possible since the only source of funds was money raised by her synagogue.

METHOD

The approach used in this case was to build a communication system from commercially available equipment that could be easily adapted if M.T.'s needs change. It was important that the system could be maintained primarily by her care givers. The system chosen consists of a Compaq LTE[a] lap top computer, Panasonic[b] dot matrix printer, MultiVoice[c] Version 1.1 voice synthesizer, Altkey[d] alternative input software version 4.07, Microsoft Word[e] Version 4.0 word processing software, and a Prentke-Romich[f] Control-1 environmental control system.

The best method found for M.T. to consistently activate a switch was to push out and down with her chin. A dual-action lever switch that provides good audio and tactile feedback was selected. The mounting system for the switch needed to allow the switch to have multiple positions as her location in her wheelchair changed throughout the day. Two rigid arms with multiple degree of freedom connectors were used to provide the desired range of positions. This also allowed the switch to be moved out of her way for transfers and eating.

Two types of input methods for text entry were considered: single-switch Morse code and audio scanning. M.T. was able to enter dots and dashes using long and short chin movements. Different pitch tones were used to indicate the dots and dashes. She initially had difficulty with the timing but improved with use. The major disadvantage of this system was related to training: while her memory was very good, she was required to know many codes and was unable to read a list of the codes associated with each keystroke. With audio scanning, she was able to immediately enter text and started writing a story during the evaluation. We agreed that she would be able to learn Morse code if she practiced but she had a strong preference for scanning and the potential speed advantage of Morse code did not seem to be a major factor.

The alternative access method chosen involved the use of a keyboard emulator called Altkey. Other access methods were evaluated; however, they did not have the programming flexibility that Altkey offered. This flexibility allowed Altkey to be configured to operate the Control 1 with a minimum of switch closures (1). Altkey is a memory resident keyboard emulator that has both scanning and Morse code options. It allows control of DOS-based application programs by using one or two-switch input methods. This is done by way of a single menu line on the screen. The Altkey menus can be changed to meet the user's needs with each application (2). The Altkey program continually accepts switch input through the computer's serial port. The switch closures allow the user to select items from the one line menu that may branch to other menus or to an action such as a keystroke.

The main use of the system was as an integrated workstation for spoken and written communication. One possible approach involved using a word processor for written communication and a separate device or a dedicated software package for spoken communication. However, this idea was not cost effective and sacrificed ease of portability. The approach that was ultimately chosen involved using word processing software to integrate written and spoken communication (3). This approach originated from the capability of most word processors to directly print output to any I/O port using a choice of printer drivers. The generation of speech on a serial speech synthesizer was accomplished by sending ASCII characters through the serial port connected to the speech synthesizer. The production of written communication on a serial printer was performed by a similar method. Using a word processor for both written and spoken communication eliminated the need for a devoted spoken communication device or program thus saving space and costs, improving portability, and decreasing the number of systems the user had to learn.

Microsoft Word 4.0 was chosen as the word processor to be used with the system. Newer versions of Word, as well as other word processors, were available, but a copy had been donated to our department with the intent that it be given to a client. There were no disadvantages of using the older version as it contained all the needed features and saved several hundred dollars from the total cost. For the communication system two windows were created in the word processor. One window was used for written text and the second was devoted to spoken communication. When entering text in the writing window, the print command sent the text to the printer; when in the speech window, text was directed to the speech synthesizer by the print command. Using the multi-windows capability of a word processor to partition speaking and writing made these activities distinct and allowed M.T. to perform them separately.

A series of audio scanning menus were developed with the Altkey system that allowed M.T. to access the communication system efficiently using a one switch input mode. When she was in the writing window a menu with choices specific for writing tasks was provided. The writing menu contained the alphabet along with choices that allowed for access to loading and saving word processor files, audio review of a document, and other options. Text was generated by selecting the appropriate letters. One of the choices was a review feature that sent her text to the synthesizer one sentence at a time. In addition, an option was provided that allowed her to switch between the text and the speech windows. Upon switching to the speech window a menu with choices specific for speaking was started. The speech menu contained the alphabet along with a choice that allowed for access to commonly used phrases.

The Compaq LTE was an inexpensive, light weight lap top computer that could be easily mounted on the wheelchair. One of the features that set it apart from it other similar computers was the ability to easily add a second serial port needed for the ECS connection. The MultiVoice voice synthesizer was selected because of its high quality output and various voice capabilities. Two miniature speakers were provided for audio output: one for output of spoken communication, the other for audio scanning output. The speaker for audio scanning was mounted near M.T.'s ear with a male voice used as the voice of the computer. The volume was set low so that only M.T. could easily hear it. A female voice, selected by M.T., was used for output of spoken communication through the second speaker with the volume set at a normal speaking level. With this method, a listener had no confusion about when the computer was speaking to M.T. and when she was speaking to them.

Both the writing and speech windows contained an option that allows her to access the ECS. Upon selection of this option, a menu specific to ECS selections was presented. M.T. was able to control several lights, AC appliances (radio, TV), and her telephone through the ECS. When she selected any device, a special menu relating to that device's functions was presented. Some options performed several related tasks with a single selection. For example, when she selected the answer option, the phone was answered and the following message was immediately delivered to the caller: "Hello, please be patient, I am using an alternative communication device." After this message, she could enter spontaneous text for her conversation or read previously written material. The ECS needed to be plugged in to the system for her to use it. The cable was long enough that it could be connected when she was in her room or in the living area. Since she was not independently mobile, this did not pose a major inconvenience for her.

The communication system needed to be portable to maximize use of the system. Because M.T. used audio rather than visual feedback, the system did not need to be mounted in her visual field. Mounting the system under her wheelchair maximized the flexibility in providing care for M.T. and in maintaining the system. She liked the system positioned out of sight so that people would feel they were talking with her and not with her computer. A small rectangular Plexiglass shelf was fabricated to fit under the wheelchair. The lap top computer and voice synthesizer both had batteries that allowed them to run for up to eight hours without recharging. All the components of the system except the printer and ECS were mounted on the shelf. Each component was placed in a protective covering to shield it against any adverse conditions. The printer and ECS were placed at her workstation and were accessed by connecting extension cables from the computer to the respective component.

RESULTS

This system provides M.T. with a reliable method for production of spoken and written communication. The use of Altkey software in developing the access method for the system allows the system to be modified to meet her changing needs. She has increased her proficiency in using the system for written communication, specifically, creative writing. M.T. is also able to communicate more easily and independently with people who aren't familiar with her, using the spoken communication capabilities of the system. The ability to access an environmental control system has further increased her independence at home. The portability of the system allows her to not only use the system at home but also use it in various other settings. Thus, the system has greatly contributed to increasing M.T.'s overall independence.

However, some problems have been encountered using the system. File management is difficult for M.T. Specifically, she must remember the names of all of her written communication documents as the system does not provide an audio method to review file names. In addition, there have been some problems in editing documents. Particularly, when M.T. reviews a document and finds an error in the middle of a sentence. She can stop the review process at this point but the cursor automatically goes to the end of the sentence. To get to the error in the middle she must back up using the cursor keys. The problem is that there is no audio feedback to where the cursor is with respect to the error in the sentence. M.T. overcomes this problem by deleting the entire sentence and retyping it which becomes quite tedious and time consuming.

DISCUSSION

Future direction involves developing more comprehensive audio scanning. A possible solution to the problem of file management could be the use of a screen reader. When loading files on most word processing software there is an option which allows the user to list the files that are on disk. A screen reader could be employed to send the output of this "file" screen to the voice synthesizer. Also, the problems encountered in editing may be solved by introducing a more basic level of reviewing a document. Presently, reviewing a document (at the most basic level) can only be done sentence by sentence. If the document could be reviewed word by word it would be easier to find and correct errors. Most word processing software allows the user to highlight one word at a time. Thus, highlighting one word at a time and "printing" it to the voice synthesizer may solve editing problems.

CONCLUSION

A custom communication system that uses commercial word processing software to integrate written and spoken communication along with other tasks has been presented. This case study illustrates the importance of matching custom designs with a person's abilities and needs. For example, M.T. although visually impaired has full hearing capacity. Using audio scanning as a means of accessing the communication system maximized M.T.'s independence in using the system.

Moreover, this case study shows that disabled people may be able to use standard word processing software to pursue education or vocational goals in both written and spoken communication. The use of a single computer for both voice output and other tasks is a highly flexible and cost-effective means of solving communication problems.

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ESTABLISHING INITIAL COMMUNICATION SIGNALS WITH ADULTS FOLLOWING A BRAIN INJURY

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ABSTRACT

Adults who suffer severe brain injuries may not be considered candidates for augmentative communication systems, due to minimal response levels after months of intervention. This presentation will discuss two adult clients who had been described by professionals as being unable to initiate any consistent volitional control. Despite this interpretation, low cost communication signals and devices were introduced. This presentation will discuss these systems, the therapeutic process, and the modifications used to mount the control interfaces.

BACKGROUND

Client: Deb

Deb was quadriplegic following a spinal cord injury during mountain climbing. No problems were noted in her verbal communications or feeding.

Following several years with no significant medical problems, she developed a sepsis at age 42. The cause was not found for 5 months. During the interim, Deb suffered a choking episode and was placed in a drug induced coma. Following the coma, Deb was unable to communicate verbally or through eye gaze and could no longer take food orally. She remained in intensive care for 58 days. After a few months, no therapy was recommended. The husband was provided with instructions in positioning and suctioning. The client was discharged to the home.

Deb was seen for an initial augmentative communication evaluation, approximately 5 months following the infection. The evaluation was requested by the husband, who felt that his wife was understanding at least some of what was said to her.

Client: Charlie

Charlie, a 26 year old male, suffered a brainstem and head injury in an automobile accident. A year post, he was described as being at Level II or beginning III on the Rancho Levels of Cognitive Functioning Scale. He was a quadriplegic and g-tube fed. His trach had been removed.

Charlie was seen for an initial augmentative communication evaluation, approximately one year post his accident. The evaluation was requested by the mother who felt that her son was inconsistently responding to some basic commands and questions.

OBJECTIVE

With both clients, the objective was to determine if basic communication signals could be developed and functionally used.

APPROACH

The evaluation considered the following areas:

<u>Auditory Abilities</u>
- Results of Audiological testing
- Response to environmental sounds
- Response to familiar voices
- Response to loud sounds

<u>Functional Vision</u>
- Ability to visually attend to objects in close view and at a distance.
- Ability to track moving objects without moving head position
- Ability to follow the movement of objects above and below eye level.. to the right and left
- Peripheral Vision
- Binocularity
- Changes in response level with tactile cues....auditory cues

- Eye gaze pointing
  - --Ability to maintain gaze on target
  - --Ability to start from a neutral position

<u>Language</u>

- Ability to follow simple verbal commands
- Ability to follow two-part commands
- Use of idiosyncratic gestures to express desires
- Any current attempts to request actions or objects
- Ability to indicate a choice between two items
- Ability to identify common objects, photographs

Likes____________________
Dislikes__________________

<u>Motor Function</u>

- Whether the client's position is influenced by:
  - --Asymmetries
  - --Contractures
  - --Deformities
  - --Tone
  - --Reflexes

- Presence of purposeful motor responses
- Switch/ Control Interface Operation
  - --Body Part(s)

RESULTS

Client: Deb

<u>Auditory Abilities</u>
Appeared to be within normal limits

Functional Vision
Deb could track a light above eye level from the midline to the right periphery. She did not track on the left side, at eye level or below. In addition, binocularity was not present.
Deb was unable to use her eyes to select any visual stimuli.

Language
Deb inconsistently followed simple verbal commands.

Likes prior to the illness: Music, certain TV shows, outdoor sports including sky diving, communicating with friends.

Motor Function
Deb's control interface access was affected by her positioning in the bed (where she spent all of her time), as well as contractures.

Deb was able to move her head laterally slightly to the right and/or left side.

Intervention Techniques
Deb was provided initially with a loud call signal. This was operated by lateral head movements to the left side. A table switch mounting was used. The base was attached by screws to the back of the bed board. The flexibility of the gooseneck allowed for the switch to be easily re-positioned as Deb's body position changed throughout the day. Her husband was provided with specific instructions to respond to all activations with the call signal. The client varied from using the call signal when she did not require assistance to not using the call signal when she required assistance. Initially accurate call signal activations were rare. It took 4 months before the client was accurately using the call signal. The use of the call signal, however, permitted the husband from maintaining an almost constant vigil in the bedroom.

A loop tape on a standard tape player, with a battery interface, was also introduced. The tape consisted of critical needs: suctioning, hot cold, and pain. A latching mechanism was used, as well, so Deb would not have to maintain contact with the switch. The switch was placed on the right side of her head.

To accommodate both the switch for the call signal and the loop tape, a bar was attached to the gooseneck table switch mounting. Both switches were mounted to the bar. Sufficient space was provided between the switches for random head movements that were not intended to be for selection of an item. Following the use of the call signal, Deb was encouraged to use the loop tape to request a specific need. The first request made after several weeks of training was for suctioning.

Client: Charlie

Auditory Abilities
Appeared to be within normal limits

Functional Vision
Charlie attended to all objects place in his view, however he frequently closed his right eye in the process. He could track an object from his left side to midline.

A complete vision assessment was conducted by a developmental optometrist, who was willing to travel to the residential care facility. The results will be discussed in the presentation.

Language
Charlie inconsistently followed simple verbal commands.

Likes prior to the illness: Watching and playing sports, skiing, rock music

Motor Function
Charlie's control interface access was affected by his positioning. Initially, the best control site appeared to be on the left side of the head. Once switch activations were more frequently obtained, the switch was moved to the right side. This decreased the number of false attempts that began to develop.

Intervention Techniques
Charlie was provided initially with a radio transmission call signal, adapted battery operated adult toys (e.g., verbal wise cracks, body sounds), and a loop tape.

All of the devices were operated by lateral head movements. A wheelchair switch mounting was used. Only one device was accessible at a time.

The loop tapes were used on a tape player that was adapted for switch input. The first tape consisted of the messages "yes", "no" and "I don't know". The second tape included messages that would provide the client with some control over his environment, such as "Turn on the TV", "Change the Channel" and "Turn on the radio". A latching mechanism was not initially used to encourage the client to maintain contact with the switch. After a couple of weeks of training, however, a switch latch control was added.

The family, attendant and professionals working with Charlie were provided with specific instructions in the operation of the equipment and their method of response.

DISCUSSION

In the early stages of the therapy program, frequent modifications were required. Family members and attendants also needed to be reminded in the appropriate use of the devices

It was felt that the success of both of the clients' therapy programs was dependent upon the consistent involvement of the family. Unless the family provided access to the equipment and consistent responses to the call signal and/or loop tape selections, there would not have been an increase in communicative skills.

Additional details of the evaluation and therapy programs will be discussed during the presentation.

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DESIGNING AN AAC ENCODING SYSTEM LINKED TO DEVELOPING LITERACY SKILLS

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ABSTRACT

Scholars in augmentative/alternative communication have noted the importance of 1) supporting the literacy skills of those individuals who use AAC systems and 2) the possibility that letter-based systems may be easy for literate individuals to remember. Consequently, it may be logical to design a developmental AAC coding system that is linked to literacy skills.

The authors will describe a three level approach to developing a letter-category coding system that is linked to literacy. It includes three levels, sequenced to 1) begin with developmentally appropriate language learning, 2) add literacy skills that depend upon recognition, and 3) culminate in efficient access through letter-category coding accomplished primarily through recall. They will also share the successes and limitations they have discovered in designing such a system.

INTRODUCTION

Pre-literate persons who use augmentative communication systems often face the challenge of learning a symbol-based system for their oral communication and a letter-based system for reading and writing (1). Time split between learning the two systems likely cuts into the speed with which either system can be learned. The dual system may leave some without an intact written or verbal communication system.

Literate individuals often resent learning a symbol system in order to communicate when they have already invested so much time in traditional literacy. The challenge of learning to think of language in a new way does frustrate many a would-be communicator (2).

Word prediction systems offer one solution to the problem. This can be effective for a literate adult. However, word prediction requires some developing skills in spelling and reading before the user can interact through the system at all. Additionally, the space needed on-screen to provide the word choices may cut into the portability of an augmentative system for mobile individuals.

The dilemma calls for an encoding option which is developmental and which the individual can enter at the point appropriate to his present literacy skills. Letter-category coding is an option, and has been shown to be a superior method for recalling message codes (3).

PURPOSE

The purpose of the presentation is to describe a developmental approach for designing a message system based upon letter-category encoding. The approach sequences developmentally appropriate language and literacy skills into three levels.

Level One develops context-based single keystroke message learning and links print to daily living experiences.

Level Two expands the messages system through key sequencing and systematic access through skills in categorization and first letter of the word spelling.

Level Three provides streamlined access by expanding dependence upon recall and adding grammatical refinements.

The end product of the system is a letter-category coding system for the augmentative communication user. The approach begins to satisfy the need to allow communication and literacy to grow simultaneously in individuals who use AAC, much as they do in typically developing individuals. (4).

LETTER-CATEGORY CODING: A DEVELOPMENTAL APPROACH

The following describes a three level sequential approach to designing a letter-category coding system that links language learning, communication, and literacy skills. Those considering adopting such a system due to the advantages may find assistance in the description of the three-level approach and the application.

<u>Level One:</u> Develop a context-based, single keystroke message system that links print to daily experience.

Current language development theory links language learning to context. This suggests an approach that connects language-learning to use. For example the words car, drive and go are linked contextually and so, would likely be best learned together.

Augmentative communication systems offer the ideal platform for these context-based word groups. Many offer the option of multiple message levels accessible through multiple overlays. Organizing pictures and symbols representing messages contextually facilitates language-learning. Underscoring each picture/symbol with the related print message links print with the picture/symbol.

At Level One designers should insure that users can establish a foundation for linking language learning skills with literacy by providing:

1. overlays that organize language in context-based units.

2. picture/symbols paired with print to form the link between the message and print.

Level Two: Expand the message system through sequencing and systematic access.

This level assumes a context-based message system has been established. The range of messages and systematic access to them can be expanded by: 1) using sequencing for message access, and 2) linking context with a letter-based category system.

At this level, the AAC user's primary focus is learning about sequencing. Overlays provide the recognition cues (5) to form the sequences. The first unit of each code is a letter that cues which context (category) the word relates to. The twenty-six letter keys form the organization of these categories, which are letter-based. The categories can be personalized to meet the AAC users particular need and can vary in abstractness.

At Level Two, each overlay contains all of the messages and cues linked to a letter-based category. For example, M can be the first signal in the code for medically-based messages the AAC user may frequently require, Z can signal zoo messages for children and other animal lovers, and J can signal Just Friends, a more abstract category which includes the social messages the individuals may desire.

The second or third letter of the code allows access to a particular message from the category. For example within the medical category signaled by "M", MN, could indicate "nurse", MP could indicate "pill". Two cues are provided so the learner can easily access all of the messages available through the overlay. First, the key letter of the category related to the overlay is highlighted to indicate "touch this key first". Second, the messages available through the overlay are evident by cues as well. Print cues indicating the sequence required to access the message are printed below the symbol/picture. Once the sequence is accessed, the message itself will appear on the visual display, another link between literacy and use of this AAC system.

When codes contain only two letters, the picture/symbol and related print can be placed on top of the key that will access the message. When codes contain three letters, the picture/symbol and related print must be placed off the keypad because each key can only signal one message due to the space available in most AAC system keyboards.

At Level Two, designers should insure that the AAC user:

1. can learn to sequence with recognition cues available

2. develop skills in categorization and first and second letter of the word spelling.

Level Three: streamline access by collapsing the multiple overlays into one through which all codes can be accessed.

This final level requires good recall(5), categorization, and first or second letter of the word spelling. Levels One and Two establish a basis for strengthening these skills. In this level, only the category and letter cues are provided. The individual can recognize the category cue for medical words "M" through the letter and picture/symbol that covers the key. However, access to MP(pill) or MN (nurse) is not cued because with a single overlay, "P" and "N" are labelled to related to their categories, not the messages of the "M" category. Therefore, first or second letter of the word spelling must be recalled to access the message. The advantages of this level are the significant increases in speed possible by access through one overlay.

LANGUAGE REFINEMENT

The three level system is primarily based upon content words. The use of content words fosters the language-learning environment the approach is designed to promote. However, the AAC user will require access to function words such as pronouns, auxiliary verbs, prepositions, articles and conjunctions. These words can be accessed through the keys remaining on a particular platform after dedicating the 26 letter-based keys to content words.

The primary goals here are 1) to provide as many words as possible through one or two keystrokes since function words occur so frequently, and 2) provide the access in a logical manner to enhance user recall.

At Level Three designers should insure that the AAC user can:

1. access messages on a broad range of topics through a single overlay

2. add grammatical refinements to their language by providing access to functor words in an easily accessible fashion.

APPLICATION

The system is currently being applied to the Say-it-All augmentative communication device. To date, developing Level One has been a reasonable task, primarily dependent upon selection of topics, messages for each topic and development of overlays to provide access to the messages. Currently, 26 topics with an average of 12 messages each have been developed. Level Two and Three have proven to be a more time intensive task. Currently, over 750 words can be accessed through the 47 key platform the Say-It-All provides. From this application the authors have made the following conclusions that may be useful to potential designers of letter-category coding systems:

1. Aspects of Level One such as organizing messages by context, and linking print to messages can be easily be employed in developing any initial AAC system.

Consequently, the design of single keystroke message sending systems may be a reasonable task for the designer engaged in developing a individual message-sending system.

2. Developing the integrated letter-category system required by Level Two/Three takes time and planning. Selecting categories, avoiding collisions between potential codes, and determining which messages to include can be time-consuming.

3. Once the system is developed, it is not that easily translated to another platform with differing keyboard configurations.

The time required to develop systems at Level Two and Three may prohibit the individual professional from developing a similar system for an individual client. However, the instructions provided here may be useful for a literate users interested in designing individualized systems for themselves.

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THE APPLICATION OF FUZZY SET THEORY TO THE STORAGE AND RETRIEVAL OF CONVERSATIONAL TEXTS IN AN AUGMENTATIVE COMMUNICATION SYSTEM

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ABSTRACT

Current augmentative communication systems for severely physically impaired non-speaking people operate primarily on a word-by-word or letter-by-letter basis. Systems based on storage and retrieval of entire sentences and longer texts have thus far proved impractical, given the difficulty of remembering what is stored and how to access it. A number of research systems are under investigation which provide the user with predictive assistance to incorporate prestored text appropriately into conversations. The system described in this paper is based on fuzzy set theory, which allows it to continuously provide the user with a predicted set of appropriate next texts, and thus assist the user to move naturally and easily within and across topics. The system was tested in conversational situations by an able-bodied user. It provided an improved performance over a version without the fuzzy retrieval method by always offering appropriate items and requiring less effort from the user.

BACKGROUND

One method for assisting severely physically impaired non-speakers to communicate at a faster rate, and with more impact, would be for a system to offer them whole phrases, sentences, or longer texts to say at once. It is well known that the difficulties with this approach include remembering that a particular text is stored, recalling how to access it, and carrying out the accessing procedure. Users have thus far not made much use of stored text, preferring to create what they wish to say anew each time [1].

It is an open research question how much of everyday conversation is in fact reusable. Given the large amount of time conversationalists spend recounting stories of all kinds to each other, many of which are told to a number of different people, this would in any case be a useful capability for an AAC system [9]. Certainly, given the difficulties in creating text faced by physically impaired non-speakers, it would seem sensible at least that a system be able to store all new utterances created, and ensure that the user did not have to recreate any of the stored items anew, the next time they had need of them.

A number of research prototypes have demonstrated the effectiveness of modelling conversation patterns in an AAC system, to assist the user in communicating more naturally and easily [3,4,9]

One characteristic of conversation is moving in a coherent way from topic to topic. This is normally handled in a stepwise fashion by conversationalists [6]. In this way, the coherence of the conversation is cooperatively maintained, while each speaker is able to take part in controlling the conversational content. For the non-speaking person using an AAC system, this is a particularly problematic part of communicating. It has been shown that a great deal of AAC communication consists of single word or short phrase responses, where the topic has been set by the unaided speaker [7]. Where the AAC user might like to introduce a new direction in the conversation, the time it takes to create and output a suitable contribution usually means the conversation has moved on.

The Floorgrabber research system has demonstrated a method which, in trials, gave an AAC user increased conversational control by providing them large amounts of their own prestored text, to hold the floor when appropriate [4]. The problem of topic change, however, still remains a difficult one. In the Floorgrabber prototype this was handled by having the user search for the next topic with a set of on-screen buttons. A predictive feature would be an effective way to assist the user to move more easily to another topic area, where related texts from other topics could appear in prediction windows for possible selection.

This would only be effective, of course, if the predictions were appropriate ones. A definition of 'appropriate' here might be contributions which the user specifically wanted to say next, but might also include items which the user had perhaps forgotten that they had stored, and which were suitable follow-ons to the last thing said. In this way, such a system could act as a 'prompt' for the user as well as a storage and retrieval system.

A FUZZY RETRIEVAL SYSTEM

With conventional database storage methods, each item is tagged with a set of descriptors, and a search for related items involves comparing these descriptors. In the TOPIC prototype, an experimental text database system for conversational data, the conversational items were given descriptors according to content (semantics) and potential use (pragmatics) [2,5]. Retrieval of the next conversational item was done from a menu of possibilities which were produced by searching on relevant semantic or pragmatic descriptors. Searching was also possible by looking for any string of characters in the store. A soundex algorithm reduced keying-in effort by allowing the key words which specified a search to be drastically abbreviated.

The TOPIC system produced coherent conversation, but further development of the storage and retrieval method was needed in order to minimise the effort in using it, and to provide a structure which could be used to predict text items. The TOPIC system had more structure in the storage of itmes than Floorgrabber, but a problem remained with the efficient and effective use of descriptors.

With a conventional database, is difficult to decide how many descriptors would be needed for a large database, and even with a large number there will be frequent problems of deciding whether or not to assign a particular item to a given descriptor. If too few descriptors are used, there will be too many candidates after any search and further searching will be needed to identify suitable ones. If too many descriptors are used, then the possibilities increase of getting a null result from a search.

Also deciding on a list of descriptors requires knowledge in advance of the material to be stored in the database, and the purpose for which it is required. This is not appropriate for a conversational database, which will grow with each individual and will need be used by them flexibly in a large number of different situations.

Fuzzy set theory is an extension to conventional set theory which is particularly appropriate for modelling complex systems where it is not possible to classify the components of the system into discreet sets [10]. The theory is mathematically rigorous, but takes as its starting point the central concept that membership of any set, instead of being a binary property (yes or no, 1 or 0), is describable as a real number between 0 (definitely not in the set) and 1 (definitely in the set). Thus, instead of 'x belongs to set Y', we have 'The membership value of x for the set Y is 0.146', which gives a relative value to how strongly x belongs to set Y.

This theory has been applied successfully in control systems of various sorts [8]. If applied to an information retrieval system, the theory allows for more flexible storage and retrieval methods. The similarities between items in the database can be captured without the need for similar items to share a number of descriptors from a given set. From the point of view of a conversational database, a fuzzy set retrieval system has the advantage that, given one item, it will always produce a set of the most similar items in the database. It will never return from a search with no items found.

A PROTOTYPE COMMUNICATION SYSTEM BASED ON FUZZY SETS

In order to test out the feasibility of using fuzzy set retrieval methods in a conversation aid, a prototype system was developed. The conversational content of the system was taken from the Floorgrabber system. For the Floorgrabber project, a non-speaking person, with the help of volunteers to interpret his word board, has been creating a database of conversational material over a period of one year. This contains stories, jokes, autobiographical material, current news, and a wide variety of characteristic speech acts for use in giving feedback to another speaker.

The fuzzy set system prototype was written in C++. For labelling the stored items, two types of descriptor were used. Based on previous work with a text database, the descriptors either represented the semantics of an item (its subject) or the pragmatics (its purpose in a dialogue, i.e. speech act) [2,5]. The system used eight subject descriptors (travel, music, sport, driving, communication, work, family, friends) and five purpose descriptors (opening, elaboration, question, joke, conclusion). Each item in the fuzzy set database had a vector associated with it which described its degree of belonging to these thirteen categories.

A number of experiments were carried out to determine an efficient and accurate way to assign these values. The optimum design was an analogue display on the computer screen (a sliding control) with which values could be set for each item. For the purposes of this feasibility test the values were set by one of the authors. It is expected that the values set will always have a certain degree of subjecivity. This is acceptable, however, and even a desirable characteristic, in a system which should model the conversational style of the user.

The control interface for the fuzzy set conversation system is shown in Figure 1. The CURRENT TEXT window contained the text being spoken at the moment. The OPTION windows contained texts predicted by fuzzy matching to be good candidates for the next text. To control the system, the user only needed to perform three actions. Using a mouse, if the user clicked on the CURRENT TEXT window, that text was spoken by a speech synthesiser. If the user clicked on any of the OPTION windows, the text displayed was spoken, that text was moved to the CURRENT TEXT window, and the three OPTION windows were updated with three text items from the entire store which were most closely related to the new current choice. By clicking the mouse on MORE OPTIONS, the OPTION windows were filled with three more choices of text, which were the next three closest matches to the item in the CURRENT TEXT window. Repeated choices of MORE OPTIONS would in effect continually widen the search criteria, each time producing a full set of candidate texts.

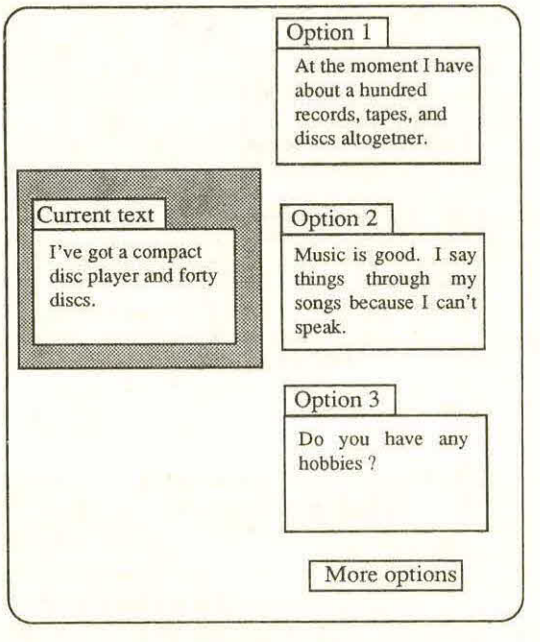

Figure 1 : Interface for the fuzzy set communication system

PRELIMINARY EVALUATION

To evaluate the performance of the system against an equivalent system based on boolean search database retrieval methods, a version of the system was created which used the same stored text items, but which depended on conventional database searching to compare stored items. As expected, the conventional system often produced no texts which matched a given text, whereas the fuzzy set system always produced a full set of candidate texts.

A comparison was done with the Floorgrabber prototype, which had 850 stored text items, retrievable through a hierarchical search method (topic -> subtopic -> text item). The same text items were loaded into each system. Conversation sequences which had been performed with the fuzzy set system, were then reproduced using the Floorgrabber system. Fewer mouse clicks were needed to produce the conversation using the fuzzy set system (20% to 35% fewer). Occasionally, the Floorgrabber system required a large number of input activations (e.g. mouse clicks) to produce an utterance, whereas the fuzzy set system tended consistently to need only one or two. Also there was a difference in the cognitive task involved. With the Floorgrabber system, the user had to form a search plan and execute it. The fuzzy set system simply presented appropriate material automatically.

It could be objected that the 'prompting' nature of the fuzzy set system was inimical to real conversation, in that one could never know what the user might have said if working with a totally free choice. Against this, it can be argued that with stored reusable material, the order in which it is said matters less than its successful and appropriate introduction into a conversation. The criterion is thus not a direct comparison with unaided speech, but with successful versus unsuccessful communication, however accomplished.

The next stage in this research will be further experimentation to improve the interface of the system, work on devising an easy to use method for labelling new conversational items for storage, and further trials of the system in actual use.

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Toward A Formal Theory of Icon Semantics with Application to Augmentative Communication

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ABSTRACT

We describe a formal theory of icon semantics for iconic languages, based upon the icon algebra and the frame representation of iconic objects. It is demonstrated that the iconic language based upon the principle of semantic compaction conceived by Bruce Baker follows a principled approach in its design. The similarity function is found to be a key element for the interpretation of an iconic sentence in this class of iconic languages.

1. Introduction

Iconic languages have been used successfully in human-computer interface and visual programming. The iconic language used in human-computer communication usually has a limited vocabulary of visual icons and a specific application domain: database access, form manipulation, image processing, etc. In this paper, we describe an iconic language for human-human communication used in *augmentative communication (AC)* by people with significant speech and physical impairment, and the formal theory of icon semantics that can be applied to this class of languages.

There are a variety of augmentative communication systems for people with physical limitations or speech impediments, ranging from unaided communication such as American Sign Language, to aided communication systems such as computerized voice output systems. The *Minspeak™* system uses the principle of *semantic compaction* conceived by Bruce Baker[1-3, 5]. It involves mapping concepts on to multimeaning icon sentences and using these icon sentences to retrieve messages stored in the memory of a microcomputer. The stored messages can be words or word sequences. A built-in speech synthesizer can then be used to generate the voice output. Over the past ten years, more than 21,000 AC units based upon the semantic compaction principle have been distributed worldwide. Swedish, German, Italian and other *Minspeak™* systems are being developed.

When the user activates the icons on the keyboard, the system produces the voice output. Thus the *Minspeak™* keyboard can serve as an augmentative communication system. For example, when the APPLE icon and the VERB icon are depressed in that order, the system produces the voice output "eat". The sequence "APPLE VERB" is called an *iconic sentence*. A different iconic sentence such as "APPLE NOUN" will produce the voice output "food". The APPLE icon by itself is thus ambiguous. The basic idea of *semantic compaction* is to use ambiguous icons to represent concepts. For example, the APPLE icon can represent "eat" or "food". Ambiguity is resolved, when several icons are combined into an iconic sentence. This principle allows the representation of many concepts (usually around two thousand) using a few icons (usually around fifty). It is important to note that the user can compose any sentence without any restrictions.

In this paper, we attempt to formalize the theory of icon semantics[7] used to design iconic languages based upon the semantic compaction principle. The paper is organized as follows. Section 2 describes the icon algebra based upon the theory of icon semantics[7]. The frame representation of icons and a few examples are given in Section 3.

2. An Algebra for Icon Semantics

The design of icon images is a crucial step in the process of designing an iconic language. For the class of iconic languages discussed above, we start by trying to design an icon for each basic concept. When doing that, the following requirements have to be taken into account[6]:

(a) The icon should clearly describe the basic concept. (b) The icon should be conceptually rich and created in such a way that when joined to other icons, some other concepts are covered. (c) The icon should be related to the alphanumeric character printed on the keyboard.

Furthermore, we need to provide a methodology to accomplish this task. In this section we will make use of icon algebra[7] as a formal basis to approach the icon design process. In order to exploit this theory, some adjustments need to be made as the original theory associates a single meaning to an icon and this assumption doesn't hold for this class of iconic language. We also will see that some extensions are needed.

Icon algebra provides a powerful way to derive new meanings of an icon by applying some formal operators on it. In that, an icon is seen as a pair (I_m, I_i) where I_m represents the meaning of the icon, or the logical part, and I_i is the image, or the physical part. An essential characteristic of an icon is that the logical part and the physical part are mutually dependent. That is, if the image is changed, also its meaning will change and vice versa[8]. In our case, all we need is to derive new meanings and not new images, so we will only use the derived concepts . In case more than one icon has been employed to derive the new meaning, those all together will constitute the iconic sentence to encode the derived concept.

Further, we will see an icon image as containing global and local features. A global feature of an icon represents the major topic of the image, whereas a local feature represents a detail of the image. So for example, we may have an icon ELEPHANT having the elephant as a global feature while it might as well have some local features such as the trunk up, big ears and so on.

The icon operators we will use are defined below. The examples are drawn from *WorldStrategy™*, a Minspeak Application Program (*MAP™*).

1. Combination COM: COM (I_i, I_j)

It makes the conceptual merge of the meanings associated to the single icons I_i and I_j.

As said above, in icon algebra we apply operators also to derive a new physical icon. For our purposes, we will only keep the physical images of I_i and I_j to form the iconic sentence encoding the new derived concept. For example:

COM ((money,),(name,)) = (check,)

because checks are money with a signature.

2. Marking MAR: MAR (I_i, I_j)

The marker operator marks the image of the icon I_i with the image of the icon I_j to emphasize a local feature. Here the second icon plays a role of "marker image". For example:

MAR ((rainbow,),(chest,)) = (gold,)

Because inside the chest there is a treasure of gold, the color of treasure is gold. Note that the treasure is a detail of the second icon and it wasn't directly represented.

3. Contextual Interpretation CON: CON (I_i, I_j)

Consider the meaning of the icon I_i in the context of I_j. For example:

CON ((apple,),(morning,)) = (breakfast,)

In fact, the apple represents the concept of food and food in the morning leads to breakfast.

4. Enhancement ENH: ENH (I_i, I_j)

This operator enhances the conceptual richness of the icon I_i by adding attributes from I_j. For example:

ENH ((thermometer,),(thumbs down,)) = (cold,)

Because low temperatures correspond to cold.

5. Inversion INV: INV (I_i)

The meaning of the icon I_i is inverted. As the inversion is an unary operator, we use an icon image to represent the operator. The "knot icon" is used, as "knot" sounds like "not". For example:

INV ((god,),(knot,)) = (false,)

God stands for True, so negation of True is False.

We need to add some new operators to the ones defined above. Even though we can cover many new concepts by applying icon algebra, there are some concepts which are derived by giving some conventional meanings to some icons. For example, in another *MAP™* for children, two "birthday cake" icons denote the sentence "when is your birthday?" In order to make also those kind of derivations in a formal way we introduce an operator "CONV" which in turn could be specialized leading to a certain number of operators according to several kind of conventional derivations. We refer to Semantic Compaction diagrams given in[4] to create these new conventional operators.

3. Frame Representation of Iconic Objects

We give an unified frame to describe by their attributes words, single icons, and iconic sentences. The structure of the frame has been conceived to model the "Types of Semantic Relationship" diagram in[4] and looks like the following. Only for explanation purposes the attributes have been grouped according to the type of features (in capital letters) they refer to.

. SOUND
.. Alphabetic abbreviation
.. Sound
.. Rhyme
.. Rebus

. TIME
.. Time sequencing

. SHAPE
.. Type of Shape

. COLOR
.. Color

. LOCATION
.. Where

. ACTIVITY
.. Use

. EMOTION
.. What does it make you feel

. CONVENTION
.. Linguistic
.. Cultural

. QUANTITY
.. Mass
.. Count

. IS_A
.. Abstract
.. Concrete

QUALITY
Quality

The frame of an object will be filled with the values for the attributes together a fuzzy parameter in [0,1] denoted by W. This parameter indicates the importance of the attribute's value for object indexing and it is very important for the aim of detecting the similarity of two objects. In fact, it is not sufficient that two objects match on some attributes. In order to give an adequate value to the similarity we need to know how appropriate is the value of that attribute to describe the relative object. For example, let us consider the fruit, orange. Most people would think of it as an object whose color is orange rather than an object of circular shape. Thus, every object having "orange" in the color attribute should be much closer to orange than any other object sharing with it the circular shape.

The frame for each word is predefined by the designer. The frame for the single icons is obtained by inheriting the frame of the word directly associated with an icon, plus some more information due to the particular graphics. The frame for iconic sentences can be derived from the component icons. We give two illustrative examples:

Example 1: iconic sentence THERMOMETER/MOUNTAIN

time sequencing:	winter	0.686475
use:	takes the temperature	0.76275
emotion:	cold	0.8475
what does it recall:	flu	0.76275
	cold	0.8475
is_a_concrete:	tool for temperature	0.76275

Example 2: icon THERMOMETER

shape:	bar	0.8
color:	red	0.8
location:	wall	0.6
	emergency box	0.7
	weather bureau	0.7
quality:	mercury	0.6
use:	takes the temperature	0.9
what does it recall:	flu	0.9
	warm	0.8
	cold	0.8
cultural conv.:	forecast	0.6
mass:	normal	0.2
quantity:	single	0.6
is_a_concrete:	tool for temperature	0.9

5. Discussion

In this paper, we presented the elements of a formal theory of icon semantics, and illustrated how the *Minspeak™* iconic language applies these semantic elements to convey meaning. We demonstrated that the iconic language based upon *semantic compaction* follows a principled approach in its design. The use of ambiguous icons in semantic compaction has helped us in discovering that the similarity function is a key element for the interpretation of an iconic sentence in this class of iconic languages. This is a valuable discovery toward the construction of a general theory of icon semantics and will be explored in further research.

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Methodological Decisions in the Study of Augmentative Communication Systems

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Abstract
The design of research in augmentative communication (AAC) requires the researcher to make many difficult decisions and to understand the consequences of those decisions as fully as possible. This paper discusses issues in AAC research design, using our particular research goals and resulting methodological approach as a framework. The intent is not to recommend one approach at the exclusion of others, but to encourage the communication of research design decisions and to stimulate further discussion on the trade-offs involved.

Introduction
There are many reasons why it is desirable to investigate the performance achieved during use of augmentative communication and computer access systems. Often, a primary goal is to provide a means of comparison between systems, or between aspects of the same system (e.g., 1,5,6). While there remains a strong need for more data on how different users perform with different AAC systems, purely empirical studies can be limited in their generality. One way to address these limitations is through the development of user performance models that integrate system and user factors and support the simulation of a wide range of user-system combinations (3,9). Several theoretical studies have been performed, but the validity of these will remain controversial until the accuracy of the predictions has been tested empirically (4,7). Theoretical model development depends on empirical data to both test and refine model accuracy.

Important questions exist regarding how to best design research that enables valid empirical comparisons and the development of performance models. This paper discusses some of the issues in AAC research design, based on experience in our laboratory. It is not intended to be a detailed account of specific methods, but rather to encourage dialogue on the trade-offs involved in research design decisions. We hope this will be valuable to researchers and non-researchers alike, as it will provide some insight into the research design process in general as well as the compromises and benefits involved in our particular approach.

Background
To provide a foundation for the discussion, the goals of our research are outlined briefly. The overall aim is to progress toward general principles underlying the way people use AAC systems and the way in which the system design affects behavior and performance. In pursuit of this goal, our current focus is on the validation of user performance models for particular AAC systems and user groups. Principles of human-computer interaction provide the basis for developing these quantitative models. User performance can then be simulated with the model, using parameter values that represent the system and the user. The resulting predictions are compared to actual performance observed over a range of user characteristics and system configurations.

The data collected in the pursuit of the model development goals will also support the evaluation of the specific interfaces under study. This evaluation includes statistical comparisons of performance across subjects, across strategies of use, and across time. While these comparisons fill an important gap in current knowledge, the model validation goals remain our priority because of their potential applicability to a much broader range of AAC system-user combinations.

Approach
The decision areas discussed below are: the type of system to be studied, subject characteristics, system input method, subjects' strategy of use, experimental protocol, and data collection. The main consideration for each decision is how well the different options support the research goals, followed by practical considerations (e.g., research budget). We outline several options in each area, our reasons for making a particular choice, and the compromises involved in that choice. Interdependencies between decisions are discussed where most relevant.

System. Modeling techniques can be applied to many different types of AAC systems. In our research, we have chosen to focus on word prediction, a general technique intended to enhance rate by reducing keystrokes (11). Word prediction is widely used clinically, and there are several well-implemented commercial systems available. However, word prediction may not always provide a significant enhancement in rate, which has been attributed to the trade-off between reduced motor actions and increased cognitive and perceptual activities (3,10). Application of modeling to word prediction provides an ideal opportunity to understand the net effect of this trade-off more rigorously.

Rather than use a commercially available word prediction system, we have chosen to develop our own system for research purposes, to gain sufficient control over the system configuration as well as the means of data collection. A main consideration is that the research system be highly representative of commercial word prediction systems. Almost all systems use the same basic method of finding words in an internal dictionary that match the initial letters entered by the user, then presenting the set of matching words that are most frequently used in English. Some systems augment this basic algorithm by one or more of the following techniques: using syntactic knowledge to remove inappropriate predictions; using recency-of-use as well as frequency-of-use to choose predictions; updating the frequency of words based on user entries; and using information about the previous word to refine predictions.

These variations on the basic word prediction algorithm share two main effects. First, they improve the success of the system's predictions. This effect is simulated in our research system by changes in the text to be entered or the dictionary used. A second effect is that there are many possible prediction lists for a given word-initial sequence. While the software is capable of simulating these changing word lists, the constant novelty limits the user's ability to learn when words will appear in the lists, which at least partially counteracts the increase in predictive success provided by more sophisticated algorithms. For this reason, the basic algorithm is often used alone in actual systems, and it has been chosen for study in our current research.

The main implication of this choice is that the results will be most directly applicable to performance with the basic algorithm. However, models that will result from this work should be general enough to simulate aspects of performance with other word prediction algorithms, by changing model parameter values (e.g., the percent of words selected from the list). And while the results will not be directly applicable to systems that do not use word prediction, any success in applying the models to word prediction should provide confidence for future applications to other systems.

Subjects. While the focus of this work is to develop models for the performance of users with disabilities, our current research employs both able-bodied and disabled subjects. The use of able-bodied subjects has three purposes. First, it provides a feasible way to gain sufficient statistical power, since able-bodied subjects are more readily available. Second, the performance measured from able-bodied subjects allows a "best-case" test of model accuracy, which will help determine if inaccuracies in modeling disabled users are due to flaws in the model itself or to increased variance in disabled user performance. Third, using both types of subjects provides a means of assessing the extent to which able-bodied performance is similar to that of users with disabilities. Our hypothesis is that the results from able-bodied subjects will prove to be generalizable at least to a large segment of the target population, specifically those individuals who have no cognitive impairments and whose physical disability does not prevent them from using the tested input method with consistency.

An important implication of using able-bodied subjects is that they generally have no prior experience with word prediction. For consistency, then, this restricts our choice of disabled subjects to those who have no experience with word prediction. This decision to employ novice subjects has affected several other decision areas, as discussed below. An alternative is to avoid the use of able-bodied subjects and employ only disabled subjects who are experienced word prediction users, following a common method in studies of human-computer interaction (e.g., 8). The resources necessary to pursue that approach are currently unavailable, which adds a practical reason to the theoretical grounds for studying novice subjects.

System Input Method. Although a variety of input methods could be modeled, early theoretical studies focused on single switch scanning (2), so our first pilot study used scanning as the input method. This initial choice has been revised in our current work. Direct selection using a mouthstick or other typing aid is now the basic input method for several reasons. First, it is frequently used by actual users of word prediction. Second, user performance with direct selection is driven primarily by user ability, since the user is free to make a selection at any time. This is in contrast to single-switch scanning, in which user skill is confounded with the system timing parameters as an influence on user strategy and performance, since these parameters determine when a particular selection is possible. Third, existing data on the performance of able-bodied subjects using a standard keyboard with a mouthstick (5) is a source of valuable pilot information. Finally, direct selection is easier to learn than a more complex system such as Morse code, which is important due to the use of novice subjects.

Strategy of Use. Strategy refers to the plan of action that guides the user's behavior while interacting with the system. In the case of word prediction, strategy involves the way in which the user employs the word list. For example, at one extreme is a strategy in which the list is searched carefully before each and every selection. Alternative strategies include postponing list search until after one or two letters have been chosen, or deciding when to search the list based on the perceived likelihood of the word's presence.

While there are important questions regarding the strategies that users develop in the absence of specific instruction, several considerations have led to our decision to teach subjects particular strategies for using the word prediction system. The main reason is our commitment to performance modeling goals. Since the model equations are based on the component actions that the user executes during use of the system, model accuracy is improved by the ability to know or predict user behavior. Because subjects are word prediction novices, strategy instruction provides an important means of reducing variation in their behavior. Without some sort of instruction, each subject would employ a different strategy or mix of strategies, requiring the development of a different model structure for each subject. By teaching subjects a particular strategy, and enforcing its use, performance models can be built prior to the collection of data, and their predictions compared with the performance of all subjects who used that strategy. As confidence in modeling techniques is established, models can be created to match any particular strategy.

The primary reason for strategy instruction stems from the modeling goals, but the approach has interest and validity from a clinical perspective as well. First, teaching explicit strategies points to the potential clinical application of the modeling tools as a means of determining optimal, or at least good, strategies for using a system. Second, it is at least as realistic as letting subjects evolve their own strategy, since actual users frequently receive at least minimal and occasionally extensive training in a particular strategy.

Experimental Protocol. Because all subjects are word prediction novices and some subjects are mouthstick novices, the protocol must allow sufficient time for subjects to develop skill. Since true asymptotic expertise would likely take a large number of sessions, the goal is for subjects to become "skilled novices" and for their learning curves to begin to level off by the last session. This approach provides data on skilled performance, as well as data on unskilled novice use and principles of learning, which can be analyzed in future studies. It cannot, however, directly address issues of true expert performance.

A text transcription task has been chosen for this research, in which subjects transcribe unique blocks of text in each session. This approach does not allow us to address important questions regarding the quality of text that an actual word prediction user might compose. However, it has the advantages of ensuring that subjects' performance can be validly compared to each other and that the same model simulations (which strongly depend on the text characteristics) can be used for all subjects who use a common strategy.

A great deal of care has been taken in the creation of transcription text samples, since text characteristics can have a significant effect on performance with a word prediction system. In particular, sessions that are intended to have the same system configuration must use texts that match with respect to the following characteristics: average word length, percent of words that can be selected from the word list, average number of letters generated per word list selection, and percent of keystrokes saved. Creation of these matched texts was facilitated by the development of software that simulates the entry of a text sample using word prediction with a given configuration and strategy, then calculates the resulting text characteristics.

Data Collection. The emphasis on performance modeling in our research places the focus of data collection on performance time, i.e., text entry rate, as measured by seconds per character. Each keystroke is recorded with its associated time of entry and encoded to reveal what parts of the text were selected letter-by-letter and which resulted from a word list selection. The number of errors committed in a session is recorded as well, primarily as a means of ensuring that all subjects are at a similar point on the speed-accuracy trade-off. Sessions are also videotaped to provide a visual record of subject behavior. This allows verification of adherence to the assigned strategy and provides a means for revising the behavioral basis of the performance models if necessary.

The focus on quantitative data is consistent with the decisions to constrain qualitative variables such as subject behavior and the text to be entered, as discussed above. This does not mean, however, that qualitative data must be ignored completely. Subject motivation and affect are observed during sessions, and subject comments are solicited after each session regarding their impressions as well as their rating of task difficulty.

Discussion

The design decisions outlined above reflect a consistent focus on model development and quantitative performance in augmentative communication. The goal is to develop a modeling framework that provides an understanding of the factors that determine text entry speed and predicts the speed that may be accomplished under a range of conditions. Commitment to this goal provides the rationale for our research design decisions, but as in any study, it also restricts the range of questions that can be validly addressed. Research on other important issues such as word prediction's effect on user spelling, motivation, or fatigue would require a different set of methodological decisions. Indeed, gaining multiple perspectives through diverse approaches is the key to advancing knowledge in the field. Our point, therefore, is not to recommend one particular approach at the exclusion of others, but to encourage the clear communication of research design decisions and the open discussion of their consequences.

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PATIENTS' PERFORMANCE WITH E-VIC, VISUAL LANGUAGE PROGRAM FOR GLOBAL APHASIA

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ABSTRACT

This paper describes a Macintosh program, E-VIC 3.0, designed for use with patients who are in the acute phase of recovery from global aphasia after cerebrovascular accident (CVA). This program provides gradually more complex tasks requiring matching and retaining visual symbols which stand for concrete objects. Data representing the experience of 11 patients who received E-VIC training indicate that the technique is accessible despite the profound comprehension deficits.

BACKGROUND

More than 400,000 people in the United States experience cerebrovascular accidents (strokes) each year (National Institute on Disability and Rehabilitation Research, 1989), resulting in approximately 2 million people with stroke-related disability and costs estimated at $13.5 billion annually (1) (Research Bulletin, October 1, 1989). Stroke is not only a disease of old age, but occurs frequently with people in their forties and fifties and, less often, with younger people. Over 20% of people who experience a stroke sustain damage to the central language processing areas of the brain and become aphasic.

Persons who still have global aphasia at one month post-onset show less recovery than any other diagnostic group (2), with fewer than 20% recovering minimal language output after one year. It is widely recognized that people with chronic severe expressive or global aphasia have little expectation of benefit from therapy and can be expected never to recover language adequate for functional communication (3).

STATEMENT OF THE PROBLEM

Spontaneous recovery of language after stroke-induced aphasia proceeds at its steepest rate in the 3 or 4 weeks immediately following the CVA. Since language therapy appears to be of most value when it is offered soon after the stroke (4), it is standard clinical practice to provide language training as soon as the patient is medically stable. The speech/language pathologist assesses preserved capacities and tailors therapeutic intervention to them. For the patient with severely reduced expressive abilities and minimal comprehension, there is little or no demonstrable spared capacity for the therapist to address. There is a need for effective language therapy intervention appropriate for patients with global aphasia in the acute stage of recovery from stroke. To the extent that recovery is possible, the acute period is critical.

E-VIC is designed to target the individual's preserved cognitive and learning capabilities in the acute phase of recovery from stroke, and engage the individual in language-like activity in which she can actively participate. With the individual actively involved in the therapy, there is at least the potential for benefit.

RATIONALE

The basic hypothesis of the E-VIC intervention is that engaging patients in language-like activities as early as possible in their recovery course may stimulate abilities underlying language and result in enhanced language recovery. Traditional speech/language therapy fails to engage patients with this severe level of disability at this stage of recovery.

DESIGN AND DEVELOPMENT

E-VIC 3.0, written in C for the Macintosh, is designed to provide graduated training in matching objects to symbols, without requiring auditory comprehension, while providing maximal experience of success. All irrelevant material is excluded from the patient's display, and immediate reinforcement is offered when the correct choice is made.

The clinician/trainer interface is designed to facilitate the management of training via a Control window which allows convenient customization of the training variables, including the object-picture pairs, number of response choices, size of the pool from which items are randomly selected for display and the locations on the monitor in which they are displayed. The Control window appears on the Macintosh monitor, and the patient's display appears on a full-page display monitor. This configuration keeps the patient's screen free of any material that could complicate the visual presentation or distract from the task requirements. The program includes default automatic progression through a criterion-based training program, and automatic data acquisition.

Basic E-VIC training consists of picture-object matching tasks. E-VIC provides prompts to the trainer on the Macintosh monitor regarding which objects to display, and displays pictures for the patient on the large monitor.

Picture stimuli were simple, representational line drawings, without perspective, each approximately 2 inches square, depicting a variety of objects drawn from the domains of containers and utensils, small items of clothing, office supplies, personal care items, and foods. Size of the response choice field was gradually increased as the patient met criterion on each smaller array. Besides the gradual increase in the number of choices presented at any one time, the pool of items from which these choices were drawn was gradually incremented, the and variety of positions on the screen in which pictures could appear was also increased, as the patient met criterion (7 / 8 correct responses) in each simpler task. Complexity was typically incremented in only one dimension at a time.

Training was provided during sessions lasting one half hour or less, two to four times per week by technicians with undergraduate degrees in speech/language pathology. Training terminated when the patient was discharged, or after a maximum of 20 sessions.

In object-picture matching, an object is placed in front of the patient, and the corresponding picture, along with one or more distractor pictures, is displayed. The participant's task is to move the cursor, by moving the computer mouse, until the cursor overlays the picture, and then only, to click the mouse button. If the choice is correct, the picture immediately acquires a reverse-video "frame".

If the participant responds incorrectly, or fails to respond within a preset time interval of 60 seconds, three times in succession, the program prompts the trainer to switch to a demonstration mode, in which all means necessary are used, including hand over hand guidance, to shape production of the correct response. Continued need for demonstrations at a given level of training results in the program's backing up to the previously mastered level.

E-VIC provides a time report to indicate how many seconds have elapsed as each trial proceeds, registers the nature of the response and provides the reinforcement whenever the correct response is produced, whether independently by the participant, or with the trainer's help. Until the correct response is provided, the program does not move on. This procedure ensures that each trial provides an experience of production of correct response. In other words, no "wrong answer" feedback is ever given to the patient, only absence of "right answer," until the correct response is produced.

Another feature of the program is management of centering of the cursor on the screen. In order for a trial to be presented, the cursor needs to be positioned within a small rectangle at the center of the large screen. If the cursor is outside this rectangle, the program prompts the trainer to reposition it, and does not proceed until it is repositioned. While this feature can assure only the cursor position, it serves as a reminder to reposition the mouse as well, so that the patient begins each trial with the mouse in a location comfortably accessible to his/her left hand, with adequate space on the mouse pad to move the cursor to the pictures without necessarily encountering the end of the mouse pad or the end of his/her range of motion. This repositioning and centering requirement was included to permit accurate measurement of response time and recording of the movement path of the cursor for the subsequent versions of the program in which these measurements were recorded. Centering the cursor and mouse also served to structure the task and orient the patient by clearly indicating that a new trial was about to begin.

In a previous study using an earlier version of E-VIC, with 7 patients, results indicated that the transition from the first type of task, in which only one picture appeared on the screen, to the task in which two pictures appeared, was difficult for some patients (e.g., Ss 2 and 3 in Table 1, below) (5). Success in the first task depends on learning how to manipulate the mouse, and learning a procedure of moving the cursor to a picture and clicking the mouse button. The two-picture task is qualitatively different. There is no longer only one image on the screen, so the clear guidance provided in the previous task is absent. The patient must recognize that object-picture matching is crucial to success in the task, and must distinguish between the two pictures in order to identify the one corresponding to the object displayed in front of the monitor. The second task involves symbolic representation, while the first task can be carried out without any recognition of the 'meaning' of the picture.

As part of the attempt to regulate the introduction of each new quantum of complexity, a further stage was introduced in between presentation of only one image and presentation of two alternatives. In the intervening stage, two windows are presented with one remaining blank. In other words, the message being conveyed to the patient is that there can be two things appearing on the screen, so that s/he cannot use the strategy of simply moving the cursor to the "lit up" location: more than one location can be active at the same time. The content of the lit up area, i.e., the picture, is also important. The subsequent stage then introduces only the additional information that both of these two locations can contain pictures simultaneously, and only one of the pictures is the right one.

Basic E-VIC training is made up of 17 levels, on each of which the participant must reach criterion in order to progress. At the end of level 17, the participant is successfully matching the object in front of him/her to one of 6 pictures which appear simultaneously, in any part of the screen.

A series of more complex tasks has been developed for individuals who complete Basic E-VIC, but who are not candidates for speech/language based therapy, and not yet candidates for alternative communication. Advanced E-VIC includes 4 modules, each divided into 10 levels: Delay, Context, Suppressed Context and Sequence. In the Delay tasks, the stimulus object is presented briefly, then removed; after a delay, the picture response choices are displayed. Delay increases gradually from 2 seconds up to 16 seconds. 4 individuals received Delay training, and one of these reached the 16-second delay level. In the Context module, two objects are presented, and the target object is pointed to for a brief period; after a delay the picture response choices are displayed. The task is to select the picture corresponding to the object pointed to, not the distractor object. In the Suppressed Context module, two objects are displayed briefly, and then removed; the location which had been occupied by tone of the objects is then pointed to for a brief period; this is followed by delay, and then display of the picture response choices. In the Sequence module, two or more objects are placed in sequence in the participant's field of view; this is followed by a delay, and then display of the picture response choices. Selection of the images in the temporal sequence according to which the objects were presented constitutes a correct response. The Context, Suppressed Context and Sequence modules were not evaluated, since no participants completed Basic E-VIC and Delay within the 20 or fewer sessions available. The Control window provides instructions to guide the clinician through each trial.

EVALUATION

All 13 participants in the E-VIC experimental group were successful in reaching criterion on the picture-choice task. 10 of the 13 participants accomplished this by the end of their 5th session (Table 1, below). 5 individuals completed Basic E-VIC within 20 or fewer sessions. By the end of session 20, 2 of these had completed the 4-second Delay level, one had received tasks from the Sequence module after achieving the 4-second Delay, and one completed the Delay module (Delay = 16 seconds).

Session number at which each participant reached criterion on selection from two alternative pictures is shown in Table 1, below.

Table 1. No. of Participants / 13 who succeed in choosing from 2 pictures

Ses.#	1	2	3	4	5	8	13	15
	1	2	2	2	3	1	1	1
Total	1	3	5	7	10	11	12	13

Table 2. Highest Level reached (/6)

S	Level	Ses. #
AA	2	13
AC	2	15
AD	6	14
AF	6	9
AG	2	1
AI	3	4
AJ	6	6
AK	2	5
AL	6	12
AM	6	13
NA	6	9
NC	2	17
NE	6	15

DISCUSSION

Individuals varied in their style and rate of learning E-VIC. Mean response times for correctl and incorrect responses did not differ significantly in 12 / 13 cases, suggesting that the task was not being performed in an impulsive manner. The rapidity with which most individuals progressed through E-VIC training is displayed in Tables 1 and 2. Three individuals progressed much more slowly, and had not reached criterion on the task of selecting between two pictures by the end of their 5th training session. The previous study had identified two potential predictors of E-VIC success: performance on a test of eye movement to verbal command (e.g., "look up"), and performance on the map location test, in which the patient is asked to point, on a free-hand map drawn by the neurologist, to the approximate location of several well known cities. While the numbers are small, there is no evident difference on performance on the eye movement test and performance on the test of map location which could distinguish "rapid" from "slow" learners in respect to these two clinical tests. Measurements of lesion size, the other clinical indicator which seemed to be related to E-VIC performance in the previous study, were not available. The neurologist's drawings and indications of preservation or involvement of three key neuroanatomical areas are available for two of these three individuals (and for 10 of the 13 patients overall). Visual observation of the neurologist's drawings does not indicate larger lesions for the two slower learners.

Initial performance with E-VIC appears to predict overall success in the E-VIC training program.

The intent of E-VIC is to stimulate abilities underlying language and recovery of language function, by engaging these individuals in language-like activity at a time in their recovery course when speech and language are inaccessible to them. There is some indication that E-VIC may provide some benefit, at least in the area of recovery of auditory comprehension of concrete object names (6). A more direct effect of E-VIC is expected in the performance of these individuals once they reach the chronic stage, if they are offered the opportunity to learn a functional communication technique using visual symbols, such as C-VIC, NEWVIC or Lingraphica. Anecdotally, families who have already had positive experience with E-VIC are willing and enthusiastic about pursuing the computerized visual communication approach.

The rapid progress of many of the patients learning E-VIC suggests that for those individuals who rapidly acquire the fundamental matching task, it is possible to move towards more complex, language-like tasks rather than requiring them to complete Basic E-VIC before going on. It may be, for example, that training in the Delay condition, in which mental representations have to be maintained in the absence of visible symbols, will provide a stronger stimulus to language recovery.

Despite the profound impairment in comprehension and in expression, which excludes language as a medium of communication for these patients at this stage of their evolution, the training built into E-VIC is readily acquired by most, and provides a sequence through which they can progress successfully. The extent to which this experience can benefit recovery of language and/or recovery of communicative function requires further exploration.

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COMPARISON OF WORD PER MINUTE RATE ACROSS FOUR INPUT CONDITIONS FOR AN AUGMENTATIVE WRITING SYSTEM

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ABSTRACT

Efficiency as measured by accurate words per minute (WPM) was examined across four input conditions for a subject with physical disabilities. The input conditions were: a. A 128 key membrane keyboard containing standard computer functions and the alphabet (Alpha); b. The same keyboard with the addition of 80 frequently occurring initial two and three letter sequences (VVOM); c. Alpha combined with word prediction features; d. VVOM combined with word prediction features. The subject's WPM rate was greater in the conditions where the VVOM sequences were available.

BACKGROUND

When people with physical disabilities (e.g., cerebral palsy, ALS) use computers to produce text, their efficiency, measured in accurate words-per-minute (WPM), is greatly reduced from that of able bodied computer users. Given this, considerable effort has focused on the development of specialized software and hardware to increase efficiency. Rosen and Goodenough-Trepagnier (4), identified three factors that influence efficiency; cost, length and time. *Cost* refers to the average number of units required to produce a word. This pertains to the inventory of units provided to the user by the device/display. Units can be letters, phonemes, syllables, whole words or even phrases. Assuming that the average word requires five units, (four letters and one space) the cost for the regular QWERTY keyboard is five. *Length* alludes to the number of motor acts required, on average, to select a unit from the device/display. For example, when a direct selection access technique is used, the length equals one. When row-column scanning is used the average length would be three. The variable of *time* refers to the amount of time required, on average, for the user to make selections on a given device/display. As strategies aimed at increasing efficiency are developed, it is important to consider the interaction of these three factors.

Development of software and hardware that reduces the variable of cost has received the most attention in the Augmentative and Alternative Communication (AAC) field. Among the most popular methods to reduce cost is word prediction. A number of word prediction programs have been developed to run on standard personal computer systems (see reviews by 1 & 2). Mathy-Laikko, Zellhofer and Jones (3) designed an overlay (called VVOM) for use with a 128 key membrane keyboard and the Expanded Keyboard Emulator (EKE) prediction program[1]. The VVOM overlay contains all of the functions on the standard keyboard, but also adds the 80 highest ranked word-initial bigrams and trigrams (two and three letter sequences) derived from an analysis of most frequently occurring ngrams in a 999,464 token sample of written text (5). Mathy-Laikko, et.al. (3) compared the keystroke savings of the standard keyboard versus the VVOM keyboard when used in conjunction with the EKE program. Across three, 400 word samples representing a cross section of genre, there was an average keystroke savings of 1.56 keystrokes per word (mean cost: 3.44) for the standard keyboard with EKE and 1.86 keystrokes per word (mean cost: 3.13) for the VVOM keyboard used with EKE. In addition to reducing cost, it was hypothesized that use of VVOM with

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[1] Developed by Words+, Inc., P.O. Box 1229, Lancaster, CA 93584.

the EKE prediction program would reduce the variable of time by decreasing the time the user must spend searching the prediction window.

RESEARCH QUESTIONS

The primary research question was does the reduction in cost provided by the VVOM sequences result in an increase in WPM rate when compared to an alphabetic keyboard alone and when the two keyboards are compared in conjunction with the EKE word prediction program?

METHOD

The subject was a 26 year old male with athetoid cerebral palsy. He was a senior in political science at a Midwestern University. He had been using the EKE prediction program with the VVOM layout on a 128 key membrane keyboard on a Toshiba 2000 laptop computer for a six month period prior to the study. The subject accessed the keyboard using direct selection with his right index finger. This system was used for spoken and written communication.

Four input conditions were compared. They were as follows: a. A 128 key membrane keyboard containing standard keyboard functions and the alphabet (the alphabet was located in the same positions as on the VVOM overlay) (Alpha); b. The same 128 key membrane keyboard with the addition of the 80 frequently occurring bigrams and trigrams (VVOM); c. Alpha combined with word prediction and the other standard keystroke saving features of EKE (excluding abbreviation expansion); d. VVOM combined with word prediction.

The text stimuli used was a passage from the Bible that the subject had previously committed to memory. The same stimuli was used for all measurements. The reason for selecting memorized text was that it did not require the subject to look away from the keyboard as he entered text. Further, because same text sample was used across all measurements, the calculation of WPM was comparable across all input conditions.

Three rate measurement trials were completed for each of the four input conditions. This data was collected, across four experimental sessions which took place over an eight week period. The order of the input conditions was counter balanced across sessions. To accommodate the subject's busy student schedule, he was seen in his dormitory room and the data collection sessions were kept under one and a half hours each (including setup). Three of the input conditions were sampled during each session. Ten minute samples were collected for each input condition with a five minute break between conditions. Keyboard acceptance time was set at the subject's usual level. The subject was instructed to type as quickly and accurately as he could but not to stop and correct his errors.

RESULTS AND DISCUSSION

The total keystrokes, the total accurate keystrokes and the overall means per ten minute measurement for each input condition across the three trials are displayed in Table one. Figure one depicts the means of the total WPM and the accurate WPM for the four input conditions. Before discussing these results, it is important to note that in all but the first trial for each input condition, there were a number of errors. Further, the most typical error was double activation of the same key which nullified the benefit of the prediction window. Although an attempt was made to control this type of variability by conducting each data collection session at the same time of day, keeping the acceptance time constant, etc., the subject's physical control varied across sessions. Because the double key hits penalized the prediction conditions more than the non-prediction conditions, we will not discuss comparisons across all four input conditions but instead restrict

TABLE 1. Total keystrokes, total accurate keystrokes and mean keystrokes per ten minute measurement for each condition across the three trials.

	Input Condition							
	Alpha		VVOM		Alph/EKE		VVOM/EKE	
	Total	Acc.	Total	Acc.	Total	Acc.	Total	Acc.
T-1	100	98	123	114	99	98	155	152
T-2	132	117	168	154	127	116	152	138
T-3	131	118	186	162	182	162	160	127
X	121	111	159	143	136	125	156	139

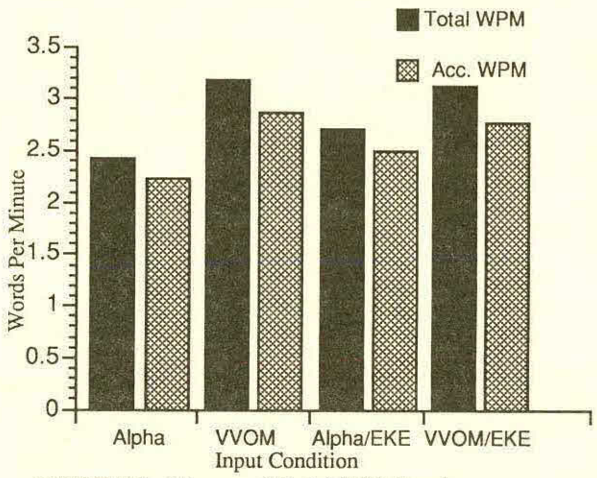

FIGURE 1. Means of Total WPM and Accurate WPM for the four input conditions.

comparisons to between the two non-prediction conditions and between the two prediction conditions. It can be seen that in the conditions where VVOM was used the subject was able to increase his average WPM. This suggests that the reduction in cost provided by the 80 bigrams and trigrams on the VVOM keyboard outweighed the additional time it took to locate targets on a more dense array. It is also important to note that even though the subject was not able to derive maximum benefit from prediction due to errors, there was an increase in WPM rate when the VVOM keyboard was used with prediction. Plans to further examine the benefit of using keyboards that contain frequently occurring letter sequences with word prediction programs for AAC users with various physical disabilities who use a variety of access techniques will be discussed.

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STEREO TAPE PLAYERS AS SCANNING COMMUNICATORS

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ABSTRACT

Auditory scanning can be used as an augmentative communication system to allow an individual with severely limited visual and motor skills to indicate choices and request information. This paper discusses the use of a simple, inexpensive auditory scanning device to explore the capabilities of C.C., a 22 year-old woman with cerebral palsy. She has been diagnosed as profoundly retarded and has been in a residential facility for the developmentally disabled since the age of 7.

Presently a stereo tape player is being used as a scanning communicator for this individual who has physical and visual impairments. Multiple endless loop cassettes are used each customized for a particular situation. These include home, work, breakfast, lunch/dinner, music/choir, snack time, recreation/leisure cooking, and shopping.

STATEMENT OF THE PROBLEM

Speech staff thought this nonverbal young woman with physical and visual impairments would be able to communicate if provided the proper equipment and training. Due to her limited vision, the review of possible devices focused on auditory voice output single switch scanners.

Background Information/ Previous Augmentative Experience/ Training

Because this individual has been successful in choosing from 3 - 4 color photographs (3" X 5"). , electronic training began with the use of a Real Voice Scan Pac.. Multiple overlays were used for different environments. Sporadic training was dropped after approximately a year, due to her visual impairment. The need to justify the expense of a Real Voice Scan Pac for such a limited vocabulary also concerned staff.

Training then began with a primitive auditory scanning device consisting of a tape recorder connected to an Ablenet controller that was activated by a paddle switch. Each of the four choices was repeated two times with a 2 - 4 second delay between the first and second presentations. She listened to the first statement, made a choice, then activated the switch for her response. This system was quite ineffective because the tape needed to be rewound and that all statements were presented to both listener and communicator. In spite of the ineffectiveness of this system it did suggest that auditory scanning was an option for this individual.

Commercially available auditory scanning products by Words+ and Adaptive Communication Systems, were considered, as well as the Wisperwolf. The first two products were eliminated due to cost and the wisperwolf was not chosen due to vocal quality. Therefore, it was decided to develop alternatives. In analysis of auditory scanning, we realized it was a two channel process. On one channel, short verbal cues are presented. When a desired cue is heard the user operates a switch connecting the second channel to speakers that allow the full message to be heard. This can be implemented by a stereo tape player, endless loop tapes, stereo amplifier/speaker, and control logic circuitry.

OPERATION

Preparation of the tapes

The users reaction time should be determined. This is the time it takes the individual to activate a switch after hearing a desired selection. The tapes are produced using two people speaking into external microphones each with an on/off switch. While recording, the first person turns on his/her microphone, says the cue, and turns off the microphone. After pausing for the user's reaction time, the second person turns on his/her microphone says the message, and turns off the microphone. After pausing for the user's reaction time, the process is repeated for the remaining cues and messages.

It is important to stop recording before the endless loop repeats. ForC.C., 7 cues/messages were able to fit on a 30 second tape 5 on a 20 second tape and the refrain of 3 songs. The user may choose the voice for each tape, and could choose a real singer for choir tapes.

for as long as the switch is activated. Again, the timeout period is restarted.

TRAINING PROCESS

While the control logic circuitry was under construction, training was conducted with a modified audio cable. This cable connected the cuing channel directly to the pillow speaker. The message channel went through the user switch to the message speaker. In this manner the cuing channel would play continuously into the pillow speaker and the message channel only when the user switch was activated.

Photo 1: C.C. with TapeRecScanComm mounted to the back of her wheelchair, control swich is mounted to laptray.

Use

The control logic has a timeout feature which turns off the tape recorder when not in use. Presently this is set at one minute. When power is turned on to the TapeRecScanCom, the cuing messages are amplified by one channel of the stereo and played through the pillow speaker. If the user switch is not activated within the timeout period , tape motion ceases. If the user switch is activated during the timeout period, the message is amplified by the second channel of the stereo and fed to the speakers for as long as the switch is activated. The timeout period is also restarted. If the timeout period is exceeded, tape motion ceases, a switch activation restarts the playing of the cuing messages. A second switch activation during the timeout period connects the message channel to the external speaker

TRAINING RESULTS

C.C. responses with the Ablenet controller/tape recorder system averaged about 50%, with multiple verbal and gestural prompting levels. Since changing to the TapeRecScanComm, she is averaging 57% in 9 different training areas, mostly with nonprofessional caregivers. This average does not totally represent her abilities since she is spontaneously using the system a great deal of the time. Also it is often difficult to measure her true accuracy during monitoring sessions due to the nonprofessionals unfamiliarity with the equipment. In areas such as cooking and snacktime where she is highly motivated, she is averaging 70-80% accuracy, with a number of spontaneous comments and requests.

The TapeRecScanCom is used in rather noisy locations. For this reason, one of the stereo amplifier channels was connected to the pillow speaker allowing for more volume, controlled by the tape recorder volume controls.

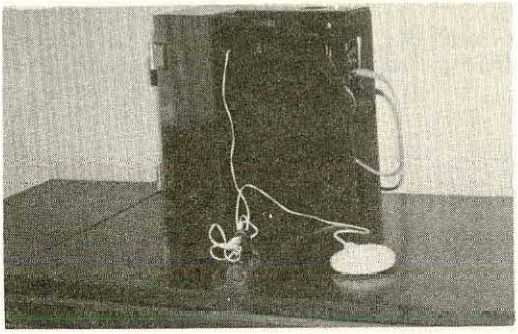

Photo 2: TapeRecScanComm in mounting case. In use the pillow speaker is mounted by user's ear.

FUTURE POSSIBILITIES

The prototype was constructed using point to point wiring. A custom printed circuit board would ease duplicating the system and improve reliability.

The present design uses three battery packs (1) four "C" cells within the stereo amplifier (2) two "C" cells to power the tape recorder, and (3) a 9 volt battery to power the system logic. The 9 volt battery insures good switching of the MOSFET transistor used to power the tape recorder. These multiple battery packs could be replaced by a single battery pack and a DC-DC converter.

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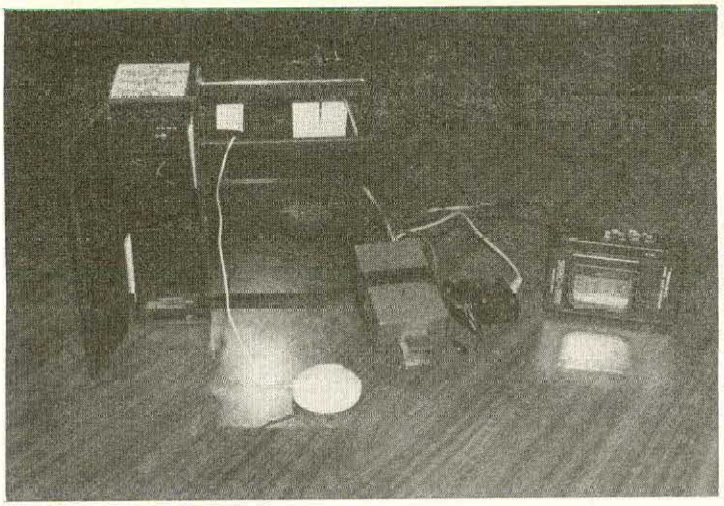

Photo 3: TapeRecScanComm. From left to right, mounting case holding the speaker/amplifiers, logic circuitry box, tape recorder battery holder, and tape recorder. The pillow speaker is in the foreground.

NON-SPEAKING PEOPLE AND MULTI-MEDIA TELECOMMUNICATIONS: THE CONTRIBUTION OF NONVERBAL SIGNALS

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ABSTRACT

Nonverbal communication is an important aspect of interaction. This means that recent advances in using telecommunications technology to aid the disabled must take account of the nonverbal dimension. One possible resource is the recent development of multi-media telecommunications systems. It is generally thought that the visual medium of such systems will offer the disabled a nonverbal signalling capacity. The following paper discusses visual medium use in a multi-media telecommunications environment. It is shown that the expected benefits for disabled users of such systems may be smaller than traditionally assumed.

BACKGROUND

Everyday communication is multi-channel, consisting of verbal and nonverbal modes of interaction. Among their functions, nonverbal gestures and vocalisations seem to be important mechanisms for maintaining communication structure (3) and for conveying social (2) and semantic (1) information. The importance of such nonverbal signals to the disabled has already been recognised (4). For those who have difficulty in using verbal communication, the nonverbal domain is an important resource which must be supported in communications technology.

This carries an important implication for those interested in whether telecommunications technology can benefit the disabled. There is some evidence to suggest that telecommunications offer people with disabilities potential for new developments in social and work-based communication (5). However, the importance of nonverbal signalling in face-to-face communication suggests that such technological developments must provide for nonverbal as well as verbal interaction.

One possible solution is the current interest in *multi-media* communication technology. These systems allow the user to employ a standard audio telephone line while, at the same time, utilising other communication media e.g. sending and receiving visual signals, sending text messages or signalling via graphical images. This may offer disabled users a greater opportunity for nonverbal communication. If an appropriate visual medium exists, users may be able to supplement their poor verbal performances by sending nonverbal, visual signals such as gestures or facial expressions.

However, such technology may impose too great a work-load on the disabled user. Communication might become such a complex task that he or she is unable to benefit from the increase in number of media. For example, non-speakers who use the text medium of a multimedia system to 'speak' via written messages will usually be forced to restrict their gaze to the text screen and to the keyboard. It follows that the introduction of a visual medium to a telecommunications system for the disabled may not, for the non-speaking disabled at any rate, provide the level of nonverbal signalling anticipated.

RESEARCH QUESTION

The purpose of this study is to assess whether a visual medium does in fact provide non-speakers with the ability to supplement verbal text with nonverbal signals when using telecommunications technology to communicate.

METHOD

The equipment comprised a multi-media communication system involving video-cameras, microphones, headsets, and text-messaging software running on two PC's connected via serial ports. Subjects, able-bodied undergraduate students, were divided into 5 communication pairs. One member of each pair simulated a form of non-speaking disability in some of the experimental conditions. This was achieved by disrupting his or her microphone output. 'Disabled' subjects were also required to type at a keyboard fitted with a key-guard, depressing keys with a stick which only just fitted into the key-guard holes. Subject pairs were placed in separate rooms and were asked to perform a short communication task via the multi-media link.

Each pair worked under three different experimental conditions. (1) No 'disability' was emulated and the visual medium, the audio medium and the text medium were open. (2) One partner became 'disabled' and could only send disrupted vocal signals through the audio medium. The visual and text media remained open. (3) The 'disabled' partner could still send disrupted vocal signals but the visual medium was closed.

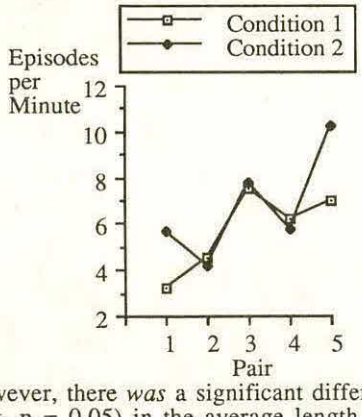
Possible familiarisation and order effects were controlled. Task success was reflected in a pair's task scores. Subjects were video-taped and computer logs created which detailed keyboard use. Amount of visual medium use was measured by analysing video tapes of the 'non-disabled' partner. Frequency and duration of periods spent by the 'non-disabled' partner in looking at the video monitor were established. Text medium use was calculated from the computer logs.

There were three hypotheses:
(1) The availability of nonverbal signals would allow subjects to perform the task better in condition 2 (visual medium open) than in condition 3 (visual medium closed).
(2) 'Non-disabled' subjects would use the visual medium more in condition 2 (one subject 'disabled') than in condition 1 (both subjects 'non-disabled'), coping with the partner's speaking 'disability' by gathering more nonverbal information.
(3) ''Disabled' subjects would use the text medium more in condition 3 (visual medium closed) than condition 2 (visual medium open) where nonverbal signals could be sent visually.

RESULTS

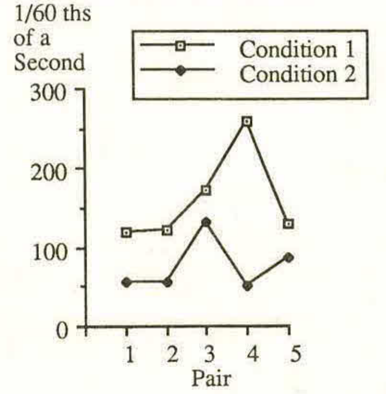
There was no significant difference among conditions in the extent to which subjects were successful in completing the task, although, as would be expected, subjects took longer in conditions 2 and 3 than in condition 1. There was also no significant difference between conditions 1 and 2 in the frequencies with which 'non-disabled' subjects monitored the visual medium (see Figure 1).

Figure 1: Effect of Having a 'Disabled' Partner on Number of Times Visual Medium is Surveyed



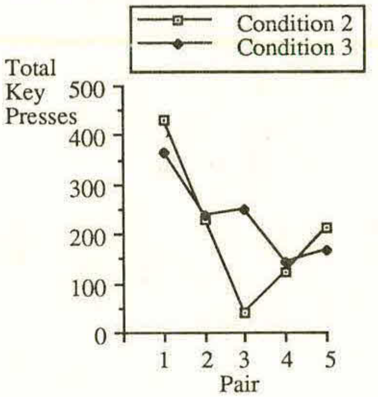
However, there *was* a significant difference (T Test, p = 0.05) in the average length of each 'watching episode' across the two conditions. On average, when 'non-disabled' subjects looked at the monitor, they looked for twice as long in condition 1 (see Figure 2).

Figure 2: Effect of Having a 'Disabled' Partner on Mean Length of Time Visual Medium is Surveyed per Episode



Subjects did not use the text medium in condition 1 and there was no significant difference between conditions 2 and 3 in the number of key presses typed at the keyboard by the 'disabled' partner (see Figure 3).

Figure 3: Effect of Availability of Visual Medium on Use of Text Medium



DISCUSSION

The results show that whether a person's communication partner is 'disabled' or not does not affect the number of times that person uses the visual medium. This means that even when one partner was 'disabled', the other partner showed no increase in attending to visual, nonverbal signals. In fact, the average length of each watching episode in condition 1 (both subjects 'non-disabled') was almost double that of condition 2 (one subject 'disabled'). 'Non-disabled' subjects attended to visual, nonverbal signals *less* when their partners were 'disabled'.

Moreover, the data from the computer logs demonstrate that 'disabled' subjects made, on average, as many key presses in condition 2 (visual medium open) as condition 3 (visual medium closed). This suggests that the visual medium's nonverbal signalling potential provided no savings in typing effort for the 'disabled' partners. Nor is there any evidence to show that availability of the visual medium improved task performance.

The conclusion to which this study points is that visual, nonverbal signals in a multi-media telecommunication system have little effect. When communicating through such a system with a 'disabled' person, people spend less time, not more time, attending to visual, nonverbal signals. Several explanations for this are indicated by fine-grain analyses of the video data. In condition 2, the 'disabled' person had to type all verbal messages. So 'non-disabled' subjects sometimes broke off from watching the video monitor in order to turn their gaze to the text screen. Subjects also found it more difficult in condition 2 to match eye-contacts, and this seemed to have a suppressive effect on visual medium use.

Nonverbal signals play an important role in inter-personal communication and should be accommodated in telecommunication systems. For ordinary users of the telephone service, nonverbal signals can be passed vocally. For non-speakers who use a text-messaging system to pass on verbal information, this is not an easy option. Multi-media telecommunication systems offer a possible alternative: the provision for visual nonverbal signals. However, the present findings suggest that this alternative may also be problematic. If this situation is to improve, designers of multi-media systems must take explicit account of the particular functional requirements associated with those who have special needs.

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A VOICE-ACCESSED PREDICTIVE KNOWLEDGE-BASED ENGINEERING SYSTEM

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ABSTRACT

A system is described which uses a word prediction module and a speech recognition system to make the use of a knowledge-based engineering system possible and efficient for persons with manual disabilities. Word prediction is used to simplify the task of writing rules in the higher-level language of the engineering system. The speech recognizer is used to drive the user interface to the engineering system and to control the detailing of product model drawings that the system produces.

BACKGROUND

Most engineering tasks require some combination of creation and manipulation of both graphical objects, such as engineering drawings, and of text, such as reports or computer programs. There is an increasing number of computer programs to handle these kinds of tasks. Creating and manipulating graphical objects can be accomplished by computer-aided design (CAD) packages, solid modelers, and parametric design systems. Creating formatted text, in the form of a report or computer instructions, can be handled by speech recognizers, perhaps in conjunction with a report formatter (2). Integration of graphical or geometric information with other kinds of engineering information (catalogs, textual rules, or design methodologies) can be accomplished efficiently by knowledge-based engineering (KBE) systems. The strategic integration of these systems along with a user interface tailored to the capabilities of a specific individual can now be built with commercially-available computer-based user input and engineering technologies (1,3). The advantages of using existing technologies are apparent when maintenance and customer support are contemplated. However, these systems have seldom been combined in ways which provide vocational tools for persons with manual disabilities. Our goal is to expand the options for vocational tools through the combination of speech recognition, word prediction, and engineering design technologies.

STATEMENT OF THE PROBLEM

Knowledge-based engineering systems form a powerful class of tools for eliminating repetitive tasks and for encoding the rules of an engineering application in the form of a language. The ICAD System is such a KBE system which is being used by hundreds of engineering firms in the United States, Europe, and Japan. During the past two years, work has been progressing to extend the capabilities of this system to allow competitive employment for individuals who otherwise might be unemployed or underemployed due to motor disabilities. The goal of the research reported here is to make accessible the KBE rule-specification features and design instantiation in The ICAD System in a highly efficient manner for use by this population.

APPROACH

The approach used in order to gain this efficiency is to employ word prediction to simplify the task of writing rules in The ICAD System and a speech recognizer to drive the ICAD user interface and to control the detailing of drawings using AutoCAD. The use of The ICAD System involves two forms of user interaction. The first is the specification in the ICAD Design Language (IDL) of the set of engineering rules which comprise an ICAD model. IDL uses both ICAD-specific keywords and user-defined names. This rule-writing task is well suited to enhancement by word prediction software. The word prediction system called Profet, developed by one of the authors, is being used to serve this function. A lexicon of words used in a particular application can easily be prepared which are predicted as the user begins to enter each word. There is also a facility for predicting the second word in a word pair as soon as the first word is entered. When the design is complete, The ICAD System can automatically translate the product model into AutoCAD drawings, or into an output file for one of a number of other CAD systems. These drawings can then be further detailed by voice control of the CAD system. During the spring of 1993, the Infovox speech recognizer will be evaluated for the task of controlling AutoCAD. (Previous work by one of the authors has included the setup of an AutoCAD system controlled by a speech recognizer, a head pointer, and a joystick.)

The second task, creating specific examples of ICAD models (instances), uses the menu-driven ICAD user interface. This kind of task is similar to controlling AutoCAD by voice. The ICAD System uses a menu-based user interface to create these instantiations of a set of rules, or examples, of entities defined by the engineering rules specified in IDL. We plan to extend our experience with menu selection by voice (1) to controlling the ICAD user interface.

IMPLICATIONS

With access to powerful engineering tools, a person can realize dramatic gains in productivity in comparison to using paper and pencil and even traditional computer programs for engineering calculations. Particularly for tasks which have a highly repetitive component, the effort to encode the procedure for performing the calculation, searching a catalog, or regenerating a drawing is well worth the time it takes to write the rules into a system. Users of KBE systems typically report gains of several-fold: for instance, a layout of a large heat exchanger that used to take approximately three months to complete by hand calculation and drawing can now be accomplished in a few hours. The startup time (the time to learn the system and encode the rules) is usually significant. For the heat exchanger project, it took approximately three months of learning and rule writing to create the first version of the system. In a sense, the first layout took about the same amount of time to generate with the KBE system as the traditional approach would have taken. However, to generate the next, and each subsequent, layout took only a few hours. Because we have seen these impressive productivity gains by users with no mobility impairment, we are confident that a person with a firm engineering skill and a manual disability, armed with prediciton and voice control, can reach a competitive skill level and thus engage successfully in vocational tasks using KBE systems for rule-based design. Examples of appropriate tasks for this kind of system include architectural layouts (the creation of house plans, or the configuration of heating and wiring systems within a building), automotive tooling (configuring the tools and molds needed to build standard parts for automobiles), and turbine blade design (calculating the paths of the cooling channels within each blade, surface detailing of the blade, and determining the shape of the attachment structure needed to hold the blade in the rotor).

DISCUSSION

Vocational tasks which can be based on some form of language control or menu selection are appropriate for access technologies such as prediction and speech recognition. The success of one quadriplegic architectural designer using voice control of AutoCAD (1) supports this opinion. Since the time of the cited report, the designer has received two jobs for pay, which he is in the process of completing using speech technology. This designer's C-5 injury is an appropriate example of the sort of person for whom the system described in this report would be appropriate: a person with good voice control, but very limited access to a keyboard or joystick.

Our further work will emphasize evaluating the effectiveness of the system described in this report, the applicability of these technologies to other individuals, and the usefulness of other combinations of input modalities for use with vocational tasks.

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THE LYNX
DIGITAL VOICE RECORDER/TOY CONTROLLER

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ABSTRACT

The education of handicapped children, especially those who experience motor, cognitive or sensory impairments is sometimes lacking in simple cause and effect experiences. The Lynx is an inexpensive voice output communication aid (VOCA) that also functions as a controller for battery powered toys. The Lynx provides the teacher or therapist with several flexible modes of operation. Four messages and or toys are available via direct select or single switch activation.

BACKGROUND

Children learn by the manipulation of their environment. Early experiments with toys, objects, things in their field of vision provide a foundation of knowledge for later years in life. The use of adapted toys, appliances and other specialized equipment can help provide some of these opportunities for physically handicapped children. Parents, therapists and teachers routinely devise clever ways that children can turn on and off toys and other devices. The most frequent modification is an interruption of power to the toy or device.

The adapted battery powered toy is a very effective tool in teaching the lesson of cause-and-effect. If the student closes the switch, the toy will operate, giving the developmentally disabled child a sense of accomplishment and control of his or her environment. This is of paramount importance if the use of electric wheelchair or electronic communication aid is on the horizon. Once the switch lesson is learned however, the intellectual leap to driving a wheelchair or composing a speech on a computer may still be a long way off.

To address the issue of fostering important discrimination skills beyond the simple cause-and-effect, it is necessary to place more than one possible event under the control of a single switch. An electric wheelchair has four possible directions of movement and a simple communication system can be realized with just "yes" or "no," consequently, the number of possible events need not be large. A simple presentation of four messages and or toys should be adequate. If an inexpensive device could be designed accomplish this task, it would fill an important niche in adaptive devices.

OBJECTIVE

The primary goal is to design a low cost device with the ability to speak four messages and control four toys. Direct select, visual scan and auditory scan selection modes should be supported. The device should be portable and easy to configure.

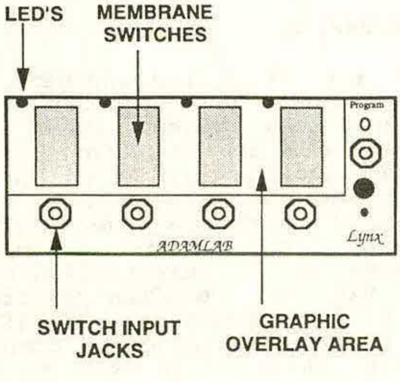
DISCUSSION

The arrival of the inexpensive low-power microcontroller has opened new possibilities in electronic design. Just a few years ago, trying to design a low cost device with some degree of flexibility was a difficult proposition. Simple functions like scanning and delay timings were often realized with shift registers, RC circuits and many discrete components. This led to complicated hardware designs and frequent compromises with functionality.

The microcontroller design presents software solutions for many problems like scanning, switch conditioning and control. It is possible to build-in intelligence and flexibility into a device by writing sophisticated programs instead of adding parts. The PIC16C55 from Microchip was chosen as the controller for this device that is now known as the Lynx.

The voice output requirements were met by Information Storage Devices ISD1016. This is a solid state digital recorder on a chip. The ISD1016 has an internal preamplifier for microphone input, 16 seconds of speech and a low-power sleep mode. The Lynx PIC16C55 software partitions the 16 second memory into (4) - four second segments and controls the RECORD, PLAYBACK and SLEEP operations.

A significant feature of the Lynx is the front membrane panel that allows for an insertable user graphic. Under the graphic area are four membrane switches with tactile feedback. Each switch area is approximately 1.0" x .9 for each message and or toy. There is a corresponding input jack for external switches and each message area is back-lighted by a high-ouput LED during operation of that particular selection.



For the Lynx to operate in a variety of ways, there needs to be a programming procedure. It is also desirable to keep the user from accidently entering the programming mode by mistake. Hidden from view under the "Lynx" on the touch panel is a small membrane switch with a 1.5 second delay. Pressing this switch in combination with the other four switch the user can switch between direct select, auditory scan, PLAY and RECORD modes.

Auditory scanning deserves some discussion here. It is a technique that presents the user selection through a private earphone. When the desired selection is heard, the user then presses his or her switch making the selection The device then repeats the selection through the external speaker for everyone to hear. This is an very effective means of single switch access. The Lynx is the first low cost device to support this selection mode.

As of the writing of this article, the Lynx just became available for $250.00 from ADAMLAB. It is far to early to have any data from the field on its effectiveness. All of the educational professionals involved in the initial design are very excited about the possibilities.

ACKNOWLEDGMENTS

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THE ECHOMETER: A USEFUL AUDIO INSTANT REPLAY TOOL FOR SPEECH-LANGUAGE PATHOLOGISTS

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ABSTRACT

Speech recording devices have long been recognized as a necessary tool for speech-language pathologists working with speech, language, and voice disorders. Presently, the use of commercially available audio recording devices is limited in many treatment situations, particularly when immediate feedback is needed. This paper describes a new voice recording device which provides high quality and immediate feedback to the clinician and the client. It is adaptable to a variety of populations.

BACKGROUND

Speech recording devices have long been recognized as a necessary tool for speech-language pathologists working with speech, language, and voice disorders. Presently, the use of commercially available audio recording devices is limited in many treatment situations, particularly when immediate feedback is needed. The Language Master (1) was introduced in 1966 to address this problem. It utilizes individual cards containing a magnetic track on which the clinician and/or client records one message which is then replayed to analyze the client's recording. The client responds without the need to rewind tapes or spend time locating the message. However, several problems limit the use of this system. These include the need for accurate timing of the message with placement of the card in the recording mode, limited recording time of seven seconds, and the dexterity needed for input of the cards.

STATEMENT OF THE PROBLEM

We determined that a speech recording device was needed with the following characteristics:

1) Immediate feedback for the client.
2) High quality recording and playback.
3) Ample recording time for sentence level information.
4) Easy to operate for both the clinician and the client.
5) Portable for bedside, home and clinic use.
6) Adequate loudness for the geriatric population with potential hearing loss.
7) Adaptable for use with a variety of disorders.

RATIONALE

Approximately two years ago the ISD 1016 (2) came on the market. This integrated circuit, with a minimum number of additional components, allows the design of a device with the characteristics listed above. We have designed a logic circuit which uses two single pole single throw momentary push button switches to enable the record and playback functions of the ISD 1016. When it is desired to record, the record switch is pressed for the period of time necessary for the recording. It can record up to 16 seconds. When playback is desired, the playback switch is pressed momentarily thereby initiating playback. No additional switching is necessary, thereby allowing a rapid sequence of record then playback, record then playback, etc.

DESIGN

In the following description, HIGH represents a logic high or one and LOW represents a logic low or zero.

Although the ISD 1016 has many features, we employ only a few of them in our device. The ISD 1016 is divided into two sections, digital and analog.

The digital section controls the analog functions by way of an input address bus (A0-A7), three input control lines ($P/\overline{R}$, $\overline{CE}$, and PD), and one output control line ($\overline{EOM}$). The address bus controls several features of the device. Since for this application only one of these features is used, all address lines are pulled LOW. $P/\overline{R}$ controls whether the circuit is in the play back mode (HIGH) or in the record mode (LOW). $\overline{CE}$ (chip enable) when LOW enables the record or playback functions. PD (power down) is used when the circuit is not in either the record or playback mode. When PD is HIGH, the circuit consumes essentially zero power. This is an extremely important feature when the device is battery operated because it draws current only when it is in the record or playback mode. $\overline{EOM}$ (end of message) goes LOW for 12 milliseconds when the recorded message is finished.

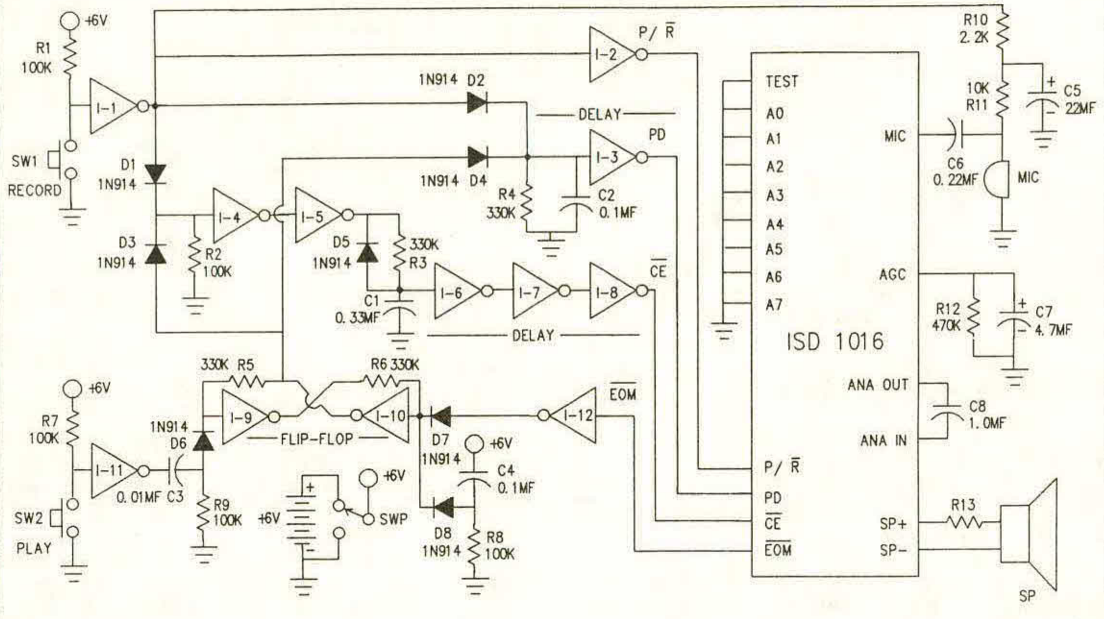
The analog section of ISD 1016 has three amplifiers, two high gain for recording and one power for playback. The first amplifier amplifies the microphone signals and employs automatic gain control. The second is a linear amplifier into which the first amplifier is capacitively coupled. The third amplifier delivers 50 milliwatts to a 16 ohm speaker during playback.

CMOS inverting buffers were chosen for our logic control circuit. In addition to their stated function, they can be used with an R C circuit to generate a delayed pulse, and coupled with resistors can be used as flip-flops. Two CD4049 (hex inverting buffers) were chosen because in their quiescent state they draw less than one microampere per device from the power supply. Of course, any appropriate logic circuits could be used to perform these functions.

The schematic and sequence of operation of our device is shown in Figure 1.

DEVELOPMENT

The following refers to Figure 1. There is an amplifier built into the case of the capacitor microphone (MIC) which draws up to one milliampere. R11 is its load resistor and C6 couples its output to the microphone input (MIC) of the ISD 1016. Normally R11 would be connected to the



SEQUENCE OF OPERATION

Power on (start up)
When power is first applied to the circuit via SWP the I-10 input of the flip-flop (I-9 and I-10) is pulled HIGH by C4 via D8. This assures that the output of the flip-flop (I-10) is LOW.

Power on (quiescent)
The I-1 input is held HIGH by R1, therefore, its output is LOW. Since the I-10 output is also low the I-2 output ($P/\overline{R}$) is HIGH, the I-3 output (PD) is HIGH (via D2 and D4) and the I-8 output ($\overline{CE}$) is HIGH (via D1, D3, I-4, I-5, I-6, and I-7). The ISD 1016 is in its power down mode. The I-11 input is held HIGH by R7, therefore, its output is LOW. The $\overline{EOM}$ output line from ISD 1016 is HIGH, forcing the I-12 output LOW.

Record
The I-1 input is pulled LOW when the record switch (SW1) is closed, making its output HIGH. This forces the I-2 output ($P/\overline{R}$) LOW which puts the ISD 1016 in the record mode. C2 will charge instantaneously via D2 thereby forcing the I-3 output (PD) LOW. This puts the ISD 1016 in the power up mode. The I-5 output is forced HIGH (via D1 and I-4). This is coupled to the I-6 input via R3 and C1 (D5 is back biased). The I-8 output ($\overline{CE}$) remains HIGH until C1 charges to three volts causing a 45 millisecond delay (I-7 and I-8 sharpen the HIGH to LOW transition) assuring that the ISD 1016 is stabilized before initiating the recording process. Recording will continue until either 16 seconds have elapsed (ISD 1016 memory is full) or the record switch is released.

The I-1 input is again pulled HIGH by R1 when the record switch (SW1) is released, forcing the I-2 output ($P/\overline{R}$) HIGH. The I-5 output goes LOW thereby discharging C1 via D5. The I-8 output ($\overline{CE}$) instantly goes HIGH and stops the recording. However, the I-3 output (PD) remains LOW because of the charge on C2. When C2 discharges to three volts through R4 (45 milliseconds) the I-3 output (PD) goes HIGH and puts the ISD 1016 in the power down mode. The delay allows an orderly shutdown of the ISD 1016.

Play
Since the I-2 output ($P/\overline{R}$) is normally HIGH, ISD 1016 is normally in the play mode. To initiate playback the play switch (SW2) is pressed then released, generating a positive pulse at the I-11 output which is differentiated by C3 and R9. The positive portion of the pulse via D6 causes the I-10 output to go HIGH. C2 is instantly charged via D4 causing the I-3 output (PD) to go HIGH, placing the ISD 1016 in the power up mode. The I-10 output is coupled to the I-4 input via D3, causing the I-5 output to go high. As in the record mode C1 and R3 cause a delay in the I-8 output ($\overline{CE}$). When the I-8 ($\overline{CE}$) output goes LOW, play back is initiated.

The circuit will stay in the play mode until the I-12 output is brought HIGH by the end of message ($\overline{EOM}$) signal from the ISD 1016. This signal resets the flip-flop to its original state (I-10 output LOW). This causes the I-8 output ($\overline{CE}$) to go immediately HIGH and the I-3 output (PD) to go HIGH after the delay. The logic circuit is once again in its quiescent state and the ISD 1016 in its power down mode.

FIGURE 1 - SCHEMATIC AND SEQUENCE OF OPERATION OF THE ECHOMETER

power supply. This would cause an unnecessary drain on the battery when the circuit is in the playback mode or power down/quiescent mode. Instead, R11 is coupled to the output of I-1 via the filter made up of R10 and C5. Therefore, there is a current drain only in the record mode when the output of I-1 is HIGH. Since the microphone amplifier has automatic gain control, no manual gain control is necessary during recording. R12 and C7 determine the time constant for the automatic gain control through the AGC input. C8 couples the output of the microphone amplifier (ANA OUT) to the input of the linear amplifier (ANA IN).

The output amplifier of the ISD 1016 is designed to deliver 50 milliwatts to a 16 ohm speaker. However, the only speakers available to us in the size that we need are eight ohm speakers. An eight ohm speaker will overload the output and cause distortion. Therefore, an eight ohm resistor is placed in series with the speaker. Of course, this reduces the power to the speaker by one half, but the sound level is still high enough for our purposes. No provision for a volume control is available from the ISD 1016 during playback. The volume could be controlled by placing a variable resistance in series with the speaker. However, because the volume is sufficient for our purposes and we want to keep the controls at a minimum, no volume control is incorporated into the design.

EVALUATION

The Echometer has been used routinely in the speech-language department of a rehabilitation hospital for ten months. The speech-language pathologists working with an adult population felt it was a useful clinical tool. The Echometer was used with aphasic, apraxic, dysarthric and voice populations, as it provided immediate feedback of the client's response.

The Echometer was used with the aphasic clients to record their jargon utterances/paraphasic responses and to increase their error awareness. Corrected responses were recorded to demonstrate effective correction strategies. As the device provided immediate feedback, it was felt to be an effective treatment tool. The Echometer was utilized for word and sentence repetition tasks with the apraxic clients to improve self-monitoring skills. The clinician commended the ease of activating the record mode and coordinating the record mode with the targeted speech output of the client. The quality of the recordings was excellent, so that phonemic distortions and misarticulations were readily apparent when the Echometer was used with treatment of the dysarthric clients. There was ample recording time so the client's word, sentence and paragraph level production could be recorded and played back for analysis. It was used by many in their rooms for independent practice of word and sentence drills with minimal instruction. The device was utilized on one occasion as an augmentative communication system with a nonverbal client who had poor motoric control. A message ("I have to go to the bathroom, could you please help me") was recorded which the client activated when appropriate. This was the first system with which she initiated interaction with the staff. Based on her success, other options were explored.

DISCUSSION

The device met all the criteria established for an effective speech trainer system, particularly in the areas of quality of recording and ease of operation. It was determined by the clinician to be an effective treatment tool with a variety of disorders. The clients also voiced satisfaction with the equipment and felt it was a helpful treatment tool. It must be pointed out that this device is not commercially available. However, it could be easily reproduced for less than $50.00 for the components. Recently several electronic speech trainers have become commercially available which seem to be similar to the Echometer in their functions. However, we have had no experience with their operation.

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VALIDATION OF EFFECTIVENESS OF MULTI-TALK II: FEEDBACK FROM TWO USERS, THEIR PARTNERS AND SPEECH PATHOLOGISTS

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ABSTRACT

Multi-Talk II, a voice output communication aid (VOCA) is currently being evaluated with five adult, physically disabled, augmentative and alternative communication (AAC) users. The aim of the project is to evaluate the effectiveness of Multi-Talk II as a VOCA using quantitative methods, and augment it with descriptive feedback from participants. This paper will present findings from completed questionnaires from two subjects, their familiar speaking partners, and their speech pathologists providing the descriptive information of the evaluation. This will also serve as a social validation measure.

BACKGROUND

Multi-Talk was the first multi-lingual, portable VOCA to be developed in Sweden (1). Initial investigations of use of Multi-Talk by younger and older AAC users were positive and encouraging (2). However, follow-up investigations revealed that successful use of the device was limited, partly due to negative attitude to synthetic speech by conversational partners (2). Feedback from users indicated the need for a smaller and lighter device.

Multi-Talk II, an updated version of Multi-Talk consists of a communication program that can be installed on any IBM or IBM-compatible computer, and an Infovox speech synthesizer. Currently, the program is available in Swedish, English, German and French, and the Infovox synthesizer is available in 10 languages. Multi-Talk II contains the features of the first Multi-Talk such as text-to-speech, access to pre-programmed expressions with single keystrokes, and a user's lexicon. There are two ways to store and retrieve messages; one is the "quick store", wherein messages that are commonly used are stored under each key and only one keystroke is needed to retrieve a message. The second store is called the "sentence store" where messages can be stored under combinations of two letters or numbers or a letter and number. In addition, the memory demands on the user are reduced as the codes and the messages stored under each code can be easily displayed on the screen. Another advantage is the flexibility of using a personal computer for communication as the user can interrupt any running program to switch into the communication mode of Multi-Talk II.

With ever more and ever changing technology, it becomes increasingly important to evaluate new communication devices. Detailed evaluations of VOCAs by users in a variety of contexts need to be documented. This information could assist users and professionals in making decisions regarding selection of devices, and provide suggestions to developers and manufacturers about future innovations.

RESEARCH QUESTION

The aim of the project is to evaluate the effectiveness of Multi-Talk II as a VOCA using quantitative methods, and supplementing it with social validation measures. This paper discusses the validation aspect of the evaluation, which will be gathered through completed questionnaires. Feedback from two of the five subjects will be presented. An aspect that is being investigated is whether the information gathered through the questionnaires corroborate the quantitative findings.

The quantitative aspect consists of videotaping and measuring baseline interactive behaviours of subjects with a familiar partner using their regular communication system, followed by training subjects with Multi-Talk II, and then measuring communicative behaviours with Multi-Talk II. Communicative behaviours will again be measured after 3 months' use of Multi-Talk II in various situations.

Five adults who are physically disabled and users of AAC are currently evaluating the device. The subjects have near normal linguistic and adequate literacy skills, and were not using a VOCA before the project.

METHOD

Subject NL:
NL is a 25 year old male with cerebral palsy and he uses an electric wheelchair for mobility. He has no

speech and uses vocalizations, eye pointing, facial expressions, a Polycom (an electronic communication device) and a Canon communicator for communication. He types his messages using a head pointer attached to an ice hockey helmet, and has fairly good spelling skills. He has completed equivalent to a high school education at a special school and has some work experience in computer data entry. He has been without a job for few years now. His speech pathologist described him as an independent person with high motivation to communicate.

Subject AO:
AO is a 38 year old female with quadriplegia resulting from cerebral haemorrhage 5 years ago. She is anarthric and uses vocalizations, her own signs for "yes" and "no," and a Polycom for communication. She types with her right index finger and has excellent spelling and writing skills. She studied to be an architect and worked as a journalist before her illness. AO has not accepted her disability completely, and had refused to use a VOCA before this investigation.

Both NL and AO have been videotaped with their familiar, speaking partners using their regular communication system in conversation and in narration of a news item. This provided the baseline measure of communicative interaction. NL chose one of his personal assistants and AO chose her occupational therapist to be their familiar partners. NL and AO were trained in the use of Multi-Talk II by their speech pathologists using a training program developed by the investigators. NL and AO were videotaped again using Multi-Talk II with the same familiar partner narrating another news item. Currently they are using the VOCA for 3 months after which they will be videotaped again.

Questionnaires:
As a final part of the evaluation, NL and AO, their familiar partners, and their speech pathologists will complete a questionnaire providing feedback and comments on the effectiveness of Multi-Talk II as a VOCA. The questionnaires will be different for each of the groups. Issues such as changes in communicative interaction and enhanced independence with Multi-Talk II, comprehension of and attitude to synthetic speech, and acceptability of Multi-Talk II will be addressed to the three groups. In addition, NL and AO will be asked specifically their views on useability of Multi-Talk II with little stress or fatigue, learnability, ability to interrupt conversation and amount of conversation with Multi-Talk II, and their preferences. Speech pathologists will be asked about the training provided to them, cognitive demands placed on the subjects, and future possibilities with the device for that user. Familiar partners will be asked about their perceptions of the communicative competence of subjects with Multi-Talk II, ease of maintenance, constraints, etc.,

RESULTS

Quantitative findings:
NL's baseline rate of communication was about 7 words/minute and AO's 5 words/minute, both with Polycom. Both their familiar partners understood the messages typed on the Polycom and there were no breakdowns. AO's partner was domineering and spoke about 90% of the total number of words in their interaction. On the other hand, NL's partner waited patiently until NL had completed typing and asked appropriate questions contributing 60% of the words in the interaction. NL and AO's communicative interaction with Multi-Talk II are currently being analysed. Communication rate with Multi-Talk II appears to be faster as they were able to describe the news item with complete sentences in a shorter time.

NL mentioned after the videotaping that he really enjoys using Multi-Talk II and it was easier for him to describe new information with Multi-Talk II. NL's partner also commented that it seemed natural with voice output and everyone could hear NL without peering over his shoulders. AO's familiar partner was impressed with the way AO could retrieve complete sentences with few keystrokes. AO has not rejected the device and is willing to try the VOCA outside the therapy situation. The communicative behaviors and feedback information will be analysed in detail and correlation between the interaction measurements and the results from the questionnaires will be investigated.

DISCUSSION

There are some differences in the attitude toward use of Multi-Talk II between NL, a congenital AAC user and AO, an acquired AAC user. However, both the users, their partners and their speech pathologists seem positive to the use of Multi-Talk II. Further analysis of the videotaped measurements and questionnaires will provide detailed information about the effectiveness of Multi-Talk II as a VOCA.

ACKNOWLEDGEMENT

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A choice-based large-vocabulary predictive writing aid

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ABSTRACT

A current research and development effort is designed to meet the writing needs of augmentative commuication users who find it difficult to use orthographic input. The program which is being developed is based on making choices, much as one would with a communication board, but with a very large underlying vocabulary. Building a sentence consists of choosing a sentence type by example, choosing among sentence subtypes (phrase sequences) by example, and choosing words to fill in the slots in a chosen phrase type. Relations to be included with the words in the underlying vocabulary will be determined by automatic parsing methods. An object-oriented representation is being pursued in the program which is being written to implement this design for text composition.

BACKGROUND

In discussions with users and professionals regarding our prediction program [1], now called Profet, there has emerged a recognition of a desire for a prediction program built upon a wide range of choices rather than abbreviations or orthographic input followed by prediction. Such a program could make writing and other communication easier for users with spelling problems, reading problems and, especially, for those having difficulty in taking initiative. It would be important that speech synthesis be available for listening to possible word choices and to partial or complete phrases and sentences.

STATEMENT OF THE PROBLEM

The goal of the project is to develop a text composition module which will allow users to compose text by making choices. The user should be able to create a text by choosing sentence type, phrase structure within this sentence type and words for each phrase that is constructed. Since most users will not be proficient in the use of grammatical terms, a method is needed to allow choices without this knowledge. The choices need to be as unrestricted as possible to allow free composition. Relationships among the words available in the vocabulary need to be part of the word database so that appropriate predictions can be made. Relationships among words in the vocabulary need to be established together with statistics for their frequency of occurrence.

APPROACH

The design of the module allows choices of sentence type, and phrase structure within that sentence type, by providing examples. The main sentence types are declarative, question, exclamation and command. For each of these sentence types, a simple example is provided. Having chosen one of these types, the user will then be presented examples of subtypes. For example, if "question" is chosen for a sentence type, a short list of examples of questions beginning with an auxiliary verb, a main verb (possible in Swedish), a single question word (such as "how") and a multiple-word expression (such as "how much") will be presented, each representing a particular phrase structure. When the subtype has been chosen, phrase construction begins. Each phrase is then built by choosing from word lists, and in some cases, specifying subphrase type, again by example. Prediction of words within phrases and of main words in adjacent phrases will be made with reference to underlying word collocations. Scanning menus in both alphabetic and frequency order will be available, those in frequency order being derived from collocation information. For the alphabetical menus, a side menu of the alphabet will be available for jumping directly to a specified first letter. Additionally, it will be possible to auditorily review any word in a menu using the speech synthesis device developed in our department [2].

The phrase structure statistics needed are being collected using an ATN parser developed by two of the authors [3]. Since it is extremely time-consuming to label large amounts of text, the approach being pursued is to use a dictionary of function words, adverbs and interjections and to use another algorithm for probabilistic assignment of possible word classes to nouns, verbs and adjectives based on word endings. This algorithm makes a correct first choice in 80% of Swedish words. Using the parser as a filter, word class assignments will be further refined. The resulting labelled phrases will be used as a grammatical database. Collocations (studies of which words appear together in a not-necessarily-adjacent context) will also be produced using the parser. Planned collocations are subject-verb, verb-object, adjective-noun in noun phrases and preposition-object in prepositional phrases.

In implementing the design in a program, an important task has been to find a suitable representation of words, phrases and sentences. An object-oriented representation has been chosen as an easy, yet powerful way to capture the properties of these grammatical entities. It allows similarities between language elements to be expressed with ease without reducing the ability to provide specific behavior when necessary. A description of the handling of word classes provides an example. All word classes are derived from a common base class which provides the operations that are common to all word classes such as printing the word on the screen. The derived classes, on the other hand, provide the operations that are specific to the different word classes. These include change of properties such as gender, number, comparison, and type of reference. Phrase classes function is a similar manner. As an example, consider the realization of a noun phrase composed of an indefinite article and a noun. In Swedish, the indefinite article and the noun it modifies must agree in number and gender. When the user selects a particular noun in constructing this noun phrase, it is the function of the "noun phrase object" to constrain the "article object" to the correct corresponding form.

IMPLICATIONS

This prediction program should be a good text composition alternative for persons who have difficulty in spelling and reading, and for persons who are passive or lack initiative. It will be possible for such a user to compose text by looking at and listening to alternatives, then choosing among the proposed sentence types, phrase types and words as one does with a commnication board. Unlike a communication board, however, it will allow users to compose messages with a large vocabulary. The statistical basis from which the supporting vocabulary with its internal relationships is built will allow for appropriate predictions within a phrase and among the main words in adjacent phrases.

DISCUSSION

There are a number of communication aids available today which provide word and phrase prediction and several stand-alone word prediction programs, some of which are memory resident and can be used with other programs. The Multi-Talk communication aid [4] and the Profet and Access [5] prediction programs, developed in our group, belong to these categories and have given us a good deal of experience in text prediction. Although complete texts may be chosen with the communication aid, text composition with these programs requires initiative from the user to begin spelling words. Some users have difficulty in taking this initiative either because of passive behavior or because of a lack of proficiency in spelling and/or reading but are able to use communication boards to make choices. This new design is intended to offer these users an alternative text composition method.

ACKNOWLEDGEMENT

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THE DEVELOPMENT OF A THIRD GENERATION FINGERSPELLING HAND

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ABSTRACT

A third generation computer-controlled electromechanical fingerspelling hand has been developed at the VA Rehabilitation Research and Development Center with NIDRR funding. The device offers deaf-blind individuals the ability to converse with able-bodied people who don't know fingerspelling and improved access to computers and communication devices. Enhancements in this design include better intelligibility, smaller size, and the ability to optimize hand positions.

BACKGROUND

The majority of the estimated 17,000 adults in the US who are deaf and blind have Usher's Syndrome, a disease characterized by deafness at birth and a gradual loss of sight in young adulthood. Most children with Usher's are brought up in the deaf community, learning sign language and fingerspelling (and/or speech and lipreading) rather than braille. As they lose their sight, individuals with Usher's Syndrome resist learning braille, as it is difficult to master as an adult and is an admission of a dual sensory loss. For this reason, augmentative communication devices employing braille may be inappropriate for people who are deaf and blind.

STATEMENT OF THE PROBLEM

Many deaf-blind people are able to communicate with others by using a hand-on-hand version of the American One-Hand Manual Alphabet. Interpreters for the deaf use this hand gesture system (fingerspelling) to spell out words for which there are no sign language equivalent. Instead of visually recognizing the gestures as deaf people do, deaf-blind individuals feel and interpret the motion and positions of the hand as the message is spelled out, one letter at a time. This method of exchange is far from ideal as it requires that both communication partners be familiar and comfortable with tactile fingerspelling and be in physical proximity. Even though professional fingerspelling interpreters can be hired, they are difficult to locate and schedule and are expensive to employ. In addition, the presence of a human interpreter may intrude on the privacy of a conversation. Without a means to communicate easily with others, deaf-blind individuals may experience extreme informational and social isolation. In summary, tactile fingerspelling can be a tedious, fatiguing, and non-private communication method that cannot be used at a distance.

RATIONALE

Electromechanical hands have been developed to provide deaf-blind people some independence in communication. These devices typically translate keypresses or standard computer-produced serial ASCII representations of letters into movements of the fingers of a mechanical hand. These movements are felt by a deaf-blind user and interpreted as the fingerspelling equivalents of the letters comprising a message. They enable the user to receive fingerspelled messages from the mechanical hand in response to person-to-person communication as well as gain access to sources of computer-based information. With a fingerspelling hand, a deaf-blind individual need not rely on a human interpreter for all communication.

DESIGNS

Initial work on fingerspelling hands was performed at Southwest Research Institute (San Antonio, TX) in 1978 (1). The next effort occurred in 1985 when the Rehabilitation Engineering Center of The Smith-Kettlewell Eye Research Foundation sponsored a Stanford class project to build an improved fingerspelling hand named Dexter (2, 3, 4).

A second Stanford student team (this one sponsored by the VA in 1988) constructed Dexter-II (5). It employs DC servo motors instead of pneumatic cylinders, resulting in a 10-fold size reduction from its predecessor. A speed of approximately four letters per second, almost double that of the original design, is possible with this design. As with Dexter, a message is typed on a keyboard by an able-bodied person wishing to communicate with a deaf-blind individual. The software translates each letter's ASCII code to a pointer into an array of data which programs the position of each of the eight DC servo motors. Wire cables anchored at the hand's fingertips and wound around pulleys serve as the finger's "tendons". As the motor shafts are energized, they turn the pulleys, pull the cables, and flex the fingers. The software used a slightly flexed neutral position to avoid finger interferences in moving from one letter to the next. Although neither Dexter nor Dexter-II can exactly mimic all the movements of a human hand, they are able to produce close fingerspelling approximations that have proven to be easy for deaf-blind users to learn. An advantage of Dexter-II's mechanical system is that it always produces the same motions for a given letter - an important factor in understanding its fingerspelling "accent".

In June of 1989, about twenty deaf-blind attendees at the annual Deaf-Blind Conference in Colorado Springs had a chance to experience Dexter-II. Their ability to interpret Dexter-II's motions varied considerably. Some were able to understand it immediately, while others had some trouble recognizing a few letters.

Although Dexter-II is much more compact and fingerspells faster than its predecessor, it does have its drawbacks: the mechanical and computer components are housed separately, the "neutral" position caused recognition problems, and several mechanical design problems have been identified. Despite much interest in the device, no manufacturer has committed to producing a fingerspelling hand.

DEVELOPMENT

In order to produce a smaller, lighter, and more intelligible version of Dexter-II, Gallaudet University, with funding from NIDRR, contracted the design and construction of two improved fingerspelling hands for clinical evaluation. The effort involved two facilities: the Rehabilitation Research and Development (RR&D) Center designed the new mechanical and computer systems, while the Applied Science and Engineering Laboratories (ASEL) provided critical hand position data and will address telephone interface access issues.

The need for greater intelligibility from fingerspelling hands called for the elimination of the neutral position strategy common to both Dexter and Dexter-II. This required identifying the finger movements from one fingerspelled letter to the next. The robotics laboratory at ASEL developed a kinematic simulation of the mechanical hand. The simulation modelled the letter-to-letter transitions as a series of static hand postures and employed a visual editor to test the viability of possible finger paths. Figure 1 depicts a hand posture just prior to reaching an "L". The data from this effort was used in the software for the contracted hands.

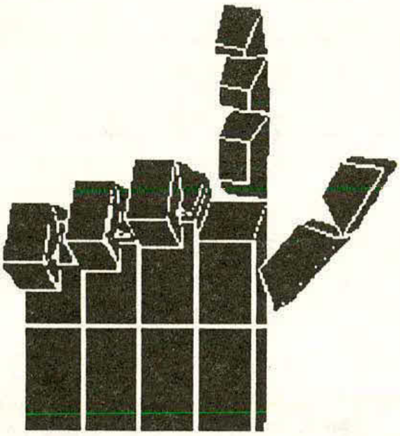

Figure 1 - Modelled hand posture

The devices constructed for Gallaudet consists of three basic systems: mechanical, computer hardware, and computer software. Mechanically, the hand (a right hand the size of a 10 year old) is oriented vertically on top of a enclosure housing the motors and computer hardware. Each finger can flex. In addition, the first finger can move away from the other three fingers in the plane of the hand (abduction). The thumb can move out of the plane of the palm (opposition). Finally, the wrist can flex.

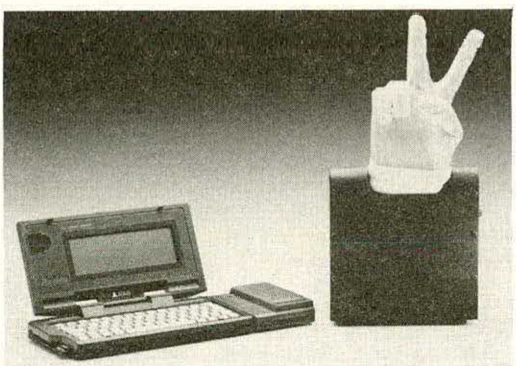

Figure 2 - Fingerspelling Hand with laptop computer

Mechanical Design

As in Dexter-II, each hand motion is driven by a servo motor. The servo motors responsible for finger flex are each connected to a pulley. A cable is wound around the pulley, routed up the finger, and attached to its tip. The fingers themselves are constructed of Delrin segments attached to each other by a strip of carbon fiber, replacing the torsion springs used in Dexter-II. The carbon fiber provides the flexible hinge and restoring force necessary to extend the finger. When the motor shaft and pulley rotates, the cable is pulled and the finger flexes. When the motor shaft rotates in the other direction, the tension on the cable is relieved and the finger straightens.

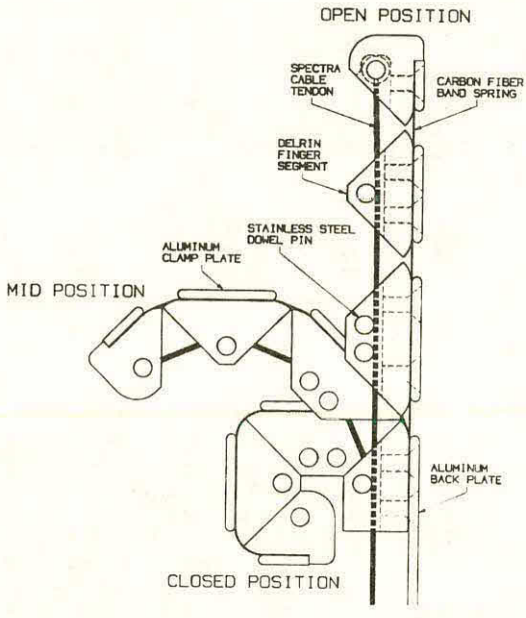

Figure 3 - Detail of finger flex mechanism

Computer Hardware Design

The system's computer hardware consists of an 8 bit microcontroller module and associated digital circuitry. This compact assembly unit is mounted behind the servo motors under the hand and replaces five 4" by 6.5" boards employed in Dexter-II.

Software Design

The software is written in Forth and is organized in 17 modules. These modules provide enhancements for the Forth kernel, an assembler (including routines that implement special I/O instructions used by the microcontroller), an ANSI display driver, serial port utilities, timer port utilities, clock utilities, servo motor pulse width modulation generation, speed switch driver, interrupt routines, input buffer software, timing control, hand data storage, fingerspelling algorithm, hand position editing support, and the user interface.

Operation

A sighted person wishing to talk to a deaf-blind individual interacts with the fingerspelling hand through an Atari Portfolio hand-held computer via a serial connection. (Actually, any device that produces RS232 serial data, including terminals, modems, computers, or modified closed caption systems, could be used to control the hand.) The user interface is implemented as a menu system which provides easy access to the unit's various functions including displaying and setting the microcontroller's parameters, testing the hand motions, editing hand position data, and entering letters to be fingerspelled.

In the fingerspelling mode, keypresses are entered on the Portfolio. The hand's software translates these keypresses into commands for the DC servo motors. As the motor shafts rotate, they pull on the cables that are the "tendons" of the fingers. It is by this coordinated series of motor commands that keyboard input is transformed into choreographed motion representing fingerspelling.

TESTING AND EVALUATION

Two fingerspelling hand have been constructed and delivered to ASEL where they will undergo testing and configuration for use with TDDs (telecommunication device for the deaf) for telephone access. Specifically, the intelligibility of the hand will be evaluated. Editing may be required for some letters to improve recognition. An interface package that can control a TDD modem and access telecaptioning hardware will be completed and tested at ASEL. Finally, the two devices will be placed in the homes of several deaf-blind individuals for extended periods of clinical evaluation through June, 1993.

DISCUSSION

Beyond evaluation, technology transfer issues must be addressed. The market for fingerspelling hands needs to be assessed. A collaborative effort with a manufacturer will be required to move this technology out of the research laboratories.

A potential solution exists for the provision of fingerspelling hands to deaf-blind people. Within California (and some other states), all telephone subscribers support a fund which provides telephone access equipment for persons with disabilities. Commercial versions of this fingerspelling hand could be furnished at no charge to deaf-blind people under this program.

All encounters with Dexter have been enthusiastic, positive, and at times, highly emotional. The increased communication capability and ability to "talk" directly with people other than interpreters are powerful motivations for using fingerspelling hands. They have the potential to provide deaf-blind users with untiring personal communication at rates approaching that of a human interpreter.

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Case Studies on Facilitated Communication
A Descriptive Research Project

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Abstract

Facilitated Communication (FC) is an experimental procedure with only anecdotal evidence to support its efficacy, and controversy surrounding its use. The tentative purpose of FC is to build the hand skills necessary to allow an individual to use an augmentative communication aid with increasing independence. Those who are thought to benefit from FC are persons who are unable to communicate effectively, have not been successful in using traditional augmentative communication approaches, and whose communication capabilities are compounded by deficient hand function and social interaction. The Case Studies on Facilitated Communication (CSFC) is a multidisciplinary descriptive research project designed to delineate intervention procedures that may be clinically useful, and to objectively measure the effects of FC on those with severe communication deficits. This presentation will focus on: a) a description of current literature, b) assessment instruments designed for and used in this project to evaluate behavior, sensorimotor, functional, emotional, and communication abilities, c) research design, d) intervention strategies and e) efficacy and validation research.

Background

FC is a training technique aimed at developing the individual's ability to accurately, and ultimately independently, point at words, letters, or pictures on a communication display in order to communicate. Training is performed by another person, called a facilitator, who makes direct hands-on contact to the person's hand, shoulder, clothing or waist and fades that contact as the individual achieves more independence. Although the influence of the facilitator in guiding the client to construct messages is unclear, it is clear that the facilitator provides input, for example, to decrease fatigue or reduce impulsivity in responding. This training technique is thought to provide appropriate sensory and motor input to increase hand function, emotional support, and in some cases training on how to use an augmentative communication system.

FC was brought to international attention among parents and service providers of people who have disabilities by Rosemary Crossley of Australia and Douglas Biklen of the United States. Although there have been many anecdotal claims of the effects of FC on persons with autism or other severe communication disorders, there has not been any quantitative research to explore the efficacy and delineate the practice of FC. Furthermore, there has been dramatic and provocative national media coverage of individuals successfully using FC and showing overall quality of life benefits. This coverage and consequent polarization of reactions by professionals, concerned parents, and the public has had repercussion for all those associated with persons having severe communication disorders.

Statement of the Problem

Currently the literature on FC is sketchy and confusing. Often those with autistic disorders are described as appropriate candidates for FC, but this diagnostic category is clearly heterogeneous and not a determinant of specific communication intervention. Others (Biklen, 1992; Crossley, 1992) have described certain characteristics such as enjoyment of books, attempts to communicate through echolalia, a tendency toward "hyperlexia", or neuromotor difficulties that may suggest suitable potential to benefit from FC. Crossley (1992) described motor deficits that include low muscle tone, impaired proximal stability, radial/ulnar instability and others which are thought to mask communication ability; but operational definitions and methods of measuring these motor deficits are absent from her research. Biklen (1992) suggested that an emotional element of support is needed by some individuals, but this emotional element is neither defined nor measured. Additionally, the pre-intervention communication status of individuals using FC has not been systematically defined or measured. Thus many questions remain such as: Who would benefit from the use of FC? What are the most appropriate clinical practices when using FC? What changes are likely to occur when using FC? How much does the facilitator influence the messages conveyed by the individual using FC?

Approach

To study FC, a multidisciplinary approach and philosophy was adopted since research questions and practice concerns transcend specialties. A resource team which includes professors from special education and communication disorders, a pediatrician, an occupational therapist, a program administrator, and a psychologist has guided the research protocol design and implementation. The research protocol and assessment instruments were designed by the authors of this paper. Consultation and training by Crossley and Stephen Calculator was included as the research protocol was developed.

Six to ten adults with a history of severe speech impairment and failure of using augmentative communication systems will be chosen from a pool of nominees from the local county. Medical, historic, and functional status information will be obtained and assessment of sensorimotor performance, behavior, communication, and independent living skills will be performed prior to intervention. This pre-testing phase of research will be followed by an introductory phase as individuals begin using FC, then a six month daily intervention phase with continual monitoring of intervention systems, followed by post-testing, debriefing, and data analysis. This research project will be ongoing throughout 1993.

Implications

This descriptive case study project should complement similar efforts to describe the clinical procedures encompassed by the term "facilitated communication," thus providing consumers with systematic guidelines for using FC, based on clinical hypotheses. These guidelines or definitions might include information about what FC is, what FC does, who should initiate its use, and how to go about using it with appropriate candidates. Furthermore, the CSFC project has developed measures and procedures to consider in pre- and post-testing, ongoing examination, and outcome analysis of this training approach which may be useful in future research. In addition, this project attempts to develop clinical hypotheses regarding the effects of FC training on sensorimotor performance, communication, independent living skills, and behavior. The data collected and documentation of procedures will help generate additional, more specific, researchable questions regarding facilitated communication.

Facilitated communication is often not viewed as a means to an end (independent communication), but rather an end in itself (a communication system). However, the focus on FC as a training technique, as suggested by Crossley (1992), challenges the assumption that its efficacy as an approach to be used with individuals who have severe communication impairment can be tested solely on the basis of the existence or non-existence of facilitator influence on generated messages (i.e., whether or not the facilitator is directing some of the messages produced). Measuring positive changes in pertinent performance areas could also validate the efficacy of its use. This does not however, negate the importance of measuring facilitator influence on the messages of those using the technique. Monitoring facilitator influence will provide useful feedback to facilitators (i.e., the individuals providing support). It might also lead to the recognition that facilitator influence is in fact most often a component of FC. In such a case it could be hypothesized that the influence itself might be an important part of the training process. In other words, it might ultimately contribute to the skill development necessary to enable the individual to become an independent communicator. The serious implications of some of the messages generated by individual's who have severe communication impairment also support efforts to measure facilitator influence.

Discussion

The label "facilitated communication" as it stands can represent a very diverse array of procedures, which are loosely related in that they involve some type of hands-on, physical support. Specific components of the technique vary along with the rationale and understanding for using them. Many times clinical hypotheses concerning the specific procedures used with individuals are absent or inadequately described. This project is an example of an initial attempt at carefully delineating specific assessment and therapy procedures to be used in implementing FC. Unfortunately, these procedures will be implemented with only a small number of individuals, limiting what is learned about the technique. A unified effort of all concerned service providers and other professionals is needed to help provide further definition of FC, including ways in which to measure its impact.

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TALES OF POWER: VOCA STORYTELLING STRATEGIES

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ABSTRACT

A fundamental goal in the field of Augmentative and Alternative Communication (AAC) is to provide the AAC system operator with increasingly functional, natural communication, including a variety of communication styles. One such style is the act of storytelling, a profound, complex communication function that people of all ages utilize. To make this communicative style available for system operators of voice output communication aids (VOCAs) requires finding a balance between the need for minimum physical and/or cognitive demands and maximum flexibility in composition, while including effective elements of storytelling form. This paper describes these elements (skeletal/basic segments; expansion/ optional segments; repetitions; intensity, voice, and rhythm) and the specific software adaptations for VOCAs which have been developed to address these needs. The paper will also target identified areas of need for further research and development.

BACKGROUND

Although relatively young, the specialty field of Augmentative and Alternative Communication (AAC) can be described as having gone through several "trends." Initial trends focused on making symbol systems available and providing access to computer technology. The next trend included information concerning training facilitators, and providing a means for literacy (Beukelman, Yorkston, Poblete, Naranjo, 1984; Blackstone, 1992).

A fundamental goal inherent in each of these trends was to provide increasingly functional, natural communication. Natural communication includes the act of "making common" or "sharing" through a variety of communication styles. A recent trend in the AAC field is an effort to make a larger variety of communication styles available for the AAC system operator.

STATEMENT OF THE PROBLEM

Norton (1983), in a study of communication styles, lists storytelling as a type of dramatic style that performs a profound, complex communication function. Schank (1990) explains that people of all ages utilize storytelling to not only interact with others, but to develop their own understanding of the events of their lives. Making this communicative style available for AAC system operators of VOCAs requires finding a balance between the need for minimum physical and/or cognitive demands and maximum flexibility in composition, while including effective elements of storytelling form.

A number of important elements of storytelling form have been identified. These include repetition; the occurrence of both skeletal or basic segments and expansion or optional segments; and variations in intensity, voice, and rhythm. Providing the system operator of a VOCA with the ability to incorporate these elements into their storytelling communication styles requires the development of specific software adaptations. Another important goal is to provide the system operator with the ability to flexibly compose and program their own stories.

APPROACH

STORYTELLING FORMS:

Schank (1990) describes storytellers as formulating a skeleton for stories from a central idea or experience and then changing the focus, length and detail based upon the purpose for telling the story in a given instance.

In a study of storytelling within everyday conversation of 28 elderly individuals, Stuart, Harrington and Jones (1992) found stories were frequently repeated but the form of the story varied. Stories were extracted as transcripts of the recorded everyday speech of the individuals of the study, and more than one version of the same story for a given individual was frequently captured (hereafter referred to as Story 1, Story 2, etc.).

In one type of analysis of the data, Story 1 and Story 2 were compared for the level of similar or identical word use, and several subjects revealed a level as low as 55% or less. However, in comparing Story 1 and Story 2 from the perspective of segments that produced information transfer, findings revealed several similar segments which often contained semantically similar vocabulary items. For example, the Story 1 segment "my Mother passed away" might appear in Story 2 as the segment "my Mom died." The compared pairs of story versions all contained two types of segments: *basic* (those which transmitted the same "core" information), and *expansion* (those which further illustrated certain points or added information which could be considered "optional" in conveying the central storyline). Basic segments were generally the same for each story (with variation in the level of formality of the vocabulary chosen) while expansion segments were often different.

In addition to the skeletal/basic segments and expansion / optional segments, a number of other characteristic elements were seen to occur in natural storytelling. One was the frequent use of repetition.

Both basic and expansion segments were often repeated, either in response to a listener's question or simply for emphasis. Repetition can be viewed as a stylistic element, and was used much more by some storytellers than others, though virtually all stories involved some degree of repetition. Another fundamental stylistic element seen in natural storytelling was the use of variations in voice quality, rhythm and intensity. Such variations are obviously important in adding emphasis, interest, and humor to a story.

ADAPTATIONS FOR VOCA STORYTELLING:

The elements described above as characteristic of natural storytelling need to be incorporated into any strategy to provide storytelling capabilities in a VOCA. An important requirement in such a strategy is that physical and cognitive demands are minimized so that the system operator is free to focus on the interaction with the listener(s) rather having to concentrate solely on operating the VOCA. This would also contribute to helping the story "flow" by enabling the system operator to be more fluent in his or her delivery, and eliminating unnecessary delays.

A simplistic approach to VOCA storytelling might involve nothing more than typing the entire story, storing it under some encoding sequence, and having the VOCA speak it aloud whenever that sequence is selected. This would fail to incorporate most of the elements described above, although some variations in the voice quality could be programmed in depending on the speech synthesizer used. However, even when being told to a novice listener (and novice listeners can often be difficult to find), this approach would not really "engage" the system operator, who could only select which story was to be told, and then listen to the same rendition as always. Adding the ability to step through the story one sentence or segment at a time would be a minor improvement, allowing the system operator to control the pacing of the storytelling, but would still fail to incorporate the above elements.

In order to enable the system operator to utilize all of the elements of natural storytelling, each of the basic and expansion segments need to be stored in the system such that the system operator can freely choose which elements are to be spoken in a given rendition. A simple solution would be to simply store each segment under a separate encoding sequence. This, however, would tend to place an undue burden on the system operator, requiring that a significant number of encoding sequences be remembered, and an even larger number of activations be performed to tell a story. A much better solution is to have a small set of encoding sequences, each of which sets up the device to tell a different story. This is the approach which the authors implemented on a commercially available AAC system based on an iconic interface and having a flexible and powerful macro capability.

In this approach, once the initial sequence is activated, signaling the system operator's intention to tell a particular story, a small set of keys become active for telling the story. Each key consistently serves a single function - one speaks the next basic segment of the informal version of the story, another speaks the formal version segments, and so on. Another key speaks the expansion segments, which only occur at certain points in a given story. If one is available at the current point of the story being told, this is indicated by the fact that the LED adjacent to this key is lit. Likewise, the LEDs adjacent to the keys used to speak the basic segments of the various versions will be lit only when there is a segment available in that version. Thus, any number of different versions (informal, formal, humorous, satirical, etc.) can easily be made simultaneously available. When a basic segment of any version is selected and spoken, the system automatically progresses to the next segment. For purposes of repetition, a single key is defined which enables the operator to go back and repeat the same basic segment or perhaps an alternate version of the same segment. Thus, the system operator need only remember the the initiating sequence for a given story, and the function of a small set of keys which is consistent for all stories in the device.

The purpose of providing storytelling capabilities in a VOCA is to enable the operator to participate in a type of communication which is both enjoyable and empowering. In order to have a truly interactive experience of storytelling, the system operator must also have quick access to everyday vocabulary and modes of communicating. A single key can be used to toggle between "storytelling mode" and the operator's normal vocabulary, allowing free-form response to questions, comments, etc. A second hit on the same key returns to the story at the point where the digression occurred.

An authoring system was developed to facilitate the creation of stories in the format described above. This system can be used by either the system operator or a support person to create the underlying structure of any story to enable it to be told using the same standard "storytelling mode" function keys described above. A story creation macro is invoked, which prompts the author to select the encoding sequence to be used to initiate telling of the story to be written. A large block of keys is then lit up which represent the segments of the story in order (from left to right across several rows). After selecting a given segment key, the various function keys representing different versions and expansions are lit. Selecting one of these creates the underlying stored segment, programmed with a small piece of text indicating its place in the story sequence and version type (e.g. "Line 7b.", "Expansion 3.", etc.).

Once the underlying story structure is created, a storyline editing macro can be invoked to easily select each of the story segments and replace the default text with the actual lines of the story. Other macros can be invoked at this time to add stress to particular words, choose different voices, vary the speech rate and volume, etc. The editing macro can be

IMPLICATIONS

Many adults with acquired communication disorders will have support people at hand who know them well enough to compose and program stories for them, ones that they had perhaps previously heard many times over a period of years. They may even know the system operator's preferred style of expression well enough to come fairly close to how that person would tell the story. One way to further empower the system operator to feel more "ownership" of the stories programmed by someone else would be to program several different versions of each segment and allow the operator to choose which versions they wish to keep. If the necessary literacy skills are present, another approach would be to enable the operator to edit each segment as desired.

However, the greatest challenge yet to be addressed is how to best enable children who have never had the opportunity or ability to engage in storytelling to compose and program their own stories. One approach might be to begin by programming a few simple stories into the system to provide the operator with some basic experience in telling stories. If possible, these would be stories related to the system operator's personal experiences, but even starting with fairy tales, jokes, or other material would be useful to introduce the operator to storytelling. The next step is a giant one - to have the support person somehow elicit the information needed to co-create stories that the operator can tell.

DISCUSSION

The system described in this paper is a start toward providing AAC system operators with access to a natural interactive communication style, and the ability to incorporate the important elements of that style. Storytelling is a powerful way for an augmented communicator to "get the floor" in a communication interaction. It is an enjoyable and natural style of communicating used by people of all ages. The process of story creation and invention is often one of adaptation based upon responses and perceived cues from listeners (Schank, 1990). Thus, it is important that the system operator can freely respond to listeners using his or her normal vocabulary in order to preserve the interactive nature of the process. This was an important goal in the development of the system.

Telling jokes is another communicative style that can serve an important function in social interaction. Some jokes are relatively long, and would be best encoded in an AAC system as stories. Others are much shorter, often consisting of a rhetorical question with a humorous answer. This type of joke often is highly dependent on the timing of the delivery of the punchline for its effectiveness. This can pose a problem for an AAC system operator, particularly someone utilizing some type of scanning access technique. If the question and answer are encoded separately, the delay is generally too long. If encoded as a single entity, the delay may be too short, and in any case, is not under the control of the system operator. However, by including a function in the AAC system which simply waits for the activation of any key or switch, the question and answer can be encoded together as a simple macro, with the wait function inserted before speaking the answer. The system operator can then select the encoding sequence for the entire joke at leisure, then simply hit the switch (without needing to scan to any particular loaction) to deliver the punchline at the desired time.

This same approach can be useful for the pragmatics of group conversation in general. Using a scanning technique to assemble a message to be spoken can require a significant amount of time. The system operator then needs to wait until the device has scanned to whatever location must be activated to speak the contents of the display, and when the scan reaches that location, begin speaking at that time even if another person in the group is in mid-sentence. Placing the "speak display" function in a macro preceded by the function which waits for any key or switch activation allows the system operator much greater control over the timing of speech acts.

Plans are underway to begin beta-testing the system described in this paper in the near future with a small group of elderly AAC system operators to evaluate its effectiveness and ease of use.

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WHAT A SUPPORT GROUP HAS DONE FOR US

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ABSTRACT

As adult augmentative communication users the ability to independently communicate has been a life long problem. Our problems are not with how we communicate, but who we communicate with. In therapy, or with that special someone communication seems to be no problem. However, with everyone else we get (excuse the expression) tongue tied. Fortunately, a support group was formed to provide us with opportunities to speak. Adult augmentative communication users discuss the affect and experience a support group has had on their lives.

BACKGROUND

Before the support group started, each of us had a communication device and attended therapy sessions to learn how to communicate with others. Some of us were afraid to talk with our devices. Some were angry with themselves because they did not know how to use their device. And still others were doing pretty well with controlling their devices. However, had problems with managing their vocabulary. Either we used our devices a little or a lot. Some of us didn't like our voices or the vocabulary we had. Many of us had limited communication partners including; friends, family, staff, and speech therapists. Most of our talking with peers, other trained professionals, and the general public took place through someone else. In October of 1990, an augmentative communication support group was founded by an augmentative communication user. Eight other aac users were invited to attend bi-monthly meetings.

OBJECTIVE

When this started we hoped to get more help with our communication devices, make new friends, help others live independently and share our experiences. In addition, we'd like to raise money to keep the group going.

METHOD/APPROACH

We meet away from home, work, or therapy in the evening in a relaxed atmosphere. Our leader makes all the arrangements for a place to meet and getting us some help. First thing we do as everyone wanders in is to take off our coats, greet everyone and chat. This is when as friends we gripe about transportation, cry about getting older, and laugh a lot. We either get together in one big group or two smaller ones to accomplish what our leader has planed. During this group time we use our communication devices to brain storm, share problems, practice talking, get ready for singing and presentations, talk about the future, help each other, and play games. We are nice to each other and just listen to each others feelings. We learn how to think for ourselves form one another. Our meetings are fun.

RESULTS

This group has given us our self esteem. We are able to make people happy. We feel good about ourselves and our abilities to help each other.

This group has given us new friends, time to practice talking, help with our device problems including how to mange them better, a chance to learn and use more vocabulary and a time to grow.

When we're away from the group we practice on our own more and talk to friends, family, staff and yes we even talk to strangers! We have noticed each other talking more and happier than when the group first started.

DISCUSSION

We enjoy getting together and seeing friends. We have been able to demonstrate our abilities to family and the general public through our everyday lives and our presentations and singing. When we present and sing we make people laugh and have a good time.

Transportation is very difficult to arrange. But it can be done. This is our biggest problem.

During the group some of us talk slower than others or not as much. But everyone is comfortable with one another and it seems like they are getting better.

Acknowledgements

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A SUPPORTED FRAMEWORK FOR ASSESSMENT OF COMPONENT SKILLS FOR COMMUNICATION INTERACTION

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ABSTRACT

The authors have proposed the use of Augmentative and Alternative Communication (AAC) hardware and software to enhance the quality and efficiency of AAC assessment. This is accomplished through development of modules related to a framework of models identifying those material and performance components most critical to determining level of functioning and technology related skills for communication. Although a single AAC device cannot mimic all of the features of all other devices (e.g. weight, visual display size, etc.), new features of AAC technology make clinical assessment applications more approachable than ever before. Technology alone cannot replace the intuitive and critical judgements made by the professional evaluator during AAC assessment. However, the framework emphasizes the use of technology to support clinical decision making, ultimately enhancing the potential for the range of opportunities and degree of success a client will experience during assessment.

BACKGROUND

Assessment of potential candidates for augmentative and alternative communication presents the clinician with many unique challenges. As a group, candidates for augmentative and alternative communication (AAC) represent a full range of age levels and etiologies related to communication disorders. For this reason, existing standardized test measures from the fields of Speech-Language Pathology and Education are generally insufficient or inapplicable. Heterogeneous complications in the motor/physical, sensory, cognitive, emotional, and/or experiential domains may further complicate application of more traditional test procedures, particularly when computer based communication prostheses are involved.

A comprehensive AAC assessment must include an evaluation of the potential for the client in using such prostheses. A variety of electronic AAC systems are commercially available for prescription. Some recently developed systems provide a wide range of options which can be configured to fine-tune the device to a particular individual's needs. To evaluate the real potential of such flexible systems, the clinician is required to adjust a large number of options, not all of which may even be relevant for a given client. Clinicians are thus faced with the prodigious task of becoming familiar with the detailed operation of a wide variety of devices, and deciding within the relatively brief time span of an assessment which device (if any) is most likely to promote the success of the client.

STATEMENT OF THE PROBLEM

Although a variety of protocols to assess AAC or device specific skills have been developed (Church and Glennen, 1992; Glennen, 1990; Goosens and Elder, 1989; Sweeney, 1992 and 1990), as well as procedural outlines for use in one or more phases of AAC assessment (e.g. Beukelman, 1988; Yoder and DePape, 1988), there remains a need to integrate components of personal communicative competence and technological features and functions to enhance the quality and efficiency of AAC assessment. Rather than focussing on domain or device specific skill assessments, the authors propose optimizing the individual's opportunities and likelihood for success in communicating by systematically controlling, in an integrated manner, those variables most likely to significantly impact performance outcomes whether they be human or technology based.

Beyond matching characteristics of individuals with specific enabling technologies, an integrated assessment system would assist the clinician by including processes and structures in the technology used for the evaluation to allow a controlled and orderly exploration of alternative strategies. Such an approach would be based on providing a modularized framework to support both software and hardware components for one or more AAC devices which are powerful and flexible enough to accommodate a broad spectrum of possible strategies. The object is to provide the clinician with a system that is flexible enough to adapt to specific individual disabilities and cognitive levels, and which can be easily and efficiently re-configured to explore different strategies and successively refine any promising approaches.

APPROACH

The current framework is based upon the models proposed by Sweeney (1989) to delineate the basic (figure 1.) and interrelated skill components (figure

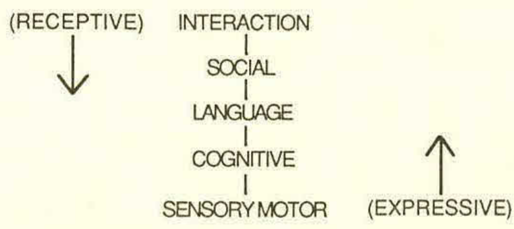

Fig. 1. Compressed Skills Model for Communication

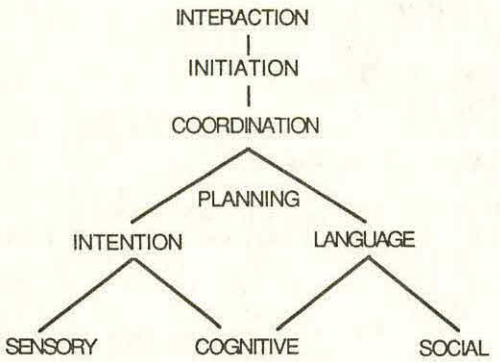

Fig. 2. Component Skills for Communication Interaction

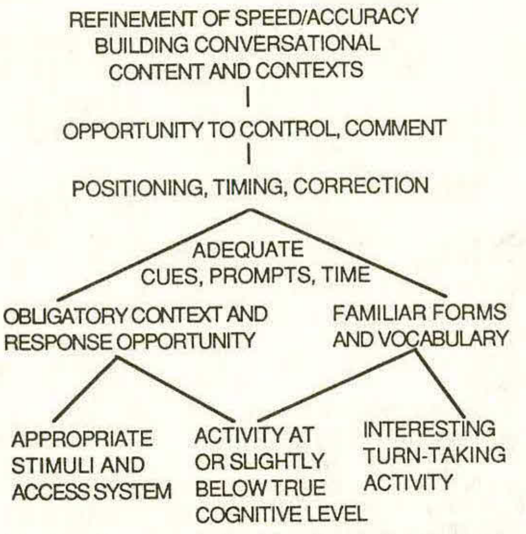

Fig. 3. Framework for Functional Assessment of Component Skills for Communication Interaction Using AAC

2.) operative in communication development and interaction, as well as dynamics for application in AAC assessment (figure 3.). Yoder and DePape (1988) have identified "... three integral components to a communication system: person, tools, and environment." While many evaluative procedures for use in AAC have focussed more intensively on individual components, Figure 2 highlights the underlying processes meshing these components. Building from this relationship, the clinician may begin to identify appropriate structures and actions for optimally accessing these component skills in the AAC assessment (see Figure 3). Ideally, the clinician should be able to alter any of these aspects by moving within a continuum of options for each. This has been accomplished in part in the past by preprogramming a variety of vocabulary levels and creating age, activity, or client specific stimulus overlays prior to the assessment. Pre-evaluation case reviews (Sweeney, 1989) have also been helpful in anticipating and planning for a range of client needs prior to assessment. However, given the range of client skills and idiosyncrasies, "on the spot" adjustments in activities and/or equipment functions are frequently necessary.

If a range of process related assessment variables were incorporated into the hardware/software of augmentative prostheses for systematic manipulation by the evaluating clinician, possible outcomes could include: a) greater customization of the evaluation process, b) increased efficiency in assessment, c) enhanced opportunities for client to demonstrate level of communicative competence or potential for same, d) decreased probability of confounding variables of client fatigue or limited motivation, e) enhanced quality assurance, f) assessment outcomes which delineate not only the most appropriate technology for meeting the client's needs but also specific entry level skills of the client and technical parameters for most effective use of equipment (i.e. acceptance time, delay, scan rate, etc.), and g) longitudinal information regarding the most effective assessment procedures with various types of clients.

A variety of specific software load modules would support different access and encoding techniques, each of which would include versions appropriate for different functioning levels. Based on clinical input, individual modules would contain options for selection at each tier of figure 3. Modules could be organized in a variety of ways such as by age/developmental levels, physical needs, etc. Starting at the base of figure 3, for example, one module would supply a menu of interesting activities (ranked by difficulty) and appropriate stimulus options for the three to five year developmental level. The activities in turn would be made tangible through preprogrammed vocabulary and language forms for the same age/developmental range. The sets of programmed forms (e.g. phrases for use in a preschool game) would provide response opportunities given the context of the activity as provided by the clinician and materials present in the assessment environment. Within the next tier of the model, the device module would not only collect a record of a particular client's responses (switch activations, keys selected, output produced, timing, etc.), but also provide the clinician with the opportunity to select sets of timing features (e.g. scan rate, technique, acceptance time, etc.) from a menu rather than having to resort to impromptu reprogramming. These sets of physical timing features could be altered at any time with simple menu selections. The same blueprint for device features would be followed throughout the remaining tiers of the model. Features common to each module would be: a) menu accessible preprogrammed feature sets for each tier of the model; b) a range of choices/difficulty levels within each set; c) potential for record keeping related to the dynamics of assessment; and d) provision for inclusion of clinician authored modules.

Module features would provide the clinician with the ability to monitor and record changes in the state of the device, the keys selected and the time required, and the resultant output produced for later (or on-going) analysis. Such information would be useful during an assessment to objectively compare accuracy using alternative strategies and to help reveal the nature of certain types of errors (e.g. perseveration) which may be difficult for the clinician to manually record. In cases where a device might be in use over a longer period of time (such as trial use during a rental period), the information collected could illuminate patterns of usage, repeated errors, rate of improvement, etc. On a broader scale, data collected for a large number of individuals may be useful in analyzing why some AAC interventions succeed while others fail.

IMPLICATIONS

New features of AAC technology make clinical assessment applications more approachable than ever before. The authors have proposed the use of AAC hardware and software to enhance the quality and efficiency of AAC assessment. This is accomplished through development of modules related to the framework of models identifying those material and performance components most critical to determining level of functioning and technology related skills for communication. The interdependent dynamics for the components are able to be flexibly and efficiently manipulated by the evaluator via menu driven options. Furthermore, device modules provide the evaluator with feedback regarding client performance which may be critical to altering the course of the assessment. Thus, the framework emphasizes the use of technology to support clinical decision making, ultimately enhancing the potential for the range of opportunities and degree of success a client will experience during assessment.

DISCUSSION

AAC assessments are generally time consuming and filled with a multitude of decision making processes. A number of clinicians and researchers have struggled with development of assessment strategies which would more objectively address these challenges. Using more advanced technology to support and simplify those processes most often addressed by evaluators has tremendous implications for the refinement of AAC assessment procedures, recording of trends which are perhaps etiology specific, improving preservice and inservice education related to AAC assessment, and influencing the development of future technology. Beyond assessment, many of the features of the proposed framework have equal and perhaps even longer term ramifications for users of AAC.

The authors are proceeding with plans to implement this framework on state of the art technology. Future research and development will involve definition of module parameters, creation and manipulation of the technology to accommodate these, collection of clinical data related to applications, and refinement of the technical elements as indicated.

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STRATEGIES FOR MAKING AUGMENTATIVE AND ALTERNATIVE COMMUNICATION "FIT" INTO THE COMPLEX LIVES OF USERS

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ABSTRACT

This paper describes and illustrates strategies developed in our facility to assure that Augmentative and Alternative Communication aids and displays are as convenient as possible so they can be implemented to the greatest benefit of the user.

BACKGROUND

One of greatest challenges in promoting spontaneous, interactive communication by users of Augmentative and Alternative Communication (AAC) is assuring ready availability of the user's communication display(s). At our facility a team approach is used including Habilitation Technology, Speech-Language Pathology, Occupational Therapy, Physical Therapy, as well as the consumer, his or her family, and others in the target communication environment, to develop methods for assuring that the accessibility of the user's communication display(s) is as convenient as possible.

PROBLEMS AND SOLUTIONS

Problem:

Many AAC users use multiple communication displays on their Voice Output Augmentative Communication Aids (VOCAs). Most VOCAs are not designed to provide a simple method for keeping such displays together and attached to the VOCA so that the user or his/her communication partner will have easy access to the appropriate display for a communicative context.

Solution:

Our team's solution to this problem was to fabricate a "Page Holder". As depicted in Figure one, the Page Holder is made of ABS plastic which is heated and molded to fit on the outer edges of the VOCA. It is attached using Velcro®. The user's displays are held inside of clear plastic page protectors that are attached to the Page Holder with two loose leaf rings. There is 1 1/2" of space left between the top of the Page Holder and the VOCA to allow for the pages to flip completely around the Page Holder so that only one page at a time is on the membrane keyboard of the VOCA. Page Holders can be made for most commercially available VOCAs.

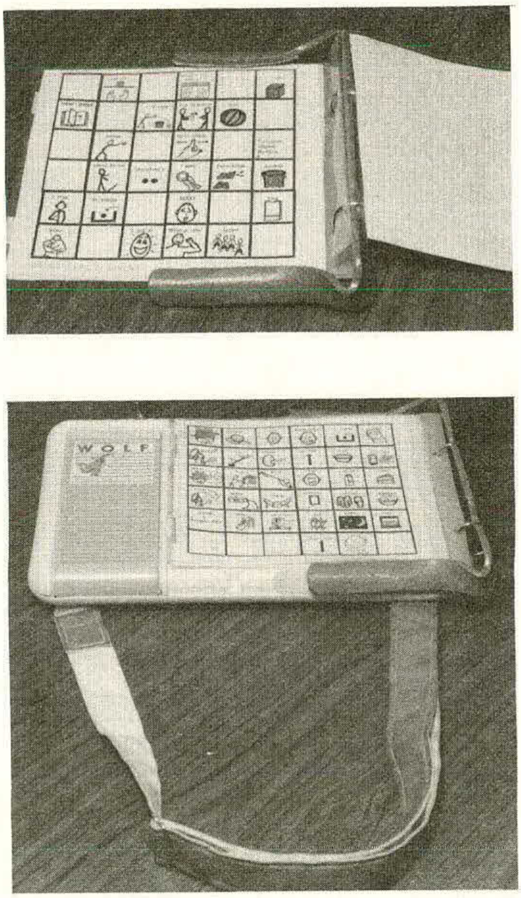
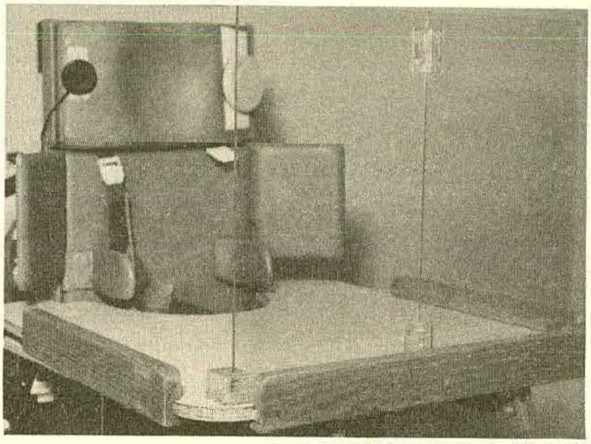


FIGURE 1. Page Holder.

Problem:

Use of eye-gaze techniques to access communication symbols provides a means of communication for individuals whose physical disabilities preclude using their upper extremities. In the practical application of eye-gaze techniques, however, we have found that the displays are often removed and set aside to get the individual in and out of the chair or for other reasons. Then, when it is needed the display is across the room or in the next room. Therefore, opportunities for communication are often lost. As is depicted in Figures two and three, we have developed strategies for storing the eye-gaze display under the laptray so that it stays with the wheelchair equipment when it is not in front of the user.

In the system depicted in Figure two, the display fits on a slotted wooden stand for use. When not in use, it folds in half to slide under the laptray on slotted wooden brackets. The display can also be used on a table or other surface with an additional slotted stand. A similar strategy was used for the system pictured in Figure three. In this case, however, standing brackets were attached to the plexiglass display. As illustrated, this allows the display to be freestanding or to attach to the laptray using brackets attached under the front end of the tray. As with the other system, this system can also be stored under the tray on slotted wooden brackets.



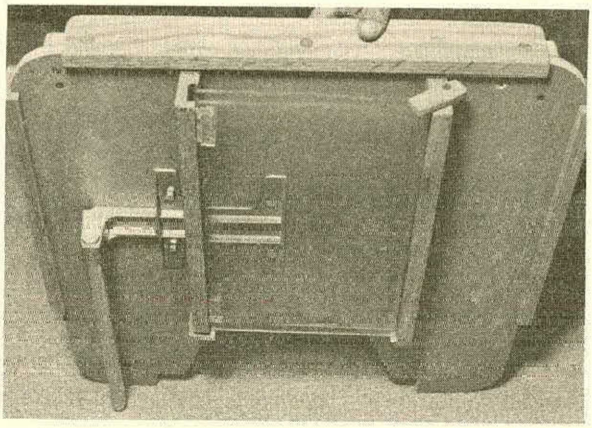
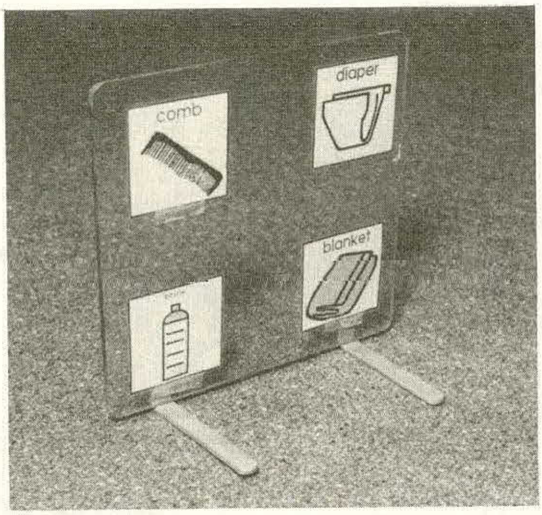


FIGURE 2. Eye-gaze display/storage strategy, version A.



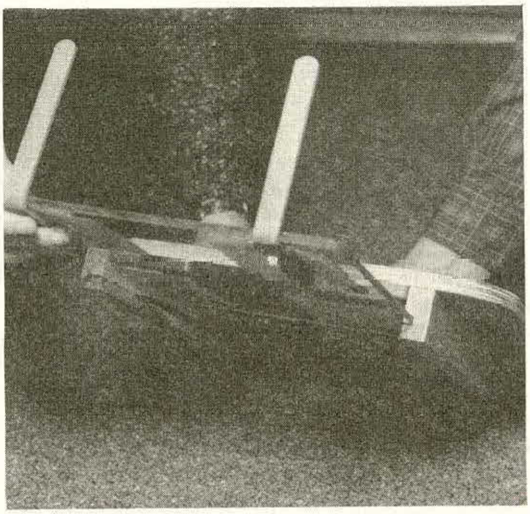
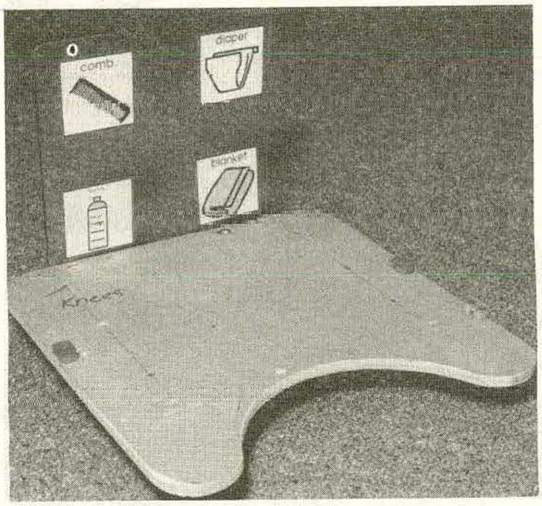
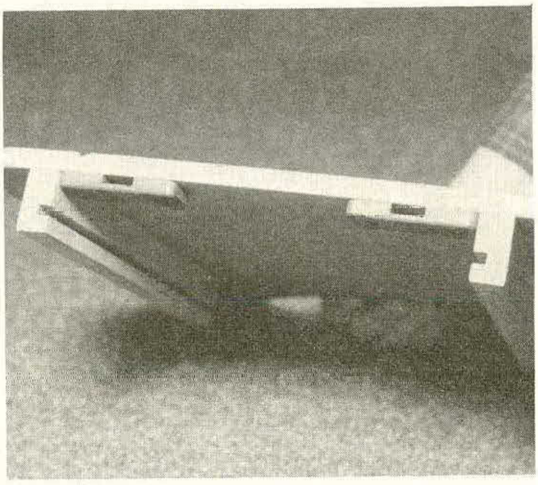


FIGURE 3. Eye-gaze display/storage strategy, version B.





DISCUSSION

The strategies illustrated in this paper represent a small sample of those developed by our team with the goal of making AAC aids/techniques as convenient as possible for users. We have received positive feedback from consumers, families and other facilitators for our efforts to make AAC "fit" into the complex lives of users.

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THE LAG TIME BETWEEN EVALUATION AND EQUIPMENT ARRIVAL: WHAT YOU CAN BE DOING

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ABSTRACT

As an evaluation center we typically recommend trial of augmentative/alternative communication (AAC) equipment prior to purchase. We have implemented an AAC equipment trial preparation service, provided by an Assistive Technology Specialist to assist community AAC teams to be prepared for the arrival of the trial equipment. The process is so successful that nearly 100% of all purchase requests are paid for through medical insurance including Medical Assistance.

BACKGROUND

The augmentative/alternative communication (AAC) team has provided AAC evaluation services since 1985. We have typically recommend trial of AAC equipment prior to purchase. To obtain equipment for trial in our state, the same prior authorization procedures as for purchase often must be followed. Prior authorization creates lengthy time delays and no clear deliverly date.

Therapists in the client's community, typically unfamiliar with the recommended equipment, were responsible for implementing it's use with the client and families. Without experience with the actual equipment or training, it was difficult for therapists to be prepared for it's arrival. Once equipment became available for trial, therapist were expected to learn the device, select vocabulary, make overlays, program the device, train the client and family, and document the effectiveness of the trial equipment to enhance their clients ability to communicate. All this was expected within the limited time allowed for use of trial equipment, about 4 to 8 weeks. We found that the first 4 weeks of the trial was spent by the therapists getting familiar with the equipment and setting it up.

With such a trial the variables were numerous, it actually put the community therapist skills on trial and did not provide the client ample time to utilize the trial equipment to develop communication interaction skills. This made it difficult to determine the successfulness of the match of equipment to the client. We found that the lack of trial documentation made securing funding for purchase difficult. We hypothesized that documentation of a trial would increase the likelihood of insurance providers purchasing equipment.

OBJECTIVE

Our objective was to provide community teams with training and technical support prior to the trial for optimal utilization of the trial equipment and time. An additional objective was to give the client time to demonstrate the effectiveness of the equipment to enhance their ability to communicate and the therapist ample time to document it.

METHOD/APPROACH

At the time the equipment is recommended for trial the preparation service is offered. The components of this service include an adapted process for vocabulary selection, equipment programming and training. Provided with an adapted vocabulary selection process developed by Sharon Glennen, Ph.D., CCC-SPL from the Kennedy Institute of Baltimore, Maryland the community team develops and organizes, the appropriate vocabulary and symbol representation to be used with the trial equipment. There are five stages to the selection process which include; identifying activities, scripting activities, organizing the vocabulary, selecting symbols and creating a corresponding overlay.

A toll free telephone number allows the Assistive Technology Specialist to provide technical support to the community team throughout the process. This involves suggestions for vocabulary and symbol selection, assisting to organize the vocabulary and providing information regarding the mechanics required for set up of the equipment. Once the vocabulary selection process is completed the vocabulary and a copy of the overlay can be sent to the Assistive Technology Specialist for programming. The original overlay can then be utilized in training sessions with the community Speech Language Pathologist. While equipment is preprogrammed, either on a computer or a duplicate device. Once funding is secured for the trail equipment, companies can deliver equipment to the Assistive Technology Specialist, who loads the pre-programmed vocabulary, before it is sent on to the client.

This is all completed during the lag time between the initial evaluation and the arrival of the trial equipment. Equipment training for the community team is coordinated to take place either two weeks prior to or at the time of delivery. Training and equipment delivery is provided by the local equipment vendor representative or the Assistive Technology Specialist. Training includes programming and basic problem solving techniques.

RESULTS

After implementation of the equipment trial and preparation service described here, we have had nearly 100% of all purchase requests paid for through medical insurance, including Medial Assistance.

Other results are noted here. Trial time is fully utilized to assess the match between device and client. The community team has ample time to collect and summarize pertinent data which is required for the procurement of the equipment. Knowledgeable community teams implement trial equipment from the moment it arrives. With training and technical support just a phone call away, they are able to make any necessary changes during the trial. Therapists report that the organized vocabulary creates a consistent system which is easier to teach and learn which encourages independent exploration. With vocabulary that is pertinent to their needs and personality, clients are able to successfully communicate in a variety of environments.

DISCUSSION

When the vocabulary selection process is first proposed to the community team, they are afraid of the time commitment. Once they begin, they realize the necessity and benefits of the process. The vocabulary selection process helps the community team to realize the varying needs of their clients. It also builds the team, by requiring everyone to have input. The vocabulary selected is backed up on disk, whenever possible, decreasing the time needed for reprogramming after system failures and when a device is purchased. Pertinent vocabulary allows clients to interact effectively, allowing the team to have appropriate documentation.

The community teams also recognize the benefit of the programming service saving them the time of learning a new piece of equipment, and allowing them to concentrate on teaching vocabulary and communication interaction. The Assistive Technology Specialist has knowledge of each piece of equipment and is able to give the vocabulary the added charm of laughter, singing or inflection. This enables the client to have fuller expressive capabilities during the trial.

Timely training enables the community team to utilize and apply the learned information while it is fresh in their minds. In addition, it is less likely that the staff receiving the training would change between the time of training and equipment arrival.

By maintaining copies of the overlays and vocabulary list, the Assistive Technology Specialist can provide personalized direction over the telephone. This knowledge of the equipment set up can ease the frustration, often accompanying phone technical support.

The effect of the equipment is proven by comparing baseline data taken prior to the trial to data taken during the trial. This documentation demonstrates the clients abilities to utilize the equipment in a manner other than "testimonial", which insurance providers reject. When this documentation is summarized and put into statical format insurance providers have the factual information for making a purchase decision.

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SIG-04
Drooling

Drooling: Current Practices and Future Directions

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Abstract

Drooling is a frequent problem in people served by rehabilitation engineering. This problem results in social isolation, narrowed educational and vocational opportunities and significant medical problems. There are limited numbers of therapeutic interventions which are inconsistently or incompletely helpful. It is felt that new rehabilitation engineering approaches to this problem are possible. This would include development of accurate measurement techniques, intraoral prosthetic devices to improve control of saliva, materials to control wetness and odor and improved guards and shields. The recently established Drooling Special Interest Group (SIG 4) will focus such efforts.

Introduction

Drooling, also known as sialorrhea, is the unintentional loss of saliva from the mouth. In babies and young children, drooling is tolerated until approximately age 4. After that time, it is considered abnormal (Crysdale, 1989). During a recent meeting concerning this topic, a multidisciplinary group of professionals (physicians and surgeons, dentists, therapists, teachers, psychologists, engineers and consumers) concurred:

> "Drooling is both a clinical sign and symptom that is most often a consequence of medical and/or neurological disorders. In itself, drooling affects the total will-being of the individual, and secondarily it may present problems for caretakers." Consensus Statement of the Consortium on Drooling, 1991.

Individuals with cerebral palsy, mental retardation, craniofacial anomalies and a variety of neurologic injuries can have difficulty with sialorrhea. It is estimated that there is a 10% incidence of this problem among the total population of people with cerebral palsy. Among those who receive rehabilitation engineering services this percentage would be expected to be much higher. The incidence among the other populations is unknown.

Persons with drooling find that it interferes with the social, vocational and practical aspects of life. In public, those unfamiliar with people with disabilities may prefer to avoid visually the individual with sialorrhea. For the school-aged child, clothing becomes odoriferous and skin becomes chafed and macerated. Sialorrhea can cause problems in school and vocational settings. Papers can become wet and illegible, electronic equipment can malfunction and books can become unusable. Dehydration can be a problem in those with marginal oral skills and profuse drooling.

Current Treatments

Interventions to ameliorate drooling include contributions from the fields of medicine, therapy, psychology, and engineering. Medically, various surgeries and pharmacologic agents have been used to manage this problem. Surgeries which have been utilized include removal of some of the salivary glands, relocation of the salivary ducts or disruption of the nerve supply to the glands. Increased dental caries and insufficient saliva to keep the mouth comfortably moist seem to be disadvantages of these interventions. Medications such as anticholinergic agents decrease drooling by decreasing saliva production. Unfortunately, these agents effect multiple organs governed by muscarinic stimulation. Potential side-effects such as drying of all mucus membranes, blurred vision, and/or increased body temperature may be more unpleasant and deleterious than the drooling itself.

Physical, occupational and speech/language therapists and psychologists focus on improving the individual's skill in swallowing and controlling saliva. Working with movement and sensation, therapists pay special attention to body position and head control, thereby indirectly influencing drooling. Some use feeding to facilitate oral motor functioning, secondarily improving the handling of one's own saliva. Psychologists have used learning and behavioral techniques together with positive reinforcement to increase swallowing frequency and decrease drooling in the clinic setting. Once control is achieved, efforts then switch to generalizing this control across settings, activities and caretakers. The efficacy and permanence of these therapies and behavioral techniques have been questioned.

Rehabilitation engineering, too, has made contributions to drooling. These contributions have focused on positional aids and protective devices such as computer keyboard guards, book guards and specialized head rests.

Future Directions

The therapies, surgeries and equipment outlined above have been helpful to people with sialorrhea but substantial problems still exist. Treatments are not curative in the majority of people. Therapies are often expensive and can demand significant commitments of time and effort. Even people with the necessary resources and motivation will see only small or transient improvements in their sialorrhea. Also, many potential interventions have such significant side-effects that people either decide against treatment or discontinue it once it's started.

Efforts to develop new or improved treatments face significant obstacles. Research has been severely hampered by a lack of adequate techniques to quantify sialorrhea. To date, many measurement devices have been bulky and hard for subjects to ignore. Many are sufficiently technical that they confine people to research settings. Efforts to measure drooling by introducing devices into the oral cavity have been found to effect both the production and intraoral management of saliva. For these reasons, current measurement techniques are suspected of perturbing the phenomenon they are attempting to assess.

Research has also attempted to determine whether individuals with sialorrhea produce excessive saliva, swallow less frequently or swallow less efficiently. These studies have also struggled with questions of accuracy and reliability. Subjects have needed to be confined to research settings and their awareness of the measurement processes raises questions of bias.

The development of quantification devices which are reliable, portable, non-invasive and allow people to engage in routine daily activities remain the most pressing need for adequate scientific investigation of this problem. Development of such devices will undoubtedly fall to rehabilitation engineers in collaboration with their colleagues in medicine, the therapies and psychology. Other rehabilitation engineering needs exist in this area.

Treatment options which utilize intraoral devices have been considered. There has been initial design work on an intraoral prosthetic device (salivary pump). This device would utilize molar contact and a minute vacuum pump to move excess saliva from the front to the back of the mouth. Devices which would rely on capillary action have also been discussed.

The odor associated with sialorrhea has been described as a significant social problems. A number of technological applications may be possible to help control odors associated with drooling. Suggestions made by participants at the Consortium on Drooling (Blasco et al, 1991) included: 1) the use of odor controlling chemicals on clothing 2) and the identification of foods which positively or negatively effect odor.

Chronic clothing wetness contributes to the social isolation of individuals with sialorrhea and can also lead to problems with temperature control, hygiene and skin integrity. It has been suggested that the technology currently used to convert waste liquids to more solid consistencies (i.e. diaper technology) might be adapted to solve this problem. This type of approach might lead to a clothing treatment much like a fabric softener which could make garments more tolerant of wetness.

Other existing materials may also be applicable to the treatment of sialorrhea. A non-toxic polymer may already exist which is capable of absorbing several hundred times its weight in water. A substance of this type might be useful intraorally (e.g. in chewing gum, lozenges, etc.) or extraorally (e.g. artificial cigarettes, etc.) as a means of keeping saliva in the mouth or making saliva easier to direct and swallow.

Though much has been done regarding shields and guards, improvements in these devices and increased accessibility of them in clinics is needed. Further development of new devices using new materials is felt to be possible.

CONCLUSION

Sialorrhea (drooling) is a common problem in persons with disabilities. Though treatments exist, there are also doubts about their efficacy, safety and ease of use. It is felt, by professionals in the area, potentially new and innovative engineering approaches to this problem have a great deal of promise. Research efforts have been hampered by a lack of adequate measurement devices and, to a certain extent, by a lack of awareness and organization among those best able to help. The recently established Drooling Special Interest Group (SIG 4) within RESNA will focus new energy and interest on this important issue.

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SIG-05
Quantitative Assessment

Assessing the Impact of Assistive Technology Using OT FACT Version 2.0

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Abstract
Measuring the impact of assistive technology devices and services is essential, particularly in this era where health care funding is being carefully examined and potentially totally reorganized. While measuring the functional outcome of assistive technology has always been critical, few measures and outcome instruments have been made available to help assistive technology practitioners and researchers quantify the impact of assistive technology. The OT FACT system available from the American Occupational Therapy Association provides a software-based measurement and documentation system which uses the power of modern computer technology to efficiently quantify functional performance. Although OT FACT is built from an occupational therapy theoretical and practice orientation, the contributions it makes towards documenting human performance with regard to the use of assistive technology is worth examining by other disciplines from a discipline-free perspective.

Background
Assessing the impact of assistive technology is becoming more critical as funding resources are anticipated to become more scarce and total reorganization of the health care system is impending. It is essential that those who provide services in the area of assistive technology find mechanisms to justify the positive impact of assistive devices and technology services. The RESNA Quality Assurance Committee is examining this issue. Assessing the impact of assistive technology, however, cannot wait. Many service providers are in current need of assessment instruments.

Unfortunately, most standard functional assessment approaches from medical rehabilitation, education, or independent living are not appropriate for assessing the impact of assistive technology. Generally speaking, current assessments do not tease out the assistive technology variable. Because of the faiulre to control for assistive technology in the quantification process, the data which result from these assessments do not provide impact information. Some current functional assessments, in fact, do not even score an individual using assistive technology as fully functional. Traditional assessments from medical models view function from an intrinsic human performance perspective. Thus, if any assistive technology is used, the person is not independent.

Statement of the Problem
New assessment approaches are necessary to fully assess the impact of assistive technology devices and services. Assistive technology interventions have been acknowledged as legitimate types of methods for improving independence, productivity, and quality of life. Better outcome measures are necessary to fully assess their impact. Such assessments, however, must be based in theory which includes a functional performance model, and one which includes assistive technology as a measured variable.

Approach: The OT FACT Model
The development of OT FACT has a history dating to 1979 when the American Occupational Therapy Association (AOTA) identified the lack of consistency in the assessment processes used by occupational therapists. At that time, AOTA developed its Uniform Terminology document and a mandate to develop assessments which use it. Much of the current OT FACT model has evolved from this initial AOTA Uniform Terminology. Several versions of OT FACT have subsequently been developed and its relevance to measuring the impact of assistive technology has already been suggested (Smith, 1987).

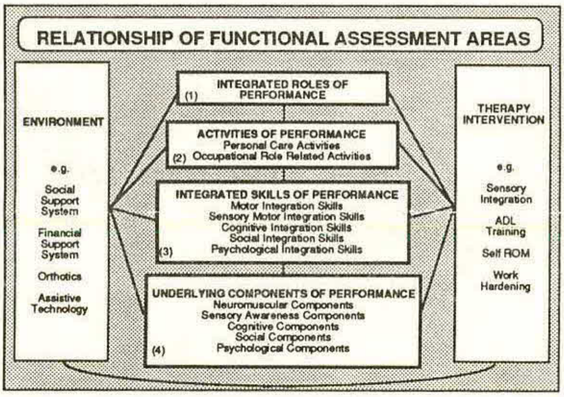


Figure 1
Model of OT FACT

Today, OT FACT is available from AOTA as a software based assessment which covers four levels of human performance and three domains of function (Smith, 1990; 1992). Figure 1 shows the overall model with the hierarchical levels of performance in the center and the environmental and therapeutic intervention dimensions off to each side. As can be seen, the human performance levels in the center are hierarchically oriented, where the higher level and most complex functions are on the top and the more component ingredients on the bottom. Key concepts of each of the hierarchical levels are roles, activities, skills, and components. An example of an item on the role integration level is role disruption. If someone has encountered some trauma such as in a motor vehicle accident, many of their current life roles may be severely disrupted and would be reflected on this level. The second level includes life activities. Classical ADLs and IADL components such as community integration, homemaking, vocational, and educational activities fit into this level. The third level includes integrated skills which contribute to the independence or dependence of an individual on the activity level. Examples of items on this level are hand function and problem solving. Lastly, the bottom level is that of components which is closer to the physiological and anatomical aspects of human performance. Items such as range of motion, strength, endurance, and memory lie on this level.

Figure 2 shows an excerpt of a more detailed breakdown of the categories. The number of question in the expanding outline set in version 1.X was around 300. This number has tripled for version 2.0. OT FACT uses an expanding outline to present the categories and definitions and a straightforward trichotomous scale. Together, these form a decision branching questioning system and a technique called trichotomous tailored sub-branching scoring (TTSS). This permits the user of the assessment a rapid and reliable way of collecting the data.

Key to the use of OT FACT in relation to assistive technology is a concept that OT FACT should be scored twice: first from an *environment-free perspective*, and second in an *environment-adjusted perspective*. This dual data set discriminates the impact of assistive technology as opposed to the therapy, rehabilitation or educational contribution to improving the function of an individual. Figure 3 highlights how OT FACT data may present over time for an individual who has a severe injury, such as a high spinal cord injury, during their rehabilitation back towards independence. The bottom line of the figure highlights the improvement of an individual over time in their intrinsic performance. This means how their intrinsic abilities and skills improve without any environmental assistance (including assistive technology). The top line demonstrates the person's overall functional performance when assistive technology and/or other environmental interventions are included. OT FACT implements this concept when a file is loaded to begin a data collection set. It requires the assessor to state which perspective is being used during the particular assessment.

OT FACT also allows for other co-variate types of scoring (Rust & Smith, 1992). A variety of co-variates can be used as a focus to score Level 2 of OT FACT. These include task attributes such as safety, rate of performance, judgement during activities; components, such as pain, range of motion, memory; or other important dimensions such as self-satisfaction. OT FACT includes a special notation so it may be used as a self-satisfaction scale where individual clients can assess each of their daily living activities (both personal care and occupational role related activities) on a scale of completely satisfied, somewhat satisfied, and not at all satisfied. This provides a quantified satisfaction outcome.

Version 2.0

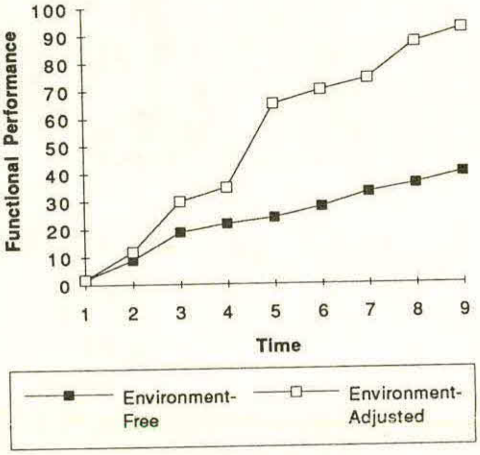
In 1993, OT FACT is being upgraded to a version 2.0. The initial version was available on MS DOS machines. Version 2.0 is designed to run under either Apple Macintosh or Microsoft Windows operating systems. Several features now have extended the capabilities of OT FACT. Briefly, these include increased detail in the question set making it more sensitive to particular areas of assistive technology service delivery and practice. Version 2.0 also includes a report writing module which assists individuals in compiling the demographic and the functional performance data and importing boiler plate interpretations, goals, and plans to expedite the report writing process. Increased attention to the environmental-adjusted scoring and the documented use of assistive technology has been made available in

- I. ROLE INTEGRATION
- II. ACTIVITIES OF PERFORMANCE
  - A. PERSONAL CARE ACTIVITIES
    - 1 Cleanliness, Hyg. & Appear.
    - 2 Medical and Health Mgmt. Act.
    - 3 Nutrition Activities
    - 4 Sleep and Rest Activities
    - 5 Mobility Activities
    - 6 Communication Activities.
  - B. OCCUPATIONAL ROLE RELATED ACTS.
    - 1 Home Management Activities
    - 2 Consumer Activities
    - 3 Educational Activities
      - a. Studentship Acquis. Acts.
      - b. Studentship Maint. Acts.
        - 1) Campus/school mob.
        - 2) Participates
        - 3) Stores materials
        - 4) Records information
        - 5) Studies
        - 6) Tools & supplies
          - aa. Writing utensils
          - bb. Computers
          - cc. Books & Ntbks.
          - dd. Fasteners
          - ee. Math tools
          - ff. Science tools
          - gg. Soc. studies tools
          - hh. PE equipment
          - ii. Art supplies
          - jj. Music supplies
        - 7) Non-classroom
    - 4 Employmt & Voluntr Prep Acts.
    - 5 Caregiving Activities
    - 6 Employer Activities
    - 7 Community Activities
    - 8 Avocational Activities/Play
- III. INTEGRATED SKILLS OF PERFORMANCE
  - A. MOTOR INTEGRATION SKILLS
  - B. SENSORY-MTR INTEGRATION SKILLS
  - C. COGNITIVE INTEGRATION SKILLS
  - D. SOCIAL INTEGRATION SKILLS
  - E. PSYCHOLOGICAL INTEGRATION SKILLS
- IV. COMPONENTS OF PERFORMANCE
  - A. NEUROMUSCULAR COMPONENTS
  - B. SENSORY AWARENESS COMPONENTS
  - C. COGNITIVE COMPONENTS
  - D. SOCIAL COMPONENTS
  - E. PSYCHOLOGICAL COMPONENTS
- V. ENVIRONMENT

Figure 2
OT FACT Outline Excerpt

the version 2.0. This includes the overt identification of which type of scoring is being used, as well as the inclusion of general memos; a specific memo to document which assistive technology was used, and a memo about the type of assistance which is provided. In both version 1.X and 2.0 versions, OT FACT provides several methods for portraying the functional assessment data in tabular summaries, bar graphs, and line graphs.

Figure 3
Environment-Free and Environment-Adjusted Performance Over Time



Implications

OT FACT is a computer-based assessment which has a comprehensive set of questions relating to the overall functional performance of an individual, and a mechanism for teasing out the impact of assistive technology devices. OT FACT has evolved out of an occupational therapy model viewing the overall performance of an individual and is designed from an occupational therapy human performance theory. OT FACT acknowledges that most traditional medical rehabilitation and other functional assessments do not adequately tease out the impact of assistive technology. Occupational therapy practice has historically applied assistive technology interventions for many decades, and thus has integrated the quantification of this intervention.

Discussion

While OT FACT is an occupational therapy oriented assessment and documentation system built from an occupational therapy theoretical perspective, many of the theoretical elements of this perspective are compatible with a discipline-free assistive technology philosophy. The computer based platform has also enabled the OT FACT assessment to use an entirely new way of documenting functional outcome using the TTSS technique. OT FACT was not feasible to administer in traditional paper and pencil functional assessments formats of the past. OT FACT, and particularly version 2.0, will be an important instrument for assistive technologists to examine as it may be a method which would be helpful to assess the impact of assistive technology in the short term. While the RESNA Quality Assurance Committee and the RESNA as a whole may develop quality assurance policies and procedures, including recommendations for outcome measurement, OT FACT is an instrument designed to deal with many of the current measurement questions posed today.

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Calibration and Force Correction of the F-Scan™ Foot Pressure Measurement System

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ABSTRACT

The F-Scan™ system is a computerized, in-shoe measurement tool used to record plantar pressure distribution patterns during standing and walking. This project compared three methods for calibrating the system; static calibration using total body weight (method I), dynamic calibration using total body weight (method II), and static calibration using free weights loaded over a fixed area for a specific time (method III). We also compared the uncorrected force values to values using simultaneously recorded ground reaction force data, obtained from a force platform. These techniques were evaluated in a group of ten normal volunteers. The results showed that the method of calibration can significantly affect the force prediction capability of the unmodified F-Scan™ system. If force correction using simultaneously recorded force platform data is incorporated, the force prediction capability of the system is significantly improved, and is less sensitive to the type of calibration scheme. We conclude that dynamic calibration combined with force platform correction gives the most accurate results from the F-Scan™ system in its current configuration.

INTRODUCTION

Measurement of plantar pressures between the foot and the floor during locomotion is an important clinical quantity for assessing gait abnormalities associated with many conditions. It is especially useful in the clinical management of diabetic patients with peripheral neuropathies, who are at risk for developing foot ulcers.

Several techniques for dynamically measuring foot pressure during walking have been devised [Alexander, et. al., 1990], however, most systems fall into two distinct categories; platform based measurement systems and insole measurement systems. As the name implies, platform based systems measure plantar pressures using a fixed measurement platform mounted flush to the walking surface. Regardless of the type and density of the sensor array used to transduce pressure, all platform based systems are of limited clinical value since only the structure in direct contact with the platform can be measured. This precludes testing subjects in their potentially damaging footwear, and eliminates the possibility of evaluating the effectiveness of pressure reducing orthotic devices.

All insole based systems can overcome this problem, but historically at the expense of resolution and repeatability. The F-Scan™ system (Tekscan Inc., Boston MA), is an improvement over previous insole systems, due primarily to the development of proprietary sensor technology [Podoloff & Benjamin, 1989]. The system uses a thin (0.004"), disposable shoe insert, designed with two layers of conductive ink, each photolithographed with parallel traces on a mylar substrate. The two layers are arranged perpendicular to each other to produce a grid of 960 pressure sensitive cells spaced 0.1" apart. Technical information obtained from the company states that the sensors have high spatial accuracy, low hysteresis, and linearity of 5%.

First generation F-Scan™ systems measured one foot at a time, and could not be calibrated in the field. Cranmer and Patterson [1992] tested the accuracy of this system and found a hysteresis of 10% for loading below 50 pounds, but the hysteresis increased to ±20% at a load of 100 pounds. Rose and colleagues [1992] used the first generation system and found it to be a reproducible pressure measurement system in normal test subjects under certain conditions. However, different sensors produced different results in the same subject, suggesting that individual sensor calibration was required. Our own experience with the first generation system is consistent with these findings. Second generation systems introduced in January of 1992 corrected some of these problems by redesigning the sensor to use a more pliable substrate, and included a technique for individual sensor calibration in the field. Unfortunately, the prescribed method of calibration (enter body weight of the subject, then record data while the subject stands on one foot) was found to consistently underestimate the actual total force, when compared to simultaneous force platform recordings. Apparently, a new calibration procedure was needed for the F-Scan™ system to be used for reliable quantification of plantar surface pressures.

The purpose of this study was to compare three different methods of calibration, and to determine if using a force platform in conjunction with F-Scan™ recording could correct for known and unknown system inaccuracies.

METHODS

Subjects: Ten young adults (4 males, 6 females) with no history of previous gait pathology ("normal") volunteered for this study. They had a mean age of 26.0 ± 6.3 years and a mean weight of 147.7 ± 29.8 pounds. All subjects read and signed the informed consent form approved by the Institutional Review Board at the University of Texas Southwestern Medical Center.

Calibration Methods: The three calibration methods tested in this study are described as follows. In method I, the subject was asked to stand on the attached F-Scan™ sensor with one foot, while an investigator recorded the sensor values using the calibration function of the software. This is the procedure documented in the F-

Scan™ operators manual. Method II required the subject to stand on the opposite foot, wait for a signal from the operator, and then transfer to the dominant foot. Immediately upon accepting weight on the test foot, the operator sampled the sensor and recorded the calibration file. This is considered "dynamic" calibration since the sensor is only loaded for an instant prior to recording a calibration value. Calibration method III used static free weights equal to the subject's body weight applied to a 3.0 in^2 area in the center of the sensor, prior to attaching the sensor to the subject's foot. Weight was applied with a block and tackle, and the calibration sample was recorded exactly 5 seconds after load application. Three separately acquired calibration files were recorded for each method and each subject, and then averaged to obtain the calibration file to be used for each subject's subsequent recording.

Testing Procedure: Each subject arrived at the laboratory at the time of their scheduled appointment wearing comfortable clothing. Height and weight were recorded in the customary way. Tracings were made of the subject's dominant foot, with the outline used to cut a fresh F-Scan™ sensor to the exact size. The edges of each sensor were then reinforced with paper tape, to prevent the individual mylar layers from delaminating, as we have previously observed. The sensor was attached to the plantar surface of the subject's bare foot using double sided tape, and then covered with a thin nylon stocking to secure it in place. The system was then calibrated in the manner described above for method I. Each subject was asked to walk at a normal, comfortable velocity down a 9 meter gait lane aligned with the force platform, until three "acceptable" passes were completed. The details of the force recording system have been described previously [Carollo, 1992]. For this study, "acceptable" is defined as a pass where only the test foot is in contact with the force platform, with no portion of the foot straddling the surrounding floor structure. Plantar pressure and ground reaction force data were recorded simultaneously for each acceptable pass, and stored on disk for later analysis. This procedure was then repeated for calibration method II and calibration method III.

Data Analysis: All F-Scan™ and force platform data were transferred from local disk storage to a network file server for analysis. For uncorrected data, the internal F-Scan™ scaling factors used to convert binary sensor recordings into either pressure or force results were left unmodified. In this way, the difference between force data from F-Scan™ and force data from the force platform reflected the ability of the uncorrected F-Scan™ system to measure vertical ground reaction forces. For corrected data, the scaling factors were modified by multiplying by a correction factor obtained by sampling the force magnitude at loading response (first peak), midstance (first valley), and terminal stance (second peak) of each measurement pair of vertical force curves, averaging these three values, and then taking a ratio of average F-Scan™ force to average force platform force. In the case where the two force recordings produced identical average force values, the correction factor would equal one, thus leaving the scaling factor unmodified. Using the new scaling factor, corrected force curves were plotted using the standard F-Scan™ software. The difference between the F-Scan™ and force platform force at loading response was then calculated for both uncorrected and corrected force values.

Separate one-way ANOVAs were used to determine if there were significant differences between the three calibration methods in the uncorrected and corrected force difference data. If significance was shown, post-hoc testing using the Tukey HSD was used to determine which calibration methods were significantly different.

RESULTS

Descriptive statistics associated with the loading response peak are shown below. Average force difference data between F-Scan™ and force platform measured forces are reported as mean ± SD for each calibration method and for uncorrected and corrected force.

	Method I avg. force difference (mean ± SD)	**Method II** avg. force difference (mean ± SD)	**Method III** avg. force difference (mean ± SD)
Uncorrected	69.17 ± 33.01	46.71 ± 25.34	102.0 ± 35.80
Corrected	7.45 ± 3.49	7.82 ± 4.10	8.11 ± 6.21

A comparison of uncorrected to corrected values for each method shows clearly that force correction can improve the accuracy of the F-Scan™ system, regardless of the calibration method employed.

Results of the one-way ANOVAs for uncorrected and corrected force differences are shown in the following tables.

ANOVA Summary for Uncorrected Force Data

source	*df*	SS	MS	F	Prob.
between groups	2	15463.6	7731.8	7.70	0.002
within groups	27	27121.0	1004.5		

ANOVA Summary for Corrected Force Data

source	*df*	SS	MS	F	Prob.
between groups	2	2.24	1.12	0.05	0.95
within groups	27	608.21	22.52		

As shown in the first table, there was a significant difference between the three calibration methods when the peak loading response force values are taken directly from F-Scan™ without correction. From the Tukey HSD multiple comparisons test, the most significant difference was found between method II and method III ($p = 0.002$). There was not a significant difference between either method I and III ($p = 0.071$) or method I and II ($p = 0.270$). As shown in the second table, we found no significant difference between calibration methods if force correction is applied to the raw F-Scan™ data.

DISCUSSION

Previous studies and personal experience have shown that the unmodified, second generation F-Scan™ system suffers from problems of non-linearity, moderate hysteresis, and temporal decay. During calibration, the force sample recorded can be affected by temperature, and the amount, position, and area of the applied load. The calibration scheme recommended by the manufacturer (method I) seemed intuitively flawed, since it did not control for any of these variables. For this reason, we devised a dynamic calibration scheme (method II) and a static calibration scheme that would control for amount, position, and area of the applied load (method III).

The results of this study suggest that controlling for some of the known inaccuracies of the system during calibration may not yield significantly better force prediction than the manufacturer's suggested calibration scheme. Although slightly better at predicting force in the uncorrected mode when compared to method I, dynamic calibration using method II is not significantly more effective. The grossly underestimated force prediction of method III suggests that even accurately applied and positioned static loads can not be used for calibration. After observing this, it is probably incorrect to classify method I as a "static" calibration scheme. The process of balancing on one foot loads the sensor in an indeterminant way, which from a static standpoint is uncontrolled, but from a dynamic standpoint may be precisely what the sensor requires to accurately scale the resulting recorded values. The unique design of the F-Scan™ sensor offers unparalleled measurement capability in an insole system. However, it has unusual transient characteristics in practice, and since its response changes dynamically, it appears it must be calibrated dynamically to obtain reasonable results when not corrected with the use of an external instrument.

An unexpected outcome of this study is the robust nature of the force correction using a modified scaling factor. When force correction is used, there is no significant difference between the calibration methods studied. Force scaling can even salvage data calibrated with the obviously inferior technique of method III. It may be argued that this would be expected since our reference value is the force platform recording, which is also being used to rescale the F-Scan™ data. However, it should be understood that only three critical points from the force platform recording were used to derive the modified scaling factor, not the entire curve. Had all values comprising the F-Scan™ curve been compared with corresponding force platform data points, this argument would have merit. By modifying the internal scaling factor rather than the entire curve, the raw data is left untouched, and only the manner in which it is converted to force by the standard F-Scan™ software is changed. This approach has the added advantage of still making available the full complement of F-Scan™ functions common to the original software, which would be lost if the data was merely transformed externally to the program. Using force platform data as the "gold standard" is also warranted, since Winter [1987] has shown that this type of data has the lowest coefficient of variation both within and between subjects, when compared to other outcome measurements.

It should be noted, however, that this study compared forces and not pressures, for which the F-Scan™ system was originally designed. When a shoeless foot covered by an F-Scan™ sensor is in direct contact with a force platform, it is safe to assume both devices are measuring the same quantity; vertical load. It is therefore appropriate to compare these two systems under this unique condition. Unfortunately, there is no human measurement analog to this in regard to pressure measurement. Since force and pressure are related by a constant (area), it is assumed that what holds for force holds for pressure. This will be addressed in a future study.

CONCLUSION

In conclusion, this study shows that the method of calibration can significantly affect the force prediction capability of the unmodified or uncorrected F-Scan™ plantar pressure measurement system. However, if force correction using simultaneously recorded force platform data is incorporated, the force prediction capability of the system is significantly improved, and is less sensitive to the type of calibration scheme. Future studies will address the affect calibration has on the pressure prediction capability of the system, and will try to identify a calibration procedure that can improve the performance of the unmodified system.

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STRESS DISTRIBUTION IN THE ANKLE-FOOT ORTHOSIS DURING PATHOLOGICAL GAIT DUE TO "DROP-FOOT"

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ABSTRACT

Pathological motion of the ankle-foot complex presents a major problem in the rehabilitation of stroke patients. They often develop "drop-foot", a problem involving excessive and uncontrolled plantar flexion. An ankle-foot orthosis (AFO) is prescribed to constrain and inhibit this abnormal motion. Because of a lack of knowledge of the stress distribution in the AFO, the fitting process in today's practice is still based on trial and error, and AFO break down due to fatigue remains a significant problem. Therefore, a 3-D finite element stress analysis was conducted and stress distribution in the AFO was determined.

BACKGROUND

The ankle-foot complex of the human body is a complex, multi-joint structure which determines motion between the foot and the shank. Pathological conditions such as stroke contribute to abnormal rotations at the ankle-foot complex that affect a person's ability to walk. For example, the "drop-foot" developed by the stroke patient creates excessive and uncontrolled motion at the ankle joint during heel strike. More specifically, drop-foot is characterized by excessive and uncontrolled Achilles tendon force and excessive plantar flexion often leading to toe strike instead of heel strike during the stance phase of the gait.

AFOs have been prescribed to alleviate the drop-foot problem. In current clinical applications, the AFOs are generally made from a variety of thermoplastic materials like polypropylene, and are custom fitted to the patient. However, this fitting process is based on trial and error procedures which cause pain and are time consuming. Problem of AFO break down due to fatigue is also significant because of lack of knowledge of the stress distribution in the AFO. Reddy et al. (4) and Lam et al. (2) formulated a 2-D model of the AFO complex which assumed symmetry of the device. In reality, however, orthoses are not symmetric. The objective of the present study was to develop and simulate a 3-D finite element model (FEM) of the AFO complex to identify locations of stress concentrations during "drop-foot".

METHOD

A 3-D FEM of a clinically available AFO system was developed using PATRAN (3). 3-D finite element analysis (FEA) of the 3-D FEM of the AFO system was conducted using ADINA (1). Pathological conditions of drop-foot were simulated.

A 3-D FEA mesh totaling 323 elements and 596 nodes was generated. Eight node isoparametric brick elements were used for the AFO, soft tissue, and foot bones. Two node truss elements were used for ligaments of the foot (Figure 1).

The upper boundary of the leg was assumed to be at one third of the height of the normal leg above the ankle joint (Figure 1). This upper boundary was constrained in all planes. The upper boundary of the orthosis was also constrained in all planes. The tibia was surrounded by soft tissue and was connected to the foot by ligaments. A vertical direction of motion between the tibia and soft tissue was assumed. The weight of the foot was simulated by mass proportional loading conditions. Ground reaction forces of heel strike, toe strike, and toe-off during the stance phase were simulated by concentrated nodal forces. Achilles tendon force and flexor and extensor muscle forces were also simulated by concentrated nodal forces.

RESULTS

The results indicated that the maximum compressive stress was highly concentrated in the heel region of the AFO during the heel strike (Figure 2). Maximum tensile stress was highly concentrated in the neck region during toe-off (Figure 3). Maximum shear stress was also highly concentrated in the neck region during toe-off (Figure 4). Toe strike produced high tensile stress in the neck region as well. In addition, the magnitude and location of stress concentration in the AFO varied with a change of the ground contact point during heel strike. However, the magnitude and location of stress concentration was not significantly altered during toe-off.

With increasing Achilles tendon force (simulating excessive force that act on the Achilles tendon due to drop-foot), the magnitude of the peak stress in the AFO was increased. However, the magnitude and location of the peak stresses were insensitive to ligament stiffness (simulating drop-foot).

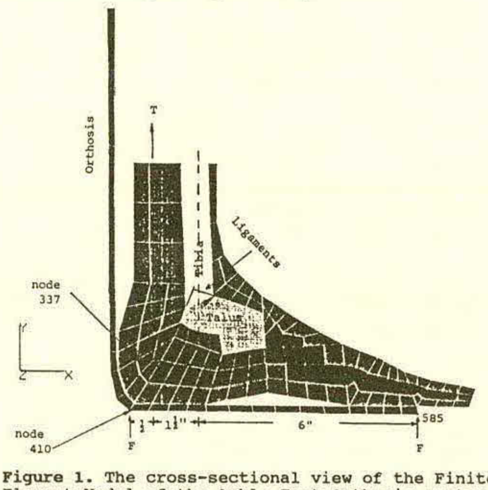

Figure 1. The cross-sectional view of the Finite Element Model of the Ankle-Foot Orthosis system.

DISCUSSION

In the field of rehabilitation engineering, the major goal is to restore the patient's ability to function normally during daily activities, as well as to provide comfort. The present study clearly demonstrated the capability of the finite element modelling technique to improve orthotic devices intended to mitigate the functional deficit known as drop-foot.

The present results represent the first 3-D FEA of the AFO complex. Notwithstanding the rudimentariness of this analysis, stress concentration in the orthosis can be predicted by the FEA of the AFO system, thus adding powerful new tools to current clinical techniques of AFO design and fitting. The present findings are consistent with earlier 2-D FEA results. In addition, this 3-D FEM has the capability of predicting medial-lateral variations of the stress concentration in the AFO. The results have also clearly shown that the stress distributions are not symmetric. This is due to the asymmetric geometry of the AFO itself.

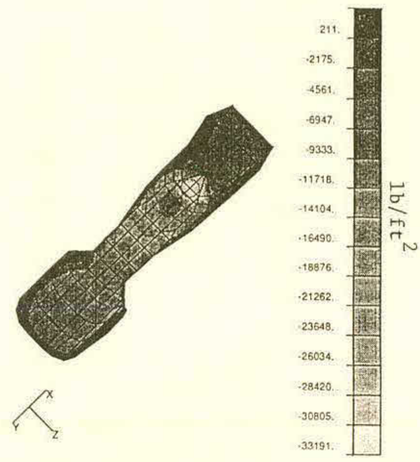

Figure 2. Compressive stress contours in the AFO of heel strike (ground contact point: center of the heel) during the stance phase under static analysis.

The present results of drop-foot revealed that a high compressive stress is concentrated at the center of the heel of the AFO during heel strike, with the ground contact point located at the center of the heel (Figure 2). But, a high compressive stress is concentrated at the neck area between the middle lateral and lower lateral edge of the neck of the AFO during heel strike, with the ground contact point located at the lateral side of the heel. A high tensile stress is concentrated in the neck region of the AFO during toe-off (Figure 3). Also, high tensile stress is concentrated in the neck region during toe strike. In addition, high shear stress is concentrated in the neck region during toe-off (Figure 4). These results suggest that the AFO is likely to fail in the neck region. This prediction is consistent with clinical observations.

Parametric analysis revealed that mechanical properties of the foot play an important role in determining stress distributions in the AFO. The excessive forces exerted in the Achilles tendon because of drop-foot, had a profound effect on the stress distribution. A large force exerted in the Achilles tendon resulted in extremely high compressive stress in the heel region, high tensile stress in the side arc edge, and high shear stress in the neck region of the AFO. However, the mechanical property of ligaments does not have a significant effect on the peak stress in the AFO.

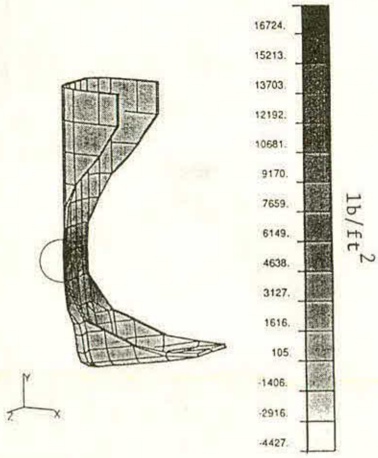

Figure 3. Tensile stress contours in the AFO of toe off (ground contact point: inner front edge) during the stance phase under dynamic analysis.

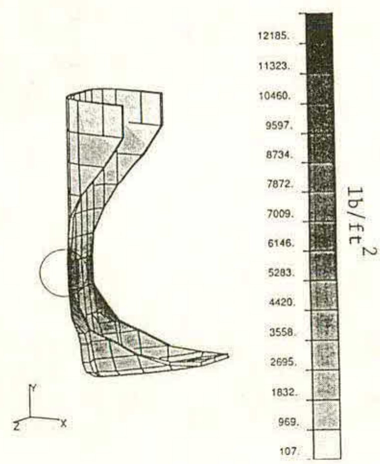

Figure 4. Shear stress contours in the AFO of toe-off (ground contact point: center of the front edge) during the stance phase under dynamic analysis.

In the present study, one type of orthosis was analyzed. The anatomy of the foot and the actual geometry of the AFO for a given patient can be derived from MRI or biplanar X-ray studies. Although the present study was a comprehensive one, mechanical properties in the analysis were assumed to be linear. In reality, the soft tissue and the ligaments are anisotropic, nonlinear, viscoelastic, and discontinuous with several inhomogeneities. Moreover, the magnitude of the actual stress developed in the AFO is dependent on the patient's physique and type of activity. For example, the magnitude of the peak stress in the AFO could be significantly altered with stair climbing, running, and/or weight lifting. However, the fatigue life of the AFO can be predicted from knowledge of the magnitudes of peak stresses. Thus, the FEA is the tool of choice and can be easily used by experienced clinicians.

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Measurement of Muscle Fatigue for Optimized Overloading in Exercise Therapy

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ABSTRACT

This paper presents a concept for the design of a rehabilitation device based on a novel sensor which measures the surface shape of a patient muscle group. It is proposed that this shape follows changes in cross-sectional areas of the muscle during an exercise cycle.

The device will be used in the long-term measurement of the effects of exercise, and in the short-term assessment of muscle fatigue.

The device will be used in conjunction with diagnostic and training apparatus designed at the Technical University of Kosice in Slovakia.

BACKGROUND

Many devices used in physical therapy and rehabilitation or sports medicine use the monitoring and processing of movement parameters for the control and evaluation of exercise training. Some of these devices also have functions for the testing of muscle strength, range of movement, and work done. Such a device, similar in concept to Cybex, Kin-Trex, or Artromot, has been designed by the Department of Measurement and Regulation at the Technical University of Kosice.

With such devices, one can pursue the study of the advantages of hydraulic, isokinetic, isotonic, or isometric loading methods where the basic approach is to accommodate the subject's strength with the appropriate loading method. But in such cases, it is difficult to control and maintain the loading and movement pattern, especially involving a damaged muscle group.

For such devices to be effective, it is important to dynamically assess short-term fatigue within a therapy session.

FATIGUE ASPECTS IN EXERCISE

If increasing muscle load is to result in efficient muscle training, it is necessary to increase muscle strength and endurance. However, overloading and fatigue can create higher risk, especially for muscles which have been immobilized. It is necessary to ensure conditions for safe overloading which will build strength while preventing excessive fatigue and muscle fiber damage.

This problem is solved by starting with low loading in the isometric contractions mode or by using technics like hydraulic resistance equipment [Guffey(1990), Grimby(1985), deVries(1978), Basmajian(1984)]. The treatment efficiency depends on rehabilitation staff experiences and patient cooperation.

It is commonly accepted that the adequate load for efficient training is that which a subject is able to repeat 10 times. The concept of progressive resistance exercise was introduced by de Lorme [de Lorme, 1945]. His training was based on the use of weights that were lifted for 10 repetitions. He called this weight the ten repetition maximum - 10 RM. This means it is necessary for a muscle group to be in a fatigued state a the end of ten repetitions. The magnitude of the weight is adjusted for the subject's immediate conditions. As the subject's muscle strength increases with repeated therapy, the weight must be adjusted to maintain the correct degree of overloading. The selection of the proper weight is important since an excessive load level can be dangerous.

STATEMENT OF THE PROBLEM

Many authors have analyzed the advantages and disadvantages of particular contraction modes used for rehabilitation exercises [Grimby(1985), Kottke&Lehmann(1990), McArdle(1991), deVries(1978), Basmajian(1984), and others]. The key question remains how to make an exercise highly efficient without causing damage. Muscle fatigue is one of the most important factors for a appropriate solution to this problem. The muscle fatigue level is assessed by tracking the number of exercise repetitions (endurance), by assessing the accommodated load level (strength), by evaluating, upon completion of task, the total work done (integration of endurance and strength), and by measuring the EMG.

The EMG method seems to be complicated for daily use on training machines, but there is no other known approach for using a real-time data to follow the effect of short-term muscle fatigue. It is this problem which has led to the examination of an alternative measure of muscle fatigue. Under consideration are different muscle properties which follow a muscle fatigue process.

Muscle contraction leads to a change in the cross-sectional area of the muscle (Zivcak et al 1992). During the fatigue process, muscle contractions and cross-sectional area decrease in magnitude. Quantifying the volume parameters of a muscle may make it possible to identify its fatigue level with a higher degree of objectivity than using the subject's assessment of fatigue. The fatigue progress could also be followed in real time during an exercise procedure.

DESIGN CONCEPT

The Department of Measurement and Regulation has been engaged in the development of training and diagnostic equipment for use in Slovak rehabilitation clinics. The design principle behind such devices is to seek modularity in order to reduce complexity and cost, while providing only the essential features needed in the specific therapy. It is also desirable to use local components and allow the components to be manufactured within Slovakia.

In conjunction with the training device, a prototype of a muscle surface sensor has been developed. This device senses the contour of the muscle bulge as the muscle is contracted. This surface contour is related to the muscle volume, and hence the muscle crossectional area.

The device consists of 2 flexible rubber units each containing a 16X16 matrix of electrical contacts which are connected to a microcomputer. One unit placed over the muscle to be studied, and the second over the antagonist muscle. The units are held in place by elastic straps so that when the muscle is relaxed, none of the electrical contacts are active.

When the muscle contracts, the resulting bulge in the surface of the skin causes some of the contacts to close. The microcomputer detects these closures and records a 2-dimensional representation of the contour of the bulge.

During a therapy session, the contours of the surface bulges produced by the repeated muscle contractions are recorded. These contours are expected to remain reasonable constant as the muscle is exercised, until the muscle begins to fatigue. When fatigue occurs, there is a decrease in muscle activation which results in a decreased crossectional area. This is reflected in a decrease in the size of the surface bulge.

With such a device, it is possible to measure changes in muscle fatigue during exercise.

USES FOR THE DEVICE

The new sensor will be used to monitor the fatigue status of a muscle being tested or trained. The availability of a real-time measurement will allow more accurate determination of the overloading parameters, and allow for optimization of the training regime.

In addition to the short-term assessment of muscle fatigue, this sensor will provide an alternative method to assess the long-term improvement due to training. Increased muscle contraction (as the result of proper training) will result in overall increase in muscle crossectional area, and will be seen as increased contour of surface bulge during contraction.

These data will be recorded for each subject across all training sessions and will be a measure of improvement.

CONCLUSION

Overloading conditions are used for strength and endurance training and to make exercise more efficient. The proper level of load is checked after completing a set of exercises. The local muscle disposition sensor enables real-time following of muscle fatigue by monitoring cross-sectional changes on a contracting muscle group during an exercise cycle. The information can be helpful in the prevention of muscle fiber damage and the improvement in exercise efficiency. The subject motivation effect is also important.

ACKNOWLEDGEMENTS

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COMPUTER APPLICATIONS FOR STUDENTS WITH LEARNING DISABILITIES

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ABSTRACT

A group of students with learning disabilities in grades 5 through 9 participated in computer assessments to identify tools which could assist them with reading and writing activities. The success that these students had with various types of technology, and the needs which could not be met by current products, is discussed.

BACKGROUND

The Department of Education has estimated that 3% of our nation's students have a learning disability (Lerner, 1981). When a student has difficulties with written language it can be particularly challenging, since the majority of their classes have a required textbook and written assignments. Difficulties with written communication continue to effect those students who pursue further education. On our campus, where 2.5% of the students have a learning disability, many of these students gravitate toward professions where they can use hands-on skills. They find that they still need to be able to read and write to complete classwork, and have thus begun to turn toward technology which can assist them with these activities. Much of this technology was developed with other disabilities in mind. Only recently is the rehabilitation technology community addressing the unique needs of students with learning disabilities (Montague, 1990).

PROJECT OVERVIEW

This past fall, a school district within our state was awarded a grant to have our Center provide technology assessments for their 95 exceptional needs students in grades 5 through 11. Of this group, 87% have a learning disability or slight cognitive delay. This project is still in progress and will be completed during the spring of 1993. So far, assessments have been completed with 42 students in grades 5 through 9 who have difficulty reading class material or communicating ideas through writing. Assessments focus on computer tools which students could use to improve their reading or writing skills.

ASSESSMENTS

Four technology groups were tried with the students to address reading and writing difficulties. Many of these programs were not designed for students with a learning disability, but proved to be useful.

Speech output systems

Originally designed for visually impaired users, speech synthesizers and screen reading programs can be used to read a computer text file to a student. Text books can be scanned into a computer, or students can listen to their own writing. Speech output systems are now being designed for individuals with learning disabilities as well. These systems are simpler for the sighted user to control, and often highlight the word which is being read. For the assessments, two systems were tested. A DoubleTalk speech synthesizer and VocalEyes screen reading program were used to represent systems for the visually impaired. HumanWare's SoundProof system for users with learning disabilities will be tested later during this project. Students were observed for their ability to understand individual words, answer questions about a paragraph read by the system, control what is read, and notice personal writing errors when spoken by the synthesized voice.

Spelling and grammar checking

A number of the students had particular trouble with spelling. Students had an opportunity to try the standard spell check program within the WordPerfect word processing program as well as the Franklin Language Master electronic dictionary. For grammar checking, the CorrectGrammar program was used. For both of these programs the student's ability to scan suggestion or word lists and make appropriate choices was noted.

Word prediction

A technology area which not normally applied to the learning disabities is word prediction software. When a user types a letter, the program displays words that start with that letter. Traditionally, this software has been used by people with physical disabilities to increase their typing speed. We found that this technology could be helpful to the students with learning disabilities, however, because the predicted word lists could be used as spelling cues. We used the HelpUType program, in combination with screen reading as needed. For successful use, students needed to be able to scan the word lists for the word they were trying to spell.

Voice input

Finally, speech recognition technology offers a means for older students to dictate papers. This option was not tried with elementary students, and would be of most benefit to those older students who are frustrated easily or have attention deficits. The enhanced speed of these systems can be particularly appealing to students. The IBM VoiceType system was used. Students were considered successful users only if they were able to consistently identify whether the system had correctly recognized their word and instruct the computer to select a different word if it had been misrecognized.

RESULTS

To date, 42 students have completed computer assessments: 21 fifth and sixth graders, and 21 junior high students. For many of these students, simply being able to edit writing on a word processor was beneficial. In addition, 45% of the students had handwriting which was somewhat difficult to read. They may find that typed assignments are easier to proofread.

The breakdown of potential users for the technology areas discussed earlier are shown in Figure 1.

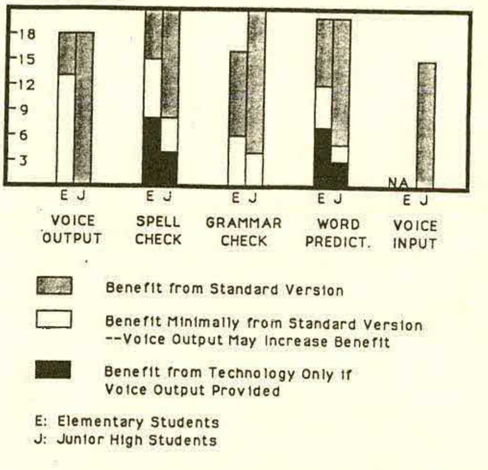

Figure 1. Students Expected To Potentially Benefit From Technology Applications

Separate bars represent elementary (E) and junior high (J) students. The students fall into three groups. First, shown in gray, are those students who can benefit from the technology as it currently exists. Next, shown in white or black are those students who would need changes made to the systems for optimum success. The students represented in white may still have minor benefits with the standard program. The students represented in black require the changes--in this case the assistance of screen reading to review option lists. Finally, those students who either could not or would choose not to use the system are represented by bars that do not extend to the top of the chart.Students who were able to successfully use word prediction technology (without voice output) were generally able to use our speech recognition system. Dictation systems require a user to be able to recognize and correct errors consistently so that words are not learned incorrectly.

The technology that we chose to test required base reading and listening skills for successful use. Students who read at or below a third grade level had difficulty using spell checking or word prediction programs unless screen reading was provided. Many students also had difficulty understanding the prompts provided by the grammar checking program. They would make the suggested change, but not know why. For these reasons, the junior high students generally had more success with these technologies.

DISCUSSION

Not all of the students were able to use the programs as they currently exist. When using voice output, many students commented that they would like to use a voice which has clearer pronunciation. For easily distractible students, the synthesizer control process needs to be more automatic. Some of these problems may be addressed by the SoundProof system which has yet to be tested. Three students also commented that although they would use screen reading to review class material, they prefer taped texts.

Spell checking programs often offer too many choices for students to decide between. Unfortunately, they also often do not offer the word which the student was trying to spell.

During the assessments, over 50% of the elementary students found themselves in a situation where the word they wanted to spell was not listed. Missing vowels and letter reversals contributed to this problem. Standard spell checking algorithms do not account for these types of errors.

Grammar checking programs also posed a difficulty. The CorrectGrammar program was chosen because, compared to the more popular Grammatix and RightWriter programs, this program had simpler dialog boxes. All three programs frequently missed grammatical errors, however, particularly homonym misuse which was common among the students.

CONCLUSIONS

The results from these computer assessments will be used to recommend equipment purchases to the school system. We expect that by using these strategies which computer technology offers, the students will be better able to compete in classes where written material in used.

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A WEARABLE COMPUTER THAT GIVES CONTEXT-SENSITIVE VERBAL GUIDANCE TO PEOPLE WITH MEMORY OR ATTENTION IMPAIRMENTS

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ABSTRACT

We have developed a wearable computer-based reminding system that is more user friendly than prior systems for activities that involve locomotion and manipulation and visual attention to the non-computer environment. Using radio and ultrasonic communication with small transponders placed on significant objects and at key locations in a building, the computer can automatically provide verbal prompts at appropriate places and times. It can serve as a cognitive prosthetic to aid memory and attention impaired users. It may also serve as a temporary training aid to reduce the tedium of training activities of daily living and vocational tasks with cognitively impaired people.

BACKGROUND

Mental retardation is estimated to affect between 1% and 3% of the United States population, depending upon how the diagnosis is defined and which experts are queried. Memory and attention deficiencies play a large role in slowing these people's acquisition of new skills. Traumatic brain injury (TBI) that impairs memory and attention capabilities affects thousands of other Americans each year. Whether from chronic retardation or recently acquired brain injury, memory deficits impair these people's ability to maintain skills over time and transfer these skills to new situations.

Many studies have shown that sequential prompts can effectively aid memory impaired people to accomplish tasks that otherwise would be beyond their capabilities. Once they learn to do either activities of daily living or job-related activities in response to the sequential prompts, then the prompting cues can gradually be "faded" to decrease a user's dependency on them. A major expense of both training using sequential prompts and later fading the prompts as learning progresses is the labor intensive nature of the training process. An instructor must be present to monitor completion of each step and prompt the client when necessary.

Use of personal computers to present sequential prompts would appear to offer one way of increasing the autonomy of memory impaired people while potentially decreasing their training costs. In past RESNA conferences, Drs. Cole, Kirsch, and Levine and others (1-3) have all reported such use of computers with clients whose memory impairments were caused by brain injury. Using custom software on standard commercial computers, the keyboard response of a client would cause the computer to prompt a client to accomplish successive sub-tasks in a well defined sequence of activities.

STATEMENT OF PROBLEM

For word processing and other computer based applications, prosthetic software running on standard computers is clearly appropriate. However, in many vocational and daily living activities a client's hands and eyes must be used for the task itself, so activating and reading from a computer become additional tasks that must be learned by a learning impaired client. In these cases, a user interface problem arises from the presumption that cognitively impaired clients are able and willing to read prompts and produce keyboard responses within the context of their other activities.

RATIONALE

Computer guidance might better be done by voice output for memory impaired clients who are doing activities that require visual attention and locomotion or manual manipulation of objects. Similarly, if the computer could automatically sense that another prompt is needed, without requiring a special button activation by the client, less cognitive burden would be placed on the computer user.

For tasks that require locomotion within a facility, it would be desirable to automatically detect whether or not progress to a goal is being made so as to help guide the client to his or her destination.

These enhancement to the computer guidance paradigm would help memory and attention impaired clients concentrate on their tasks while minimizing the cognitive burden of using computer guides.

For client safety, if the computer is easily wearable by the client and can detect that its instructions are not being followed or that the client is going towards a potentially dangerous area, it should be able to call for human assistance for its user. Finally, if the computer can be programmed to automatically help fade prompting cues, it can help reduce the costs of training people with mental retardation and rehabilitation of those with TBI.

DESIGN

To make the system easily wearable and usable, we decided to build a custom pocket-size computer. Since processing power is not an issue in this application, we selected the Motorola 68HC11 as the heart of our wearable computer. It is a single chip microcomputer that incorporates sufficient on-board program memory, time keeping and input/output capacity to minimize the need for support chips. We use standard telecommunications circuits to do real-time voice digitization and data compression for storage efficiency. A plug-in flash memory card provides the capacity to store extensive user schedules and hundreds of voice prompts. Most significantly, we have the ability to query small, external transponders to determine where the computer is in a building and whether significant objects have been manipulated on schedule or in the correct sequence.

DEVELOPMENT

The key proprietary technology in our system is the wearable computer's ability to interrogate small, remote transponders and receive information back about distance, direction and transponder state. Initially, pulse-coded infra-red (IR) light was used to communicate from the computer to the transponders. IR usage has the advantage of being virtually unregulated at power levels used for communication. However, while IR communication is effective for directed beams, such as are used in television remote controls, in our application undirected signals from our belt-worn computer depended on multiple reflections to reach their targets. Dark carpets and walls, high ceilings and very large rooms all tended to degrade system performance. Ultimately, we found that high frequency digital radio, licensed under FCC Code Part 15 regulations, was more reliable. We considered using returning radio signal strength as a means for gauging transponder distance. The vagaries of indoor radio propagation lead us to use ultrasound for transponder response.

Sound travels through air at about 1 foot per millisecond. On that time scale, radio transmission is virtually instantaneous. By timing the latency between the transmission of a radio interrogation and the arrival of ultrasonic pulses returning from a transponder, we can calculate the approximate distance from the computer to the transponder. With 2 tuned ultrasound receivers on the wearable computer separated by 3" horizontally, we can determine whether the wearer is facing toward or away from the transponder by comparing the relative reception latencies. As the average latency changes over successive transmissions, we can determine if the wearer is making steady progress toward or away from the transponder location. Finally, depending on the radio code broadcast, we can determine whether switches attached to each transponder have changed state since the last interrogation.

By programming into the computer the logical sequence of transponders that are placed in a building, the computer can iteratively interrogate the transponders (each of which has a unique digital address) and measure the distance to the nearest one(s). In use, a client's schedule is programmed together with digitally recorded voice prompts. The voice can be anonymously authoritarian, a familiar one, or even the client's own voice! Preliminary evidence suggests that the latter is especially effective.

As a user goes about his or her schedule, the computer monitors its position against a pre-programmed schedule using its measured distance from pre-placed transponders. Based on either time of day or place in a behavior sequence (as measured by transducer event switches changing state), it can automatically offer voice prompts if it detects that the user is not adhering to scheduled activities. Continued evidence of difficulty in adhering to the schedule can cause the computer to automatically radio an automatic telephone dialer to call for human assistance for the computer user.

EVALUATION

An early prototype of this system was evaluated under the supervision of Drs. Cavalier and Ferretti of the University of Delaware's Special Education Technology Group. Two subjects who had mild mental retardation were taught to do a vocational task (wiring a wall switch-plate) that required over 50 sequential steps to complete. Neither of these subjects, students at a regional vocational high school, could follow written instructions to successfully complete the task.

A special education graduate research assistant taught each subject to do each of the steps, individually, after she spoke its descriptive verbal prompt. These tasks included getting and replacing electricians' tools from a tool board on one wall of the room, getting supplies from bins on a table, and doing the installation on a vertical test board for wiring skills. Each of these three locations had transducers installed that could monitor the students' activities at that site via switches under the bins, the tool board, and behind the test board. Independently, the subjects were still unable to correctly complete the wiring task. Then, the subjects were individually introduced to the wearable computer by the graduate assistant. They were shown that as they completed steps in the wiring task, the assistant's voice would automatically prompt them to do the next step. On the first use of the computer, each student was able to follow the prompts to correctly do the 50+ steps needed to wire the switch plate. They used the computer once each, on three successive days, and continued to successfully complete the task. Each day their speed of completion improved. Finally, they were tested without the use of the computer. One student completed the task, but did some steps out of order. The other student got most of the way through, but omitted a vital step.

DISCUSSION

The evaluation of the prototype wearable prompting system showed some of its promise. The students used it willingly and were able to correctly heed its prompts on the first day they were exposed to it. The wearable computer was able to automatically give appropriate verbal sequential prompts in a timely fashion after it detected the student's location or action merited the next prompt. The subjects clearly learned the task as they were following the complex, preprogrammed sequence of computer generated verbal cues.

This and other, less formal, evaluations show that the wearable voice output computer can enable retarded students to maintain complex behavior sequences whose components have been taught by conventional means. These clients needed little prior exposure to the computer system before they could use it successfully. The experience that they get using it may help them learn the sequences so that they may ultimately not need this computer aid. Thus, the system shows promise both as a prosthetic to maintain behaviors of impaired users and as a temporary teaching aid to decrease the labor intensive process of teaching cognitively impaired users.

We have not yet explored the system's capability to increase user autonomy by allowing non-linear scheduling. In this application, any of several different activities may be permissible at any given time. Similarly, we have not tested our system's capability to automatically fade prompts. It does this by sensing if the next step in a task sequence is self-initiated without prompts. If so, it can immediately offer verbal praise and record the accomplishment to document progress.

This system is not intended to supplant human instructors of people with cognitive deficits. Rather, it is intended as a productivity aid to reduce their tedium of monitoring correct performance of recently taught skills. It is intended to allow instructors to teach more students while being on call for their students whose behaviors are being computer prompted and monitored. It may also enhance the autonomy of those cognitively impaired users who may need it as a cognitive prosthetic.

ACKNOWLEDGEMENTS

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COMPUTER RELATED EMPLOYMENT AND STUDENT TRAINING

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ABSTRACT

C.R.E.S.T. is focusing on training and employment for Special Education high school and transition students with the use of assistive technology. Students with physical and cognitive disabilities given the needed training, job seeking skills, and assistive technology. Training occurs in both classroom and on-the-job sites. An analysis of the success and failure encountered thus far is described. Evaluations on various technologies and resources are provided.

BACKGROUND

The status of special education students after leaving secondary school programs has become a national concern. Recent studies have found that these youths do not make adequate adjustments in their transition from school to adult living in the community. The current statistics on employment show that 67% of all Americans with handicaps between the ages of 16 and 64 are not working and 65% of working-age unemployed persons with disabilities say that they want to work. (Wehman et al, 1985) To alleviate these tragic statistics, the variables of secondary programs are being closely examined. A federal initiative was enacted to focus on improving the transition elements and outcomes for this unique population (Will, 1984).

OBJECTIVE

The Richmond Unified School District is conducting a job placement and training program for disabled high school students. The focus is on the use of assistive technology to enhance the job training and placement of physically and mentally disabled high school students. The overall goal of C.R.E.S.T. is to incorporate assessment and training to facilitate long-term job placement for disabled students using assistive devices and adaptations at the employment site.

APPROACH

By surveying 32 San Francisco East Bay area businesses, the most frequently used computer systems and programs were determined.

Workshops on the available assistive technology and the use of computers in the work place were provided to RUSD teachers, staff, students and parents. Also provided was instruction on computer literacy and how to incorporate the use of adaptive technology into existing curriculum.

Purchased computers and adaptive computer equipment was made available to students in job training environments either on the high school campus, the Regional Occupation Program classes, or community employment sites.

Students were recommended to the project based on their age, "job-readiness" and potential benefit from the program. A Vocational Assessment Checklist was prepared for each student to identify whether the student has been provided with the opportunity for, or has the ability to conduct job related skills in, the following areas: job exploration, job search techniques, getting a job, keeping a job, and leaving a job.

Individual assessments are conducted to determine needs for adaptations, assistive technology, and training. Job site accommodations are taken into consideration along with any modifications necessary for actual job tasks.

With every job site, an assessment specialists works with the student(s) and is responsible for the on-the-job training, assessment, data collection, and monitoring of the student's progress.

The overall goal of C.R.E.S.T. is to incorporate assessment and training to facilitate long-term job placement for disabled students using assistive devices and adaptations at the employment site. The philosophy and methods behind C.R.E.S.T. are being transplanted into the existing Transition Department to make this project one of the many facets of services provided to all Special Education students within the Richmond Unified School District.

DISCUSSION

Net findings from the business survey resulted a fundamental shift in the initial concept of C.R.E.S.T. The project originally proposed facilitation of training and job placement in computer data entry positions. However, employment trends indicated a decrease in the number of entry-level positions, a lack of computer-based jobs, prohibitive speed requirements for competitive employment for some disabled individuals. Consequently, the focus of C.R.E.S.T. was altered to include a wider range of computer "related" jobs and jobs were students needed assistive technology to complete a task (computer based or not).

Initially, the project intended to use a short period of on-the-job training to prepare the student with the necessary skills for an entry level position, and an Assessment Specialist was to conduct the training. However, we have learned that many disabled students are faced with barriers above and beyond those addressed by on-the-job training. These barriers can be generally delineated into attitudinal, independent living skills, education, and technology.

These barriers, and the methods used to overcome them, are as diverse as the personalities of the students. Early on, it was determined that some of the more severely impaired students, or students who do not have substantial family support, needed additional assistance in preparing for independent living.

Therefore, the grant employed a part-time specialist to make recommendations for curriculum changes that addressed the identified needs. The student's program was comprehensively reviewed to investigate all possible avenues for training in the use of technology and independent living skills. This person also served as a mentor for some of the disabled students enrolled on the grant.

Furthermore, to assist the students in life after school, inter-agency collaboration has become a critical component.

The training and employment sites have provided students with hands-on experience in a real life work environment. In addition to job skills, they have also learned to address issues like transportation and many other independent living skills and responsibilities. Most of all, they are learning the skills necessary to be self-advocates for independence in a society that is just beginning to acknowledge the rights of the disabled.

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PROJECTS WITH INDUSTRY: TRANSITIONING STUDENTS WITH SEVERE DISABILITIES INTO THE WORKPLACE

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ABSTRACT

Projects With Industry combines the resources of school system and area businesses to create and expand job and career options for students with severe disabilities. At the end of the first project year, 14 persons had been successfully placed in employment situations.

BACKGROUND

Making a successful transition from school to the world of work has major impact on the lives of young people with disabilities. The high unemployment rate of people with disabilities in our society suggests that training programs and service providers have not fully addressed this problem.

For many years, the Lansing School System has had an active vocational program for special education students who are physically able. However, the population of students with severe disabilities was underserved for both job training and job placement. This population included students with birth defects, traumatic injuries, health impairments, and neuromuscular disorders.

Because of their unique problems, these students posed a challenge to the professionals responsible for their vocational training and placement. Although cognitively capable of participating in work experiences, their physical concerns greatly limited their opportunities to do so. Physical management concerns were an integral part of their daily routines. Lack of adequate muscle control made jobs involving handling a variety of materials impossible. Physical and postural adaptations were necessary for these students to cope with a work environment. Impaired mobility, problems in gross and fine motor control, lack of stamina, unintelligible speech, and sensory limitations required that potential employers modify job tasks and facilities.

OBJECTIVE

Projects With Industry is a transitional program which creates and expands job and career opportunities for students with severe disabilities by combining the resources of the school with resources and businesses in the community.

APPROACH

The Projects With Industry program began October 1, 1991, funded jointly by the U.S. Department of Education, Rehabilitation Services Administration, with a 20% match from the Lansing School District.

A business advisory council comprised of representatives of labor, private industry, and individuals with disabilities was given the charge of identifying job and career availability in the community, identifying the skills necessary to perform the identified jobs, and prescribing training programs to develop those skills.

Area employers were invited by letter to participate in the project, which was described as a "federally funded program which assists young persons with disabilities in becoming competitively employed in the community." Benefits to employers included: prescreened applicants who are job-ready candidates, help with worksite modification and accessibility, PWI Job Coaches for training and post-training consisting of disability awareness, and legislative clarification on the American with Disabilities Act (ADA) was available.

Project staff consisted of Project Director, Job Coordinator Specialist, Job Coach, and Secretary. Additional substitute job coaches are added when necessary. Staff provided training in realistic work settings, and job placement and support services. When appropriate, the Project also provided for development and modification of jobs to accommodate special needs, distribution of rehabilitation technology, and modification of facilities or equipment. A state-wide assistive technology center provided consultation on the selection of adapted computer input and loan of devices for trial, on job site, use.

DISCUSSION

During the first year of Projects With Industry, 19 persons, 18 of whom had severe disabilities, were served. Major disability categories included cerebral palsy (47%) and hearing impairment (21%). At the time of project entry, 15 persons served had been unemployed 6 months or more.

Assistive technology required by project participants ranged from none to a combination of voice input and miniature keyboard for entry of data into a micro-computer.

By October 1, 1992, 14 persons had been successfully placed in employment situations.

CONCLUSION

Projects With Industry has greatly enhanced the vocational training and placement programs of the Special Education Department of the Lansing School System. Closing the gap to the goal of 100% employment for students who exit special education will be realized with the employment of a formerly underserved population.

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TRAINING TEACHERS TO USE ASSISTIVE TECHNOLOGY IN THE EDUCATION OF STUDENTS WITH DISABILITIES

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ABSTRACT

The goal of the Student Access to Technology (SAT) Project is to provide quality training for teachers, both inservice and pre-service, in the appropriate use of alternative input and output devices for computers and other technologies; making existing technology accessible and applicable for students with disabilities. Not only do students with disabilities represent an important portion of the school-age population, they are the population most likely to be positively influenced by the effective use of technology, and demonstrate the greatest need of the benefits of technology.

BACKGROUND

The Utah Educational Technology Initiative (ETI) is a state sponsored program designed to promote the use of technology in public schools in Utah. Funds are available to local school districts and state sponsored universities for the purchase of technology and applicable programs. The author applied for, and was granted a $15,000 grant for the SAT Project through the College of Education at Utah State University. The Utah Assistive Technology Program (UATP), Utah's "Tech Act" sponsored state program also has contributed $5,000 towards this project.

The project will be completed during the 1992-93 school year with information beyond what is contained in this paper available for the RESNA '93 Conference.

IMPORTANCE OF THE PROJECT

Assistive technology (AT) is redefining what is possible for children served in special education programs. AT is designed, developed and implemented for children with an increasingly wide range of cognitive and physical disabilities. AT in the classroom enables students with disabilities to be more independent, self confident, productive, and to be integrated to a greater extent in the mainstream of society (Lahm and Elting, 1989; Wilds, 1989). Bragman (1987) states that "it is the responsibility of educators to see that advanced technology is used to maximize student potential and allow the handicapped student full access to society."

Recent advances in technology and rehabilitation engineering have led to a dramatic surge of interest in the use of assistive devices, and to a proliferation in the commercial availability of equipment and devices designed for persons with disabilities. AT includes adapted toys, alternative input and output devices for computers, eating systems, powered mobility devices, augmentative communication devices and special switches. Thousands of commercially available or adapted devices and solutions, that improve a student's ability to study, learn, compete, work, and interact with family and friends, are now available.

Technological advances have had a tremendous impact on all our lives. We see, hear, write, calculate, feed and amuse ourselves daily through the use of technology. For most of us it is a convenience. However, for those with disabilities, technology is a vehicle by which many obstacles can be circumvented and disabilities overcome (Fifield, 1990). Access to technology promotes efficiency, increases accuracy, promotes student performance in the basic curriculum areas, and acts as a motivation and stimulation to learn. In particular, access to appropriate technology holds great promise for enriching educational opportunities and effecting the lives of students with disabilities (Gradel, 1990; Barker, 1990).

Technological advances also hold unique attributes for teaching students with disabilities (Lahm, 1989). Computers as well as other technology-related learning applications have expanded and enriched lives and given many children with disabilities options not imagined a decade ago (Lahm & Elting, 1989). Technological advances in speech recognition and reproduction allow greater communication and interaction for those who lack verbal skills or the physical ability to talk. Technology can be an effective tool for teaching children spoken and written language (Meyers, 1990). Individuals who cannot isolate keys on the computer can perhaps use "mice", track balls, touch screens, or even their voice for word processing, entering data, and conducting analyses.

The Utah ETI has provided technology widely across the state. It is important however, to provide educational opportunities to all of Utah's students. Although many students with disabilities will benefit from the general application of technology, many of them cannot access the technology being purchased by schools. This project proposes to make that accessibility more universal. A major emphasis of the project will be the accessibility of computers currently in the schools for students with disabilities. Teachers will be exposed to alternate input and output devices which are available for the computers students already haveand use in school libraries, computer labs and classrooms.

This project, as proposed, has the potential to impact every education major at USU as well as teachers already in the field. The UATP is requested on a regular basis to make presentations in various College of Education classes on assistive technology. This proposal would allow for this instruction to be more practical and allow pre-service professionals actual hands-on experience with assistive technology. It would also provide an additional resource for inservicing professional who apparently lack knowledge and are seeking additional information about applicable technology.

A survey of service providers in Utah, conducted in March, 1991, found that 50% of the respondents felt they didn't know enough about what technology is available to help consumers. This same survey found that 99% of the respondents felt their agency needed to learn more about technology. Those respondents included special education teachers, regular education teachers, and speech and language therapists.

OBJECTIVES

#1 Identify and prioritize the 30 most appropriate pieces of technology designed to increase the accessibility for students with disabilities to the technologies commonly found in schools.

#2 Purchase the identified technology in a form that is as portable as possible.

#3 Develop at least 20 self-directed instructional material packages to instruct teachers to use each piece of technology purchased.

#4 In at least 4 sections of SpEd 301, make presentations using the purchased technology and the instructional materials. 80% of the students in SpEd 301 will use the technology and instructional packages in a hands-on experience outside the regular class presentations as requested by course instructors.

#5 The technology and the instructional materials will be presented to at least 150 inservice teachers around the state through at least 4 conference presentations, 2 inservice workshops with UAAACT team members, having materials available at the CCCD, and having materials available through the state-wide network already established by the Utah Assistive Technology Program (UATP).

#6 Evaluate the project and prepare a final report on the effectiveness of the entire project by compiling the evaluation data collected in each phase of the project and incorporating a third-party evaluation.

METHODS

Much of the technology that is currently available is not used even if it is available in the schools. Many teachers have a very limited knowledge of technology, no experience with assistive technology, and some are even "technophobic". For these reasons, this project will develop instructional materials, designed for teachers, to accompany all technology purchased. The intent of the instruction will be for teachers to actually use the technology. Materials will be written accentuating "hands-on" experiences. All materials will also contain examples and suggestions for practical use of the technology. Field-testing and revision of all materials will be an important part of this project. Final forms of all instructional materials will be available in alternate format.

These material will be self-directed modules that use a modified direct instruction approach and include the following principles:

1. The instruction will be teacher/self-directed.
2. The instruction will be designed to induce some activity by the student.
3. Advanced organizers will be used to inform the participant what they will learn and what is expected of them.
4. The instruction will elicit overt response from the participants.
5. The participant will receive feedback on results.
6. Prompts will be used to identify critical attributes of the technology.
7. Practical application examples will be included.

The overall objective of the instruction is to provide knowledge about how the technology can be used to compensate for a disability. Instruction will incorporate the materials that accompany the technology, i.e. instructors manuals, technical manuals, owners manuals, etc.

A comprehensive selection criteria for the technology will be developed following the review of the current literature. This selection criteria will include consideration of the cost of the technology, its applicability in instructional situations, the compensation function of the technology, maintenance and durability, the necessity of prerequisite skills, and the ease of use for the students and the teachers.

The methods and activities correspond with the goals and objectives of the project. The objectives and activities are designed to meet the objective of the ETI and "prepare pre-service and inservice teachers and teacher education faculty to be more effective users of technology to enhance teaching."

DISCUSSION

The application of assistive technology for students with disabilities is an increasing important concern for all educators. With increased attention on mainstreaming, transition and universal accessibility as a result of the Americans with Disabilities Act and the Individuals with Disabilities Education Act, all teachers will need a working knowledge of AT.

This project is unique in that it is centered around the actual devices which will likely be encountered by teachers. It is anticipated that a practical, "hands-on" approach, will better prepare teachers. In addition to basic information, this approach will also instill a level of confidence and familiarity that will help guarantee success.

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A PARTNERSHIP: UNIVERSITY ELECTRICAL AND COMPUTER ENGINEERING AND SPECIAL EDUCATION

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Abstract

This paper describes an approach to develop enabling technology based on special education students' needs, integrate technological innovations into special education programming, and provide electrical and computer engineering students with practical application of textbook knowledge. A joint project between Wayne State University's College of Engineering and Wayne County Regional Educational Service Agency provided a unique blending of experiences mutually beneficial to university students and special education students and educational staff.

Background

Wayne County Regional Educational Service Agency (WC RESA) is an intermediate school district providing direct and support services to 34 local school districts, including Detroit, in southeastern Michigan. WC RESA operates five center programs for students who are severely physically, mentally and/or emotionally challenged.

Wayne State University's Department of Electrical and Computer Engineering offers a senior / first year graduate school level design course, "The Design of Enabling Technologies". While most of the students do not pursue careers in Biomedical Engineering or Rehabilitation Engineering, this course sensitizes students to the needs of disabled individuals and introduces the principles of universal design.

Objective

Through a school improvement survey process, WC RESA staff determined vocational training to be a priority school need. The main focus was increasing special education students' participation and independence in work activities. Four specific areas which could be enabled through electromechanical means were identified.

1. Students who are switch users need simple motor actions automated, such as moving items from one place to another, placing caps on items, etc.
2. Students with limited range of motion or who have limited workspace due to use of jigs need frequent replenishing of supplies and assistance removing completed work from their work space.
3. Provision of consistent, repetitive, multi-sensory feedback during training activities for students with severe cognitive impairments.
4. Provide students with severe cognitive impairments varied levels of assistance to accurately count items (i.e., for packaging jobs) or measure supplies (i.e., laundry or dishwasher soap).

Wayne State University (WSU) offers design courses to provide practical, hands-on experience with theoretical concepts. It is important to identify functional projects that are small enough to be completed by a team of two to four engineering students in a given semester.

Approach

A partnership was formalized between Wayne State University (WSU) and the Wayne County RESA. The intended outcomes of the partnership were completion of design projects for Wayne State University students and provision of customized enabling technology for special education students. Both parties acknowledged that the partnership was expected to provide a learning experience for everyone involved and that intended outcomes were not guaranteed.

Specific vocational project ideas were gathered from special education staff at four center-based school programs and one community workshop. Transdisciplinary teams of special education teachers, paraprofessionals, administrators, occupational therapists, job coaches, and speech pathologists were used during this idea formulation stage. Twenty potential project ideas were identified.

WSU offered the four credit course, "The Design of Enabling Technologies". The twenty project ideas were reviewed by the WSU professor. The professor selected six projects based upon potential meshing with design course requirements and expectations. Twelve WSU students divided into four teams. Each team chose one of the six projects based on the team members' interests and expertise.

WC RESA agreed to pay the costs for project components. Past experience by WSU indicated semester project costs typically fall between $300 - $400. An assistive technology resource person served as project coordinator; with responsibilities of compiling initial ideas, providing orientation for the university students, and handling budget issues. Individual school occupational therapists acted as project leaders at the school sites. These individuals met with the university students to detail project requirements and to address functional specifications including user needs, durability, safety, and hygienic considerations. A discussion of possible design features led to prioritizing of functional specifications.

WSU student teams developed work plans, timelines and design specifications. The students met weekly with the university professor. Contacts with school staff were frequent initially during design specification and at the end of the semester during project finalization and delivery, with minimal contacts necessary during the middle of the semester.

Results

Twelve engineering students produced four prototypes: a switch activated packaging dispenser, an assembly trainer, a dispenser for soap powders, and a switch activated turntable.

<u>Packaging Dispenser</u>
This device provides an opportunity for students who are switch users to participate in packaging jobs. A dispensing mechanism drops a specified object into a container upon switch activation. Counting of items may be controlled either by the user or automatically by the device.

<u>Assembly Trainer</u>
Visual, auditory and/or vibratory feedback prompt a student's time on-task and correct sequence of assembly or packaging jobs.

<u>Soap Dispenser</u>
The device dispenses a predetermined amount of soap powder upon switch activation. The mechanism also provides auditory prompting and verbal reinforcement.

<u>Switch Activated Turntable</u>
This switch activated turntable may be used in one of several ways. The turntable device can be set up to present only one item at a time to a student for beginning training on assembly jobs. It may be used to bring many work items to a person who has limited reach or limited workspace, thereby allowing the student to continue working for longer periods independently without restocking. Jigs may be placed on the turntable to stabilize presented items during assembly jobs for students with hemiplegia or difficulty using two hands together.

In addition, as a demonstration project, robotic arms were incorporated into the designs of the measuring dispenser and the turntable to remove parts from and load supplies. The robotic arms were on loan for one semester. The four projects listed above will remain as property of the school system. The loaner robotic arms allowed WC RESA staff to become familiar with the capabilities of robotic technology and begin to determine appropriate applications of rehabilitative robotics in special education. Please refer to a companion paper "Mechatronic Systems as Vocational Enablers for Persons with Severe Multiple Handicaps," in these proceedings, for a more detailed discussion of mechatronic system uses in vocational rehabilitation and special education.

The prototypes are in various stages of field testing at two school workshops. The community workshop setting was not used during initial field testing, but will be involved in future project activities. If the field testing uncovers the need for modifications or redesign, either WC RESA will produce version two of the product, or WSU students in a subsequent class take on the redesign and production of version two.

Discussion

This partnership is a mutually beneficial arrangement, but is possible only with substantial effort on the parts of everyone involved. For success, the special education staff must be allowed the time and flexibility in their schedules to collaborate with each other and work with the engineering students.

The completed projects provided several significant results in the special education programs.

- Increased student participation in work activities.
- A positive experience for school staff to brainstorm ideas and participate in a process which develops and creates those ideas.
- Increased awareness for special educators to consider the impact of technological innovations on student success.
- Recognizing the valuable contribution an electrical and computer expert may offer the school team.

The engineering students indicated they learned numerous lessons through participation in the design course.

- Practical application of textbook concepts.
- The importance of communications, i.e., the need to clearly understand the users needs and the ability to translate these into technical design requirements.
- An appreciation for the time necessary to integrate software and hardware systems.
- The valuable experience of the benefits and drawbacks of working with a team as preparation for future work experiences.
- The challenge of producing designs based on a consumer's capabilities and specifications when all variables are not under the students' control.

The WSU students stated that the opportunity to create a prototype which directly benefited a group of users was a reinforcing experience. As expected, this process presented occasional difficulties. Several university students found it challenging to communicate technical concepts with consumers who had relatively minimal computer expertise. Students typically underestimated the amount of time required for integration of hardware and software systems. Two prototypes were not completed within the semester timelines. Numerous problems were encountered during system integration even though separate testing of software and hardware systems had been successful.

A great deal of concern must be given to the scope of the projects and the relative strengths and capabilities of the student groups. The projects must be useful to the client, but should also be completed in one semester. The instructor must carefully monitor progress and identify potential problems. Ordering and the delivery of components must be monitored. If a vendor is slow in responding the groups must be ready with an alternative plan.

Future considerations

Several ideas are being considered to further enhance the success of this partnership.

- Field test the projects at community work sites.
- A two semester concept could allow a university team to continue this process through from concept to prototype to initial field testing and design modifications.
- Include other WSU departments, such as mechanical or industrial engineering, or perhaps even colleges other than engineering.
- Expand program to include areas other than the vocational domain and involve additional Wayne County school programs.

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MYOELECTRIC PROSTHESIS TRAINING PROGRAM: A SCHOOL BASED APPROACH

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ABSTRACT

With increasing numbers of students with physical disabilities being mainstreamed into standard public school programs, agencies providing special education diagnostic and intervention services must take lead roles in ensuring that students with disabilities are able to utilize their assistive technology devices effectively in regular classrooms. Using a case consultation model to implement intervention, this study determined that successful completion of a 10 step competency based training program in the utilization of a new myoelectric prosthesis improved overall fine motor skills of an elementary school student who received two new myoelectric prostheses between May 1988 and January 1992,

BACKGROUND

For the last eighteen years, public schools have mandated by Public Law 94-142, the Education for All Handicapped Children Act of 1975 (EHA) to place students with disabilities in the least restrictive environments. For most students with physical disabilities, the least restrictive environment is the regular classroom, but some teachers without special education training are reluctant to deal with the assistive technology devices some of these students require for life task equalization, particularly in the area of school activities.

Assistive technology, first defined in Public Law 100-407, The Technology Related Assistance for Individuals with Disabilities Act of 1988 (Tech Act), was included when EHA was reauthorized as Public Law 101-476, the Individuals with Disabilities Education Act of 1990 (IDEA). IDEA requires multidisciplinary teams to examine each student's assistive technology needs at least once per year. According to the Tech Act, a myoelectric prosthesis qualifies as an assistive technology device since this piece of equipment is used to increase, maintain, or improve functional capabilities. Few regular education teachers have knowledge of myoelectric prostheses, so the special education resource personnel (teachers, psychologists, social workers, therapists, therapy assistants, etc.) must be responsible to train regular classroom staff in basic device information including the wearing schedule, the proper functioning, the appropriate activities, the assistance needed, and the application and adjustment (1).

An effective method of transferring assistive technology information for use in the classroom environment is the case consultation model, a service in which expertise of one or more related services professionals is used to help the educational system achieve its goals and objectives for an individual student (2). The case consultation model efficiently transfers the responsibility of the student's school performance from the related services staff to the personnel in the classroom, the student's natural environmental context.

OBJECTIVE

The objective of this study was to determine whether successful completion of a competency based training program in the utilization of a new myoelectric prosthesis would improve overall fine motor skills of an elementary school student.

METHOD

This study employed a single system ABAB design with the A phase signifying baseline performance with a new myoelectric prosthesis, and the B phase indicating performance following intervention. The study, which took place between May 1988 and January 1992, examined the performance of an elementary student who received two new myoelectric prostheses during the time period.

In May 1988 JR was a four year, three month old right handed girl who was referred by a public school district for an outside occupational therapy assessment in an effort to obviate the need for a due process hearing. JR has a diagnosis of congenital amputation of her left upper extremity three inches distal to the elbow. She had been successful with the body powered hook prosthesis she received when she was 12 months old, but was having difficulty with a myoelectric prosthesis she had received in August 1987. In April 1988 the occupational therapist who worked for the district had recommended discharging JR from occupational therapy services after determining that JR was functional in school related tasks with her preferred upper extremity.

The Fine Motor Subtest of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) was selected to assess JR's fine motor performance. A standardized instrument, the BOTMP examines preferred hand and bilateral upper extremity achievement in the areas of initiation of response, school tool utilization (pencils and scissors), and manipulation skills. For each composite standard score (e.g., Fine Motor Subtest), the BOTMP utilizes normalized standard scores with a mean of 50 and a standard deviation of 10 (3). Visual inspection was used to examine the changes in fine motor performance that occurred between baseline testing (A phase) and post intervention testing (B phase) for each of the two new prostheses.

RESULTS

On May 17, 1988 JR was evaluated. Following a routine myoelectric prosthesis checkout that determined the device worked and fitted appropriately, standardized testing was performed. On the Fine Motor Subtest of the BOTMP, JR received a composite standard score of 39 that corresponds to a percentile rank of 14 and a stanine of 3. Since she performed below the average range, it was recommended that occupational therapy services provide consultation services to design a myoelectric training program and to train classroom staff and related services personnel to implement the intervention. In the multidisciplinary staffing held later that month, the school and family team decided to accept that recommendation.

A ten step myoelectric prosthesis training program, designed to be competency based, was designed for JR. The ten competencies were: 1) stringing seven round one-inch beads within 60 seconds; 2) unstringing 15 various sized and shaped beads, one at a time, within 60 seconds; 3) taking apart and stack five nesting measuring cups within 30 seconds; 4) completing a 15 item pegboard task within 90 seconds; 5) sorting a standard deck of cards into face cards and number cards within 180 seconds; 6) building a tower of eight blocks within 15 seconds; 7) sorting five pennies and five nickels into two containers within 30 seconds; 8) catching a beach ball with both hands; 9) unbuttoning three one-inch buttons within 90 seconds; and 10) cutting out a two inch square; staying within ⅜ inch of the line. Documentation consisted of a competency chart upon which each competency was written and JR's performance was recorded for each day. A competency was considered achieved when JR performed the specific competency a minimum of three consecutive days of data collection.

Four classroom and related services personnel as well as JR's parents were trained in the myoelectric prosthesis training program which was implemented in the fall of 1988. JR worked on the program under the supervision of classroom and related services staff on a daily basis. Following JR's successful completion of the 10 step myoelectric prosthesis training program, JR received weekly monitoring from related services staff and occupational therapy consultation on an as needed basis.

During the reassessment of May 2, 1989, JR scored within the average range on the Fine Motor Subtest of the BOTMP composite standard score of 56 that corresponds to a percentile rank of 72 and a stanine of 6. During her annual review JR's multidisciplinary team accepted the recommendation to continue weekly monitoring of JR's progress with her myoelectric prosthesis during the 1990 school year. On March 12, 1990 JR was reevaluated using the BOTMP Fine Motor Subtest. With composite standard score of 67 (corresponding to a percentile rank of 95 and a stanine of 8), JR showed above average performance in fine motor skills. However, during this assessment it was noted that JR had outgrown her myoelectric prosthesis: the socket was causing irritation and the length of the device and hand size were visibly smaller than JR's right upper extremity.

JR received a new myoelectric prosthesis on August 23, 1990. Following a routine myoelectric prosthesis checkout that determined the new device worked and fitted appropriately, standardized testing was performed on September 6, 1990. At this time JR scored below average on the BOTMP Fine Motor Subtest with composite standard score 41 that corresponds to a percentile rank of 18 and a stanine of 3. The same myoelectric prosthesis training program was implemented and then discontinued when JR had successfully completed the ten competencies.

Weekly monitoring continued, but formal testing did not occur in 1991 as the occupational therapy prescription had expired and was not renewed for the school year. On January 23, 1992 JR was reevaluated and performed above the average range on the Fine Motor Subtest of the BOTMP with a composite standard score of 77 (corresponding to a percentile rank of 99+ and a stanine of 9). At that time a multidisciplinary staffing approved the recommendation that JR be discontinued from occupational therapy consultation. Her parents were advised to refer JR for a new occupational therapy assessment when she receives a new prosthesis.

Visual inspection of Figure 1 shows the differences between JR's below average fine motor performance during the A phases that signify baseline performance with each new myoelectric prosthesis, and JR's average and above average fine motor performance on the B phases which indicate performance following intervention. In the case of the first prosthesis, comparing JR's baseline performance with the two subsequent tests, she showed a 17 standard score point increase from the A phase and to the first testing of the B phase (a 12 month time period) and a 28 standard score point improvement when comparing the A phase with her performance during the second testing of the B phase (a 22 month period of time). Improvement in standard score points is also evident after the delivery of the second prosthesis: JR showed a 36 point change from A phase to B phase over a period of 16 months.

DISCUSSION

The results of this study suggest that a case consultation model used to implement intervention was appropriate in assisting JR to become effective with each new myoelectric prosthesis. Additionally, the results of this study suggest that the competency based myoelectric prosthesis training program worked twice for JR. While the myoelectric prosthesis replaced JR's nonpreferred upper extremity, her overall fine motor skills improved after successful completion of the 10 step program. However, there are limitations. One limitation is related to the time intervals of testing and duration required for successful completion of the training program. While the time intervals followed natural patterns (schedules for testing and retesting, and the length of time JR needed to complete the competencies successfully each time), from a pure research standpoint, the variations in timing were not ideal. Another limitation is related to the external validity of the study: since JR is a single subject, generalization of the results of this study cannot be assumed and replication of these findings is needed before the results can be generalized.

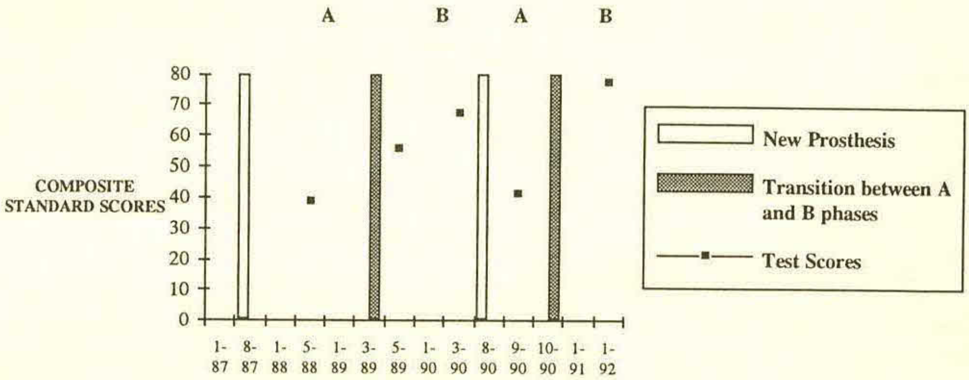

FIGURE 1: Composite standard score performance on the Fine Motor Subtest of the BOTMP during baseline periods (A) and following intervention periods (B).

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The Use of an Intelligent Cognitive Aid to Facilitate the Self-Management of Vocational Skills by High School Students With Severe Learning Disabilities

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Abstract

Students with cognitive disabilities often have difficulty monitoring and regulating their use of task-specific skills. This lack of self-management skills adversely impacts their transition to more normalized environments, such as school, work, and the community. Recent research shows that directly teaching self-management skills holds considerable promise for improving the functioning of these students. The current training regimens, however, require supervision by teachers to prompt use of the self-management skills. This study investigated the utility of an intelligent cognitive aid in reducing this need for external supervision and assisting students in self-managing their performance on vocational tasks. Results demonstrated greater independence and accuracy by both students when using the cognitive aid. Implications of these findings are presented.

Background

The transition from school to the workplace continues to be one of the most pressing problems facing America's adolescents with disabilities (8). Data on their high school performance engender little optimism about the career prospects for students with disabilities. Twenty-two percent of students with disabilities dropped out of school between their sophomore and senior years and only 29% participated in vocational education programs (7). The smooth transition of students with disabilities from school to work is exacerbated by their excessive dependence upon external agents for structuring settings, monitoring behavior against performance standards, and consequating behavioral outcomes (4). Implicit in the principle of normalization that underlies the transition process, and explicit in its "least restrictive" implementation, is that people with disabilities will become less dependent upon highly structured learning programs and become increasingly self-regulating.

Until recently, the transfer of behavioral control to the student was seen solely as a matter of gradually fading the external controls and assistance provided by structured educational programs. Students were rarely taught actual self-management skills. Self-management typically involves a sequence of mental and behavioral processes that is initiated by a person to achieve a goal that has been set by that person or some other agent (2). There has been a recent upsurge of interest in the benefits of teaching the self-management of academic and vocational skills to people with disabilities (2, 5). One of the principal goals of this work has been to increase the productivity of workers with disabilities because low productivity is most often identified as the reason for being fired (6).

In these studies, however, it often has been necessary for supervisors to monitor and prompt workers with disabilities to employ their newly-acquired self-management skills (2). This reliance on other persons manifests a quite limited definition of *self*-management and an overly qualified notion of independence. Intelligent technologies now exist that offer unprecedented possibilities for significantly reducing the worker's need for constant supervision by other persons in the performance of these skills and for facilitating the transition to completely internalized self-management.

Research Questions

The goal of this pilot study was to evaluate the utility of an intelligent cognitive aid in assisting high school students with severe learning disabilities to self-manage their performance of vocational skills that were originally acquired under human supervision. Our principal objective was to investigate the amount of human supervision that was required both with and without the use of the cognitive aid. We also sought to determine the accuracy of task performance with and without the use of the cognitive aid.

Method

Subjects. Two students, one female and the other male, participated in the evaluation study. They were in the 9th grade at a vocational-technical high school in New Castle County, Delaware. Both were diagnosed as having severe learning disabilities based on a severe discrepancy between general intellectual aptitude and achievement in the classroom. The female student was 16.7 years of age, attained a Full Scale IQ score of 80, and performed at or below the fifth grade level in spelling, reading, and mathematics on standardized achievement tests. The male student was 17.3 years of age, had a Full Scale IQ of 85, and scored at or below the fourth grade level in spelling, reading, and mathematics. Both students were reported by teachers to have memory difficulties in performing academic tasks.

Equipment. The cognitive aid is a portable remind-and-guide device, developed by AugmenTech, Inc. of Pittsburgh, PA. It is comprised of a belt-worn microprocessor unit (including miniature radio transmitter, ultrasonic sensors, and speech output capability) and a variable number of miniature transponders that can be attached to significant components of the vocational task or items in the student's environment. The cognitive aid can guide a student to objects and locations on student demand or automatically cue the student at pre-specified times. It can orally instruct a student about component steps to be performed and on demand can remind the student about the goal of an ongoing activity. An important feature of the aid is its ability to monitor under some conditions the student's compliance with the instructional prompts. The aid also creates an electronic record of the movement of the student. The hardware specifications of the device have been reported previously (3).

Criterion Task. The criterion task was adapted from a skill taught in the electrical maintenance shop at the vocational-technical high school. A student was required to wire a switch box to complete an electrical circuit to a low-voltage light bulb. There was no risk to students because a 9-volt power source was used and the flow of electricity was always controlled by the teacher. In this task, students were also required to move back and forth among a table with a board that contained tools, a desk that contained materials, and a board at which the wiring task was performed. Therefore, the criterion task was comprised of navigational and assembly steps. In total, the task consisted of 47 component steps.

Procedure: Acquisition Under Human Supervision. In the basic acquisition condition, a teacher followed a prescribed training protocol to teach the students the individual steps of the electrical wiring task. Instruction began by teaching students to identify the 17 items that were used in the criterion task. The teacher labelled each item and then asked the student to point to the object that corresponded to the label. After identifying each item, the teacher then labelled each item in random order and asked the student to point to the corresponding item. Both subjects were perfectly accurate in identifying items on the first opportunity.

After completing item identification training, students were taught to perform the electrical wiring task. In this condition, the teacher delivered a series of instructional prompts necessary for task completion using the System of Least Prompts (1). The criterion for success was the successful completion of each individual step of the task, rather than completion of the whole task. Students were given prompts that were increasingly explicit until they correctly performed the step.

Four levels of prompts were used: (a) *Self-Initiation* - the student perfored the step without prompts or assistance from the teacher; (b) *Vocal Prompt* - the teacher provided an oral prompt to the student to perform the actions that comprised the step; (c) *Modelling Prompt* - the teacher performed the step while delivering the oral prompt; the student then performed the actions that comprised the step; and (d) *Physical Prompt* - the teacher physically guided the student through the actions that comprised the step while delivering the oral prompt. During this phase, we recorded the number and kinds of prompts that were needed to ensure the correct performance of each step.

Procedure: Maintenance Under the Supervision of the Cognitive Aid. In the maintenance condition, the cognitive aid delivered oral prompts to perform actions corresponding to the steps of the task. Approximately three seconds after a student's correct performance of a step, the cognitive aid delivered an oral prompt to perform the next step. The device "knew" that a step had been performed correctly in one of two ways: (a) the environment had been configured such that completion of the step would be detected by a switch closure that communicated wirelessly with the device, or (b) a research assistant pressed a switch that signalled to the device correct performance of those steps that could not be detected by the physical environment. If a student failed to respond to an oral prompt, the teacher intervened by either modelling the correct action or physically prompting the student. At each step, students could self-initiate the actions corresponding to each step. During this condition, we recorded the number and kinds of prompts that were required for the correct performance of each step. We were especially interested to see if the cognitive aid reduced students' reliance on human supervision.

Results

Student 1 (female). During the acquisition condition, the student responded correctly to oral prompts for 42 (89%) of the 47 component steps. The student required modelling from the teacher on 2 (4%) of the steps and self-initiated the correct action on 3 (6%) of the steps. Thus, human intervention was required for the correct performance of 44 (94%) of the component steps. In nearly all of these cases, an oral prompt was sufficient to ensure correct performance.

During the maintenance condition, the student correctly self-initiated 5 (11%) of the 47 component steps and needed oral prompts from the cognitive aid on 42 (89%) of the steps. Modelling or physical prompting was never required during maintenance. More importantly, direct human intervention was not required to ensure correct performance by this student.

Student 2 (male). During acquisition, the student responded correctly to oral prompts for 40 (85%) of the 47 component steps, needed modelling on 1 (2%) step, and self-initiated 6 (13%) of the steps. This student seemed to have a better intuitive understanding of the task requirements but still required oral prompting for most steps of the task.

During maintenance, the student correctly self-initiated 9 (19%) of the 47 component steps and needed oral prompts from the cognitive aid for 36 (77%) of the steps. The student successfully completed the task without performing 2 intermediate steps of the task. This occurred because he retrieved all the tools for the wiring task during one visit to the tool board. As during acquisition, this student showed considerable insight into the task. However, he still required oral prompting from the cognitive aid to correctly perform most of the steps.

Anecdotal Observations. After completing the acquisition and maintenance conditions of the evaluation protocol, we permitted both students an opportunity to perform the task without any supervision from a person or the device. The male student performed the task quickly and accurately without any intervention. The female student completed all but two of the steps correctly. As a result of these errors, the electrical circuit was not completed. These errors were not made when the student used the cognitive aid.

Discussion

The use of the cognitive aid by two students with severe learning disabilities reduced their dependence on external supervisors for prompting the self-management of vocational skills. They performed with greater independence and accuracy. This was accomplished by having the cognitive aid (a) monitor the student's spatial position with respect to the locations at which various tasks were to be performed, (b) monitor the student's execution of the tasks, (c) issue prompts about the requirements associated with these locations and tasks when appropriate, and (d) give feedback on his/her performance.

The results of this pilot study are encouraging for the further development and application of cognitive prosthetic aids for students experiencing deficits in memory and self-management skills. This includes not only students with severe learning disabilities, but also students with mental retardation. The anecdotal observations mentioned above anticipate the two major projected applications of such cognitive aids: with students who can benefit from a training phase of intermediate assistance (i.e., from a device) en route to completely-unaided self-management and with students who need continued assistance from a cognitive aid to function independently. With either population, the objectives of lessening students' dependence on external supervision and improving their productivity will be facilitated. This in turn should advance the ultimate goals of successful transition from school to work and full inclusion in society.

In conclusion, the evidence obtained in this pilot study suggests that the cognitive aid is useful in assisting students to self-manage vocational skills originally acquired under human supervision. Virtually no direct human prompting was required when the device was used. Future evaluations should determine the appropriateness of the device for maintaining the performance of students who are more severely disabled and, with extended use, for facilitating their complete internalization of the self-management process.

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SIG-07
Technology Transfer

ASSISTIVE DEVICES IN A CAPSTONE DESIGN COURSE

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ABSTRACT

A new emphasis on designing assistive devices for disabled persons has strengthened a traditional undergraduate design curriculum in Mechanical Engineering. Mechanical and electro-mechanical assistive devices have provided an excellent source of "real-world" problems to challenge and motivate student design teams. These problems have proven to be very effective in teaching design *methodology* and providing an industrial design *experience* in a two-semester senior capstone design course sequence. Approximately thirty such projects have been completed over the past three years. Among these, several have been selected for patenting and possible commercialization with the goal of providing a funding mechanism for future student projects. Due to the success of this program, a certificate program in rehabilitation engineering is planned.

BACKGROUND

With no major industries to support its design program, the Department of Mechanical Engineering has been assisted by the Office of Technology Transfer and Economic Development (OTTED) to establish a local clientele among private and governmental rehabilitation agencies including the Rehabilitation Hospital of the Pacific (REHAB Hospital), Hawaii Assistive Technology Services, and the State of Hawaii Vocational Rehabilitation Division. These "clients" have provided design projects and funding to pay for materials to construct working prototypes.

OBJECTIVE

The American Accreditation Board for Engineering and Technology (ABET) requires that all accredited engineering programs provide a meaningful design experience in a senior capstone design course. In response to ABET's guidelines on this matter, the Department of Mechanical Engineering has made substantial progress in meeting this objective. The senior design capstone course has evolved from a one-semester course where mockups of a paper design were created to a two-semester sequence where working prototypes are manufactured for clients. In this process, students experience the design process in realistic circumstances.

METHOD

A two-semester design course sequence is now required for all seniors. Two instructors are involved in teaching this sequence beginning in alternate semesters. Thus, students can enroll in any semester, but must continue their project over two consecutive semesters. Also, each instructor works with the same group of students for the two courses. A similar approach to teaching design is used at the University of Delaware [1].

The first course, **Engineering Design Methodology**, formally introduces students to the design *process*. Lectures on the methodology of design are given concurrently with a design project. With this approach, abstract design philosophies can be demonstrated realistically with a parallel design *experience*. Lecture topics include conceptual design (creative synthesis), decision making, concurrent engineering, selection of materials, manufacturability, quality control, economic decision making, computer-aided engineering (solid modeling and finite element analysis), planning and scheduling, written and oral presentations, and engineering ethics.

At the beginning of the first semester, the class is given orientation lectures by physical and occupational therapists and a field trip to the REHAB Hospital. Following this brief introduction to the rehabilitation professions, written descriptions of needed assistive devices are submitted to the class for consideration. These descriptions address project needs (constraints) and wants (optional) which are expressed in the requestor's own technical or nontechnical language. Some project ideas are generic and some are specific to individual needs. Students must interpret these descriptions in terms of engineering requirements and decide which projects are of the most interest. Each student lists three project choices from which the instructor tries to organize design teams of two to four students. Every effort is made to place students on their preferred project.

The students interact with the rehabilitation staff and patients to gain a clear understanding of the problem and then produce a report defining their own interpretation of the project in terms of the required functionality, safety and cost of the device. Once the problem has been clearly stated, the student design teams conduct a literature and product survey to obtain information needed for the design effort. Each team generates between ten and twenty preliminary design concepts, from which the best three concepts are selected. These are then discussed with the client and subjected to engineering and economic analyses. The final design concept is selected based on technical merit and cost. A final written report is submitted to the instructor, and a written proposal and oral presentation of the final design concept is made to the client for funding consideration. The proposal consists of a technical description, budget and schedule to complete a working prototype. An important feature of this proposal is the graphical presentation of the design concept as a three-dimensional solid model defining the assembled device and its component parts as shown in Figures 1 and 2 [2, 3]. A computer-generated solid model can relate the design concept to the client readily and is a very effective tool to describe how it functions. Figure 1 depicts a battery-powered scooter intended as a training device to teach disabled children how to operate an electric wheelchair. The problem statement provided by the client states that the

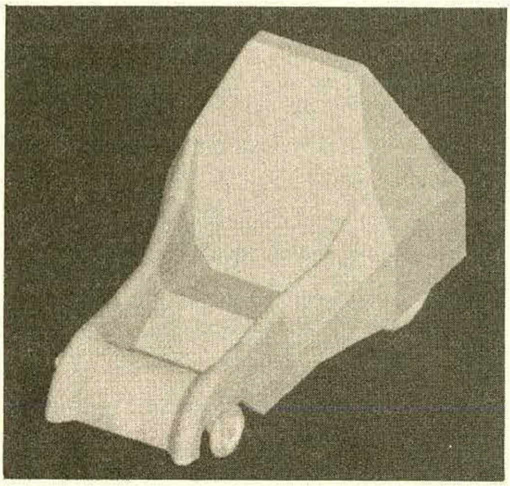

Figure 1. Training Scooter

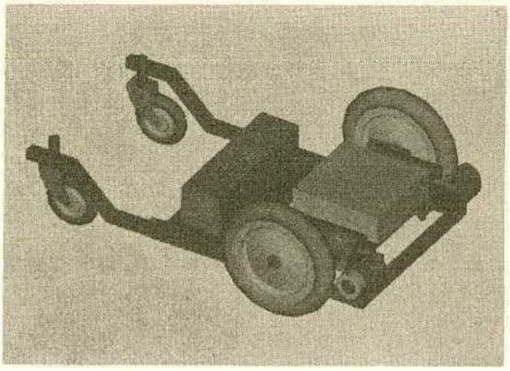

Figure 2. Scooter Chassis

scooter must fully support the child in a slightly reclined and secure position. The solid model gives the student design team and the client an excellent focal point to exchange ideas about the shape of the molded shell. Another design objective is that the scooter should be able to turn away from obstacles in a small maneuvering space. In Figure 2, the students can easily demonstrate how the vehicle is propelled with a two-wheel drive system having a small turning radius. It is possible also to use animation at a computer workstation to illustrate the operation of mechanisms.

The design concept proposed in the first semester is developed in the second course, **Design Project**. The critical factor, of course, is the availability of funding. The client has the opportunity to study the proposal between semesters and writes a technical assessment of the proposal and funding level. A project that does not obtain funding from the client can obtain limited support from the ME Department to construct a scale model of the prototype. In this way, the continuity of the academic objectives is preserved.

Milestones for the second course include project scheduling, detailed engineering analyses, checking geometric tolerances to confirm compatible assembly of all structures and components, production of shop and assembly drawings, supervising prototype construction, prototype assembly, performance evaluation, redesign, and a written report of the year-long design effort. Finally, the students compete in the Francis R. Montgomery design competition sponsored by the local section of the American Society of Mechanical Engineers. This competition includes an oral presentation before a panel of local practicing engineers and a poster session where judges conduct a hands-on evaluation of the design projects.

A growing design library is available for student use. The most important of these are design codes, periodicals, engineering handbooks, a product source encyclopedia, catalogs of materials and components, and numerous rehabilitation equipment catalogs.

RESULTS

Table 1 lists student projects completed since this new design program began. Students have benefitted by *experiencing* the design process with realistic projects. Although most prototypes would require redesign to be put into actual service, a few of the projects possess the simplicity and usefulness to make them candidates for future commercialization. To date, two of these projects have been identified for further development and patenting by the university. These are the sliding tub/shower bench shown in Figure 3 and a page turner. Projects receiving funding are given to the client for evaluation and use upon signing a release of liability. Many of these projects have inspired follow-on design efforts aimed at bringing viable concepts to a practical conclusion.

DISCUSSION

Designing assistive devices for the disabled has strengthened teaching senior design in Mechanical Engineering. In a locality where industrial support is unavailable, student projects had been limited to paper reports and mockups or crude prototypes to demonstrate design concepts. Students often would spend too much time engaged in fitting their own poorly fabricated parts. By gaining the support of local rehabilitation agencies, it has become possible for students to carry out projects of real-world

Table 1. Student Designed Assistive Devices

Mobility

- Hemiplegic steerable wheelchair
- High-low tilting wheelchair seat
- Adjustable weight-bearing walker
- All-terrain wheelchair tire
- Battery-powered scooter

Transfer

- Universal transfer device (five concepts)
- Portable wheelchair lift for van
- Wheelchair lift for private home
- Tub/Shower rolling transfer bench
- Conveyor belt chair-bed transfer bench

Self-Help

- Electrical and mechanical reachers (five concepts)
- Writing tablet for visually impaired
- Page turners (four concepts)
- Wheelchair umbrella (three concepts)
- Portable vertical storage system (two concepts)
- Artist easel
- Wheelchair fold-away writing desk
- Book retriever for library stacks (two concepts)
- Trunk lift
- Computer diskette changer
- Adjustable computer workstation support system
- Arm exerciser

Figure 3. Sliding Tub/Shower Bench

problems for real clients that result in working prototypes manufactured by professional machinists. This approach has proved to be an excellent vehicle to teach design and has challenged and motivated students to perform their best.

The success of this new program is manifold. Students receive a design education which better prepares them for industry, clients obtain a prototype for only the cost of materials, and technology developed in the classroom will be transferred to industry resulting in additional financial support for the design program. This approach has been so well received by students and faculty, a Rehabilitation Engineering certificate program in Mechanical Engineering is planned.

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Appropriate Assistive Technology: The PATH Program in Brazil

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Abstract

This paper will summarize the results of a study visit to Brazil from mid-April to mid-May, 1993 under the sponsorship of the World Institute on Disability. The study will analyze results of the PATH program, as a case study of an appropriate technology, community based rehabilitation effort which has had centralized support from the Partners of the Americas, a sister-state organization. The principal focus of the study will be on the achievements of the program in the area of assistive technology.

Background

Persons with disabilities in developing countries have a need for assistive technology which is frequently not met by devices from developed countries, due to cost, energy supply, maintenance, or the work or home environment. Throughout the world, however, there are individuals and groups who are developing assistive technology which "works" in their environment. The issue is not "high tech" or "low tech", but the "right tech." Unfortunately, many of the appropriate technology efforts remain unknown outside a small geographic area.

One of the few large-scale efforts to encourage and support appropriate assistive technology was the PATH program (Partners Appropriate Technology for the Handicapped) of the Partners of the Americas, a volunteer sister-state organization. Because of its somewhat unique nature in supporting local efforts through an international program, it would be instructive to study some of the achievements of PATH. Appropriate assistive technology initiatives in developing countries tend to be spontaneous and unplanned. By contrast, the PATH program was a systematic, programmatic initiative. This is a feature of PATH which make the analysis of the potential and limitations of such an approach so important.

The PATH program of the Partners of the Americas is one of the few examples of a program to systematically identify, stimulate and support appropriate technology efforts throughout the hemisphere. Brazil is the country with the greatest number of Partners chapters in Latin America. The PATH program in Brazil thus represents a unique opportunity to see a wide variety of assistive technology projects as they were conceived and implemented in different parts of a diverse country.

Objective

A one-month visit does not permit an exhaustive study of all that PATH accomplished in Brazil. The goal of this study is not to perform a complete evaluation of PATH, but rather to collect information about a small number of recognized successes.

Method/Approach

Four PATH projects will be visited in different parts of Brazil. The basic information to be sought is: the specific need or problem which the project addresses; the devices or interventions which have been tried; the processes by which the projects were developed, the involvement of persons with disabilities; and the results. A series of meetings will be held with project staff, clients, members of the community and local service providers.

Results

Exemplary products and practices, especially those which are unique or which are potentially transferable, are the results which will be sought. These include devices, forms of organization, and mechanisms for collaboration.

Discussion

Discussion will focus on the potential of PATH-like approaches for linking local, community efforts with international cooperative networks. Successes and difficulties encountered by local PATH, as well as alternative forms of action, will be discussed.

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A COLLABORATIVE MODEL FOR TECHNOLOGY EVALUATION AND TRANSFER

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ABSTRACT

The literature on technology evaluation and transfer for assistive devices demonstrates the need for a collaborative model process involving a partnership between the three essential participants: research centers for technical evaluations, businesses for marketing and sales, and consumers for conducting user evaluations.

STATEMENT OF THE PROBLEM

The assistive device marketplace is a difficult environment for both device producers and device consumers. Despite the presence of many assistive devices, providers and consumers operate in an inefficient and often precarious marketplace. The findings of the U.S. Congress summarizes the marketplace problems: "Many individuals with disabilities do not have access to the assistive technology devices and assistive services that such individuals need to function in society commensurate with their abilities [at the same time] marketers perceive insufficient incentives for the commercial pursuit of the application of technology devices to meet the needs of individuals with disabilities."[1]

The Electronic Industries Foundation's Rehabilitation Engineering Center (REC), organized marketplace problems under three areas: a) Identification - providers have difficulty identifying consumers, and consumers have difficulty finding the provider's devices. b) Selection: Providers lack enough knowledge about the needs of consumers to produce and distribute more appropriate assistive devices, and consumers lack enough knowledge about the device's capabilities to choose optimally. c) Financing: Providers face a relatively small and specialized group of consumers, who typically have limited resources, and consumers typically have limited resources and lack knowledge of programs providing funding support.[2 3] How can the technology evaluation and transfer process be improved to mitigate these marketplace problems?

A. The Role of Research Centers

Research centers are engaged in device development, evaluation and technology transfer. The REC at Rancho Los Amigos Medical Center found that a majority of research centers surveyed cited commercialization as a factor considered in selecting research projects and a major factor in selecting development projects.[4]

The National Rehabilitation Hospital's REC conducts comparative evaluations of assistive devices with ECRI, a nonprofit company specializing in the evaluation of medical and health care technology. Their evaluation process has three stages: a) Literature Review - searching for existing standards and previous reports on the device's technical performance; b) Protocol Development - developing new or adapting existing methods; c) Product Testing - evaluating three attributes of the device: performance, safety and ease of use.[5 6 7]

Research centers also fulfill the critical function of documenting the technology evaluation and transfer process, and disseminating that information to practitioners in the field. Most of the literature cited in this paper was generated by research centers

B. The Role of Consumers

Basing consumer evaluations on criteria that reflects their practical needs as end users, is more effective and informative than using criteria established for technical evaluations. One study found that experienced users relied on four key criteria when evaluating assistive devices -- regardless of the device involved: a) Effectiveness - the level at which the device's functions improve the consumer's ability to perform activities of daily living, including the consumer's perception of functional capability and independence; b) Affordability - the costs associated with the device's purchase, maintenance and repair, as compared to the consumer's discretionary income; c) Operability - the ease with which the consumer is able to start-up, control and use the device for desired purposes. Operability includes controls, displays and instructions; d) Dependability - the device's ability to continually function under all reasonable conditions and circumstances of use.[8]

The context of device use is also important to consumer's evaluation criteria. One study compared evaluations for devices used in work settings with evaluations of devices used in activities of daily living.[9] The two groups agreed that mobility aids were the most important devices. Beyond that, the work group valued devices that were durable, had a pleasing appearance, made the user proud to operate them, and that functioned well with other devices. This work group looked for features of sturdiness, efficient operation and durability in new devices. In contrast, the group considering devices for independent living valued convenience, comfort and ease of use. They looked most for sturdiness, simplicity and functionality when selecting new devices.

Thus, consumers bring their own perspective to the evaluation process, a perspective that may be quite different -- and arguably more appropriate -- than researcher's criteria for technical evaluations.

C. The Role of Business

Several studies report the problems and pitfalls inherent in commercializing new products, particularly involving issues of intellectual ownership and shared investment. These reports help document the process so that others may avoid the problems.[10 11] Their recommendations are summarized in six points: a) The technology transfer process is largely driven by manufacturer considerations, so potential manufacturers should get early and frequent looks at outside designs. The technical research and development agency must share information on products under development, given the appropriate protections for disclosure. b) Establish effective communication outlining each partners needs and requirements. The overt action of establishing the partnership presents the perfect opportunity to define and articulate each partner's role and responsibility. c) Develop solid business, legal, and financial arrangements. The business entity has a primary mission to establish solid business plans, with the requisite legal and financial arrangements, given oversight and input by the partner's legal counsel.
d) Completion of comprehensive market survey. The business partner performs the requisite market analysis to quantify the expected demand, while the community-based agency conducts the user trials to provide a qualitative sense of the device's value to consumers.
e) Manufacturer needs to know time involved in fabricating design prototypes. The technology transfer partnership should assume the cost of fabricating "reduced to practice" prototypes, through program funds or through external support for a particular device.
f) Develop specific guidelines for roles and responsibilities of staff. These roles and responsibilities must be defined within and between the partner agencies.

The business community addresses the mechanics of production, marketing and sales, and financial considerations, in the evaluation and transfer process. Essential issues for eventual commercialization.

APPROACH: A Collaborative Model

An article by Mann argues that a major impediment is the absence of a clearly defined and comprehensive service delivery model.[12] For example, consumers acquire devices directly, clinicians prescribe devices in service facilities, and community agencies provide guidance in the selection process. Each of these models serves a valuable purpose, but none is broad enough to reach the entire population of persons with disabilities. A new, more inclusive model is needed, to integrate the available resources both vertically or horizontally.

The successful technology evaluation and transfer process must include all three of these essential participants: consumers, researchers and businesses. Ideally, the effort should be directed by the end users -- the consumers -- with direct and continuing support from research centers (technical expertise) and the business community (marketing and selling expertise).

The notion of a collaborative model for technology evaluation and transfer, based on a partnership structure, is derived from the principle of Participatory Action Research (PAR), an accepted strategy for conducting activities in organizations that involve both theory and practice. The NIDRR is currently developing a policy called Constituency Oriented Research and Dissemination (CORD), based on the PAR principles. PAR, by definition, involves the practitioners (users, consumers, caregivers and service providers) in the entire research process, from the project's initial design, through the data collection, analysis, decisions and finally the actions resulting from the research.[13]

The Electronic Industries Foundation REC's model of technology transfer shows the relationships of research and development, manufacturing and marketing, and the evaluation of products.[14] This model reinforces the value of PAR principles to assistive devices by including researchers that develop and test, businesses that market and sell, and consumers that evaluate and purchase.

IMPLICATIONS AND DISCUSSION

A collaborative process involving persons with disabilities -- with full support in technical areas from a research center and in marketing areas from the business community, offers a fundamentally different set of opportunities for training and employment, provides a role model for persons in the community, and directly serves the needs of consumers by developing new assistive devices. Such a process presents a real opportunity for consumers to pursue new business opportunities by commercializing useful devices.

This collaborative model process could serve as a model of self-empowerment. Self-employment represents the highest form of empowerment -- empowerment embodied in the concept of "inclusion." The term empowerment typically means consumer's participating in existing systems of training, education or employment opportunities. However, these existing programs more accurately embody the concepts of "integration" and "mainstreaming" -- they constrain the consumer to the limits imposed by existing systems. In contrast, the concept of "inclusion" changes the focus to a vision of new systems and different approaches. As Berko (1992) states: "Inclusion lies at the heart of the true community."[15]

A collaborative process is also important to future success in a changing marketplace. The National Council on Disability recently completed a major study, "The Financing of Assistive Technology Devices and Services for Individuals with Disabilities."[16] The report contains sixteen policy recommendations which would implement statutory authority to coordinate service delivery, and require reimbursement for devices and services from private health insurers. They would create financial incentives for private industry to invest in the assistive technology marketplace, establish universal design guidelines, and collect the kinds of information on assistive device needs and use that aids market analysis. The expected increase in market activity from the combined effects of these recommendations, will facilitate and the implementation of collaborative models for technology evaluation and transfer.

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WORKSTATION ROBOTICS:
A Pilot Study of a Desktop Vocational Assistant Robot

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ABSTRACT

Robotic aids can serve to restore manipulation abilities and improve the quality of life for persons with severe mobility impairments. A major challenge has been making this technology functional, practical, and affordable for the end-user. A technology transfer process is presently underway that will validate the safety, reliability, and effectiveness of a Desktop Vocational Assistant Robot (DeVAR™) system. The purpose for developing the DeVAR workstation was to provide persons with severe disabilities a measure of vocational independence. Through voice recognition and preprogrammed tasks, the user commands a PUMA 260(TM) robotic arm to manipulate objects within the workstation envelope. This paper discusses the pilot study and technology transfer process of the DeVAR system.

BACKGROUND

Robotics technology appears to be in a developmental stage similar to that of business computers in the early 1960's (1). Industrial robots are constantly gaining advanced language and mobility resulting in greater commercial availability. The application of robotic devices has pervaded the health and human services field giving rise to the area of rehabilitation robotics. Computer-based robotic manipulators can provide persons with bilateral upper extremity dysfunctions an interactive aid for performing personal and vocational activities. By replacing or augmenting a person's manipulation skills, the robotic aid can enhance their quality of life by decreasing dependence on personal attendant care, improving self-esteem, promoting mental stimulation, and allowing greater mastery of the physical environment.

Rehabilitation robotics can be divided into two main categories: workstation (fixed-location) and mobile (portable) systems. This paper focuses on a workstation-based manipulator intended for use by persons with severe motor impairments within a vocational environment. In the past, employment opportunities for these individuals were extremely limited. Today's electronic technologies have created a shift in the job market that is evidenced by the influx of information-processing professions. Coupled with the passage of the Americans with Disabilities Act, this movement towards a more information-intensive job market has provided the impetus for employment of persons with severe disabilities. Access to appropriate assistive technology and training, allows these individuals to become effective and productive members of the workforce. Additionally, spinal cord injury (SCI) research has shown that increased client involvement in purposeful activity enhances personal health and increases longevity (2,3).

SYSTEM DESCRIPTION

The Palo Alto VA Rehabilitation Research & Development (Rehab R&D) Center, in collaboration with Stanford University's School of Engineering, developed a Desktop Vocational Assistant Robot (DeVAR) system. The DeVAR system utilizes a voice recognition system thus allowing persons with severe physical impairments to control a robotic arm and manipulate objects within the workstation envelope. The manipulation capability is built around a PUMA-260 robot arm with a modified Otto-Bock Greifer(TM) prosthetic hand as the gripper. The robotic arm is suspended on a four foot overhead track located above a four foot by three foot main worksurface. This main worksurface is flanked by two side surfaces to form a "U" shaped workstation for the user. The track allows the robot to access overhead shelving and side work- surfaces.

A Compaq computer is used as the high-level robot controller. A Macintosh Classic serves as the user's application computer and is separate from the robot controller to clearly delineate user and robot tasks. As a backup control method, the user can use the Macintosh to send robot commands. An X-10 environmental control unit permits the user to operate the lights, Macintosh, and a call-help module.

The DeVAR utilizes preprogrammed, computer-controlled movements to execute specific tasks that the user initiates through robot task commands. The workstation is arranged in a predetermined fashion with all peripheral equipment positioned in specific locations. The system is designed to blend in with existing office furniture

Since the robot maneuvers close to the operator's head, safety is of the utmost importance. For this reason the following features have been built into the system:

1) operation at relatively slow speeds;
2) a lightweight (15 pounds) mechanical arm with a limited force level of five pounds; and

3) three methods by which the user can stop the arm (giving the command "stop", making a loud noise, or hitting an emergency stop switch mounted near the user's face).

No prior computer knowledge is required to operate the DeVAR; the robot controller is preprogrammed to perform complex tasks in response to one or two word commands from the user. The user can also "pilot" the arm using simple directional commands. Tasks are divided into three categories: vocational support, activities of daily living, and environmental control. At present, the DeVAR is programmed to: manipulate and file computer print-outs, select/load/return disks, select/dispense medication (throat lozenges), retrieve/return mouthstick, operate a speaker/private phone, perform facial scratching, and operate lights, computer, and call-help module. The DeVAR is programmed with a standard set of tasks that can be used as is or adapted to meet individual user needs.

Developer's clinical trials performed on several prototypic versions of the DeVAR system provided sufficient data to move forward with the technology transfer process. One major step is a field evaluation accomplished independently from the developer's arena. This is a critical step that must be carefully reviewed prior to validating the device/system for commercialization. A pilot study was recommended due to the sophisticated level of technology involved with the DeVAR. Results gleaned from the pilot would assist in ensuring an effective national, multi-center, clinical evaluation.

OBJECTIVE

The primary goals for the pilot study were to verify all levels of built-in safety along with all operational and performance features. The study also examined the DeVAR's utility in assisting high-level quadriplegics to attain independence in a vocational environment. This included assessing the appropriateness of the current task set and need for additional tasks as identified by the subjects.

In addition, the study assessed the supplied instructional materials (manuals and videotapes) for installation, staff/subject training, and technical support information. Level of on-site technical support required to maintain system operation, on a routine basis, and resolution of system failure(s) were also evaluated.

METHOD/APPROACH

With collaboration from the VA National Director, Spinal Cord Injury (SCI) Programs, site selection for the pilot was accomplished. Two pre-commercial DeVAR systems were procured for evaluation purposes. The DeVAR 001 system was placed at the VA Technology Transfer Section (TTS), Rehab R&D Service, Baltimore, MD. while the DeVAR 002 system was located at the VA Medical Center SCI Service, Richmond, VA.

The placement of the DeVAR 001 system at the TTS site allowed the project monitor and biomedical engineering technician, assigned to the project, to become familiar with the operation, training techniques, and technical management of the system. The DeVAR 002 system was evaluated extensively by four males with quadriplegia who were between the ages of 32 and 51. The levels of injury were C-4 and C-5, and included one ventilator-dependent user. The following results focus primarily on their experiences.

RESULTS

Subjects learned to operate the system optimally in three to five hours. The DeVAR performed all tasks reliably, safely, and in an efficient manner. Three subjects recommended more efficient use of workstation space. Suggestions included:
1) adding a motorized reference carousel,
2) replacing one of the copy stands with a page turner, and
3) relocating the prompt monitor next to the Macintosh computer to minimize head/neck fatigue for the user.

Tasks rated as most beneficial were paper handling, retrieving medications, and handling of floppy disks. The mouthstick and retrieval of the phone receiver were questioned due to assistive technology presently available to accomplish these activities. Tasks that were added to the system, during the pilot, were retrieving a drink and paper filing. A task to access books/manuals was also identified by the subjects as being vocationally important if they were to rely on the DeVAR to perform a job.

A Sony Desktop microphone and a hand-held VOTAN microphone were included for use with the VOTAN voice recognition system. Though all subjects liked the voice recognition interface, problems were noted with the microphones. These problems involved speech recognition quality and interference from extraneous background noises. Both proved frustrating to all subjects but especially for the ventilator-dependent user. Frequent recognition errors and continual repetition of commands were very disturbing to the users. The issue with background noise also raised concern for user safety. Based on these findings, a SHURE noise-cancellation microphone (model 562) was tried with the system and did help to improve recognition capability and minimize interference from background noise. It is now provided as a third microphone option for use with the system throughout the remainder of the evaluation phase.

Based upon staff and subject input, the technical and training manuals were updated and revised for clarification. On-site biomedical engineering staff proved adequate for diagnosing a faulty encoder in the gripper and faulty hard drive in the Compaq computer. Developer and manufacturer support were required to recalibrate the robot nesting program, resolve a tracking problem, and program two tasks.

Subjects also suggested adding a method to permit independent access to the system i.e. wheelchair-activated floor on/off switch. All subjects indicated that their purchase of a DeVAR system would depend upon the addition of more vocational-related tasks i.e. book/manual retrieval and improved utilization of worksurface space i.e. motorized carousels and page turners. If these changes were incorporated, all subjects felt the DeVAR could prove to be a practical and useful assistant to persons with severe physical disabilities.

DISCUSSION

Proceeding to the multi-center evaluation is warranted as a result of the pilot. It is evident that additional data is required to further explore the vocational application of the DeVAR system. Presently, both systems are undergoing a national, multi-center, clinical evaluation. The following VA Medical Centers (VAMC) are participating: Brockton/West Roxbury, MA., Seattle, WA., and Tampa, FL. The Seattle VAMC will utilize the expertise and resources of the Assistive Technology Center of the Resource Center for the Handicapped (RCH). The RCH is a vocational training institute for persons with disabilities. Designated staff from the Seattle VAMC and RCH will collaborate on the evaluation project. Only through this technology transfer mechanism can the system's practicality, clinical utility, cost- effectiveness, and commercial readiness be best determined.

In a related VA-funded research project, the Palo Alto VA Rehab R&D Center and SCI program are using the DeVAR system as part of a Vocational Training Facility for high-level quadriplegics.

IMPLICATIONS

As human service robots become more commercially available, the final measure of user acceptance will only come from prolonged operation under actual daily living and vocational conditions. Robotic aids should be flexible, functional and affordable enough to allow persons with severe mobility impairment expanded and independent access within their home and/or work environments.

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Open and Closed-Captioning Alternatives

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ABSTRACT

There are over 22 million deaf or hard of hearing individuals in the United States that can benefit from video tape and television programs that are captioned. With the passage of the Americans with Disabilities Act and other legislation, it is becoming harder to produce video tape programs without making them accessible to all individuals. With the new low cost yet high quality video equipment in use by industry and educational entities today, there is a big need for localized captioning alternatives. A background of captioning as well as equipment, captioning resources, and options is discussed.

BACKGROUND

Captioning began in the early days of movies. At that time there was no sound and captions were placed in between scenes to provide the viewer with the dialogue. Captioning for the deaf and hard of hearing was first seen in 1971 when WGBH in Boston, the local public broadcast station, placed subtitles at the bottom of a broadcast of Julia Childs, "The French Chef". Hearing impaired individuals loved it and requested more captioned programs, especially news. WGBH formed the Caption Center to pursue captioning of televisions shows and news.

Ten years later PBS developed its own captioning system. This one was different. The captions were placed in the video signal and visible only to those with a special decoder. This was a big hit as popular television shows could now be closed-captioned and the captions were only seen by those who wanted to see them. PBS gave the rights to the system to the National Captioning Institute (NCI) who did not share the technology. NCI was the only one capable of doing closed-captioning and open-captions or subtitles became a thing of the past. Producers of video and television programs wishing to close-caption programs had to send them to NCI . In 1984 the Caption Center developed its own closed-captioning system compatible with the one developed by PBS.

OBJECTIVE

Over the past few years closed and open-captioning equipment has slowly become e available. Some of it is very expensive. Knowing where to find equipment is not an easy task. Once equipment is purchased there is usually little or no training of the operator on proper captioning techniques such as paraphrasing or text placement. This paper will provide an overview of captioning. How it is done. Where videotapes can be sent to be captioned, and where equipment can be purchased for in-house captioning.

DISCUSSION

Captioning is the process of displaying the spoken word or dialogue of a program on the screen. Traditionally captions appear as white text on a black or grey background overlaid on top of the video picture, usually appearing at the bottom. Open-captions are visible to everyone. Closed-captions are placed on line 21 of the video signal by an encoder and are invisible unless recovered by a decoder. A decoder at the viewers home recovers the captions and displays them on the television screen. Closed-captions make it possible to caption all programs without disrupting the picture for those who do not need the captions. Those wishing to caption video programs have two options. They can send it out to be captioned, or they can buy the equipment and caption it themselves. One important thing to remember about captioning: The captions are not encoded on the original tape. They are encoded as a copy is made.

There are several ways that captions are displayed on the screen. Pop-on, Paint-on , and Roll-on. Pop-on is the most popular and allows the captions to be placed anywhere on the top or bottom of the screen. Because captioning is usually an after thought to video programs, pop-on allows the captions to be placed without covering critical information that is part of the original program. Paint-on captions are similar to pop-on captions except that the captions appear right to left as though they were typed or painted on in one stroke. Roll-on captions appear at the bottom of the screen in two, three ,or four lines. As a new line appears at the bottom the top line disappears in a scrolling motion. This mode of captioning is most popular with live captioning especially news.

The two largest known captioning centers are the Caption Center in Boston Massachusetts and the National Captioning Institute (NCI), in Falls Church, Virginia (see acknowledgement section for a complete list of addresses). These centers employ full time "captioneers" and are responsible for most of the captioning of television and videos. Costs for captioning run approximately $1,300 for a 30-minute video. In addition programs are required to be submitted on 1-inch videotape, along with a copy of the script, and a 3/4 -inch time-coded copy (audio on channel 1 and time-code on channel 2). The Caption Center will also accommodate tape formats other than 1-inch. Computer Prompting Corporation, a manufacture of captioning equipment, will also caption programs for considerably less than the other two. They will also accommodate other tape formats. All captioning centers have an information packet available. It will describe all that is required to caption a tape sent to them.

The following equipment is needed to close-caption a video tape.

1 Captioning station
1 Line 21 encoder
1 Decoder
1 Television monitor
2 High quality Video cassette recorders

To caption a video tape program the operator uses a 3/4-inch or VHS copy of the program to format the captions. If pop-on or roll-on captions are used then the operator will determine where the captions will appear and when they will appear. This is usually done with time-code which makes the actual captioning process automatic once they are formatted. The tape to be captioned is played in one VCR and the "video out" signal passes through the line 21 encoder on its way to the"video in" of the record VCR. Captions are sent to the encoder form the captioning station which is usually a PC computer with captioning software. Once captioning is complete, the caption master is the videotape in the record VCR. The master videotape in the play VCR is left untouched. Any type of VCR may be used, but the encoder requires a clean video signal from the play VCR. Some consumer Vcr may not work properly. Industrial or Broadcast quality decks are recommended.

Open-captions are made by taking a already captioned tape and placing a decoder between the play and record Vcr. A decoder can also be placed right after the encoder to open-caption an program.

Captioning is a great tool for providing access to individuals with hearing impairments. As more and more corporations, government agencies, and educational institutions, start producing there own videotapes, the need for captioning resources will increase.

ACKNOWLEDGEMENTS

Much of the information on the history of captioning was provided by the Caption Center, 125 Western Avenue, Boston, Massachusetts 02134.

Below is a list of captioning centers, equipment manufactures, and guides to captioning. This list has been compiled over several years and may not be complete . The authors have been involved with captioning for just a few years and would greatly appreciate any additional information on captioning & equipment.

Captioning Hardware

Computer Prompting Corp. 3408 Wisconsin Avenue, N.W., Suite 201 Washington D.C. 20016 (202) 966-0980	low cost captioning systems uses eeg or Softouch encoder
eeg enterprises, inc. 1 Rome Street Farmingdale, N.Y. 11735 (516) 293-7472	captioning systems encoders decoders
Image Logic 6807 Brennon Lane, Chevy Chase MD 20815-3255 (301) 907-8891 (301) 306-1382 (TDD)	captioning systems uses eeg, softouch or shibasoku encoder
SoftTouch, Inc. 1310 Braddock Place Alexandria, VA 22314 (703) 549-8445	encoder
Shibasoku Co., Ltd. 12509 Beatrice Street Los Angeles, CA 90066-7007 (310) 827-7144	encoder
Instant Replay 2601 SO. Bayshore Dr., STE 1050 Miami, FL 33133 (305) 854-8777	consumer VCR with decoder built in
National Captioning Institute 5203 Leesburg Pike, 15th Floor, Falls Church, VA 22041 (703) 998-2400	consumer decoders models 4000, VR100 Available at many retail outlets. Call 1-800-533-9673 for retail outlets in your area.

Caption Centers

Caption Center
125 Western Avenue
Boston, Massachusetts 02134
(617) 492-9225 voice or TDD

National Captioning Institute
5203 Leesburg Pike, 15th floor
Falls Chruch, VA 22041
(703) 998 2400

Computer Prompting Corp.
3408 Wisconsin Avenue, N.W.
Washington, D.C. 20016
(202) 966-0980

Captioning Resource Book

How to write and Caption for Deaf People
TJ Publishers, Inc
(301)-585-4440

Kevin L. Reeve
Computer/Video Specialist
Center for Persons with Disabilities
Utah State University
Logan, Utah 84322-6800
(801)750-3106
(801)750-3944 fax

WALL MOUNTED ELECTRIC WHEELCHAIR ARTIST EASEL

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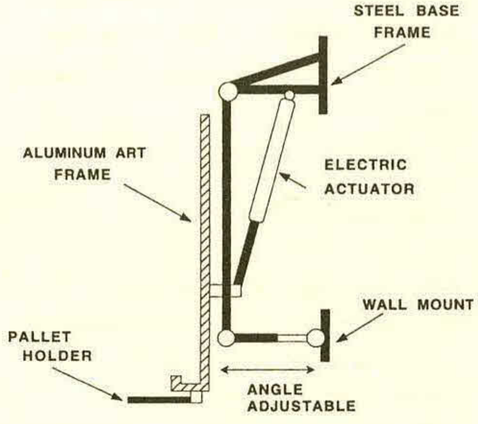
ABSTRACT

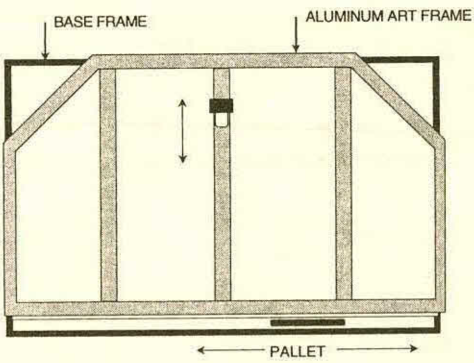
A need was identified to design an easel that could be accessed and operated by a quadriplegic in a power wheelchair. The inherent problems with a typical easel are paintings need to be raised and lowered, so an artist in a wheelchair can reach them, and an easel that sets on the floor does not allow wheelchair access. The solution was to design a wall mounted easel that would allow wheelchair access and could be repositioned by the use of switch. The easel needed to hold paintings up to 10 foot long, have an adjustable angle, and a movable pallet holder.



SIDE VIEW

CONSTRUCTION

The easel was constructed of two separate frames. A steel rectangular base frame mounted to the wall 30 inches off the floor and an outer frame, which holds the paintings, constructed of aluminum. A 24 inch linear actuator was used to raise and lower the outer frame on machined nylon glides. The outer frame has a channeled base that holds the paintings and prevents them from kicking out. A machined nylon friction block assembly holds paintings at the top. A sliding pallet holder was constructed of stainless steel tubing and mounted to the aluminum channel base. The pallet slides easily the length of the outer frame and utilizes a friction lock.



FRONT VIEW

RESULT

The easel allowed the wheelchair artist to access the entire painting. The artist is able to independently adjust the height of the painting easily by a wall mounted toggle switch. The angle of the painting was adjusted to a comfortable working position. The sliding pallet provided a rigid base for the artist to set his paints on but also was easily moved by a simple lifting and sliding motion.

CONCLUSION

This simple device allowed the wheelchair artist to work independently and much more efficiently. Since its design, several non-wheelchair artist have expressed an interest in the easel because it can be used in a sitting position to reduce fatigue.

ACKNOWLEDGMENT

This work was supported by the Indiana Department of Human Services.

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A STUDY OF ISSUES RELATING TO THE PURCHASE OF CONSUMER ELECTRONIC PRODUCTS BY PERSONS WITH DISABILITIES AND FUNCTIONAL LIMITATIONS

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Washington, DC

ABSTRACT

In recent years there have been major developments in the area of assistive technology product development to enable persons with disabilities to increase their functional capabilities in activities of daily living. However there are many mass market consumer products available that could be usable by these persons. This study explores some of the issues relating to the acquisition of these products by persons with disabilities, and offers their opinion on the desirability of a concept entitled a "Seal of Accessibility."

BACKGROUND

In recent years the accessibility, or usability, of consumer products has become the focus of much discussion. Member companies of the Consumer Electronics Group of the Electronic Industries Association seek to investigate methods to inform consumers of the usability of consumer electronic products by people with disabilities. As part of this process, a survey was conducted to study consumers' electronic product shopping practices and preferences, the relative importance of operational design features, and their attitudes towards the proposed "Seal of Accessibility." The seal would be a symbol or label, placed voluntarily on the product, packaging, and/or literature, which would indicate the degree of usability of the product by persons with different functional limitations.

METHODOLOGY

While an effort was made to select a sample population that represented a broad base of disability, it is important to note that because of cost and time factors, a scientifically determined random sample of consumers with disabilities was not used to conduct the survey.

A total of three hundred and forty-one (341) completed questionnaires were returned, representing a strong 24.4% response rate. Of these 341 respondents, 274 identified themselves as having one disability, and 65 two or more disabilities. Two respondents represented non-disabled caregivers who were not screened out.

Survey findings are based on the information provided by the 274 respondents identified as having one disability. It should be noted, however, that after a review of the responses from those with two or more disabilities, the inclusion of their responses would not have significantly changed the overall results of the survey.

The findings presented on the following pages are organized by question. The figures presented indicate the response to each question across all disabilities, with individual disability opinions expressed for clarification where necessary.

RESULTS DISCUSSION

Where do you currently shop for consumer electronic products?
Where would you prefer to shop?

The clear overall shopping methods are retail electronic stores 175 (63.9%), and department stores 185 (67.5%). However, the numbers who indicated these as their preferred choices as somewhat to most desirable were 211 (77.0%) and 204 (74.5%) respectively.

The differences between current choice and preferred choice suggest problems at these shopping locations which may have to do with lack of availability of appropriate products, problems of access to these store facilities, and, as is discussed later, the levels of product knowledge and helpfulness of sales staff.

It appears that the desire to use a particular shopping mode exceeds the current ability to access these modes, and suggests problems with all five shopping methods for persons with disabilities. Investigation of the difficulties encountered by these individuals may represent a future area of research.

What magazines/publications do you read as a potential resource for information on consumer electronic products?

While a broad range of magazines and publications were reported as being sources of information on consumer electronic products, overall, the three major information resources were:

Consumer Reports 21.9% (60)
Popular tech. mags. 17.5% (48)
Disability pubs. 16.4% (45)

An important point to note is that 39.1% of the respondents either did not answer this question, or indicated that they did not use newspapers or magazines as resources for information on consumer electronic products.

How do you presently determine if an electronic product is suitable for your needs?
To what degree are the above methods satisfactory in helping you determine if a product meets your needs?

Talking with other consumers was the first choice of the respondents as being the most satisfactory method to determine if a product would meet a need. This was especially the case with deaf and visually impaired individuals (91.7% and 84.0% respectively).

A broad range of opinions were cited by 34 respondents regarding methods used to determine if a product met needs. Several respondents perceived sales representatives as a problematic resource, even though they were the second most frequently chosen. They were often seen as less than objective, lacking in knowledge of the product, and more interested in making a sale than in providing accurate product descriptions. One respondent reflected "...store personnel are often unaware of the needs of the disabled, and very little help is available in most stores."

Several respondents offered recommendations for making wise consumer electronic product purchases. One explained, "...the prospective buyer must always precede the purchase with research that is careful and thorough...." Another suggested charging for a service where a product would be delivered to the potential buyer's home for inspection and trial use prior to purchase. Others praised telephone sales services, computer bulletin boards frequented by people with disabilities, and family members or friends without disabilities who are knowledgeable about electronics.

Please rate the importance of the following operational design features when deciding to purchase an electronic product.

The findings can be summarized as follows:

Control location is an important feature, particularly to people with dexterity limitations (100%).
Remote control, while generally considered important, is much more important to persons with mobility limitations (82.0%).
Visual display, as might be expected, is a significantly more important feature to persons who are deaf (82.1%), those with mobility limitations (74.4%), and those with hearing limitations (93.8%).
Audio display is similarly a much more important feature to those who are blind (86.7%), or visually impaired (84.0%).
Ease of assembly is, understandably, more important to blind persons (86.7%), but, surprisingly, a feature important to hearing impaired persons (87.5%).

Operating instructions were rated by respondents overall as being important, but again, surprisingly, by an even higher percentage of hearing impaired persons (93.8%).
Adaptable to an assistive device was one of the lowest rated operating features overall, but for blind persons (80.0%) and those with hearing impairments (87.5%) it is considered one of the most important.

What is your perception of a "Seal of Accessibility" illustrating a product's usability by people with functional limitations?

All survey respondents who answered this question agreed that such a seal would improve their ability to make satisfactory purchases. The seal of accessibility was generally perceived as a starting point. While some consumers had doubts about the ability to develop a seal that could meet diverse needs, the majority perceived it as a useful tool in evaluating consumer electronic products, and improving their ability to make a satisfactory purchase.

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SIG-08
Sensory Aids

THE *NAVBELT* - A COMPUTERIZED TRAVEL AID FOR THE BLIND

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ABSTRACT

This paper presents the *Navbelt* - a new travel aid for the blind. The device consists of a portable computer, ultrasonic sensors and stereophonic headphones. The computer applies navigation and obstacle avoidance technologies that were developed originally for mobile robots. The computer then uses stereophonic imaging techniques to process the signals arriving from the ultrasonic sensors and relays them to the user by stereophonic headphones. The imaging techniques produce several informative parameters, which provide the user with an acoustic "picture" of the surroundings, or, depending on the operational mode, with the recommended direction of traveling. The acoustic signals are transmitted as discrete beeps or continuous sounds. Each of the operational modes requires different levels of attention, thus allowing different degrees of assistance. In the *Navbelt*, adaptive control methods are combined with optimization techniques to minimize human workload and to reduce the user's conscious effort during travel.

1. BACKGROUND

The most widely used travel aid is the *long cane* which can detect obstacles on the ground, uneven surfaces, holes, steps, and puddles [1]. The cane can detect obstacle only within its reach (3-4 feet) and therefore it provides only limited information about the environment. Furthermore, the traveler is required to constantly scan the surrounding with the cane, a time and effort-consuming process.

During the past 20 years a number of *Electronic Travel Aids* (ETA's) have been developed. Best known are the *Laser-cane*, the *Mowat Sensor*, the *Russell Pathsounder*, and the *Binaural Sonic Aid (Sonicguide)*. While all these devices improve the detection range of the long cane, they still require active scanning of the environment by the user. Furthermore, once an obstacle is detected, the user is required to perform further measurements in order to avoid the obstacle, again a process that requires time and conscious effort.

Another type of assistive devices is called *Global Navigation Aids* (GNAs). GNA systems are not concerned with local obstacle avoidance but rather with globally directing the user toward a desired target. These devices aim at providing the absolute position of the user (e.g., an intersection of two streets, an entrance to a building, a bus stop), or directional information (e.g., "go straight 30 meters," "turn left," "go up the stairs"). Examples for GNAs are the *Talking Signals*, the *Sona System*, the *Freeston device*, and the *Gilden device*. Since these devices were not designed to perform local obstacle avoidance tasks, travelers had to use additional assistive devices which complicate the traveling process.

2. GENERAL CONCEPT OF THE *NAVBELT*

In order to overcome the shortcomings of existing travel aids, we have transferred an obstacle avoidance technology, originally developed for mobile robots, to a portable device - the *Navbelt* [2]. The *Navbelt* consists of a belt, a small computer, and ultrasonic sensors. Applying the obstacle avoidance system, the computer processes the signals arriving from the sensors and relays them to the user by stereophonic headphones, using a stereo imaging technique. The concept of the *Navbelt* design is illustrated in Figure 1. The electrical signals which originally guide the robot around obstacles are substituted by acoustic (or tactile) signals. However, the computation of the free path and the sensing techniques are similar in both applications.

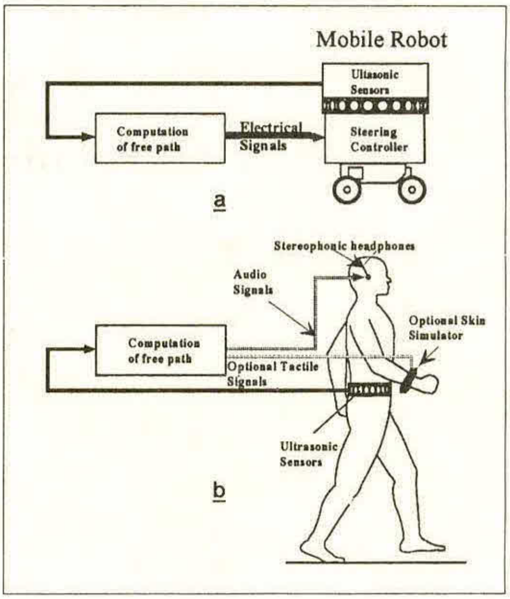

Figure 1: The concept of the *Navbelt*.

The obstacle avoidance system (OAS) [3] scans the environment with several sensors simultaneously and employs a unique real-time signal processing algorithm to produce active guidance signals. The strength of the OAS is based on its gradual reduction of data complexity (from multiple sensors) to a level suitable for real-time guidance of robots or humans. The sensors' data is stores in a world model, and is updated continuously in real-time. The OAS computes the recommended traveling direction according to the user's current position, target location and the obstacles in the surroundings. In the absence of obstacle, the recommended direction is simply the direction toward the target. If, however, obstacles block the user's path, the OAS computes an alternative path which safely guides the user around it.

An additional algorithm generates acoustic signals for the user. Part of this algorithm is a sophisticated optimization model based on a *human's performance model*. The model reflects the user's ability to perceive and analyze the signals, and is continuously adjusted according to the up-to-date performance of the user.

3. DESIGN

The user wears the *Navbelt* around the waist like a "fanny pack." In our first prototype, the user must also carry a portable computer as a backpack. Further developments will reduce the size and weight of this computer considerably. Eight ultrasonic sensors, each covering a sector of 15^0, are mounted on the front pack, providing a total scan sector of 120^0. More sensors will be installed in the future for more complete coverage.

Small stereophonic headphones provide the user with the auditory data without precluding perception of acoustic signals from the environment. A binaural feedback system (BFS) based on internal time and amplitude difference (phase and volume difference between left and right ear) creates a *virtual direction* (i.e. an impression of directionality of virtual sound sources).

The *Navbelt* is designed for four operational modes, which offer different levels of assistance to the user.

1) **Guidance Mode** - The acoustic signals actively guide the user around obstacles in pursuit of the target direction. The signals carry information regarding the recommended direction and speed of travel and proximity to obstacles.
2) **Image Mode** - This mode presents the user with a panoramic *acoustic image* of the environment. A sweep of stereophonic sounds appears to "travel" through the user's head from the right to the left ear. The direction to an obstacle is indicated by the spatial direction of the signal, and the distance is represented by the signal's volume.
3) **Directional Guidance Mode** - The system actively guides the user toward a temporary target, the location of which is determined by the user. The user indicates this location with a joystick, and when the joystick is not used, the target is located five meters in front of the user. In case an obstacle is detected, the *Navbelt* provides the user with information to avoid it with minimal deviation from target direction.
4) **Selected Image Mode** - In this mode the user is presented with a selectable section of the environment, as with the image mode. However, unnecessary information is suppressed and only the most important section of the environment is transmitted to the user.

4. ADVANTAGES OF THE *NAVBELT* OVER EXISTING DEVICES

- The *Navbelt* not only detects obstacles but can also guide the user around them. This combination of obstacle detection and avoidance reduces the conscious effort required from the user.
- Continuous scanning of the environment relieves the user from additional actions, therefore reducing the required physical and mental effort.
- The *Navbelt* can provide the user with a panoramic view of the environment, covering a sector of 120^0.
- The *Navbelt* can automatically guide the user alongside walls. Consequently, the traveler can easily detect corners of buildings or rooms, doorways, windows etc.
- Using the *Navbelt*'s computer as a training device reduces training cost significantly. A computer-based simulator can systematically train the user in various types of environments and circumstances with absolutely no danger to the user's safety, requiring only limited assistance from a professional trainer.
- The *Navbelt* adjusts itself to changes in the environment and to the user's needs. It suppresses insignificant information and transmits only the most relevant and crucial data so that the user can react with only a minimal conscious effort.
- In a commercial product based on the *Navbelt*'s design, the portable computer can be used just like a conventional computer, making the purchasing cost of more economic.

5. IMPLEMENTATION

We have built a prototype of the *Navbelt*, which comprises of an IBM PC 486 33 MHz computer, 8 ultrasonic sensors and stereophonic headphones (see Fig. 2).

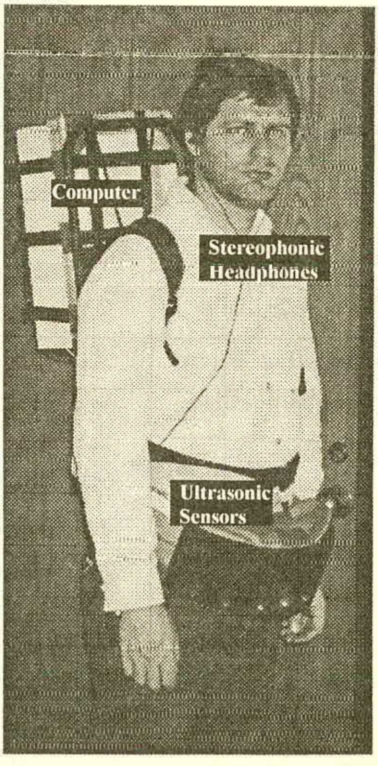

Figure 2: The *Navbelt*'s prototype

Five programmable timers produce the binaural feedback, allowing control over the signal wave form for the stereophonic effects. The ultrasonic sensors are controlled by an I/O board via interrupt handler for efficient utilization of CPU time. A joystick attached to the computer allows the user to specify directional commands to the computer while traveling. Out of the four modes of operation listed in Section 3, we have currently implemented only the image mode and the directional guidance mode.

6. SIMULATOR EXPERIMENTAL RESULTS

A simulator, based on the same hardware as the *Navbelt*, assists the user in the training procedure. The same acoustic signals that guide the user in the real *Navbelt* are used in the simulator. The user's response to these signals are relayed to the computer by the joystick. Several maps are stored in the computer representing different types of environments.

We conducted initial experiments with the *Navbelt*'s simulator to asses the performance of the binaural feedback system, different formats of acoustic signals, and the user's ability to react quickly to such inputs. In the first experiment the image mode was tested. Acoustic images were created continuously, with a sweep-time of 0.55 sec. After 20 hours of training, users could "travel" at an average speed of 30 cm/sec.

Next, the guidance and directional guidance modes were tested. The test persons were able to "travel" (again using the joystick) among different types of obstacles toward a pre-defined target (guidance mode) or a user's specified temporary target (directional guidance mode). Depending on the user's experience and the type of the environment, test persons moved through the simulated environment based only on the acoustic guiding signals. Figure 3(a) illustrates an experiment using real sensor data while the experiment in figure 3(b) is based on computer generated obstacles. In both experiments the dots represent obstacles while the continuos curve is the user's traveling path. In Fig. 3(a) the user traveled at an average speed of 0.75 m/sec and in Fig. 3(b) at an average speed of 0.54 m/sec.

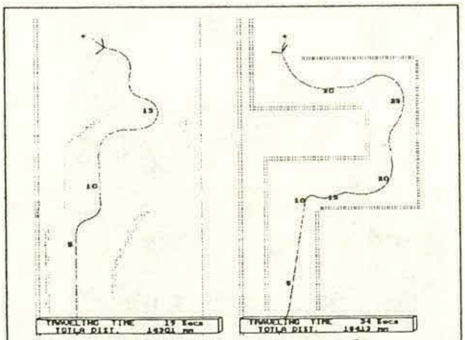

Figure 3: Simulation results for real sensor data (a) and computer generated data (b).

A self-training computer program which includes 10-20 hours of training with the simulator (for the directional guidance mode only) gradually and systematically exercises the user for safe and quick travel. Furthermore, an adaptive user's-model and optimization algorithm enable the training procedure to be adjusted to the user's individual progress. Additional experiments to be conducted in the future will investigate the effect of the adaptive training on human performance.

7. EXPERIMENTAL RESULTS WITH THE *NAVBEL*

The experiments with the *Navbelt* prototype included investigation of the *Navbelt*'s ability to detect obstacles and construct an environment map. We also observed the reaction to the acoustic signals in a real environment. Test persons were asked to travel through an unknown environment in a pre-defined direction using the directional guidance mode without using the joystick. Subjects were able to travel in cluttered environments, avoiding obstacles as small as 10 cm in diameter. Classifying human performance in term of their walking speed, deviation from recommended direction and ability to avoid obstacle, we found that training has the dominant effect on performance. Subjects with more experience traveled faster and generally were more comfortable while traveling. A subject with 10 hours experience with the simulator and 10 hours of practical experience traveled at an average speed of 0.6 m/sec while a subject with 20 hours of practical experience traveled at 0.8 m/sec.

8. CONCLUSIONS

We have built and tested a new travel aid for the blind - the *Navbelt*. The device, based on technology originally developed for mobile robots, integrates fast and reliable obstacle detection with obstacle avoidance technology. The *Navbelt* is designed to offer four operational modes, each requiring a different level of conscious effort from the user. Adaptive information transfer and optimization techniques adjust the signals transmitted to the user according to changes in the environment. Signals are also adjusted according to the user's skills and requirements to improve human and machine integration.

The *Navbelt*'s built-in simulator can train the user systematically and independently according to the individual progress. after 10-20 hours of self training users were able to travel with the *Navbelt* at 0.6-0.8 m/sec while avoiding obstacles as small as 10 cm in diameter.

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3. Borenstein J., Koren Y., "The Vector Field Histogram - Fast Obstacle-Avoidance for Mobile Robots." *IEEE Journal of Robotics and Automation*, Vol. 9, No. 5, June 1991.

AN ALTERNATIVE MOBILITY DEVICE FOR SPECIAL ADULT POPULATIONS

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ABSTRACT

The purpose of this project is to investigate existing devices to determine the advantages and disadvantages of each design and to develop an effective mobility device for special adult populations. Many visually impaired individuals are unable to use the traditional long cane to achieve independent mobility. These populations include preschoolers, multiply-impaired adults, and elderly adults. Alternative mobility devices (AMD) have been developed to provide preschoolers and multiply-impaired adolescents with the ability to travel independently. These devices are easy to use and only require the user to push the cane in the direction of travel. However, Orientation and Mobility (O&M) Specialists have expressed dissatisfaction with several aspects of the current devices.

BACKGROUND

Most people who are visually impaired use the long cane and the two-point touch technique to achieve a high level of independence. These individuals perform most activities of daily living independently and are able to go to work, go to the grocery store, and participate in social activities without the assistance of another person. Using the long cane requires cognitive abilities, to learn to use the cane properly, coordination, to synchronize the tapping with the footsteps, and strength, to manipulate the cane for extended periods. However, some visually impaired individuals such as preschool children, multiply-impaired adults, and elderly adults do not posses these skills and are unable to use the long cane and the two-point touch technique.

For visually impaired people, a significant part of orientation and mobility training is learning to use the long cane and to travel independently. Individuals who do not have an effective mobility aid are unable to travel independently. This can effect their ability to perform many activities of daily living and to participate in social activities. Friends and relatives must be relied upon to accomplish simple tasks. This total dependence on others often produces loneliness, isolation, and depression.

Statistics show that people who are visually impaired are five times more likely to be institutionalized than any other group and that the older blind population is institutionalized more often than the older sighted population. Many are institutionalized, not for medical reasons, but because they have not been taught orientation and mobility skills and independent living skills and are unable to care for themselves (Rinaldo, 1985; Crews, 1985).

STATEMENT OF THE PROBLEM

Since the long cane is not an effective mobility aid for many visually impaired people, O&M Specialists have been developing alternative mobility devices (AMD). A variety of adaptive devices have been developed and are being used primarily by congenitally blind preschoolers both as precursors to the long cane and as permanent mobility aids.

These alternative canes have several features in common. They are easy to learn and require minimal skills to use, enabling the user to travel independently, immediately. The user pushes the cane in the direction of travel, but does not need the fine motor strength and coordination that the long cane requires. The canes provide full coverage across the width of the body. The devices are in constant contact with the ground, providing optimum tactile and auditory feedback. Most designs have a bumper bar across the bottom to clear a wide path. The materials used to construct the devices are flexible to absorb impact. In some cases, individuals with poor gait have experienced significant improvement in gait when using an alternative cane.

The Hula Hoop has been implemented as an independent mobility device for preschool children (Bosbach, 1988). It is wide to provide full protection and flexible to absorb shocks when the child bumps into obstacles. The user does not need a specific hand grip and only needs to push the Hula Hoop in the direction of travel for full protection. The Hula Hoop plastic is flexible and smooth and slides easily over most surfaces. It is inexpensive and readily available. However, the Hula Hoop is awkward to handle because of its large size. It has one contact point in the center of the travel path and cannot detect side drop-offs or obstacles low to the ground.

The Hoop Cane and the PVC Cane are trapezoids constructed from Hula Hoop plastic and PVC, respectively. Rollers are attached to the bottom bar which slides along the ground and functions as a bumper bar. The width of the bar is determined by the width of the user's shoulders or of the user's gait, whichever is greater. The top bar is wide enough to be gripped with both hands. These canes provide better coverage, are smaller, and are less awkward than the Hula Hoop. However, the bumper bar tends to snag on uneven terrain as it slides across the ground and does not improve the user's ability to detect side drop-offs.

The Connecticut Precane is similar to the PVC Cane with two critical modifications. The Precane has two curved runners attached to the bottom of the cane. This adaptation allows the device to glide smoothly over most surfaces and enables the user to detect side drop-offs. Also, the bumper bar has been raised so that it does not snag on uneven terrain (Foy, 1991).

These devices have been successful because they require little coordination, provide total body coverage, and can be used effectively and safely with minimal training. However, there are limitations to the designs. The most significant problem reported by O&M Specialists working with these devices is the wear of the runners or bumper bars which slide along the ground. Constant contact on sidewalks and other abrasive surfaces wears through the wall of the PVC pipe or Hula Hoop plastic after a few hours. Since most canes are constructed of hollow pipe instead of solid rod, the wear produces sharp, rough edges that are a safety hazard and make the canes difficult to push.

Several designs do not allow the user to detect side drop-offs. The runners on the Connecticut Precane detect side drop-offs, but protrude ahead of the bumper bar and tend to snag on obstacles, making maneuvering difficult. The bumper bar, included in some designs, slides along the ground and clears a wide path, but does not glide smoothly over uneven terrain.

With few exceptions, the AMDs are designed and produced by O&M Specialists who are able to determine the features that make a mobility device effective, but have limited experience with mechanical design, construction methods and material selection. Because custom made parts and specialized materials are expensive unless purchased in large quantities, the choice of construction materials is limited to products that are available at local hardware stores. The O&M Specialists may not have access to the necessary tools to properly construct the canes. Finally, the Specialists must spend valuable teaching time constructing and repairing canes.

DESIGN

Most of the alternative mobility devices have been used by preschool children and multiply-impaired adolescents. The devices have been successful for these individuals, but may need to be adapted for use by elderly and multiply-impaired adults.

A search is being conducted to locate O&M Specialists who have experience with alternative mobility devices. Those who agree to participate in the study will complete survey questionnaires to determine the most desired features for an AMD. Specialists contacted during the initial stages of this project have indicated that the following criteria are considered the most critical in the design of an alternative mobility device:

- o The handles of the cane must enable the user to maneuver the cane and maintain a straight line of travel while providing a comfortable grip for the user.
- o The parts that slide along the ground must allow the user to detect side and forward drop-offs in the path of travel in time to react to the change.
- o The cane must be easy to maneuver around obstacles and through doorways.
- o The structure must be flexible to absorb shocks.
- o The cane must provide tactile and auditory feedback and enable the user to assess the environment and detect changes in the surface.
- o The criteria for determining the appropriate size must be determined.
- o The criteria for determining the appropriate weight must be determined.
- o The design must have potential for commercial production.
- o A collapsible design is an option that would improve the convenience of the cane.

The Connecticut Precane has been modified as an initial step in determining the cane design. Two modifications were made. The PVC runners were replaced with curved pieces of metal pipe. The bumper bar which was located behind the runners was repositioned in front of the runners to prevent snagging on obstacles. Several adult-size prototypes were constructed and used by young adults. The new runners provided excellent tactile and auditory feedback. However, the metal runners wore through as quickly as the PVC runners. When the metal wore the edges were very sharp and more dangerous than the worn PVC. The new bumper bar position was successful.

The metal runners were replaced by castor wheels and tested by blindfolded volunteers on a neighborhood sidewalk. The wheels were effective in enabling the user to detect drop-offs and changes in surface texture and in providing good auditory and tactile feedback. However, this design has not yet been tested in the field, and O&M Specialists are concerned that the wheels will tend to lead the user.

DISCUSSION

Several prototype designs will be developed and constructed based upon the information provided by the survey questionnaires. O&M Specialists will provide prototypes to their clients for evaluation. The Specialists and the clients will be asked to evaluate the effectiveness of the prototypes. The results of this final survey will be used to determine a design for the Tandem Cane, an AMD designed for special adult populations.

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An Electroluminescent Lighting Aid for Persons With Low Vision

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Abstract

Research is being conducted to determine whether electroluminescent (EL) lamps may be useful for low vision readers. EL lamps offer the advantages of a thin profile, cool temperature, and almost no infrared or ultraviolet radiation. They may also be configured to mount on spectacles, or be inserted into stand magnifiers.

Introduction

Illumination is a requirement for seeing. Because of the nature of visual impairment, readers who have low vision generally require higher than average room lighting levels in order to read or write optimally. The additional lighting necessary for reading or other close work has traditionally been provided in the form of flex-arm lamps with incandescent or fluorescent bulbs. However, incandescent bulbs produce considerable heat after a prolonged period of use, and fluorescent bulbs flicker and provide a harsh light that many individuals find uncomfortable.

Objectives

The purpose of this research project was to investigate the practicality of using electroluminescent (EL) panels as lighting devices for low vision readers. The specific objectives of this research project were threefold:

1) to determine which available EL lighting source provides the most optimal combination of brightness and color content.
2) to design an optimal portable, low-energy, battery driven power supply.
3) to evaluate performance on the tasks of reading and writing when illumination is provided by electroluminescent light sources.

Methodology

The following criteria were established as effective objective measures of the practicality of using the EL panel for reading:

-the device will provide similar amounts of incident light for close working distances as provided by incandescent and/or fluorescent lighting sources.
-the device will not impose extreme or uncomfortable postures on the low vision reader.
-the device will provide light without significant glare.
-even after extended use, the device will remain cool to the touch.
-the device will not require any additional lighting (i.e. can be used under dim illumination).
-the device will increase contrast on the printed page by emitting only longer wavelengths of light.
-the device will be adjustable for lower levels of illumination.
-the device housing and connections will be able to withstand the same amount of handling as a low vision optical aid.
-the device will be powered by a safe and inexpensive AC power source.
-the device will be inexpensive to produce (less than $20).

Initial research focused on the proper EL lamp for the reading device. EL lamps are available in several different colors and intensities. Characteristic data were supplied by the manufacturer on each of the lamps. The data included power spectral density, color, and brightness. The lamps were specified as being driven by a 120VAC, 400 Hz power source. The investigators proposed achieving greater brightness by lowering the voltage and increasing the frequency. The rationale was that although the power emitted by the power supply was well within safe limits, 120 volts can provide an uncomfortable shock if the user is exposed to a defect such as a bare wire. Therefore, tests were performed on-site to collect characteristic data on the lamps driven with an adjustable voltage, adjustable frequency power supply. It was discovered that when the frequency of the power supply was increased, it caused a blue-shift in the power spectrum. In other words, the EL lamps emitted more short-wavelength light when the new power supply was used. Because part of the methodology dictated that the EL lamp should emit as little short-wavelength light as possible, it was necessary to conduct further research with several other colors of EL lamp samples supplied by the manufacturer. An EL lamp with the spectral density displayed below was chosen for the lamp:

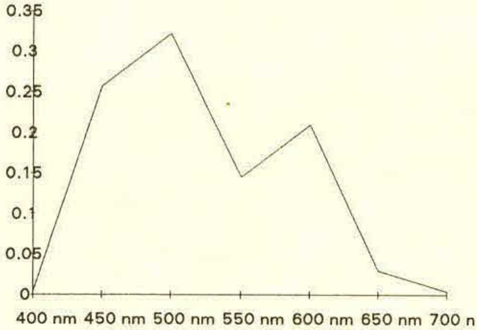

Figure 1: Spectral Density of EL Lamp

Results
The research revealed that increasing the frequency of the power supply could not adequately offset the loss in brightness due to the decrease in voltage. Furthermore, the brightness was increased significantly increasing the frequency to 1000 Hz while fixing the voltage at 120VAC. Therefore, the decision was made to drive the lamp with 120VAC at 1000 Hz. Higher frequencies tend to use more power, yet do not add any additional light.

Hz\VAC	40	60	80	100	120
400	1.19	3.26	6.37	9.73	12.0
600	1.27	4.45	8.92	13.9	18.8
800	1.70	5.56	10.8	16.8	23.6
1000	1.89	5.78	11.8	19.3	26.8
1200					
1400					

Table 1: Brightness (Foot-Lamberts)

A thermometer was fastened to the face of the EL lamp with electrical tape. Another thermometer was use to measure the temperature in the laboratory during the experiment. The following data were collected:

Time (min)	Lamp Temp (°F)	Room Temp (°F)
0	75	75
5	76	74
10	76	74
15	77	73
20	77	73
25	78	73
30	78	73
35	79	73
40	79	73
45	79	73
50	79	73
55	80	73
60	79	73

Table 2: EL Lamp Surface Temperature

The collected data revealed that after one hour of use, the EL lamp never rose above 80 °F, or 7 °F, above the temperature of the laboratory. This data indicates that the EL lamp will remain cool to the touch throughout the duration of its use.

A portable power supply was assembled using a 6VDC to 120VAC (1000Hz) inverter. The input voltage is currently supplied by a 1.3AH lithium photographic battery. (The final product will incorporate a rechargeable battery system.) The power supply is controlled with a SPDT switch, which allows a "high" and "low" brightness setting .

Conclusions
This research has shown that electroluminescent lighting is useful to persons who need 8x or higher magnification when reading or performing other near tasks. Efforts are being made to determine uses for EL lighting that may be of use to a greater population.

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THE NATURE OF TACTILE PERSISTENCE AND IMPLICATIONS FOR TACTILE READING

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ABSTRACT

Vibrotactile stimuli containing temporal gaps were presented to the fingertip via an OPTACON, and the detectability of the gaps as a function of the gap's duration and temporal location was investigated. The duration of the gap between stimuli (inter-stimulus interval, or ISI) was found to provide a better account of performance than the time between onsets of stimuli (stimuli onset asynchrony, or SOA). The results were compared to existing accounts of temporal integration, and differences were noted. The possible implications for sensory substitution and tactile reading were discussed.

BACKGROUND

The tactile sense has been considered a promising substitute or augmentative information channel for people with visual impairments. An important goal of tactile sensory substitution is to present information as efficiently (i.e., as quickly and accurately) as possible. One of the main drawbacks to this approach, however, is an effect called "masking." Masking is the degradation of one vibrotactile pattern by another, and arises when the patterns are presented within sufficient temporal and spatial contiguity to each other. It is imperative that the nature of this temporal effect is understood, so that its effect on tactile information processing can be minimized.

There is evidence that vibrotactile masking is produced by temporal integration of patterns (2, 4). That is, when two patterns are presented in succession such that the second stimulus is presented before the internal representation of the first stimulus has not sufficiently decayed, the two patterns are integrated (5). It was found that temporal integration occurred at short SOAs (i.e., under 10 ms); performance reached asymptote at longer SOAs (i.e., over 100 ms).

This explanation implies that at long SOAs there should be little or no temporal integration, and that performance should not be affected by other factors such as the various combinations of stimulus duration and inter-stimulus interval (ISI, the time between the offset of the first stimulus and onset of the second) that combine to make up the SOA. If SOA is solely responsible for performance, the amount of integration should decrease as SOA increases. To test this hypothesis, a temporal gap detection task was employed, in which observers were required to detect gaps of different temporal durations located between two vibrotactile stimuli also varying in duration. It was expected that a temporal gap would not be detected if stimulus presentation conditions cause the the stimuli to be integrated.

RESEARCH QUESTIONS

The purposes of this study were to (a) investigate how the temporal integration function of the skin is affected by variations in gap duration and gap location, (b) determine the relative utility of these temporal variables in describing performance versus that of SOA, and (c) suggest possible implications for tactile reading.

METHOD

Subjects: Four sighted participants (two female, two male) with no formal OPTACON training served as observers in both Parts of the study.

Apparatus: An OPTACON (OPtical-to-TActile CONverter, TeleSensory Inc.) under the control of an IBM PC XT microcomputer was used to deliver the tactile stimuli. The OPTACON's tactile display consists of a matrix (6 columns 24 rows) of piezoelectric bimorph reeds or "pins" that vibrate at 230 Hz when activated.

Stimuli: In Part I and Part II, stimuli consisted of static (i.e., non-moving) patterns presented on the uppermost 16 rows of the display. Within this selected display area, the patterns activated either 100% of the matrix (96 pins) or 50% of the matrix (48 pins), with activated locations chosen at random on each trial. In Part I, each stimulus had a duration of one second, whereas each stimulus in Part II was presented for two seconds.

Temporal gaps, during which the activation of all pins was suspended, were systematically placed into one stimulus on each trial. A gap of 5, 10, 15, or 20 ms was presented in one of four temporal locations (called "gap midpoints") in a stimulus. In Part I, the gap midpoints were 125, 375, 625, and 875 ms; in Part II, 250, 750, 1250, and 1750 ms gap midpoints were used. The gap midpoints were located at proportionally equal locations (i.e., 12.5%, 37.5%, 62.5%, and 87.5% of the way through the stimuli) in both Parts I and II. All gaps were centred around the gap midpoints. For example, a 10 ms gap occurring around the 250 ms gap midpoint would begin at 245 ms and end at 255 ms. Note that gap duration corresponds to ISI, and that SOA may be approximated in this experiment as: SOA = gap midpoint + (gap duration / 2).

Procedure: The observer rested his or her left index finger on the OPTACON's tactile display matrix. Because the auditory system is highly capable of making the fine temporal judgments required in this experiment, and because the OPTACON produces an audible "buzz" when the pins are activated, it was necessary to mask this auditory cue. Observers wore headphones delivering white noise of sufficient intensity to make auditory feedback from the OPTACON imperceptible.

A two-alternative forced choice procedure was employed. On each trial, two stimuli were presented in succession: one contained a temporal gap; the other did not. The location of the gap-stimulus (first vs. second) was counterbalanced across trials. The observers' task was to identify the stimulus that contained the gap. Observers indicated their choice by means of pushbuttons mounted on a switchbox. Responding to a trial automatically led to the presentation of the succeeding trial.

Each observer received 25 repetitions of the 64 conditions, for a total of 1600 trials in each Part. This data was collected in approximately half-hour sessions distributed over several days. Parts I and II were alternated after every five repetitions to compensate for any practice effects.

RESULTS

For both Parts I and II, gap detection performance was poorer at the shorter gap durations (see Figures 1 and 2). These findings were confirmed by statistical analysis. Three-way (gap duration, gap midpoint, and amount of activation) repeated measures analyses of variance (ANOVA) were performed. In Part I, a significant effect of gap duration was obtained, $F\ (3, 9) = 40.60$, $p < .05$. Post hoc analysis (Tukey's HSD method) showed that the 5 ms gap was detected less frequently than all other gap durations, and that performance in the 10 ms gap condition was poorer than in the 20 ms condition (HSD = 7.5% between means, $p < .05$). It was also found that the gap duration gap midpoint interaction was significant, $F\ (9, 27) = 3.34$, $p < .05$. Post hoc analysis revealed that performance in the 5 ms gap duration condition improved from the 125 ms to the 875 ms gap midpoint conditions, whereas performance in the 20 ms gap duration decreased from the 375 ms to the 875 ms gap midpoint conditions (HSD between means = 8.9%, $p < .05$).

In Part II, a similar three-way ANOVA was performed; only the gap duration effect was found to be significant, $F\ (3, 9) = 42.03$, $p < .05$. Post hoc comparisons revealed that the performance in the 5 ms gap condition was poorer than in all other gap duration conditions, and that the 10 ms gap was detected less often than the 20 ms gap (HSD = 5.1% between means, $p < .05$).

A three-way (stimulus duration, gap duration, gap midpoint) ANOVA was performed to examine the differences between Parts I and II. A main effect of gap duration was obtained, $F\ (3, 9) = 36.21$, $p < .05$, and was determined to be a result of poorer performance in the 5 ms gap duration condition (Tukey's HSD = 6.8% between means, $p < .05$). The stimulus duration x gap duration interaction was significant, $F\ (3, 9) = 6.53$, $p < .05$. Post hoc comparisons showed that the 5 and 10 ms gaps were detected more frequently in Part II (HSD between means = 3.7%, $p < .05$).

DISCUSSION

Past research has provided evidence that the internal representation of a vibrotactile stimulus starts to decay beginning at the onset of the stimulus (2), predicting a monotonically increasing function of gap detection performance with SOA. However, such a result was not obtained in this study (see Figures 1 and 2; data are collapsed over the non-significant effects of subjects and pin activation amount). Rather, it appears that ISI provides a better account for the findings. The 5 ms ISI (gap) condition did not produce complete integration (indicated by at least 65% correct gap detection performance); it may be that complete integration occurs at less than 5 ms ISI. Note that the finding that performance in the 5 and 10 ms gap conditions in Part II was superior to that in Part I provides only weak evidence for an SOA-based account of gap detectability.

If the "trace" or internal representation of the stimulus begins to decay at the onset of the stimulus, then SOA would be the critical factor in temporal integration, implying that with increases in stimulus duration (approximated by the gap midpoint), gap detection performance should increase. For example, all stimuli presented around the 375 ms gap midpoint have less time to decay than the stimuli presented around the 625 ms gap midpoint, thus stimuli at the earlier gap midpoints should be integrated, indicated by poorer gap detection performance. Yet performance in the 375 ms gap midpoint-20 ms gap duration condition is better than in the 625 ms gap midpoint-5 ms gap duration condition. This outcome is not expected if SOA alone were responsible for performance: gap detection performance at the greater gap midpoints would be expected to be better than that at smaller gap midpoints.

Investigations of tactile temporal integration have typically employed a masking paradigm. That is, the task has been to recognize or identify a target presented in close temporal proximity with a masker, or to discriminate between a target and a masking stimulus. Masking has frequently been found at SOAs over 100 ms (1). It has been suggested (3) that this effect was caused by the masker interfering with the extraction of higher order, relational information in the target at longer SOAs. The current study, though, employed a detection task that required little higher-level cognitive processing. Also, the stimuli were not created to have detectable features. Thus, it does not seem likely that the interference account provides a suitable explanation of the findings in the current study. However, it is imprudent to rule out the possibility of another, lower-level type of interference effect. For example, because it is extremely difficult to extract features from a pattern of random activation, it may take longer (or even be impossible) to construct an internal representation of the stimulus, which would likely affect the persistence function.

This study suggests some implications for tactile sensory substitution applications, such as tactile reading using the OPTACON. Although scan mode, in which letters move laterally across the fingertip, is the most common mode of OPTACON operation, advances in computer technology

(6) allow for other modes of presentation. There is some evidence that an alternative means of presentation, static mode, in which letters are presented motionless, may be more efficient than scan mode (7). Inserting a relatively small temporal "buffer gap" (around 10 to 20 ms) between letter presentations in static mode could reduce any degradation of pattern integrity caused by temporal integration, and may provide a further increase in tactile reading performance.

If inserting a buffer gap between letters reduces masking, it might not necessarily decrease the reading rate. For example, it may improve accuracy for those OPTACON users who have sacrificed accuracy for the sake of speed. Thus, the cost of a few milliseconds per letter may prevent the loss of seconds spent rescanning misread words. Conversely, a buffer gap might allow for an increase in speed for those readers who have sacrificed speed for the sake of greater accuracy; these OPTACON users may increase their reading rate without sacrificing accuracy.

This project constitutes an integral part of ongoing research, the goal of which is to delineate the information processing capacity of the tactile modality. It is hoped that an optimally efficient means of symbolic information delivery may eventually be developed based on this and other, similar research. Specifically, future research should be directed at determining the extent to which a buffer gap affects tactile reading, in both static and scan modes. It is also imperative that the temporal nature of the internal representation be further delineated. Research to this end has been started in our laboratory.

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Figure 1: Temporal gap detection performance (1000 ms stimulus)

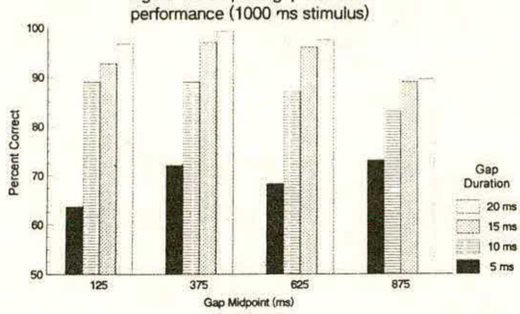
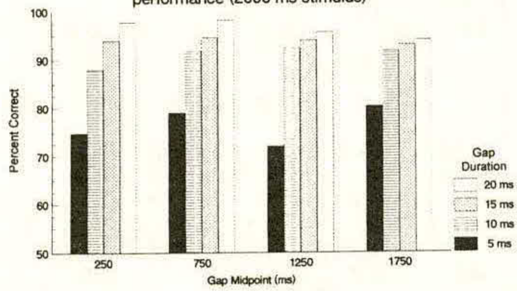


Figure 2: Temporal gap detection performance (2000 ms stimulus)



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REMOTE SIGNAGE AND ITS IMPLICATIONS TO PRINT-HANDICAPPED TRAVELERS

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ABSTRACT

The Americans with Disabilities Act has left open the question of the specific implementation of accessible signage appropriate for open spaces where tactile signs are inappropriate. Infrared remote signage provides a solution to this need by labeling the environment for distant viewing. This paper outlines uses for infrared remote signage, specifically describes a model urban signal light installation, and summarizes system technical specifications.

INTRODUCTION

With the passage of the Americans with Disabilities Act (ADA), questions arise as to how the environment should be labeled for blind and visually impaired travelers. During the rulemaking process a question raised by the Architectural and Transportation Barriers Compliance Board (ATBCB) for public comment stated, in part, "In areas where overhead signage is typically provided such as conference centers and bus stations, how can information on these signs be made accessible to persons who use raised and brailled characters?" (*Federal Register*, January 22, 1991). As a result of written and oral testimony given before the ATBCB by our institute, the final Rules and Regulations (*Federal Register*, July 26, 1991) stated that "Although technology is available for making overhead and remote signage accessible, the Board plans to further study this issue to determine where and in what type of buildings and facilities such technology may be necessary for future revisions of the guidelines." No doubt, various systems (radio, inductive loops, infrared and satellite navigation) will be considered.

RATIONALE

This paper does not deal with the general issue of accessible signage for persons who are blind or otherwise print-handicapped. Rather, it discusses *remotely* accessible signage -- signs which do not have to be specifically approached to be read -- a technology which is most consistent with the conventional signs available to nondisabled individuals.

Specifically, *remote signs* allow people to directly know not only *what*, but *where*. Just as sighted persons visually scan the environment to acquire both label and direction information, remote signs *directly* orient the person to the labeled goal and constantly update the person as to his progress to that goal. That is, unlike braille, raised letters, or voice signs which passively label some location or give mobility instructions to some goal, the remote signage technology developed at our institute provides a repeating, directionally selective voice message which originates at the sign and is transmitted to a hand-held receiver. The direction selectivity is a characteristic of the infrared message beam and ensures that the person using the device gets constant feedback about his relative location to the goal as he moves towards it.

What other characteristic of signs are valuable to the traveler? Mainly, signs provide identification. However, in the broadest sense, signs comprise a menu of choices for the traveler; they confront him with the options available to him at any given point in his travels. In a sense, signs act as a form of memory for the traveler; they "remind" him about important characteristics of the environment. In transit situations, the sighted traveler receives adequate preview of vehicle arrival and he knows which buses/trams or stops are irrelevant to him. Early identification of distant objects (buses or stops) is an especially important attribute of an effective remote signage system.

Street signs can serve as a simple and revealing example of how signs are used. What do sighted people know as they approach an intersection? They know the names of the streets; they know the block number, which orients them in the city's scheme of things; they see the presence of a crosswalk or the lack of one; and white lines tell them crosswalk directions. Observing traffic patterns and noting the presence of walk/wait signs, they know if the intersection is controlled by a signal; they also, with a quick glance, determine whether or not the signal is controlled by a pushbutton.

What do blind people know as they approach an intersection? They know by listening to traffic patterns whether or not the intersection is controlled by a traffic signal. Where intersections involve three or more streets, the listener can at least determine that it is a complex intersection. By noting the direction of signal-controlled traffic, the times when it is permissible to cross can usually be determined. The blind traveler may not notice the pushbutton if there is one. Like the print-handicapped, the blind traveler may not know the name of the street he is crossing. To learn an address number, he must find an open establishment and ask the proprietor.

WORKING URBAN STREET SIGNAL

The infrared transmitter and photodetecting receiver developed at our institute became a product of Love Electronics called Talking Signs™. They go beyond the concept of mere indicators; they are full-featured information systems. Recognizing this, Mr. Gordon Chester of the San Francisco Department of Parking and Traffic specified a design for Talking Signs™ which would give the user six pieces of information:

1. The name of the cross-street can be heard through the user's receiver. (The name of the street parallel to his direction is heard when the receiver is pointed across that street.)
2. The address number of the block ("zero hundred block," "100 block," etc.) is also announced through the user's receiver.
3. Since Talking Signs™ use directed beams of infrared light, the direction in which the user's receiver is pointing is also announced (facing southwest, for example).
4. The "color" of the light controlling the traffic is announced ("red," "green," or "yellow").
5. The crosswalk information is transmitted via a narrow beam which is confined to the boundaries of the crosswalk. Therefore, when red, green, and yellow information is heard, the traveler knows that he is in the crosswalk.
6. By scanning the receiver left and right, the precise direction along the crosswalk is indicated; the user searches for the clearest signal.

The City of San Francisco has installed eighteen Talking Signs™ units of the above specifications at busy downtown pedestrian intersections.

Another consideration in choosing aids for the blind traveler is the intrusion caused by their presence. Where audible traffic signals have existed (such as San Francisco's early crosswalk experiment, which used a bell and a buzzer), residents have insisted that they be turned off at night. At the very least, they draw needless attention to the accommodation made for the blind traveler.

The receiver of the Talking Signs™ system is a personal listening device. Its small speaker is in the hand of the user and causes no high-volume signal to be produced for others to hear. Furthermore, if the traveler is familiar with all aspects of an intersection which he uses regularly, he may choose not to actuate the receiver at all, but to depend on standard mobility skills to negotiate the intersection.

Because Talking Signs™ speak the names of streets and address numbers, they address the needs of the *print-handicapped* as well. Other services, such as closed-circuit newspapers by radio and the Talking Book library, have expanded to their current levels because of their use by the print-handicapped.

Our institute has made its infrared remote signage technology available in the public domain in the form of braille, cassette, and computer disk (1).

TECHNICAL DATA

The following technical specifications are for those familiar with communications theory:

Transmission System

An infrared lightwave carrier (880 to 950 nanometers) is generated with single or multiple IRLEDs. Multiple subcarriers are possible, but they will require a sinusoidal drive to reduce intermodulation products; this is at the expense of transmitter efficiency. The

IRLED source is either pulsed or sinusoidally driven, with a standard subcarrier frequency (fc) of 25kHz. Reducing duty cycle to 10% while maintaining constant average current in pulsed mode produces a 30% to 60% increase in effective radiated power for maximum range, single subcarrier applications.

carrier frequency (fc) = 25kHz (or auxiliary frequencies as described above)

audio bandwidth (fm) = 300-3300Hz (telephony voice bandwidth)

subcarrier deviation (fdev) = 2.5kHz

modulation index = 0.76

Receiving System

A low-noise PIN photodiode is fitted with a Kodak 87C Wratten filter. This feeds a modified transresistance preamp designed for high dynamic range and full-sun background illumination. The Love Electronics product uses a tuned radio-frequency design with a conventional limiter and a Travis discriminator with noise squelch.

Capture of the receiver by the stronger of two signals in the receiver field of view requires a received power ratio on the order of 20dB for negligible interference. Adjacent transmitter carrier frequency tolerance of 50Hz to 100Hz improves the intelligibility of interfering signals.

audio output level = 85dB maximum at 1 ft., 10% distortion

maximum receiver sensitivity = 0.3nW optical power in

worst case full in-line sun-induced shot noise reduction of receiver range = 5 to 1 (e.g., 200 ft. to 40 ft.)

system range for 50-degree beam at 16mW/steradian source and 12 dB input s/n ratio = 10 meters (no receiver optics)

CONCLUSION

The emergence of sensitive infrared devices and nonvolatile memory have made this technology low cost, highly efficient, low maintenance and easy to install. It serves the mobility needs of the blind, visually impaired, and print-handicapped. "Signs" which can be discretely identified at a distance promote direct paths of travel. Short range indicators (fixed speakers, braille or raised letters) divert travelers even when they can be located. With infrared remote signage, the choice of travel path is at the discretion of the traveler.

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NEW LOW VISION DEVICES AND TESTS

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ABSTRACT

There is a need for improved vision tests which are of practical clinical utility and relate more closely to visual performance problems experienced in the real world by the visually impaired. We have developed a number of such tests which are now under evaluation. Similarly, there is a need for improved low vision aids and devices which are specifically designed to address particular types of visual deficits and the performance of diverse everyday tasks. The present paper describes several new solutions for these problems.

INTRODUCTION

We have developed a number of new aids, devices, and tests to assist in the diagnosis and rehabilitation of the 2-3 million persons in the United States with insufficient vision to read regular newsprint using conventional reading glasses.

LOW VISION TESTS

The conventional vision tests used in eye clinics are relatively unsuited to predicting real-world visual problems of patients with modest vision deficits associated with normal aging and early or mild eye disease. In particular, the conventional tests do not allow detection or measurement of problems relating to poor viewing conditions such as low contrast, poor lighting, glare, etc. Elderly individuals with early eye disease, as well as those with more advanced visual impairment, commonly suffer from these types of problems (1, 2). We are developing a number of low-cost, rapid, and easy-to-administer vision tests to address this problem. The first of these is the SKILL Card -- a black-on-gray near acuity card for testing vision under conditions of low luminance *and* low contrast (akin to driving at dusk or in fog, etc.). A new Retinal Recovery Rate test measures the rate at which the retina recovers from exposure to a glare source (obviously important in such tasks as night driving). A new Attentional Visual Field test has been developed to test the patient's ability to perceive objects approaching from the periphery while concentrating on a central visual task. Performance on this test has been found to correlate with accident rates in driving (3).

LOW VISION AIDS AND DEVICES

We have developed advances in low vision telescopes, including a design proposal for the use of advanced aspheric optics incorporated in a spectacle clip-on telescope featuring dual magnification (2X and 4X). We have designed a new ergonomic telescope grip (Figure 1) which allows a much steadier hold on the telescope to avoid jitter, and even allows one-handed operation (both holding and focusing). The user can therefore keep his other hand free to hold a walking stick, handbag, shopping bag, etc.

Increased illumination can make a major difference in the ability of many persons with visual impairments to see clearly. We have developed a portable, battery-powered, head-mounted lamp using modern quartz halogen technology with a focused dichroic reflector. This lamp provides a major boost in illumination while reading, sewing, or performing tasks which require moving around. A second illumination device is a small, spectacle-mounted clip-light intended for persons who read with high-powered spectacles requiring a reading distance of approximately two inches. Normally, use of these spectacle lenses causes occlusion of much of the ambient light by the user's head and reading material, making it difficult to see. The new spectacle clip-light solves this problem by directly illuminating the page in front of the spectacle lens. It can be easily attached to and removed from the user's spectacle frame, and utilizes a small pocket- or purse-carried battery pack.

SUMMARY

By addressing the need for improved clinical assessment procedures for the visually impaired, we hope to allow clinicians to detect

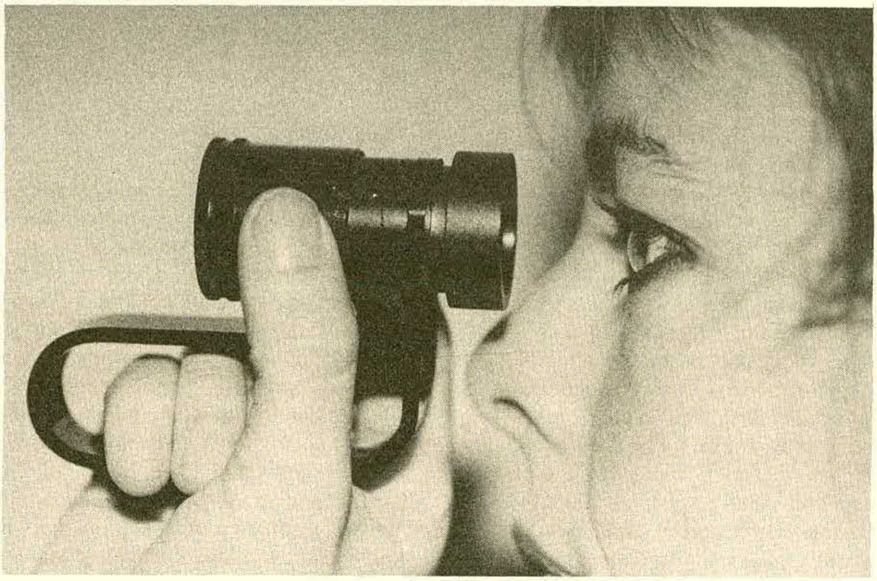

Figure 1. New ergonomic telescope grip for one-handed operation.

vision problems earlier and quantify them better in terms of real-world visual performance -- thus allowing better targeted rehabilitation methods and devices to be prescribed and applied. Devices such as those described here, targeted at particular vision deficits and visual performance tasks, should increase the resources available for effective rehabilitation of the individual with visual impairments.

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External Tactile Transducers for Lost Sensation

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ABSTRACT

Technological improvements in sensory feedback have largely been driven by competition in the automated manufacturing and robotics industries. Present tactile sensors, therefore , are generally too large and too insensitive, particularly to shear forces, for direct application to the human body. The development of more precise tactile sensors and their integration into existing functional neuromuscular stimulation (FNS) systems would have a significant effect on improving the safety and motor function of people with tactile impairments. This paper describes the investigation and evaluation of tactile sensors based on a variety of existing technologies. Unlike robotic sensors, these tactile transducers were subject to clinical evaluation using the Semmes-Weinstein monofilament assessment.

BACKGROUND

Loss of the sense of touch severely impacts an individual's safety and ability to perceive his/her immediate environment. Lost tactile sensation in the hand, even if motor function is present or replaced by a powered prosthesis or stimulating system, places the hand at risk. In addition to this risk, the motor activities of people without sensory feedback take more time, which may have a negative effect on the quality of their lifestyles. For example, existing powered prostheses users are burdened with the task of visually estimating the forces needed to grasp an object without damaging it, and typically must maintain eye-contact throughout the procedure. This diverts his or her attention from other tasks, and also increases the time needed to complete simple acts of locating, grasping, moving, and replacing objects.

Several manufacturers were known to produce tactile sensors using capacitive, force-sensitive, optical fiber, micromachined silicon, and magnetic-sensing technologies. Manufacturers of conductive gels and elastomers were also encouraging about the use of their products for tactile sensing.

METHOD

Specific Goals

(1)Purchase silicon, resistive, capacitive, optical, hydrogel and Hall effect sensors and measure the properties of each.
(2)Assemble individual sensors into arrays sized and positioned to fit on a fingertip or palmar surface; arrays may include more than one type of sensor.
(3) Test arrays using clinical assessment tools such as the Semmes-Weinstein monofilament test for comparison with normal and minimal human sensation.
(4) Test the arrays on a mechanical simulated "finger" equipped with actuators for exerting known forces against a fixed plate.
(5)Using the simulated finger fixture, determine the ability of sensor arrays to detect slippage under uniform conditions.
(6)Operate the finger fixture in a closed-loop mode to determine effect of response time and resolution of sensor arrays on stability of force control.

Test Equipment

A pneumatic cylinder with a calibrated pressure sensor was originally chosen for applying loads to the sensors. Lacking finer sensitivity and inhibited by excessive friction in its piston shaft, it was eventually replaced by a 5 LB Chatillon gage bolted to a lathe milling head attachment. The milling head attachment allowed the Chatillon gage--which has a precision spring that measures force directly--to be linearly advanced by a precision screw for loading. The increment of loading for all tests was typically 0.1 LB and continued until the sensor was saturated. Sensors were subjected to normal load, shear load/tangential displacement, step response, and edge detection tests.

RESULTS

After a thorough search for available tactile sensors, it was determined that there was an abundance of product advertisements but no available sensors. Fabrication difficulties and low demand were cited by manufacturers as the primary reasons for lack of sensor availability. It was necessary, therefore, to construct capacitive, force-sensing resistive, optical fiber, Hydrogel (conductive gel), and conductive elastomer tactile transducers using workbench scale fabrication methods. Samples of micromachined silicon and magnetic (Hall-effect) sensors were obtained and modified.

As expressed by many sensor manufacturers, most tactile sensors displayed one or more of the following problems--excessive noise, inter-elemental cross talk, hysteresis, brittleness, poor miniaturization capability, and sensitivity to moisture and oxygen. Of all the sensors tested, the optical and magnetic Hall-effect yielded the best overall performance.

The optical sensor contained a spring-loaded shaft that would progressively occlude LED light falling onto a cadmium sulfide photoresistor (Figure 1). Normal testing results were favorably linear, and an improvement could be made by using a stiffer spring (not preloaded), or the substitution of a suitable elastomer (Figure 2). The step response output was sluggish, possibly caused by the friction or memory of the photoresistor. Exposing the photoresistor to constant and low level illumination would minimize this problem. Despite the somewhat favorable results of this device, however, the sensor's 3/8"X3/8"X5/8" measurements are beyond the useful limits of this application. For finger mounting, a custom sensor with radius of 10 mm or less is needed.

The magnetic Hall-effect sensor performed well with both normal and tangential loads. Tests were conducted with either a silicon rubber or open-cell foam intermediate layer between the sensor and the magnetic source(Figure 3). The silicon rubber exhibited no appreciable deformation between the loading and unloading cycles as indicated by the absence of hysteresis in Figure 4. This suggests it would be more accurate than the open-celled foam which experienced a delay in restoration once the load was removed. The open-celled foam, however, possessed superior compressibility which provided a larger range in which to sense pressure--150 millivolts compared with 8 mv for the silicon rubber. Both materials and the Hall effect sensor were highly repeatable for normal pressure sensing.

Discussion

The original goals of the project were impeded by the necessity to build nearly all the sensors needed for the research. Despite this, the test data was useful and is the basis for a current proposal to continue research on tactile sensing using both the optical and Hall-effect sensors.

Optical

Continued research on the fiber optic sensor should attempt to reduce the capacitance of the wire, and improve the intensity-to-frequency converter signal. If this is achieved, then experimentation with light intensity modification schemes should take place. Also, existing components and practices appear incompatible with the 2 mm point-to-point spacing desired for miniaturization. This effort may benefit by investigating micromachining of an optical occluding sensor, including a search for alternative arrangements of occluder shafts for shear sensing.

Hall-effect

Appropriate miniaturized packaging is needed for this sensor. Ideally, this would include more effective and higher density methods of magnetizing tape (chromium dioxide video tapes may have 3 times the capacity as computer magnetic tape (900 Oersteds compared to 300 Oersteds). An annular magnetizing scheme for both normal and shear sensing may improve the sensor performance.

One concern in using the Hall effect sensor is controlling its response to extraneous magnetic fields. Sensitivity to external fields could be reduced by a Mu-metal shield overlying the outer layer and/or by adding Hall sensors outside the range of the magnetic spot which detect only the external source.

Acknowledgments

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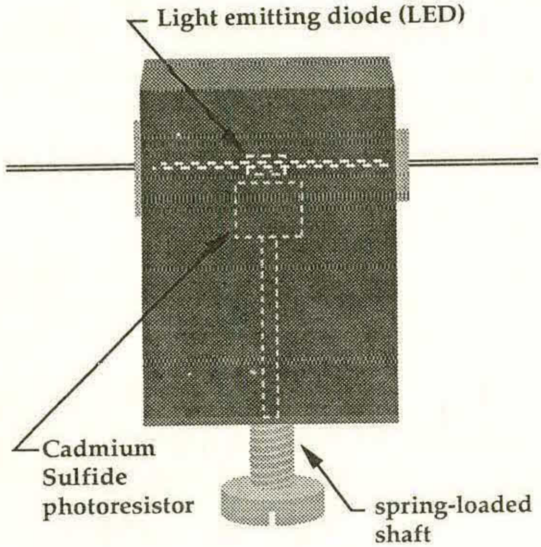
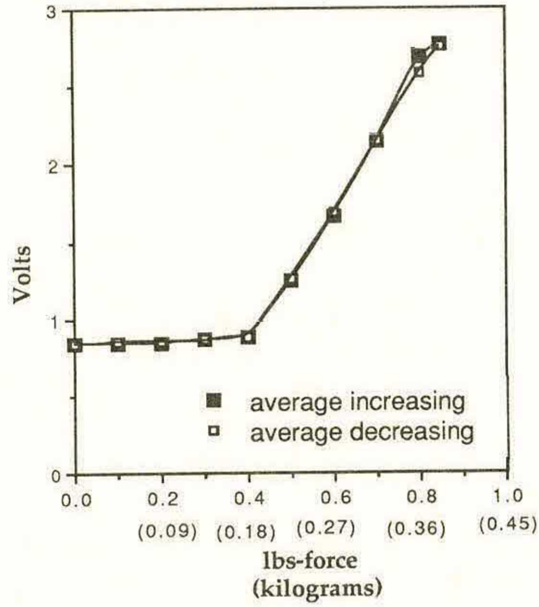


Figure 1: Optical Sensor scale: 6/1

Fig 2: Optical Sensor Hysteresis Test



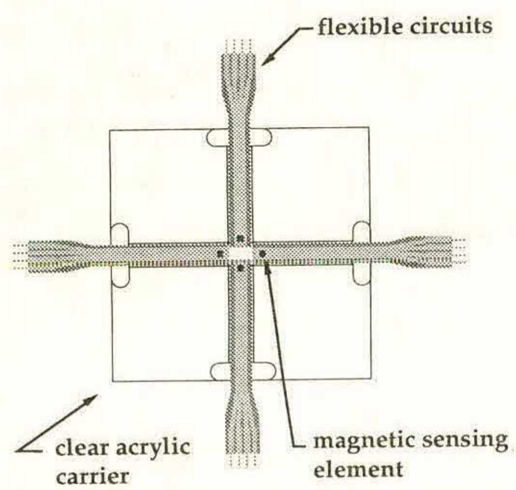
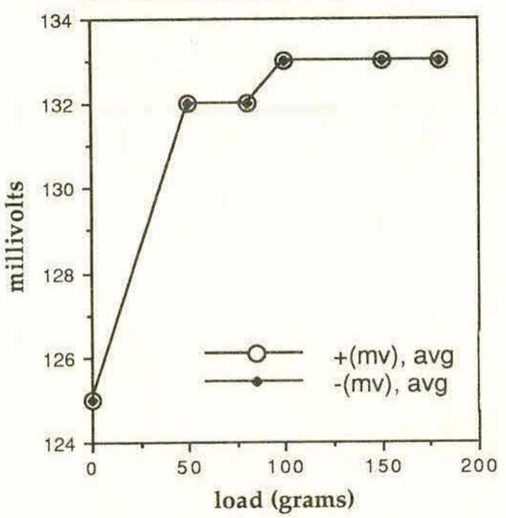


Figure 3: Hall Effect Sensor scale: 1/1

Figure 4:
Hall effect sensor, average of normal loading (+) and unloading (-) 0.06 in silicon rubber spacer



SIG-09
Wheeled Mobility and Seating

Resolution of Infertility Using Adapted Wheelchair Cushion A Case Study

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ABSTRACT

Individuals who spend much of their day sitting, may experience an increase in interscrotal temperatures leading to reduction in spermatogenesis. People using wheelchairs, especially those with foam cushions, may be particularly susceptible to this problem. In this case study, a custom seating system was designed for an individual with severe cerebral palsy who was experiencing infertility. The seat allowed increased ventilation in the testicular area without sacrificing supportive positioning. This configuration produced an increase in sperm quality and led to conception of a healthy child.

INTRODUCTION

Information regarding the fertility of individuals using wheelchairs has been extremely limited. It is known that spermatogenesis and sperm motility are adversely affected by elevated scrotal temperatures (1, 3). Linsenmeyer and Perkash (4) attributed one of several causes of poor semen quality in men with spinal cord injuries to testicular hyperthermia. Brindley (1) found that men who were seated had higher scrotal temperatures than those who were standing and active. The use of a foam cushion, as is very common for individuals using wheelchairs, may serve to insulate the scrotal area and thus increase the heat retention (2).

Although men who are ambulatory have the option of attempting to reduce interscrotal temperatures in a number of ways, those using wheelchairs due to neuromuscular impairments are more restricted in the options available. For example, some individuals depend on their wheelchair cushion to provide pressure relief to prevent pressure sores. Others require the seating system to provide resistance and body support to improve distal function.

In this case study, we examined whether a change in wheelchair seating configuration could increase fertility in a man with severe cerebral palsy.

BACKGROUND

TG is a 38 year old man with severe spastic/athetoid cerebral palsy. He is non-verbal and non-ambulatory, and has used a wheelchair for all mobility throughout his life. Until he was seen in the seating clinic, in 1989, he had received no positioning intervention and used only the naugahyde sling seat and back in his power wheelchair. After a comprehensive evaluation, it was determined that TG would benefit from a custom contoured seating system including hip adductors, an abductor pad between his knees, lateral supports, and a headrest. The seat and back were fabricated from plywood and foam, covered with naugahyde, and installed into TG's wheelchair. With his new seating system, TG experienced significantly improved distal function, as evidenced by his increased ability to access his computer, Touchtalker, and power wheelchair. His comfort and appearance also improved.

In May, 1991, TG returned to the clinic to inquire whether we knew of any intervention to improve his fertility, to increase the likelihood of him and his wife conceiving a child. After more than three years of attempting conception, TG and his wife had recently undergone extensive fertility testing. TG had been found to have a sperm count of 710,000/cc with a motility of 0% after 1/4 hour. Since a level of 20,000,000/cc with motility of 60% has been identified as an approximate threshold between fertility and infertility (4), he had been told that there was little chance that he could ever father a child.

OBJECTIVE

Our objective was to determine whether this client's sperm quality (including density and motility) could be improved using a seating system that reduced the heat stored in his scrotal area, while at the same time provided him with the same positioning and support as his existing seat and back.

APPROACH

We determined that there were five factors that were necessary to include in the seating system. First, it had to retain custom contouring. Second, it needed to include a hole in the seat to allow optimal air flow in the scrotal area. Third, it had to be made from natural materials that allowed good heat transfer. Fourth, it had to be comfortable enough for TG to sit on it for 8-10 hours per day. Finally, it had to be fabricated from easily obtainable, inexpensive materials.

We chose to use cotton batting (available in fabric stores) as the material for padding the seat and providing the contours. This is the same material that is used to fill futon mattresses and has the properties of being both comfortable and accommodating to the body. We first cut an 8" long x 6" wide oval-shaped hole in the center of an 18" x 18" wooden seat board. We padded the seat with two inches of the packed cotton batting. Additional cotton was packed to build approximately four inch contours around TG's hips and between his legs. The seat was covered with cotton terry cloth, which was stapled to the underside of the seat board. It was mounted into the wheelchair frame using standard seat hardware and drophooks. The total cost of the supplies was under twenty dollars. TG found the seat very comfortable and had no trouble sitting on it all day.

RESULTS

Sixty days after our intervention, TG returned to the fertility clinic for further testing. At that point, he was informed that his sperm count had risen to 18,000,000/cc with approximately 40% motility after 1/2 hour. One month later, we were informed that TG's wife was pregnant. A healthy baby boy was born in May, 1992.

TG used the seating system for approximately four months. By the end of that time, the cotton was beginning to lose its supportive properties and was quite dirty. As it was no longer needed, it was discarded and replaced with the original contoured seat.

DISCUSSION

Poor sperm quality in men with spinal cord injuries has been attributed to a number of factors including urinary track infections, use of medications, contact with urine, stasis of prostatic fluid in addition to testicular hyperthermia (4). It is only logical to assume that some of these same factors can contribute to infertility in other men who use wheelchairs.

Only the last factor, testicular hyperthermia, can be easily addressed by the seating clinic. There are many issues to consider when prescribing a wheelchair seating system for a client. While fertility requirements are not usually discussed in a seating evaluation, it should be noted that composition of the wheelchair cushion may have a significant effect on spermatogenesis. Since there does not seem to be any indication that future spermatogenesis is affected by temporary testicular hyperthermia, it may be possible to address fertility issues as they occur, without anticipating them in advance. Nonetheless, it is valuable for the clinician to be aware that the equipment prescribed may have far greater impact than was its original intent.

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TOWARD OBTAINING USEFUL CONSUMER FEEDBACK FROM YOUNG CHILDREN WITH PHYSICAL DISABILITIES

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ABSTRACT

As part of a project to develop a new line of adaptive seating for children, a hands-on evaluation session was organized for 26 primary grade students from The Hugh MacMillan Centre School in Toronto. The students were asked to choose which colours and shapes they liked best, what they thought of materials they felt but could not see, and how comfortable they were sitting on different seats and using different types of lap belts. Seated anthropometric measurements were also taken. Following this, teachers led group discussions to discover what the children thought of this experience.

Results of the pilot session demonstrated this to be an excellent means for obtaining feedback from young consumers. The children also indicated that they enjoyed the experience. In addition to assisting in the development of the new seating system, it is suggested that some of the methods developed be used in clinics to obtain opinions from young clients during the prescription of seating systems.

BACKGROUND

To aid in the development of assistive devices for individuals with disabilities, the traditional approach has been to consult knowledgeable service clinicians. While clinical involvement is important, perspectives from target consumers early in the design process are necessary if a useful and useable product is to be created (1).

Many investigators have attempted to involve consumers in the development and/or evaluation of assistive devices (2,3,4). However, these studies primarily focus on determining the needs of adult consumers and on the prescription and evaluation of appropriate assistive devices. There is no information provided on how to obtain useful design information from a group of young paediatric consumers with disabilities.

The difficulty that arises is how to acquire meaningful information from young children. The protocol selected must be both understandable and motivational for the child. Researchers investigating the treatment of pain in young children have found that children as young as 5 years of age can effectively use category scales, such as a scale of happy to crying faces, to describe their level of discomfort (5).

This paper describes a unique approach to surveying the preferences of one group of young consumers.

METHOD

The goal of the approach taken was to have a group of young children with disabilities evaluate features of specialized seating that included colour, seat shape, cushion firmness, covering texture, and pelvic belting. It was intended that the children be offered selections that would not compromise essential functional and operational aspects of the adaptive seating device.

Planning meetings were held with primary grade teachers and therapists from The Hugh MacMillan Centre (HMC) School in Toronto to determine the most suitable approach for polling their students. From these meetings, a hands-on "Seating Experience Day" was organized for the students (6-8 years of age). Of the 26 children who participated, 23 had cerebral palsy while the remaining three had other neuromuscular disorders. Ten children required wheelchairs with postural support systems.

Five "experience" stations were devised:

Station 1: Cushion Firmness Four visually-identical seat cushions were constructed and secured to small wooden chairs to assess the preferences of each child with respect to cushion firmness. Every child was allowed to sit for a short time on each cushion before being asked to rate it using a face scale (Figure 1). The children were asked to indicate whether they liked the cushion (by selecting the happy face), did not like it (by selecting the sad face), or were not sure whether they liked it or not (by selecting the middle face).

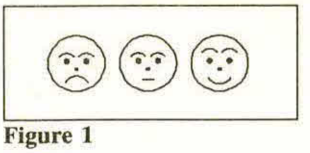

Figure 1

The seats were arranged such that each child was asked to make a choice without knowing the selection of the other students. The seating sequence was randomized to compensate for influences due to presentation order.

Station 2: Texture Four different types of seating upholsteries were evaluated. Each was glued to the bottom of one of four shoe boxes. The shoe box was covered and at one end a hole was cut to allow the children to put their hands inside. A small cloth flap was added at the opening to prevent the children from seeing the material inside. As at first station, the children were each asked whether they liked or disliked the textures by using the face scale. Again, the order of presentation was randomized.

Station 3: Colour and Shape Both colours and shapes were presented at this station. Four-inch square samples of four different colours (black, grey, purple, and lime green) were provided. The children were individually asked to indicate the colour they would choose for a seat. Two models of seating inserts were constructed from structural foam blocks. One seat had rounded corners, while the other had conventional, rectilinear sides. Each student was asked to indicate which seat shape they preferred.

Station 4: Lap Belt Two different types of 90 degree lap belts were evaluated by the children at this station. An appropriately-sized seat was mounted into a paediatric wheelchair and each child was positioned with the lap belt secured. Rails on the sides of the seat allowed for individualized placement of the belt. Each child was given a soft ball and asked to put it through a hoop in front of them. The hoop was placed such that the child had to lean forward to complete the task. After using both belts, the students were asked to indicate their preference.

Station 5: Measurement To assist in determining the range of sizes needed for the seating system under development, a measurement station was included. At this station, the child was asked to sit in a low wooden chair while eight body measurements were taken.

One or two researchers were assigned to each experience station. Each was provided with a script to ensure that each child was provided with the same instructions. Randomization schedules were prepared for each station to compensate for any influence due to the order of presentation. As a choice was made, the attending researcher recorded the selection.

One day before the experience day, teachers prepared their students by discussing what to expect. The children were also shown the face scale and told how to use it to indicate their preferences.

Two one-hour sessions were held with the 26 students divided into two manageable groups. At the start of each session, teachers divided the children into smaller groups of three or four. In this way, simultaneous evaluations were conducted at four of the five stations, with the fifth being used to accommodate "early finishers". The stations were separated by partitions to prevent children from being distracted by the activities of their classmates.

Experience day "passports" were also provided to each student so that as each passed through a station, a sticker was provided. In addition to being motivational for the child, the passport was used to keep track of the completed stations.

On the following day, teachers and a research team member held a group discussion (i.e. during "circle time") with their students to hear their opinions regarding the evaluation day. One week later, one researcher returned to the classrooms to discuss the cumulative results of the experience day with the students.

RESULTS

From the results of Station 1 (Figure 2), it appears that the children generally preferred the softer cushions. Only two of them disliked the softest seat. The children were on the seats for a short period of time, hence the design team will need to consider whether there are concerns in sitting on softer cushions for longer periods.

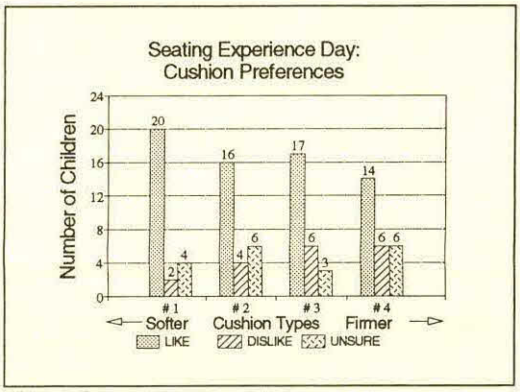

Figure 2

There was some uniformity in the children's preferences regarding the material textures. Generally, the students rated them all favourably as suggested by their selections (Figure 3).

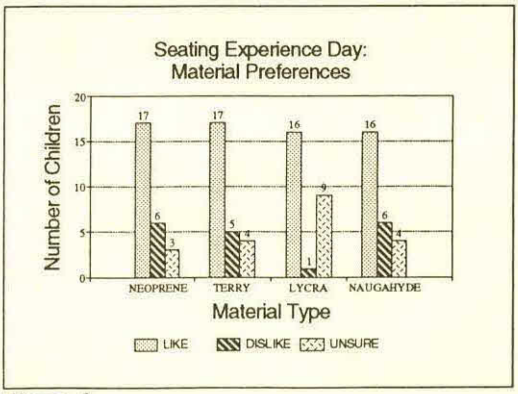

Figure 3

With the exception of one covering, the materials were disliked by either five or six children. It was interesting to see that a stretchy Lycra™-like material received a relatively high "not sure" rating. This may be attributed to its bidirectional nature (slippery one way and rougher the other). Only one child did not like the feel of this material.

There was a pronounced preference for non-neutral colours (purple and lime green, with more selecting the former). Twenty-two of the 26 children preferred these colours over the neutral black and grey. At the follow-up discussions with the children in the classroom, this preference was reinforced. However, some children also said that they would have chosen pink and blue had these selections been available.

Regarding their choice of seat shapes, most appeared to prefer the rounded shapes of seat and back, as opposed to the rectilinear version.

There did not appear to be a significant difference between the preference of lap belts used by the children at this station. It is difficult to judge why this was so. At this station, each child was asked to choose between one strap and the other, whereas at other stations, they were given the choice of "not sure". Perhaps the belts were too similar for the children to discern a difference, thereby making their selections arbitrary.

The anthropometric data obtained was relatively consistent and will be used to assist in sizing the adaptive seating system under development. From the feedback of project team members at this station, and based on classroom discussions with some of the students, this was an enjoyable experience for the children. For instance, many of the children found that the instruments used to take the measurements tickled them.

During the circle time discussions with their teachers on the following day, the children agreed that the favourite part of the experience day was getting the passport stickers. However, they were also positive about each of the experience stations.

DISCUSSION

As a pilot study, this approach to obtaining feedback from young children was successful. In general, it seemed that the children enjoyed Seating Experience Day. Integrating survey techniques that are both age-appropriate and fun for the children made the evaluation process meaningful for both the device developers and the students.

Participation in the planning stages by the teachers and school therapists was essential in creating a practical, enjoyable session that matched the abilities of the children polled. Some of the evaluation tools used may need refinement and tests of reliability and validity. It may also be interesting to judge whether a more sensitive face scale could be used to investigate to what degree they liked or disliked a stimulus.

This method of obtaining feedback from children may also prove useful in obtaining the perspectives of paediatric clients during the prescription of seating devices and in the development of other assistive devices.

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A HABILITATION SWING FOR A CHILD WITH CLOVERLEAF SYNDROME

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ABSTRACT

To aid in the habilitation of a nine year old boy with severe congenital defects, a novel swing was developed. The new swing, with its inverted pendulum design, allows the child to achieve instant motion when he presses a switch. This feature aids in the environmental control habilitation of the client, as he is able connect his actions with the motion of the swing.

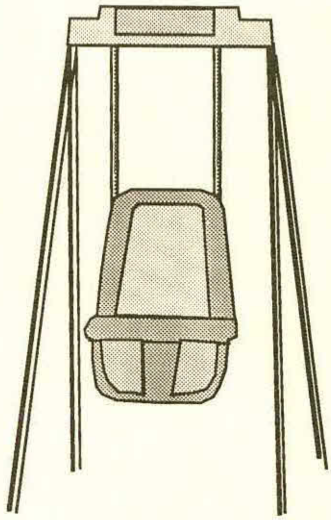
In addition to the instant motion feature, the new swing has several other advantages over conventional swings, both for the client in question and in general. The inverted pendulum design allows for much easier entry and egress of the client. The swing is also quite durable, having logged hundreds of hours of service to date, outlasting its commercially available predecessors.

BACKGROUND

In a previous study [1], the case of T.D., a nine year old child born with cloverleaf syndrome, was described. T.D. is deaf, blind, mute, and non-ambulatory. He enjoys the sensation of motion, such as in a car or buggy, but particularly the harmonic motion of a swing.

To aid in T.D.'s habilitation, the previous investigators wanted to improve his ability to communicate and control his environment. In terms of environmental control, it was felt that it was imperative that an activity be selected that the child both enjoyed and actively sought out. Because of its pleasing harmonic motion, they selected a swing as the environment that they wished to enable T.D. to control.

A commercially available child swing was obtained. This swing's design consists of a simple A-frame from which a child seat is hung, pendulum-like. A battery-powered electric motor at the top of the A-frame powers the swing in the familiar oscillatory manner. This swing was equipped with a switch that enabled T.D. to operate the swing by pushing the switch with his hand. The previous investigators wanted T.D. to be able to associate his pressing of the switch with the motion of the swing. One of the difficulties with the conventional swing used in the previous study is that the swing starts slowly, swinging back-and-forth through a short arc, and gradually building up to a much longer arc.



Typical A-frame style child swing

OBJECTIVES

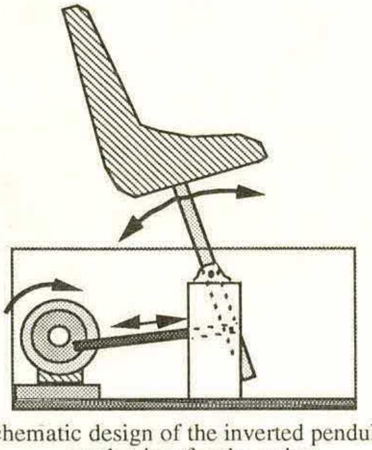
It was clear from the previous study that T.D. was able to connect the pressing of the switch with the commencement of motion (a critical result). However, the previous investigators wanted the mental connection between T.D.'s action (pressing the switch) with the motion of the swing to be crystal clear. An "instant on" swing, that would very quickly go from a dead stop to its normal speed, was thus desired. Several other swing improvements were deemed important. T.D. spends a great deal of time in his swing (up to four hours per day). At his current weight of about forty pounds, this results in short swing service lives and frequent replacement. Thus, a much more robust machine was desired. The A-frame design of most commercially available swings is somewhat inconvenient, in that it is difficult for a care-giver to place a child in the swing, because the A-frame itself gets in the way of the care-giver. This is a particular problem with T.D., because of his weight. T.D. has a younger, non-disabled brother. It was necessary for the swing to be safe and reliable in the presence of this rambunctious youngster. It was also desirable for the swing to be lightweight and portable, and as inexpensive as possible.

DESIGN AND DEVELOPMENT

A team of four senior mechanical engineering students was enlisted to design and build a machine for T.D. meeting the above objectives. Detailed results are contained in [2]. Machine concepts that incorporated several types of motion were considered. These included rotating motion ("washing machine" style), sliding motion (as along the coupler arm of a four-bar linkage), the incumbent type of motion (A-frame pendulum), rocking motion (as in a rocking chair), and an inverted pendulum.

Based on an analysis of the objectives described above, the inverted pendulum concept was adopted. To ensure the efficacy of the concept, the design team constructed a simple wooden model that employed the inverted pendulum concept. This mock up was used in a test involving the client. T.D was placed in a child seat atop the inverted pendulum mock up, and the mechanism was manually powered back and forth. T.D. clearly enjoyed the motion, which was of course slightly different from the motion of the A-frame pendulum design. Thus it was determined to proceed with detailed design and construction of the device.

The design of the machine is quite simple, as shown schematically below.



Schematic design of the inverted pendulum mechanism for the swing.

While the mechanism may be simple, the design of the machine included some critical parameters, such as the size of the electric motor and of the various members of the linkage. A computer program analyzed the motion of the linkage and allowed for proper sizing of the motor and linkage elements.

The completed prototype features a rigid frame supporting the motor, linkage and seat. A box encloses all moving parts except the seat and top end of the seat mounting post. The top of the box is just above the pivot point of the mounting post, thus reducing the pinch-point hazard. (The slot in the box through which the post extends includes a rubber boot, further reducing the pinch problem.) The machine is equipped with a variable timer such that it will run continuously for a preset amount of time each time T.D. presses the switch. After the preset time has elapsed, the swing stops.

EVALUATION

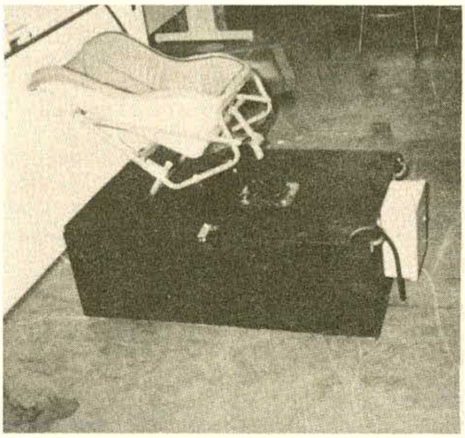
The machine was tested extensively with dead weights up to and exceeding T.D.'s forty lb. weight. After minor modifications, the machine was ready for testing with T.D. Initial tests with T.D. were satisfactory, and shortly thereafter the machine was turned over to T.D. and his family for home use. Immediately, the swing became a favorite activity of T.D., in which he continues to engage for three to four hours each day. After about two months, the machine suffered a minor failure when the plastic child seat developed a small fatigue crack due to the alternating stresses of the swing cycle. This problem was repaired, and in the ensuing six months, no further problems have developed. T.D. and his parents remain satisfied with the swing. The parents have found, as expected, that T.D. is much easier to move in and out of the new swing than in any of their previous A-frame models. This last improvement suggests that the new swing would offer some advantages in the general child swing market, and not only specifically for special children like T.D.

FUTURE WORK

A second-generation model of the swing is currently being designed for T.D by a new team of mechanical engineering students. While the existing swing satisfies the most important objectives admirably, it falls short in some secondary areas. The swing is rather heavy and not as portable as desired. The base is also rather large. Thus, it is difficult to move the swing from one room to another in T.D.'s home. The second generation swing design team is also attempting to use a smaller electric motor in the new device. The current model uses a large electric gear motor, which, when operated for three to four hours per day, makes a significant addition to the parent's electric bill! The new team is looking at various ways to reduce the amount of torque needed to start the swing in motion, currently the critical factor in the sizing of the motor. Various other refinements are also planned for the second generation prototype. The overall goal is to better serve the needs of T.D. and his parents, while at the same time broadening the appeal of the swing to other potential users.

ACKNOWLEDGMENTS

Funding for T.D.'s new swing was provided by the Tamera Lilly Brown Memorial Fund of the University of Tulsa. Mr. Charles J. Laenger of the Kaiser Rehabilitation Center in Tulsa provided technical support and encouragement throughout this project. T.D.'s parents, and T.D. himself, were gracious and patient customers and an invaluable aid to the swing design team.



Photograph of the new swing.

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GUIDE TO RESEARCH RESULTS
SEATING MATERIALS AND FABRICATION METHODS OF 12 NORTH AMERICAN CENTERS

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ABSTRACT
Wouldn't it be great to take off in a van to visit other centers like your own and talk shop- and I mean shop. In the September-October issue of the Resna newsletter, Andrew Brule of Sunny Hill Hospital in Vancouver suggested a personnel exchange program as one way of learning different techniques and sharing information. Well, I didn't have the resources for either suggestion, but I wanted to do something along those lines. The result is a collection of telephone interviews on materials and fabrication methods used in seating. This is a guide to the text of those interviews, and is meant as an invitation to review the full text.

BACKGROUND

Our services, like many others, grew organically, and are in their present shape because of the nature of the original organization. This research effort grew out of our need to learn from the experience of others, while putting all the small details in context by gathering general facility information.

RESEARCH QUESTIONS AND METHODOLOGY

Twelve centers that (a) serve people with developmental disabilities, and (b) are capable of fabricating their own seating systems were asked to participate in a one and one half hour phone interview. We discussed the nuts and bolts of seating- literally. Topics included seating fabrication and mounting, upholstering, laptrays, clients, and personnel.

This is not meant to be an objective, comprehensive survey of national practices. Nor does it make a claim to best practices. It is, rather, meant to elucidate specific ways in which seats, backs, and laptrays are made and put together.

> NOTE: A center name next to a comment means that the comment can be traced back to the text of their interview. The absence of any particular center name does not mean the converse; it simply means that the particular comment cannot be traced back to that center's interview text.
>
> This notation facilitates your search for details within the full interview text.

GUIDE TO THE RESEARCH RESULTS

<u>Seat and Back Base Materials</u>
Plywood continues to be the principal material used as a base for foam. Fir (CHC, MFB), nine-ply birch (LDC), and sign board (UHS) are variations, with comments that fir is strong, but has patches (non-cosmetic if it will show); while the number of plys increases overall strength. Sign board (from the road sign industry) is sealed to moisture and so needs no refinishing, allowing it to be reused. **Plastics** such as high density polyethylene are used with metal reinforcement to form the base (RIC, MHSB). Kydex has many advantages: it is strong and light, is easily heated and shaped (i.e., to provide a one-piece seat and back, or to provide a bi-angular back), and is esthetically pleasing (PCH@S, LDC).

Alternative Materials Sintra, a foamed PVC, is being used in trials (LDC, MFB), but has found to have the same weakness as ABS- it cracks (MHSB). Also unique is the vinyl covered aluminum pans from Metalcraft (UW) (removing questions of susceptibility to moisture or flexing).

<u>Seat and Back Mounting</u>
Here again is a standard for half the centers- **hooks and brackets**. Comments included .75 inch width having adequate strength (as compared to hardware of 1 inch width; MHSB, MFB), and a center moving towards black powder coated hardware (UW- powder coated but same base material). There were many alternative mountings, from a simple seat and back one-piece with a velcro strap in the back (which allows the system to be used on the floor, in a chair; SHHC, HMC), to permanent mounting of seat and back (LDC, SDC).

The question of what components to purchase versus what to make in-house is complicated by another choice- subcontracting the work. One center has found that this method not only saves money and allows customization, but allows their own staff to concentrate on more demanding tasks (MFB).

<u>Accessory Mounting</u>
Thoracic Supports Much more variety here, with most respondents making their own mounts. Custom bent metal brackets like those from Metalcraft have high marks for strength (AS, MFB, PCH@S, UHS). To build in

adjustment, some centers go to an I or T back (MHSB, SHHC) or mount to the front of the backrest (PCH@S, SHHC). **Swing-away mounts** are made custom by RIC, but bought by most, with no one company standing out (MFB, MHSB, UMI).

Pads vary in the base material (plywood, kydex) as well as the foams used (self-skinning foam- LDC, polyurethane foam- PCH@S, sunmate- UMI). Most respondents use commercial in addition to custom pads (PCH@S, RIC, UW).

Headrests Many facilities are using Otto Bock headrests (HMC, MFB, MHSB, RIC, SHHC, UHS, UMI), with some fabricating their own variations (AS, LDC, MFB). As a result, most mounting goes that way. There is some use of Miller's flip-down mount (UMI) as well as trial use of the new S.O.F.T. headrest system from Whitmeyer Biomechanics (MHSB, RIC, UHS).

Abductors When it comes to flip-down brackets, most respondents went to AEL (MFB, MHSB, RIC, SHHC, UHS, UMI), even though they were perceived as expensive. More standard mounts followed the stainless steel strap and slide-on style like that from Metalcraft. Finding that commercial pads tend to break away from their mounting base, and that upholstering the abductor is a chore, one center is looking at using two pads and a unique mount that allows adjustment (MHSB).

Straps A plethora of strap designs was reported, with most centers using nylon webbing and doing much in-house fabrication. Variations included an x-strap of sewn rubatex about nylon webbing (MFB), and the use of tubular webbing, of the kind that climbers use. This webbing prevents straps from slipping in adjustable plastic buckles (due to greater thickness) and affords more comfort since there are no edges to cut into a person (LDC, SHHC).

One novel way of keeping seat belts from being ripped out while at the same time keeping them above the wheels, was to sew several inches of 1/8 inch kydex to the end of the belt, using a hole in the kydex as your mount (MFB).

<u>Vacuum Forming</u>
The usual reasons for and against the use of vacuum forming vinyl were repeated here. On one side, it is believed to make the seat harder, may deform the foam, and may not handle complex contours (PCH@S); one center said that for clients who need the contouring for pressure relief, they wouldn't use vinyl (UW). On the other side is ease of application, time savings, no seams, and aesthetics (AS, HMC, LDC, MFB, MHSB, SDC, SUNY, UMI). All who use vacuum forming acknowledge its drawbacks, remark on skills needed to make it work, and have alternative methods for upholstering. Two centers were still considering the possibility (SHHC, UHS), and one did not have the room for the machinery (RIC).

The variety of machines used is of interest: 2 pizza ovens (MHSB, SDC), 1 infra red heater formerly used for packaging (LDC), 1 use of heat lamps (SUNY), 1 oven element (HMC), and 1 ceramic fiber heater (AS). Vacuum power came mostly from shop vacs or vacuum pumps. Most respondents have made modifications to their early systems- some have totally remade them; two centers who had purchased Pin Dot vacuum formers have replaced their heating systems (MFB, UMI).

<u>Upholstery Materials</u>
Use of vinyl continues to be popular, with its ease of use when vacuum forming, its waterproof quality, and its ease of cleaning. Those who turn to using **Rubatex** for its pressure relief qualities use the lycra covering (HMC, MFB, MHSB, PCH@S, UHS) or the nylon (LDC, SHHC, UW). Terry covered Rubatex got low points for getting dirty easily (RIC, UHS). Some are not using Rubatex, either because it is difficult to sew, or it holds odors more than does vinyl (SDC, UMI). Of those that use Rubatex, two do not suggest it for individuals who are incontinent (MHSB, UW).

Darlexx is being investigated as an alternative to Rubatex (has thin stretchy plastic where Rubatex has neoprene; LDC, SDC, UHS). Another center has cushions dipped by Danmar (UMI). Several centers make washable slip covers (HMC, PCH@S, RIC); removable covers make replacing the foam an easier task.

<u>Technician Training</u>
Seven of the respondents have sent technicians to national conferences (AS, HMC, MFB, MHSB, PCH@S, SDC, SUNY), mostly sending one or two technicians per year, or every other year. Other training includes monthly inservices (by manufacturers or in-house), local workshops, and visits to nearby centers.

Of most interest was the way in which technicians are defined. Those who are doing the fabrication are not easy to replace; they often gain knowledge and expertise which blurs the line between salaried "professionals" and hourly paid staff. Solutions vary from getting the job classified as professional staff (AS-though still not the same wage scale), to defining a third category of seating assistant or seating specialist (PCH@S, UMI).

Square Pegs and Round Holes
In my attempt to find a dozen centers that (a) served many people with developmental disabilities, and (b) did much fabrication in-house, it seemed inevitable that I would talk to some that did not fit- but that were interesting for their own reasons. I hope that you will read their individual profiles.

University of Wisconsin A seating "center" which operates away from a central building. A very interesting and successful outreach based operation, they make use of commercial components and have established relationships with local facilities.

State University of New York at Buffalo A relatively new seating service, using methods few others are using as extensively (Bead Seat, Matrix system). Emphasizing the science of seating and mobility through the use of seating simulation and database product information.

Helen Hayes Hospital Interviewed before the questionnaire was formalized, there is much information here on evaluation for equipment needs, as well as on the entire process and each professional's role.

DISCUSSION

By asking a wide variety of questions, I did not get the level of detail which a self-proclaimed details survey sought to do (like the material of the hooks and brackets used- stainless steel, steel, or aluminum; and the materials and head types of nuts and bolts used). Although the purpose of the general questions on services was to put all other answers in context, I believe the materials questions could be answered and judged without background information.

ACKNOWLEDGMENTS

Thanks go to every participant. With much energy, they gave their time and shared their knowledge. It is my hope that the results are as useful to them as they are to me. Special thanks to Jean Minkel of Helen Hayes Hospital, who allowed me to interview and visit her facility at the point at which I was figuring out what questions to ask. One of the most important lessons was that, as much as possible, know when to abandon the generic questionnaire in front of you and let people talk about what they think is most important.

Seating Centers Participating in the 1992 Interviews

AS- Assistive Solutions
Martin Tieg- IA

HMC- Hugh MacMillan Rehabilitation Center
Linda Mochan- Ontario

LDC- Lanterman Developmental Center
Brian Allison- CA

MFB- Mary Free Bed Orthotics and Prosthetics
Steve Anderson- MI

MHSB- Memorial Hospital South Bend
Kerry Jones- IN

PCH@S- Packard Children's Hospital at Stanford
Hugh O'Neill and Paul Trudeau- CA

RIC- Rehabilitation Institute of Chicago
Bill Armstrong- IL

SDC- Sonoma Developmental Center
Emmet Band- CA

SHHC- Sunny Hill Hospital for Children
Dave Cooper- British Columbia

SUNY- State University of New York, Buffalo
Nigel Shapcott- NY

UHS- University Hospital School
Fred Tchang- IA

UMI- University of Michigan, Ann Arbor
Valerie Musselman- MI

UW- University of Wisconsin, Madison
Bob Jones- WI

Helen Hayes Hospital
Jean Minkel- NY

The preceding has been just a taste of the information available from the actual interviews. To receive the full text, please write or call:

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Each interview is equivalent to 3 pages of text, and is separated by categories for easy scanning. Each takes 15 minutes to read.

Evaluation of three bowel care / shower chairs

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Audrey L. Nelson, RN, Ph.D., James A. Haley Veterans' Hospital, Tampa, FL.
Thomas L. Amerson, Ph.D., US Naval Medical Research Institute, Bethesda, Md.
Richard Saltzstein, MD, Clement J. Zablocki VAMC, Milwaukee WI.
Joseph E. Binard, MD, James A. Haley Veterans' Hospital, Tampa, FL.

Abstract

Bowel care is a critical aspect of daily living for persons with disabilities; ineffective bowel care can lead to severe and costly complications. An evaluation of three bowel care shower chairs was conducted and led to the conclusion that existing bowel care chairs were unsafe, inconvenient and ineffective for showering and bowel elimination. The study has determined that a new and enhanced design would also improve the safety, effectiveness, and efficiency of caregivers who perform bowel care procedures.

Background

There are over 200,000 persons with spinal cord injuries in the United States today. The majority of these patients have neurogenic bowels, requiring bowel care an average of three times a week. Because bowel care procedures can be lengthy, proper seating posture and comfort is necessary to prevent pressure ulcers. Patient falling is another common problem occurring during transfer, transport, or during actual bowel care or shower.

An interdisciplinary research team, comprised of an industrial designer, a nurse, a human factors/psychologist and two physicians collaborated to address this important problem.

Method

An evaluation of three commonly used bowel care chairs was conducted at the SCI Centers at the Milwaukee and Tampa VAMC's between January and August 1992. A total of 39 patients and 25 caregivers from the two SCI Centers participated in the study. Procedures developed by the investigators for related studies were adapted as necessary for this study. These included (1) evaluation of bowel care chairs with videotaping of caregivers and subjects simulating bowel care in a toilet room setting; (2) still photography of these bowel care chairs with and without patients and caregivers and (3) administration of questionnaires to patients and caregivers concerning bowel care procedures and effectiveness with the chairs.

Evaluation results

Traum-Aid chair model 494

Described as a bathing and toileting chair for use with trauma patients this chair offers unique features such as head support, high back, and adjustable leg and foot rests. Many of these features are however unnecessary for SCI patients.

Comfort: The chair offers extensive safety straps (legs, foot, chest, head) for stability and protection against falls. The seat, backrest, armrests and leg rests are padded to protect against skin breakdown, but the seat support board can be felt around the ischial area. Furthermore, the seat is too small (41x41cm-16x16 in.) to hold properly patients. In addition the seat surface has a seam, which can cause pressure sores. The arm rests are too narrow and mounted too high for proper use. The footstraps are held by exposed bolts that can cut the feet of patients. The backrest offers head and neck support for patients; but this feature is rarely needed for SCI patients. The backrest reclines, which is an excellent feature for patients with postural hyper-tension, however, the chair in reclined position was found to take too much space in a bathroom.

Photo #1: Traum-Aid chair.

Patient transfer: The brakes, described as "active dual-plunger floor brakes," cannot be easily used because their levers located below the seat are beyond the arm-reach of patients. In addition when activated by a caregiver they do not provide the stability necessary for safe patient transfer. The armrests are removable and the leg rests swing-up to an horizontal position but are not removable, making transfers difficult. Transfers were effective only when using a patient lift, impeding independent patient transfers.

Patient mobility: The 60 cm (24") wheels aid in mobility, however, the chrome rims on the wheels are prone to chipping and cutting the fingers of users. They are very slippery when wet, making self-propulsion very difficult after the shower.

Accessibility for bowel care: The seat has a 4-way adjustable opening for hand access. Although the opening seems wide enough, the support bar under the seat blocks hand access for digital stimulation (see photo #2). Furthermore, when the opening is positioned in the front, the patient is forced forward in an awkward, unsafe position. In addition, the position of the wheels is such that the chair cannot be properly rolled over a toilet. Finally the armrests do not facilitate locking the patient's arm in order to gain the necessary stability for reaching down.

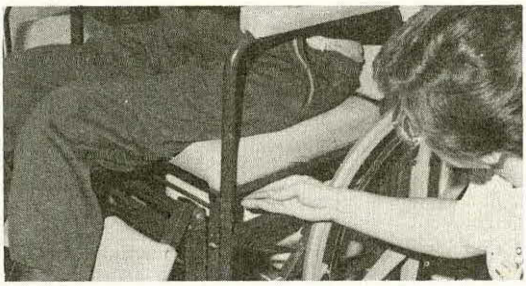


Photo #2: Close-up of hand access.

Accessibility for showering: The multiple Velcro straps deteriorate over time in the shower. The vinyl seat covering is easily cleaned but cracks easily, trapping water and odor inside. Too much of the body surface (head, neck, back, perianal area, back of the legs) is covered by the chair, limiting effective access for showering. Furthermore, if patients do not have good sitting balance, caregivers must hold them forward in an unsafe position for showering.

Lumex chair model 6872

Described as a chair for SCI or stroke patients this non foldable chair is used for showering, toileting and patient transport.

Comfort: The self-skinned, 4 position seat does not absorb water or urine, even when cut. The seat is too small (37.5x37.5 cm-14.75x14.75") to support properly patients and the hole in the seat is too big. This results in major difficulties in maintaining proper body alignment in the chair because patients have the tendency to fall in the hole. In addition this seat forces the spine of patients forward, putting unnecessary pressure on the ischial area and at times, pinching the scrotum. The seat cushioning does not wrap around its supporting board and leaves the wood exposed. This can lead to cuts or pressure sores. The armrests are not padded, too high, and too narrow for comfortable use by patients. The footrests offer good heel support and are coated to prevent the feet from slipping. However, the footstraps are held by bolts with exposed sharp edges that can cut the feet of patients. The foot-rests are also difficult to adjust up and down. The backrest of the chair is not height or angle adjustable.

Patient transfer: The swing-away footrests and drop-arms promote patient transfers in and out of the chair. The release mechanisms are designed for easy release, even for patients with impaired finger dexterity. The brakes mechanism protrude over the wheels which has resulted in cuts or bruises on the patient's hand. When the wheel tire pressure is low the brakes are not locking on the wheels. Furthermore, the brake mechanism do not work overtime, causing serious patient injuries due to falls.

Patient mobility: The 60 cm (24") wheels with pneumatic tires roll smoothly and the chair can be self-propelled. The wheel rims are corrosion resistant but smooth, and are therefore slippery when wet. Patients feel the chair lacks substance and are afraid that it will tilt during transport. Furthermore, the front casters are too small and don't take up the shock of a curb.

Accessibility for bowel care: The open frame combined with the U-shaped seat was designed to facilitate hand access for bowel care, but the structural member of the chair limits accessibility for digital stimulation (see photo #4). Furthermore, the wheels protrude in the back and interferes with getting the chair positioned directly over the toilet (see photo #4). When a patient has a bowel movement part of the stool falls on the floor. In addition the armrests need to be lowered to gain adequate hand access, which is difficult for quadriplegics who need a stable armrest to wrap their arm around for stability in order to reach down.

Photo #3: Lumex chair.

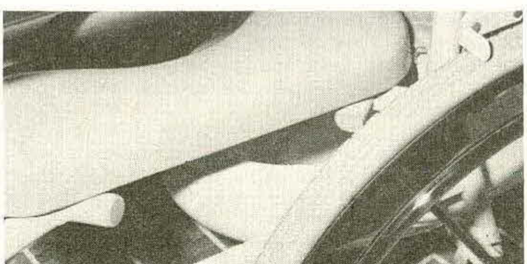


Photo #4: Close-up over toilet fixture.

Accessibility for showering: The mesh like material of the back-rest facilitates bathing, dries fast, and is easier to maintain than padded vinyl. The "open-frame" design provides reasonable access to all parts of the patient's body for showering.

E&J shower commode chair.

Described as designed for toileting and showering. This chair folds easily for storage.

Comfort: The chair has a foam cushion seat covered with a vinyl material, with no obvious seams. However, patients feel there is insufficient padding for safety and comfort. The seat is considerably larger (43x46 cm 17x18.25"), than the seat of the other two chairs. It has an un-broken oval hole and cut out sides for closer hand access (see photo #5). Both the armrests and legrests/footrests are removable to facilitate access and transfer, but over time they do not fit properly. The armrests are not padded and are not adjustable. The footrests are adjustable but do not have the heel-straps needed to prevent injury due to spasms. The chair has high and low back options but no width adjustment. Larger patients tend to press up against the armrests, which results in pressure ulcers.

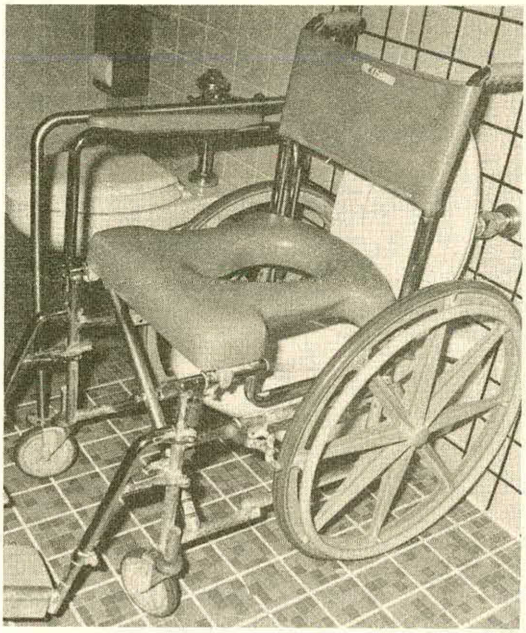


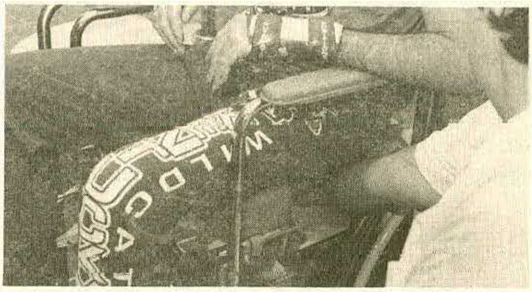
Photo #5: E&J chair.

Patient transfer: The brakes handles are reached easily by patients and covered with rubber. Initially, the brakes lock well and are tight. Overtime the brakes have failed resulting in falls and injuries during transfers.

Patient mobility: The wheels have rubber coated rims, allowing patients to self-propel even when the chair is wet. However, the rim's hand area is too narrow for quadriplegics to hold and push independently. The largest drawback, however, is that the chair is unstable and has a tendency to tip over during transfer or transport. Patients complain that they do not feel safe in this chair.

Accessibility for bowel care: Overall, accessibility is poor; the wheels and brakes partially block the two cut-out side openings (see photo #6). There is insufficient space between the seat and the toilet bowl to insert suppository or provide digital stimulation. Furthermore, there is no available space for hand access in the front or the back which is the area of choice for some patients.

Photo #6: Close-up of hand access.



Accessibility for showers: The open frame chair design allows reasonable access to the body to shower. However, the seat vinyl covering tears easily resulting in water/urine getting inside the foam padding. Patients tend to stick to the seat which can cause reddened areas or tears in the skin.

Conclusions

This study indicated that there were severe design deficiencies in the three and most commonly used bowel care chairs evaluated. Patients reported serious problems and complications from these chairs, including injuries from falls and pressure ulcers.

The results of this evaluation were incorporated in a VA Rehab. R&D research proposal to design a new bowel care-shower chair that addresses the functional, safety, and comfort needs of SCI patients and their caregivers.

Acknowledgements

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The views expressed in this paper do not necessarily represent those of the Department of Veterans Affairs or the United States government.

THE BACK SUPPORT SHAPING SYSTEM: AN ALTERNATIVE FOR PERSONS USING WHEELCHAIRS WITH SLING BACK UPHOLSTERY

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ABSTRACT

The back support shaping system was designed to address the postural problems wheelchair riders experience using chairs with sling backrest upholstery. Six individuals with spinal cord injuries evaluated the back support shaping system in a pilot study. Design specifications were optimized and used to develop a prototype which is currently being evaluated by sixty participants.

THE NEED

It is clinically accepted that sitting in a wheelchair with a sling backrest promotes rounding forward of the spine (Bergen & Presperin 90, Presperin 2/90), posterior tilting of the pelvis, which can lead to back and neck pain, and even long-term deformities of the spine and pelvis. Furthermore, these postures cause shearing because the tissue between the skin and the underlying bones becomes stretched and distorted (O'Neill 88). Hobson (1989) found that in general, a person with spinal cord injury will sit with a pelvis tilted posteriorly 15 degrees greater than a non-injured person. Most sling backrest upholstery sags within two to three months. A variety of back supports are commercially available and were evaluated by the authors. Most commercially available back supports do not have the ability to adjust for the different needs of the wheelchair user during the day, require removal in order to fold the wheelchair, do not work with the existing sling upholstery, and are not able to adapt to different people's back contours.

DESIGN CRITERIA

A back support is needed that satisfies the following design criteria:

a. Postural Control
For optimal stability and function, the back support must stabilize both the upper part of the pelvis, the sacrum, and the lumbar spine, if lumbar mobility is available (Zacharkow 90). If the person has limited lumbar mobility, a lumbar support will push the person out of the wheelchair. Applying a force to the posterior pelvis and sacrum is critical in achieving a neutral spinal position because of the fundamental importance of pelvic stability on postural alignment, and to take advantage of lumbosacral joint mobility (Margolis 92). Lateral stability provided by the curvature of standard sling upholstery should be retained.

b. Adjustability for Function
The back support should be **dynamic and flexible** for slight position changes and must adjust for the user's different seating needs, i.e.. static sitting and active propulsion. Also, the back support needs to accommodate and **adapt to each individual**.

c. Ease of Use
The back support should be **easily adjustable**: by the user while sitting in the wheelchair; with one hand; and by people with limited hand function and strength. This system must be able to **attach to different folding wheelchairs with sling upholstery,** and between the vertical upright members of the wheelchair frame. **The foldability of the wheelchair should be preserved**. The back support should not need to be removed in order to fold the wheelchair. Finally, a back support should add minimal weight to the wheelchair.

d. Performance Specifications
A back support should ideally **extend the life of the sling upholstery** of a standard wheelchair to five years. The back support system should **cost** less than $250. A back support should be **aesthetically pleasing** and acceptable to the wheelchair user.

Back Support Shaping System
The back support shaping system will provide wheelchair users with an affordable, lightweight, comfortable, posturally supportive, easily adjustable, back support alternative which does not need to detach from the wheelchair in order to fold the chair. No other commercially available back supports are able to meet the above design specifications. This system utilizes ergonomically shaped support pad(s) with tension straps. The support pads hook onto the vertical upright frame members of the wheelchair behind the sling backrest upholstery. The horizontal strap(s) can be tightened or loosened causing the pad(s) to press forward through the upholstery against the pelvis and spine in the desired location. Persons with a wide variety of functional limitations will be candidates for the back support shaping system. Persons inappropriate for the back support system include those with significant hip extension contractures, severe pelvic and spinal deformities, poor postural stability, and severe tonal and movement abnormalities.

PILOT STUDY

A pilot study was undertaken to: validate the need for a back support shaping system, determine the preferred spacing of the back support pads, and to take postural and pressure measurements with and without the back support. Six people with spinal cord injuries (ranging from C4 to L5 levels) served as participants and one non-disabled male served as a control. First, background information was gathered with regard to the person's wheelchair and seat cushion. Secondly, each person was fitted with the Evaluation Back Support (EBS) which is a plastic plate with two vertically oriented foam pads. The plastic plate was attached to the wheelchair frame by straps, and the tension of the straps was then adjusted by the therapist. The preferred lateral and vertical placement of the pads was determined individually with feedback from the participant. The displacement of the person's spine relative to the back frame members of the wheelchair was measured with and without the EBS. Pressure measurements were taken at the spine, greater trochanters, sacrum, thighs and ischial tuberosities with and without the EBS on four participants. Finally, the participants completed a questionnaire which asked questions about their functional level and their opinions about the EBS itself.

FINDINGS OF PILOT STUDY

Preliminary data showed the following. The participants' preferred spacing between the pads ranged from 12.5 to 14.3 cm., with the average span equaling 13.1 cm. The forward displacement of the person's spine with the EBS ranged from 0.5 to 5.2 cm. with the average displacement equaling 3.1 cm. This means that most people preferred over an inch of forward displacement when using the EBS. The preferred vertical placement of the pads varied for each individual. The following illustration shows a side profile of a wheelchair user's spine with and without the back support in place.

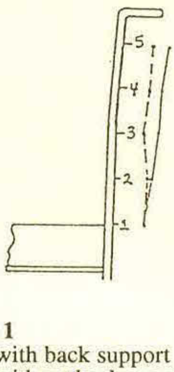

Figure 1
------ with back support
____ without back support

Subjectively, the users' sense of their own postural stability during functional activities changed when using the EBS. Some people felt more stable, some felt less stable during certain wheelchair maneuvers. The pressure measurements were inconclusive.

The feedback received verifies the need for a back support shaping system that works with sling back upholstery. The mean values obtained during the pilot study for the pad spacing were used to design the back support shaping system for current work as explained below.

WORK IN PROGRESS

a. Overview
The purpose of the current project is to optimize the design specifications for the back support shaping system through a fitting and interview process. Different configurations of foams, pad placement, and strapping are being evaluated by sixty participants. Each participant uses a wheelchair with sling back upholstery on a full time basis, has reliable expressive communication skills and does not have abnormal tone/movement patterns caused by brain damage. Persons with spinal cord injuries, polio, spina bifida, amputations and other neuromuscular diseases are participants in this study.

b. Methods
Subjects are evaluated by a physical therapist as to his/her appropriateness for using the back support shaping system. Participants are then fit with various configurations of the back support shaping system. Once the most comfortable and posturally beneficial position is obtained, the examiner records the participant's preference for each of the following criteria:

- Support pad configuration/shape, including length, width, and thickness
- Stiffness of the support pad material
- Position of support straps

c. Postural Measurements
The contour of the user's back in the sling upholstery before and after the back support shaping system attached to the wheelchair is measured. Measurements are made of the subjects' spine relative to the vertical frame members of the wheelchair. The information is then graphically displayed in a side profile.

d. Interpretation and Analysis of Data. The data is directing the design and fabrication of the back support shaping system, which will undergo more extensive evaluation in the future. The measurements direct the thickness of the support pad(s). Optimal contours and configurations of support pad(s) are decided upon such that ultimately each person will have the choice of support pad(s) according to his/her preference and comfort level. Depending on feedback regarding the ease of use of the adjustment hardware, a second design may be developed for people with limited hand function. The results of the above tests will be presented at the RESNA 1993 conference.

CONCLUSION

The development and testing of the back support shaping system is designed to enhance the physical and functional abilities in people using sling back wheelchairs. The results of this study will have implications for postural measurements in the clinic, and will encourage the development of seating options which are more functional and dynamic for the wheelchair rider.

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A Recursive Back Propagation Algorithm for Computing Net Muscle Moments and Net Joint Forces

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ABSTRACT

Calculating joint moments of the critical joints (wrist, elbow, shoulder) during wheelchair propulsion may help to further the understanding of possible injury mechanisms. A model was developed using the Newton-Euler method based on a variable degree of freedom body coordinate system (i.e., the number of body segments is not fixed). A recursive matrix back propagation algorithm was derived for determining 3-dimensional joint moments from kinetic and kinematic data. The algorithm is computationally efficient and numerically stable.

BACKGROUND

Evaluating joint moments during wheelchair propulsion of the shoulder via kinetic and kinematic analysis may identify causes of musculoskeletal overloading and rotator cuff injuries [2]. Carpal tunnel syndrome and other wrist and hand injuries are also experienced by wheelchair users. Research in this area suggests that carpal tunnel syndrome may be the result of nerve compression which occurs during forceful exertions with the hand and wrist in hyperflexion or hyperextension [1]. Repetitive strikes of the heel of the hand against the pushrim may cause pain and numbness of the thumb and fingers. The ability to accurately calculate joint moments for the wrist, elbow, and shoulder may help in establishing preventative measures for wheelchair users.

Knowledge of the time profiles of joint forces and moments are necessary for an understanding of the cause and implications of any movement [5]. Muscle and tendon forces of humans must be determined indirectly from available kinematic, anthropometric, and reaction force data. Rigid link-segment models are used to calculate net joint reaction forces and net muscle moments. Useful calculation of net joint reaction forces and net muscle moments requires a full kinematic description, accurate anthropometric measures, and a full description of the external forces [3]. The inverse dynamic model for the link-segment system using the Newton-Euler method was applied. The summation of all muscle activity at each joint is very useful information for the surgeon, therapist, and kinesiologist in their diagnostic assessments.

RESEARCH QUESTION

Net joint moment equations can be derived from the free-body diagrams of the link segment model [4]. However, the equations of motion can be programmed in any number of forms: some more efficient than others. The purpose of this study was to develop a numerically stable algorithm for efficiently computing 3-dimensional net muscle moments and net joint forces for n-degree of freedom link-segment models.

METHOD

A matrix approach was used to develop an algorithm for computing 3-dimensional net muscle moments and net joint forces. The similarity of the structure of the free-body diagrams for link-segment models was exploited.

Assumptions

1) Accurate measures of segment masses, centers of mass, joint centers, and moments of inertia are available. Each segment is of fixed mass which is modeled as a point mass located at the center of mass (COM). The segment COM remains stationary w.r.t. the segment, i.e. no relative motion. The mass moment of inertia of each segment about its proximal end remains constant during the motion. The length of each segment remains constant during the motion, i.e. no migration.

2) Accurate kinematic and external force-torque (kinetic) data are available. Kinematic and kinetic data are temporally and spatially synchronized.

3) All body joints are considered either hinge or ball and socket joints.

Forces Acting on Link-Segment Model

Three basic types of forces act upon link segment models: (1) gravitational forces; (2) external forces; (3) muscle and ligament forces. Gravitational forces act downwards through the COM of each segment and are equal to the mass times acceleration due to gravity. External forces must be measured using an external sensor. Such forces typically act over some area and are modeled by a force vector acting upon the center of pressure. Muscle and ligament forces are computed in terms of net muscle moments and net joint forces. Cocontraction, joint friction, and passive properties of muscle and tendons prevent determining actual muscle forces.

Basic Link-Segment Model

Each body segment acts independently under the influence of reaction forces, muscle moments, and force due to gravity. A feature of link-segment models is that the free-body diagrams for each segment are similar. This feature can be exploited to develop a single recursive algorithm with back propagation to calculate net muscle moments, and net joint forces.

To develop a 3-dimensional net muscle moment model and net joint force model, three free-body diagrams will be used. Muscle moments and joint forces are determined from the free-body diagrams using force and moment balance equations.

$$\sum F_x = Ma_x, \sum F_y = Ma_y, \sum F_z = Ma_z$$
$$\sum M_{Px} = I_{Px}\alpha_{Px}, \sum M_{Py} = I_{Py}\alpha_{Py}, \sum M_{Pz} = I_{Pz}\alpha_{Pz} \quad (1)$$

The moments and forces acting in the sagittal plane were determined with vector addition using force and moment balance equations, figure 1.

$$R_{xP} + R_{xD} - m\ddot{x}_{com} = 0 \quad (2)$$

$$R_{yP} + R_{yD} - m\ddot{y}_{com} - mg = 0 \quad (3)$$

$$M_{zP} + M_{zD} + R_{xD}y_{DP} - R_{yD}x_{DP} + mg(x_{DP} - x_{com}) - I_{Pz}\alpha_{Pz} = 0 \quad (4)$$

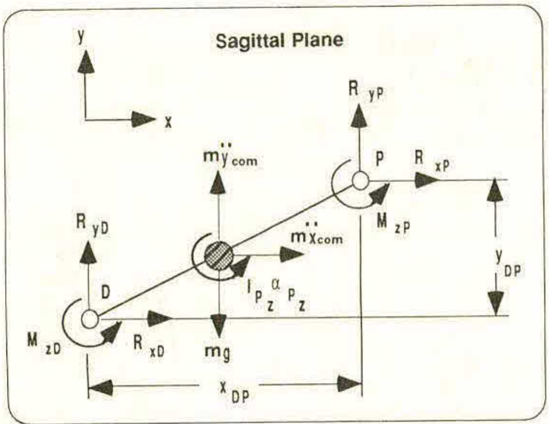

Figure 1. Complete sagittal plane free-body diagram of a single segment

The moments and forces acting in the frontal plane were determined with vector addition using force and moment balance equations, figure 2.

$$R_{zP} + R_{zD} - m\ddot{z}_{com} = 0 \tag{5}$$

$$R_{yP} + R_{yD} - m\ddot{y}_{com} - mg = 0 \tag{3}$$

$$M_{xP} + M_{xD} + R_{zD}y_{DP} - R_{yD}z_{DP} + mg(x_{DP} - x_{com}) - I_{Px}\alpha_{Px} = 0 \tag{6}$$

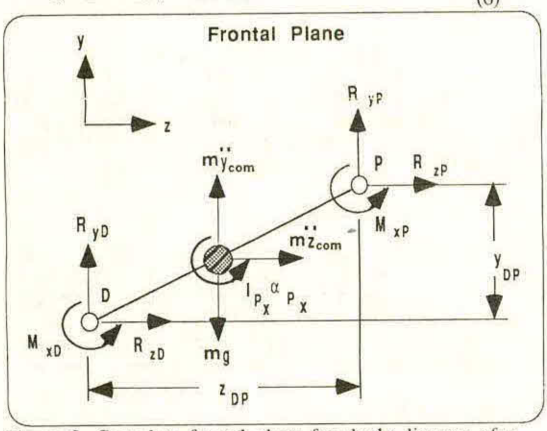

Figure 2. Complete frontal plane free-body diagram of a single segment

The moments and forces acting in the transverse plane were determined with vector addition using force and moment balance equations, figure 3.

$$R_{zP} + R_{zD} - m\ddot{z}_{com} = 0 \tag{5}$$

$$R_{xP} + R_{xD} - m\ddot{x}_{com} = 0 \tag{2}$$

$$M_{yP} + M_{yD} + R_{zD}x_{DP} - R_{xD}z_{DP} - I_{Py}\alpha_{Py} = 0 \tag{7}$$

Matrix Implementation of Joint Moments and Forces

The following definitions simplify transforming equations 2-7 into matrix form:

$$a_{xP} = \ddot{x}_{com},\ a_{yP} = \ddot{y}_{com},\ a_{zP} = \ddot{z}_{com} \tag{8}$$

For $x_{com} = Kx_{DP}$, $y_{com} = Ky_{DP}$, $z_{com} = Kz_{DP}$, then

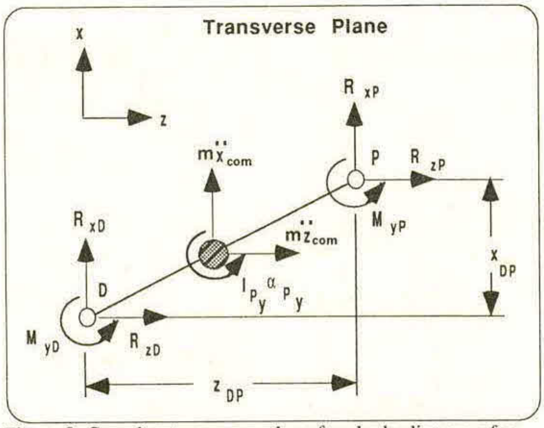

Figure 3. Complete transverse plane free-body diagram of a single segment

$$a_{xP} = \left[K(\ddot{x}_p - \ddot{x}_D)\right],\ a_{xP} = \left[K(\ddot{y}_p - \ddot{y}_D)\right],\ a_{xP} = \left[K(\ddot{z}_p - \ddot{z}_D)\right] \tag{9}$$

The angular accelerations about the proximal end, α_x, α_y, α_z, are the 2nd derivatives of each segment absolute angle about the appropriate axis.

Equations 2-8 can be written as a matrix equation using the following definitions:

$$\vec{r}_P = \begin{bmatrix} R_{xP} \\ R_{yP} \\ R_{zP} \\ M_{xP} \\ M_{yP} \\ M_{zP} \end{bmatrix}, \vec{r}_D = \begin{bmatrix} R_{xD} \\ R_{yD} \\ R_{zD} \\ M_{xD} \\ M_{yD} \\ M_{zD} \end{bmatrix}, \vec{a} = \begin{bmatrix} a_{xP} \\ a_{yP} \\ a_{zP} \\ \alpha_{Px} \\ \alpha_{Py} \\ \alpha_{Pz} \end{bmatrix}, \vec{M} = \begin{bmatrix} 0 \\ m \\ 0 \\ m(1-K)z_{DP} \\ 0 \\ m(1-K)x_{DP} \end{bmatrix}$$

$$I = \begin{bmatrix} m & 0 & 0 & 0 & 0 & 0 \\ 0 & m & 0 & 0 & 0 & 0 \\ 0 & 0 & m & 0 & 0 & 0 \\ 0 & 0 & 0 & I_{Px} & 0 & 0 \\ 0 & 0 & 0 & 0 & I_{Py} & 0 \\ 0 & 0 & 0 & 0 & 0 & I_{Pz} \end{bmatrix}, \Omega = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & z_{DP} & -y_{DP} & -1 & 0 & 0 \\ z_{DP} & 0 & -x_{DP} & 0 & -1 & 0 \\ -y_{DP} & x_{DP} & 0 & 0 & 0 & -1 \end{bmatrix}$$

The variables defined above can be combined to form a single matrix equation.

$$\vec{r}_P = \Omega\vec{r}_D + I\vec{a} + \vec{M}g \tag{10}$$

Equation (10) can be used to calculate 3-D net muscle moments and joint reaction forces for a particular "snap-shot" of a single segment.

RESULTS

The particular application determines the implementation of equation (10). For real-time implementation, the joint moment vector is calculated for the most distal end, the point where the reaction vector is measured, and then its negative is used as the reaction vector for the next most proximal link-segment model. This process is repeated until all desired joint moment vectors for a particular snap-shot have been calculated. The authors know of no combined kinematic-kinetic data acquisition systems with real-time capability. With the anthropometric, kinematic, and most distal joint-segment kinetic data defined, a real-time algorithm for each snap-shot can be outlined as follows:

for j = 1,n (11)
$\vec{r}_{Pj}(t) = \Omega(j)\vec{r}_{Dj} + I(j)\vec{a}(j) + \vec{M}(j)g$
$\vec{r}_{Dj+1}(t) = -\vec{r}_{Pj}(t)$
end

where j is the joint-segment index, and n is the number of joint-segments of interest in the model. The most distal joint-segment is defined as joint 1, figure 4. The algorithm in equation (11) would be called each snap-shot, time sample, to compute the joint reaction vector for joint-segments of interest.

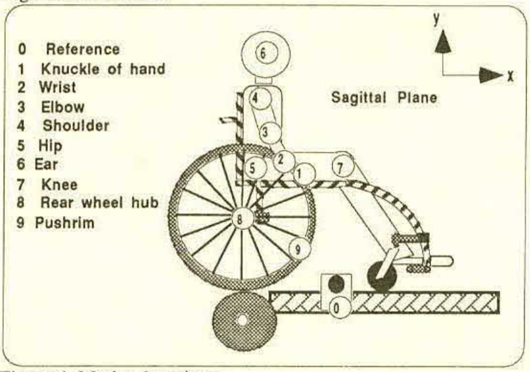

Figure 4. Marker locations

Currently, post processing is the only means of determining muscle moments and joint reaction forces. This is due to limitations in image processing systems, and the integration of kinetic and kinematic data. When post processing all of the anthropometric, kinematic and most distal link segment kinetic data are available. Most systems store this data in matrix format.

The kinetic data set for the most distal link-segment is defined as the reaction matrix.

$$\vec{R}_D(j,t) = \left[\vec{r}_j(t_0)\ \vec{r}_j(t_1)\ldots\ \vec{r}_j(t_N)\right],\ \vec{R}_D = R^{6 \times N+1}$$

The accelerations (linear and angular) for each joint segment can be written as an acceleration matrix.

$$\vec{A}(j) = \left[\vec{a}_j(t_0)\ \vec{a}_j(t_1)\ldots\ \vec{a}_j(t_N)\right],\ \vec{A} = R^{6 \times N+1}$$

The mass and moment arms of the Earth's gravitation can be combined into a single matrix for each joint-segment.

$$\widetilde{M}(j) = \left[\vec{M}_j(t_0)\ \vec{M}_j(t_1)\ldots\ \vec{M}_j(t_N)\right],\ \widetilde{M} = R^{6 \times N+1}$$

Selecting the form of the kinematic data matrix can improve the efficiency of the algorithm.

$$\vec{X} = \begin{bmatrix} x_{1DP}(t_0)\ y_{1DP}(t_0)\ z_{1DP}(t_0)\ldots\ x_{nDP}(t_0)\ y_{nDP}(t_0)\ z_{nDP}(t_0) \\ x_{1DP}(t_1)\ y_{1DP}(t_1)\ z_{1DP}(t_1)\ldots\ x_{nDP}(t_1)\ y_{nDP}(t_1)\ z_{nDP}(t_1) \\ x_{1DP}(t_N)\ y_{1DP}(t_N)\ z_{1DP}(t_N)\ldots x_{nDP}(t_N)\ y_{nDP}(t_N)\ z_{nDP}(t_N) \end{bmatrix}$$

All of the matrices are of the proper dimension to calculate the muscle moments and joint reaction forces. However, the reaction matrix requires some preconditioning which makes the post processing algorithm slightly more complex than the real-time algorithm.

for j = 1, n (12)
for t = 0, N
$\widetilde{R}_D(j,t) = \Omega(j,t)\vec{R}_D(j,t)$
end
$\vec{R}_P(j) = \widetilde{R}_D(j) + I(j)A(j) + \widetilde{M}(j)g$
$\vec{R}_D(j+1) = -\vec{R}_P(j)$
end

DISCUSSION

A general approach to determining 3-D muscle moments and joint reaction forces was derived. Methods of implementing the algorithm for real-time and post processing applications were developed. This approach is computationally efficient because the matrix structure takes advantage of computer data structures. The algorithms only require simple matrix multiplication and addition. The matrices are triangular which simplifies computation. All transformations are numerically stable. The algorithms can be implemented with any number of languages (C, Basic, or Fortran) or software packages (Matlab, Mathcad, or Mathematica). Computations of muscle moments and joint reaction forces show a substantial speed-up with the matrix approach compared to directly programming model equations. In addition, the algorithm is independent of model order. This makes the algorithm useful for any number of biomechanical models.

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CRASH SIMULATIONS FOR WHEELCHAIR-OCCUPANT SYSTEMS IN TRANSPORT

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ABSTRACT

An approximate method is described for determining the best and worst possible responses of a wheelchair-occupant system during a crash. The results obtained by this method for a computer simulated crash with an ISO(International Standards Organization) deceleration corridor are given. Since the responses for any two simulations which have decelerations that lie within the ISO corridor must fall between the best and the worst response curves, the results are useful as a measure of sensitivity when comparing data from different tests.

INTRODUCTION

The system under consideration is an occupied wheelchair attached by tiedown bars to the floor of a transporting vehicle. The response of this system to impact loads during a crash is simulated in sled tests by forcing the deceleration of the sled to lie within specified time -varying upper and lower bounds. If this bounded deceleration is subjected to further controls to make the peak tiedown stress assume its least possible magnitude, this deceleration is characterized as the best disturbance and the resulting system response as the best response. On the other hand, if the deceleration is such that the peak tiedown stress takes on its greatest possible value, the deceleration is the worst disturbance and the system response the worst response. In general, when loading constraints for a linear elastic structure are expressible as linear inequalities, the best and worst disturbance problem can be solved by linear programming. The purpose of this paper is to find the best and worst deceleration functions for a simplified model of the wheelchair-occupant system to which linear programming can be applied and to study the behavior of the original, nonlinear system with these deceleration functions. This is a game theory approach that provides an approximate best and worst disturbance analysis for a wheelchair-occupant system under impact loads during a crash.

A single degree-of-freedom linear spring-mass system with mass equal to the total mass of the wheelchair and the occupant dummy - about 193 lb - and with stiffness equal to that of the tiedown bars - about 600 lb/in - is the model of the wheelchair-occupant system to which a best and worst disturbance analysis is applied. One end of the spring is attached to a rigid body representing the sled, whose velocity change during the crash is taken to lie between 30 and 36 mph. An acceleration corridor defined by ISO(International Standards Organization) is used.

The AAMRL Articulated Total Body Model simulating package(ATB) has been used to calculate the best and worst responses of the occupant and wheelchair under the best and worst decelerations obtained by linear programming as mentioned above. The occupant is a Hybrid III dummy. This simulation gives the possible minimum and maximum wheelchair and occupant responses during sled tests whose decelerations are specified by standard corridors. A response sensitivity analysis can be performed for crash pulses falling within standard corridors.

RESULTS AND DISCUSSION

The decelerations of the sled corresponding to the best and worst tiedown forces were computed using linear programming for the spring-mass model of the wheelchair and occupant. These decelerations and the ISO acceleration corridors within which they lie are shown in Fig. 1. The tiedown force graphs in Fig. 2 and the safety belt forces in Fig. 3 use the best and worst decelerations of Fig. 1 for the sled, but are obtained using a multi-degree of freedom model for the wheelchair and an articulated, nonlinear dynamic model for the dummy. Figure 4 shows this nonlinear model at three different instants during a best response crash simulation run with the computer program ATB. An animated display of a sequence of such pictures can be used to follow the instantaneous kinematics of the system during a simulated crash.

As long as the deceleration of the sled is constrained to lie within the ISO corridor, the least peak tiedown force which must be exerted during the crash is as shown in Fig. 2a. This corresponds to the best disturbance. The tiedown force whose peak value is the largest possible varies with time as shown in Fig. 2b. This corresponds to the worst disturbance. The results show that the tiedown force ratio between the worst and the best decelerations is R = 1559 (lb)/991(lb) = 1.57 for a polyester tiedown bar. This means that the responses (tiedown forces in this case) for two different test sled runs, both of which have decelerations that fall within the ISO corridor, can vary by 57 percent.

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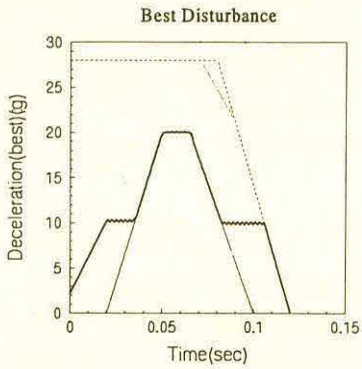


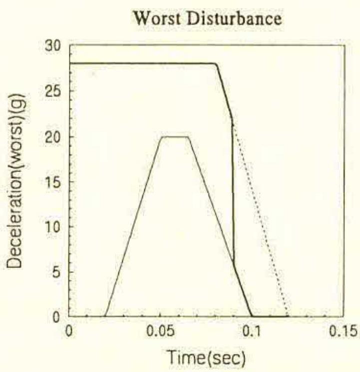
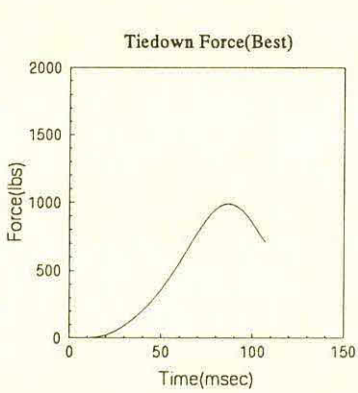
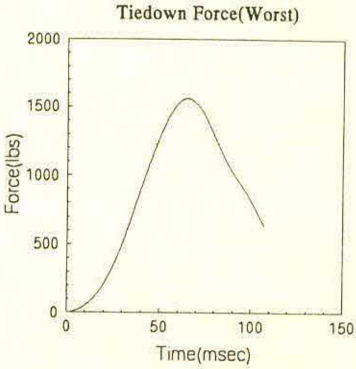


Fig. 1 Best and worst decelerations within the ISO corridor(shaded) corresponding to the least and maximum peak tiedown forces

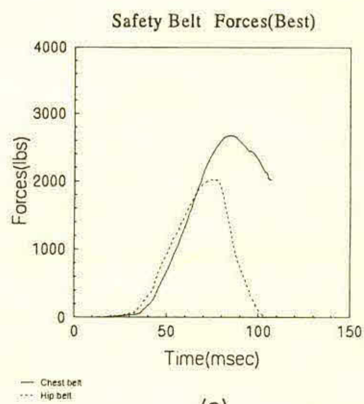


(a)

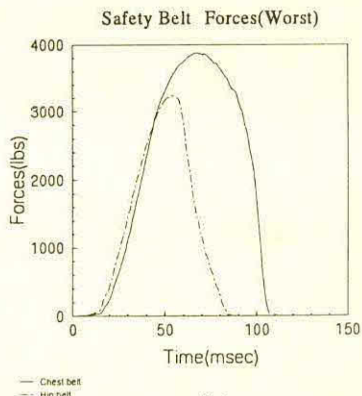


(b)

Fig. 2 Best and worst tiedown forces



(a)



(b)

Fig. 3 Best and worst safety belt forces

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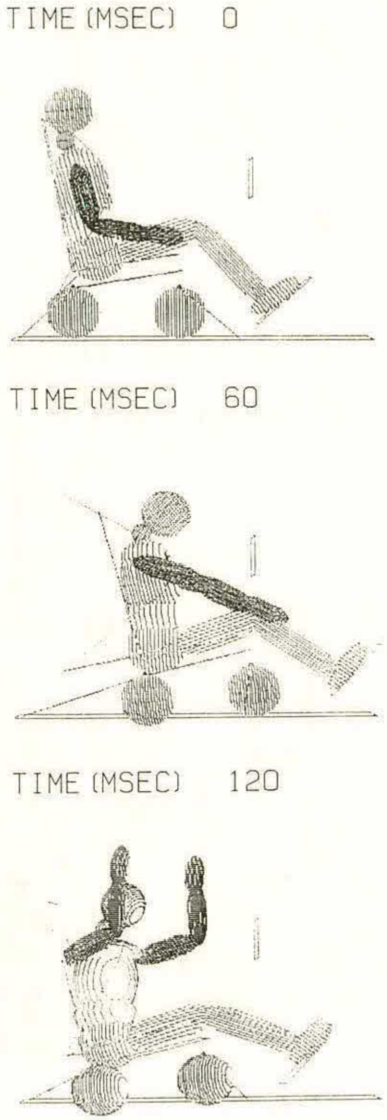

Fig. 4 Motion of wheelchair-occupant during crash

Design of an Anthropomorphic ISO-RESNA/ANSI Wheelchair Test Dummy

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ABSTRACT

A set of standards has been approved by the American National Standards Institute (ANSI) and by the International Standards Organization (ISO). Test dummies are intended for tests in which the wheelchair is required to be loaded. With the large variety of wheelchairs to be tested there is need for some modifications to the dummies. Currently a contoured loader gage is used for measuring seating dimensions and a planar fatigue dummy is used for testing durability. The lack of anthropomorphic contours of fatigue test dummies may mask failures that would occur during actual use. The design of a contoured dummy suitable for fatigue testing and seating measurements may make test results more meaningful and reduce the amount of test equipment required.

Background

There are numerous persons in the World who rely on wheelchairs for their mobility, and for their well being. Nearly 1.2 million Americans use wheelchairs as their primary source of mobility (Pope A.M., Tarlov A.R., 1991), and over 20 million people across the World could use wheelchairs (Hotchkiss R., Knezevich J., 1990). A substantial number of people depend on research in wheeled mobility for their quality of life.

Standards are required to establish minimum performance and durability criteria for wheelchairs. Standards benefit consumers, manufacturers and third party providers. The ANSI Technical Advisory Group (TAG), organized by RESNA is made up of representatives from many different disciplines (McLaurin, C.A., Axelson P., 1990). This helps to ensure that engineering, ergonomic, aesthetic and performance needs are considered. Standards help manufacturers in comparing their products on a quantitative basis with other manufacturers' products, and with establishing minimum design criteria. Consumers benefit by being able to evaluate wheelchairs before they are purchased. Purchasing agencies are assisted in establishing reasonable acceptance criteria.

Standards consist of two primary components: 1) Tests and 2) Normative Values. The tests have been developed, though no doubt there will be some refinement. The normative values can only come by applying the tests. The development of normative values is starting to show several things, not the least of which are: 1) the need to modify some of the standards, 2) the need for independent evaluation, 3) the need for disclosure. The application of the standards requires intimate knowledge of the standards and the intentions of their developers. Clarification and simplification of some standards is required (Tam E.W.C., Chiu Y.M., Evans J.H., 1992)

This paper shall focus on some improvements in the design of wheelchair test dummies (ISO 7176/11) and of the loader gage device (ISO 7176/7). There are four dummies used for wheelchair testing (25, 50, 75, 100 kg.). Dummies can be used for all tests where the wheelchair is to be loaded. The loader gage is used during measurement of seating dimensions.

Statement of the Problem

The dummies described in the ISO/RESNA standards are linear and may not load wheelchairs realistically. On some wheelchairs the seat and back of the dummy are support by the wheelchair's seat and backrest frame members. On other wheelchairs the dummy is supported by the upholstery. The inconsistency in the manner in which the dummy interfaces to the wheelchair can alter fatigue test results. The objective of this design project was to develop a test dummy which meets ISO/RESNA standards (at least intentions) but is contoured to load the wheelchair more realistically.

Rationale

The ISO/RESNA dummy should be similar anthropometrically and anthropomorphically to a human wheelchair rider and should be much more durable than any wheelchair being tested. The dummy should load the wheelchair similarly to how a wheelchair user would load the wheelchair. The seat and back of the dummy should be contoured similar to a human. However, the seat and back of the contoured dummy must be durable enough to withstand numerous fatigue tests. The feet of the dummy should be able to rest properly on the footrest(s) of a wide variety of wheelchairs. The back should lean properly against the backrest and the base should sit properly on the wheelchair seat. The design suggested in the standard has been observed to shear the seat upholstery on some wheelchairs, or to sit directly on the frame for others. The 100 kg. dummy is commonly used to test many wheelchairs, and must be designed to sit properly in a number of designs.

Design

The design outlined here was for a 100 kg. test dummy. However, the process could be extended to the other sizes as well.

Design Criteria:

1) The dummy was to meet the intent of ISO/RESNA standards for both fatigue testing (ISO 7176/11) and for seating measurements (ISO 7176/7).

2) The dummy was to be capable of withstanding 10 million cycles in a wheelchair on an ISO/RESNA Double Drum Tester.

3) The dummy was to be used as a linear test dummy or as a contoured dummy.

4) Materials were to be commonly available, and simple to apply.

Material Selection

The dummy frame was constructed of 3/8 inch aluminum (6061T6) plate. This material was selected because it is a relatively inexpensive structural aluminum, which is easy to machine, and is widely available. Steel plates were used for additional mass. Steel is very durable, is readily available and is easy to work with. All fasteners were grade 8 (SAE).

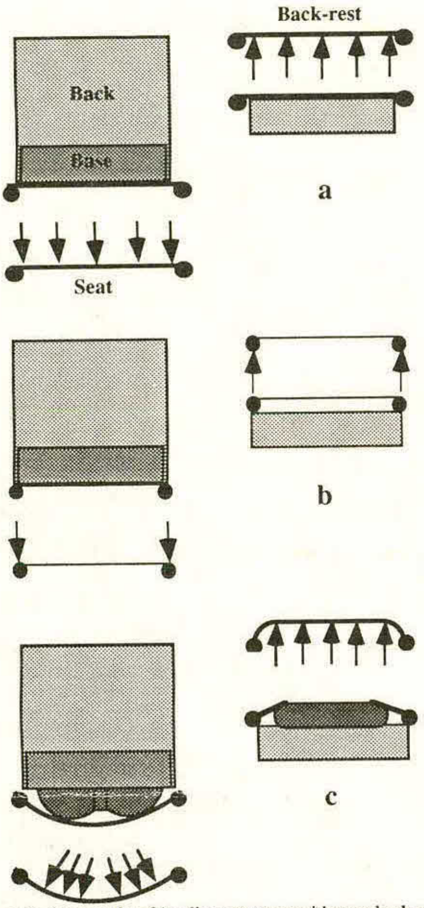

Figure 2. Schematic of loading patterns with standard and contoured dummies, (a) standard dummy where back and base of dummy are narrower than the wheelchair seat and backrest supports, (b) standard dummy with back and base of dummy equal to or wider than the wheelchair seat and backrest supports, (c) contoured dummy with loading more similar to human.

The buttocks of the dummy were constructed from sections of a composite, epoxy resin shell and epoxy resin with cork core, 10 pin bowling ball. A bowling ball was chosen for its availability, low cost, and precision. The thighs and back contour of the dummy were constructed of red oak. The thighs and back are bolted to the dummy base and back, respectively. Red oak is a commonly available, inexpensive hardwood.

Frame Geometry

The basis for the dummy was constructed as per ISO/RESNA standards. The seat was modified by adding slices of a bowling ball to the posterior end of the dummy. Slices from opposite sides of the bowling ball were mated and bolted to the rear portion of the dummy base.

The slices were chosen to mimic a human buttocks, and so as not to sit on the frame tubes for most common adult wheelchairs.

The base was further modified by adding contoured oak thighs anterior to the bowling ball slices. The thighs are rounded to mimic human thighs, and are mated to the buttocks. The back of the dummy was modified by adding a contoured oak back supplement. All contour elements were bolted to the existing aluminum dummy. The contours were designed to match human contours and to be suitable for making wheelchair seating dimension measurements (ISO 7176/7). The dimensions and layout of the contour elements are depicted in Figure 1. The legs are the same as those reported previously (Cooper R.A., Ster J.F., Myren C., Pettit D., 1992).

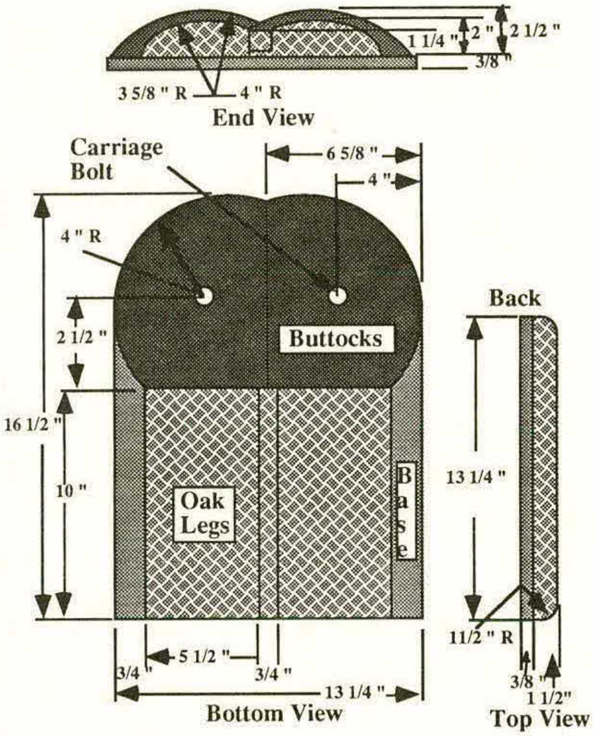

Figure 1. Layout for contoured fatigue-loader gage dummy

Development

The design specifications developed out of experience gained by testing wheelchairs to current ISO and RESNA/ANSI Standards. Upon testing a variety of styles of wheelchairs from several manufacturers, it was discovered that the dummy did not sit consistently on all types and sizes of wheelchairs. It was hypothesized that the results of some wheelchairs may be biased because of dummy loading. Sometimes the dummy would sit on the seat support tubes, others it would seat just between the seat support tubes (often shearing the upholstery), and others it would sit between the seat support tubes.

This created a variety of different load cases, making comparison of fatigue results difficult, Figure 2. In addition, the loader gage used for seating measurements can be expensive, and adds to the number of test dummies required to evaluate wheelchairs. Use of the same dummy for fatigue testing and seating dimensions would help to make results more meaningful, and reduce the amount of specialized test equipment required by testing centers.

Typically, wheelchairs are tested for approximately 200,000 cycles on an ISO/RESNA Double Drum Tester, and 7000 cycles on an ISO/RESNA Curb Drop Tester. The contoured dummy had to be designed and built to withstand several tests without damage or deformation.

The dummy was constructed first by determining the appropriate geometry using a CAD, EZ-CAM, package. The parts were than rough cut on a band saw, and finished cut on a milling machine. The final finish work was done by hand. The components (back, seat, legs) of the dummy were weighed than appropriate steel weights were cut and bolted to the frame in the proper locations. The frame was bolted together. An adhesive was applied to all bolts to inhibit loosening. Because of the dummy contour, a layer of high density foam was not added to the base and back of the dummy, rather sheets of high density foam were placed between the wheelchair and dummy during testing.

Evaluation

The contoured dummy has survived over 600,000 cycles on an ISO/RESNA Double Drum Tester and 21,000 cycles on an ISO/RESNA Curb Drop Tester without any signs of wear or fatigue, Figure 3. The dummy has experienced no loosening of any of the bolts or screws which hold it together. The use of foam sheets placed between the chair and dummy has minimized the problem of foam damage and breakdown accompanied by glueing foam to the dummy.

The use of the dummy as a loader gage has proved effective. However, its size and weight make it awkward.

A comparison study between fatigue test results using a standard linear ISO fatigue dummy and the contoured dummy is in progress. The results should indicate any difference in fatigue life based upon contoured and linear dummies.

Discussion

Several improvements to ISO/RESNA dummies can still be made. The standards ISO 7176/11 & RESNA WC/11, and ISO 7176/7 & RESNA WC/7 should be changed to permit use of the proposed contoured dummy for all tests requiring the wheelchair to be loaded. The loading scheme of a contoured dummy is probably more consistent with that of a wheelchair user, and will likely yield different fatigue failure than the current linear dummy. Contouring the dummy back and base resolves the problem of the dummy and seat support tubes conflicting.

Acknowledgements

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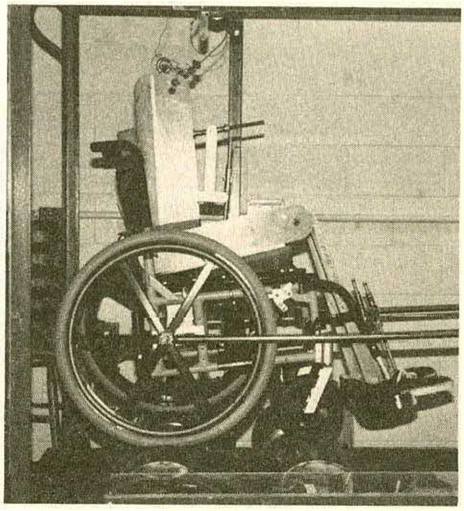

Figure 3. Photograph of contoured dummy during fatigue testing.

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Effects of Undeformed Contour and Cushion Stiffness at the Buttocks - Seat Interface

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ABSTRACT

The primary focus of this project was to investigate the hypothesis that the optimal pressure distribution at the buttocks-seat interface is achieved by matching the shape of the enveloping surface to the unloaded shape of the buttocks. A gel buttocks model with a wooden core representing the ischial tuberosity was used to load cushions that were contoured to match the shape of the model. Cushions of various indentation load deflection (ILD) rating (an index used to measure cushion stiffness) and various contour depths were tested. Cushion deflection, internal pressures at the wood-gel interface and external pressure at the gel-cushion interface were measured and used to determine the efficacy of contoured cushions. The lowest cushion deflection and lowest internal and external pressures were measured with the cushion of the deepest undeformed contour. A strong linear relationship was found between internal and external pressures.

INTRODUCTION

Wheelchair users who maintain a seated posture for lengthy periods of time are at risk for developing pressure ulcers. Pressure ulcers are most common underneath bony prominences such as the ischial tuberosities in the buttocks. There are over one million wheelchair users in the United States. This presents a need for the investigation of the mechanics of pressure sore formation and approaches to reduce the likelihood of their occurrence.

Chow [1974] inferred from his experiments that a purely hydrostatic loading would incur minimum tissue distortion, reduce shear and the resultant occlusion of blood vessels. He concluded, based on Hertz Contact Stress Theory, that hydrostatic loading would be achieved if the seat surface matched the undeformed shape of the buttocks. This hypothesis has been the driving force behind efforts to build devices that measure the shape of the buttocks-cushion interface. At the University of Virginia Rehabilitation Engineering Center (UVA REC) an electronic shape sensor (ESS) was developed to measure seat interface contours. Clinical studies involving human subjects showed that contoured cushions are more effective in reducing interface pressures than flat cushions [Sprigle et al., 1990]. The contour of the buttocks that is measured when an individual is seated on the ESS reflects the shape of the loaded buttocks after tissue deformation takes place. This is a "deformed contour", not the "undeformed contour" that Chow's hypothesis prescribes. Currently, no shape measurement systems measure the undeformed shape of an object.

This research project was designed to determine the influence on the buttocks of cushions that are contoured to match the undeformed shape of the buttocks. Since knowledge of the undeformed shape was necessary, a buttocks model of defined shape was used to load the cushion. A gel-based model was used to represent one-half of the buttocks designed as a section of a sphere with a wooden core in the middle that represented the ischial tuberosity.

Cushions contoured with the undeformed shape to various depths were loaded with the buttocks model. Material properties (ILD) of the seating surface also play an important role in the distribution of forces. When prescribing contoured cushions the therapist must often choose a cushion with a high ILD rating in order to provide lateral stability and to avoid bottoming out the cushion. Cushions of 3 contour depths and 3 ILDs, comprising a total of nine cushion configurations, were evaluated. Among the measured parameters were cushion deflection core, pressure at the interface of the wood core and the gel (internal pressure) and pressure at the interface of the buttocks model and the cushion (external pressure). All of these were measured in the area immediately beneath the wooden core, representing the ischial tuberosity. Reduced magnitudes of these parameters would diminish the risk of pressure ulcer formation.

METHODS

A model shaped as a section of a sphere, 177.8 mm in diameter (Fig. 1), was fabricated based on previous work [Chow, 1974]. The core representing the ischial tuberosity was 32 mm in diameter with a flat upper end, a rounded lower end and a total length of 38 mm. A transducer (XTM-1902-50A, Kulite Semiconductor, Inc.) was threaded into the center of the core so that the pressure sensitive area was flush with the rounded lower edge of the core. Gel representing soft tissue was cast around the instrumented core by Southwest Technologies in Kansas City, Missouri. The gel used was a mixture of glycerol, cross-linked rubber and water.

A wooden base disk was attached to the upper edge of the core to transfer the applied load to the model. The model was assumed to represent one-half of the buttocks of a medium framed person weighing about 68.2 kg. The upper body accounts for about two-thirds of a person's total body weight. Since only one-half of the buttocks was modeled, a weight of about 20 kg was applied to the model.

The cushions that were tested included flat cushions and cushions contoured with the unloaded shape of the model to varying depths. The 100 mm thick cushions were of three ILD ratings - 45, 55 and 70 lbs, and contour depths were 20 and 60 mm maximum depth. Three flat (non-contoured) cushions were also tested, constituting a total of 9 cushion configurations that were included in the study. The undeformed contours were generated in Quattro Pro using the equation of a hemisphere. A resolution of 5 mm was used between points. Once the contour of the hemisphere was generated, the contour of the cushions was obtained by globally subtracting the required value so that maximum depth of the contour was 20 mm and 60 mm. This was done using software developed at UVA-REC. The contours were then cut into foam cushions using a numerically controlled cushion carving machine that was built at the UVA REC [Brienza, 1990].The buttocks model was also loaded on a flat rigid surface to obtain baseline information. However, the load applied in this case was 8.4 kg to avoid rupture of the model.

Final testing was performed using the foam contour gauge which was one of the earliest versions of the electronic shape sensing system. Using this system it was possible to measure cushion deflections. Internal pressure was measured using the XTM transducer. The routine to obtain internal pressure transducer information was incorporated into the software controlling the contour gauge. Pressures were measured before loading and after loading and the difference between the two - a gauge pressure - was used to compare the different cushions. External pressure was measured using an Oxford Pressure Monitor.

RESULTS

Five trials were performed for each of the ten configurations and then averaged to obtain the data in the table below.

ILD	Depth	Cushion		Pressure	
		Deflection		Internal	External
lbs	mm	mm	%	mmHg	mmHg
45	0	55	54	128	85
45	20	44	55	90	67
45	60	8	21	78	48
55	0	42	42	142	101
55	20	30	37	106	77
55	60	6	15	84	61
70	0	33	33	151	110
70	20	18	23	136	90
70	60	4	10	80	58
rigid	0	-	-	332	214

Fig. 2. is a graph of cushion deflection versus contour depth. The raw data for each of the five trials of the nine cushion situations, were then pooled together for statistical analysis. Univariate analysis of Variance (ANOVA) was used to determine the influence of each independent variable (ILD and contour depth) on each dependent variable. The p values in all cases was found to be 0.001 or less. ANOVA was also done to study the combined effect of ILD and contour depth on each dependent variable. Again, the p value for each dependent variable was 0.001 or less.

DISCUSSION

The p values obtained in the statistical analysis indicate that the combined effect of ILD and contour depth have a very strong influence on the variations in the magnitudes of the dependent variables. This is clearly exemplified in Fig. 2 which is a plot of cushion deflection against contour depth. As ILD was increased cushion deflection was found to decrease. At the same time, as contour depth increased the disparity in cushion deflection over cushions of varying ILD was found to diminish.

A reverse relationship was observed between ILD and pressure. Here as ILD increased, pressures were found to increase. Again increasing contour depth served to reduce the disparity in the magnitudes. The two factors contributing to the observed relationships were the increase in cushion stiffness as ILD increased and increased load distribution area due to increased contouring. The interplay between these two factors, which explains the low p values calculated for the combined effect of ILD and contour depth, is more extensively analyzed and explained by Mathew [1993].

Lateral external pressures were also calculated using the Oxford Pressure Monitor. For the flat cushions, the medial pressures were greater than the lateral pressures by 22.7%, 31.4% and 36.2% for the cushions with ILD of 45, 55 and 70 lbs respectively. This difference was greatly reduced in the case of the 60 mm contoured cushions where medial pressures were 6.4%, 25.% and 17.6% greater than lateral pressures for the 45, 55 and 70 lb cushions. This indicates that contouring of cushions with the undeformed shape of the indentor induced a tendency towards more uniform distribution of interface pressures.

Another important result of this project was the strong linearity which was found between internal and external pressures. The correlation coefficient between the two parameters was found to be 0.95. The clinical application of this result is that use of pressure sensors which provide information regarding external pressures are highly representative of internal pressures as well. Thus it seems reasonable to make a determination regarding a cushion based on external pressures..

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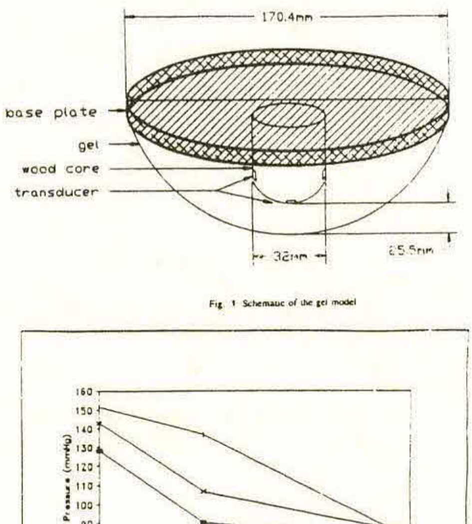

Fig. 1 Schematic of the gel model

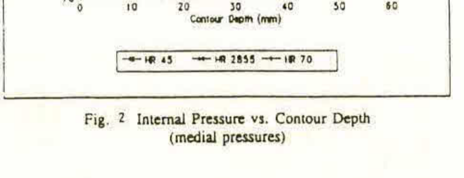

Fig. 2 Internal Pressure vs. Contour Depth (medial pressures)

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AN ANALYSIS OF STRUCTURAL AND FUNCTIONAL ANTHROPOMETRY OF WHEELCHAIR MOBILE INDIVIDUALS FOR WORKSTATION DESIGN

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ABSTRACT

This papers reviews the current anthropometric data available concerning individuals who require a wheelchair for mobility. These data are summarized and reviewed with respect to the information necessary for workstation design. Summary data and a list of future research needs are presented.

INTRODUCTION

There are a variety of regulations and programs operating in various countries which have been implemented to increase accessibility in the workplace. These regulations and programs are designed to increase employment opportunities and to limit forms of discrimination to the workplace of individuals who are "disabled". These programs provide an economic benefit to society and a social benefit to both society and the individuals protected under these regulations.

The current legislation refer to documents which have a direct impact on the design and functional use of the workplace. In particular, dimensions are provided for traffic areas, points of ingress and egress and areas for personal use. However, there does not appear to be any specific reference to the design of personal work areas (workstation design). Therefore it was the intent of this paper to analyze the available anthropometric data for individuals who require a wheelchair for mobility in order to determine the dimensions relevant for application to workstation design.

METHODS

A comprehensive list of available data sources was prepared and from this list general demographic information regarding the age, gender, number of subjects and origin of the papers was prepared. Then a summary was made of the measurement techniques and the mathematical and statistical procedures employed in the papers. Finally a comparison of the structural and functional anthropometric dimensions obtained from the various was performed. Whenever possible the reported values were adjusted in a similar manner to allow for greater ease of comparison. For example, seated stature, eye height and similar vertical dimensions were corrected with respect to the seat pan instead of the floor. When necessary the 5^{th} and 95^{th} percentile values were calculated from the reported mean and s.d. values. Summary tables were compiled for the body dimensions for the 5^{th}, 50^{th} and 95^{th} percentile separated by gender. From these values the mean (X), standard deviation (SD), coefficient of variation (CV), the minimum (Min) and the maximum (Max) values were calculated for the body dimensions based on the available data.

RESULTS

Ten papers were reviewed which covered a range of physical impairments which could necessitate the use of a wheelchair. In total the information collected was based upon direct measurements of 588 individuals. Two of the ten papers were summaries of previously existing data and did not perform any direct measures. The number of subjects tested varied from 15 to 203 per study. The paper with the greatest number of cases (203) was by Boussena and Davies (1987). However, they included measurements for individuals with mental as well as physical disorders. The actual number of people with physical impairments requiring the use of a wheelchair was estimated from the description given in the paper to be 25. This reduced the overall number of subjects who required a wheelchair for mobility from 588 to 410 and also meant that the paper with the greatest number of subjects was the paper by Floyd et al. (1966). Their study was based on measures taken on 91 males and 36 females with spinal cord injuries. Considering all the papers reviewed, the age of the people studied ranged from 15 to 70 years and there were 390 males and 198 females. The compiled data represented measurements for individuals from 3 continents.

The most common (8 papers) measurement technique employed was direct measurements using mechanical measurement systems. This includes standard tapes and measurement rods to various mechanical reach measurement systems used by Floyd et al. (1966) and Smith and Goebel (1979).

Diffrient et al. (1974) presented previously published data in a convenient handwheel method. However, the exact source of the data used by Diffrient et al. and alterations made to the data by the authors was not provided. Pheasant (1986) developed his data using a mathematical technique he had previously described in 1982. The advantage of his technique was the ability to quickly estimate various dimensions for a sample based on the mean and standard deviation of the stature of the sample compared to a standard directly measured database. This approach avoids the cost and time of a direct measurement approach.

Table 1 presents the data for the 50th percentile males from all sources reviewed. The summarized data for the 50^{th} percentile male and female data are presented in Table 2. Similar tables were prepared for the 5^{th} and 95^{th} percentile male dimensions as well as the 5^{th}, 50^{th} and 95^{th} percentile females dimensions however, due to space limitations they will not be presented. The order of limitations they will not be presented. The order of presentation of the dimensions has been subdivided into three sections. The first group of data are all vertical, structural dimensions in the sagittal plane. The second group are horizontal measures in either the sagittal or frontal planes. The remaining group are dimensions associated with functional (reach) dimensions. The data reviewed was collected on more males than females and the number of papers reporting data for females was also less than for males.

Important in the design of an industrial workstation are structural measures of seated stature, eye height elbow height and knee height. The mean seated stature data ranged from 724 mm for the 5^{th} percentile females to 917 mm for the 95^{th} percentile male. The CV of the seated stature varied from 2 to 8%. The eye height was as expected, lower than the seated stature and ranged from 601 to 817 mm. The CV for the eye height dimension was also low ranging from 2 to 4% across the data. The elbow height values (measured from the seat pan), ranged from 132 to 273 mm for the 5^{th} percentile female to the 95^{th} percentile female respectively. The CV varied from 4 to 31% for this dimension. The reported knee height values were measured from the floor. The mean values ranged from 482 to 586 mm for the 5^{th} percentile male and 95^{th} percentile male respectively. The CV for the knee height values ranged from 10 to 15%.

The next group of data are less important in industrial workstation design. The CV for all of these measures ranged from 2 to 17% for the shoulder breadth, 95^{th} percentile female to the thigh thickness for the 5^{th} percentile female respectively.

The reach dimensions demonstrated the greatest variability of the three subgroups of data. The mean overhead reach ranged from 951 to 1347 mm for the 5^{th} percentile female and 95^{th} percentile male respectively. As expected the values for males were greater then females within each percentile group. Mean arm reach forward values ranged from 501 to 755 mm. The CV for the arm reach forward ranged from 17 to 21%. Arm reach down is the measure of the reach below the seat pan. The mean values for this dimension ranged from 36 mm for the 5^{th} percentile male to 141 mm for the 95^{th} percentile female. The associated CV values ranged from 3 to 96%. Mean values for lateral reach varied from 471 to 755 mm for the 5^{th} percentile female to the 95^{th} percentile male respectively. The CV for this dimension ranged from 20 to 25%. The arm span dimensions ranged from 1269 mm for the 5^{th} percentile male to 1723 mm for the 95^{th} percentile male. The corresponding CV values were unable to be calculated due to the limited number of papers reporting a measure.

CONCLUSIONS

In summary, the conclusions reached by this investigation are:

1) Some of the data presented demonstrated a great deal of variability specifically for body dimensions related to work surface heights and reach dimensions. Part of the variability is associated with a lack of consistent measure techniques and measurement definitions.

2) Vertical work surfaces should adjust between the values of 132 mm and 273 mm above the seat pan of the wheelchair to match the seated elbow height. 3) Tasks requiring visual monitoring for prolonged periods should not exceed the seated eye height which ranged from 601 to 817 mm above the level of the seat pan.

4) For fixed work surfaces the minimum knee clearance necessary is 586 mm above the floor for the 95^{th} percentile male.

5) The required maximum forward reach should not exceed 501 mm (from the shoulder) to accommodate the 5th percentile reach.

6) The maximal overhead reach should be less than 951 mm from the seat pan in order to accommodate the 5th percentile reach.

FUTURE RESEARCH AND DESIGN ISSUES

The future research and designs needs are:

1) The existing data for wheelchair mobile individuals should be compared with the able-bodied population for the purpose of redesigning existing industrial workstations.

2) A comprehensive and reliable study must be conducted to ensure that the mean values reported in this paper reflect the true user population. Large CV values were associated with some measures.

3) There was a low CV for all measures of seated stature but progressively larger CV values for other critical dimensions for workstation design. Therefore additional dimensions other than seated stature must be used in the design process.

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Table 1: A presentation of the variation in 50th percentile male values for different anthropometric measures (mm).

Body feature	8*	3	4	2	9	1	5	7	6	10
Seated height	858	848	-	851	835	893	700	840	-	-
Eye height	744	739	-	739	720	-	-	-	-	-
Shoulder height	561	554	481	531	580	-	480	567	-	-
Elbow height	223	210	183	-	185	223	210	191	-	-
Knee height	512	-	-	648	-	535	400	-	-	-
Popliteal height	444	-	377	-	-	427	-	546	-	-
Trunk depth	218	-	-	-	-	-	-	352	-	-
Buttock-popliteal	495	-	399	-	-	472	460	503	-	-
Thigh thickness	122	163	-	-	150	141	-	-	-	-
Shoulder breadth	388	427	-	-	445	433	400	442	-	-
Elbow breadth	468	-	382	-	-	-	-	-	-	-
Max. elbow breadth	751	-	-	-	-	-	-	-	-	-
Arm overhead reach	1171	1179	-	1146	1165	-	-	-	-	1351
Arm reach forward	765	686	779	541	455	623	-	-	-	833
Arm reach down	98	89	-	89	65	-	-	-	-	-
Lateral reach	748	447	-	505	645	-	-	-	-	941
Arm span	1496	-	-	1645	-	-	-	-	-	-

* The number denotes the paper as presented in the reference list.

Table 2: A summary of the 50^{th} percentile male and female values for different anthropometric dimensions.

Body dimension	50^{th} percentile Male						50^{th} percentile Female					
	N	X mm	SD mm	Min mm	Max mm	CV %	N	X mm	SD mm	Min mm	Max mm	CV %
Seated height	7	833	61	700	858	2	5	800	29	765	853	4
Eye height	4	736	11	720	744	2	4	682	13	660	696	2
Shoulder height	7	536	41	480	580	8	4	503	18	485	526	4
Elbow height	7	204	17	183	223	8	4	203	22	170	224	11
Knee height	4	482	72	400	535	15	3	535	62	487	622	12
Popliteal height	4	449	71	377	546	16	2	413	-	409	416	-
Trunk depth	2	285	-	218	352	-	1	234	-	234	234	-
Buttock-popliteal	5	466	41	399	503	9	2	476	-	467	485	-
Thigh thickness	4	144	17	122	163	12	4	126	17	100	145	13
Shoulder breadth	6	423	23	388	445	5	4	382	14	363	401	4
Elbow breadth	2	425	-	382	468	-	1	428	-	428	428	-
Max. elbow breadth	1	751	-	-	751	-	1	665	-	665	665	-
Arm overhead reach	5	1202	84	1146	1351	7	4	1067	36	1011	1109	3
Arm reach forward	7	669	137	455	833	20	5	569	99	410	692	17
Arm reach down	4	85	14	65	98	16	4	91	3	87	95	3
Lateral reach	5	657	198	447	941	30	4	535	126	399	720	24
Arm span	2	1570	-	1496	1645	-	1	1440	-	1440	1440	-

* N denotes the number of papers reporting a value for the respective body feature.

A STRAIN GAGE FORCE SENSOR FOR A COMPUTER AIDED SEATING SYSTEM

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ABSTRACT

A strain gage based force sensor designed for use in a force sensing array for a computer aided seating system is described. The sensor is designed to measure vertically applied forces acting on a motor-actuated probe. The sensor consists of a cantilever beam equipped with strain gages. Sixteen force sensing probes were built and tested and found to measure vertically applied loads from 25 to 4500 grams with percentage errors of 5%.

BACKGROUND

A computer aided seating system described in a previous paper [1] is being constructed to measure and control the seating interface forces of a seated human. The seating system contains an array of motor-actuated, force-sensing probes which make up the seating support surface. The forces sensed from each probe are sent to a computer which then determines how the probes' positions should be adjusted to produce the desired force distribution. In this sense, the system can be characterized as a closed-loop system. A number of designs for the force sensor have been tested, but none have been found to be satisfactory for the system. It was desired to obtain force sensors which could be positioned in each of the 128 seating probes which would measure the vertical forces acting on the probes by the seated person. Commercially available strain gage load cells were prohibitively expensive so a number of different designs were studied. A number of fiber optic sensors using microbending and reflecting techniques were reported in [2] but found to be unreliable, hard to service, and difficult to manufacture with the local machine shop resources. A commercially available piezo-resistive pressure transducer with a built-in flexible membrane was also studied in [2] and found to work well for relatively small loads (1-1000 grams). However, the manufacturer stopped selling the device. A design employing a liquid medium pressure transducer with a reservoir containing silicone fluid and sealed with a rubber diaphragm reported in [1] was found to be prone to slow, but unacceptable leaks. The modification of a force sensitive resistor for use in seating systems was reported in [3]. The resistance varies nonlinearly with load which would lead to reduced precision when digitized for computer input. A design employing strain gages which could be manufactured with locally available resources was then investigated and is described below.

STATEMENT OF THE PROBLEM

The object of this project was to design a force sensor which could be positioned inside a seating probe which could measure the vertically applied force to the probe head surface, see Fig. 1. The force sensor would measure the force transmitted down a rigid piston. The desired vertical static load range to be measured was 25 to 5900 grams with a 95% accuracy. The sensor should be excited by a DC voltage in the range of 5-15 volts with an impedance of 100-10000 ohms. The output of the sensor should vary linearly with the applied load and produce rated outputs no smaller than 1 mV/V excitation. The sensor should not be too sensitive to temperature fluctuations. The total cost of materials for each sensor should be under $30 (not including the cost of labor).

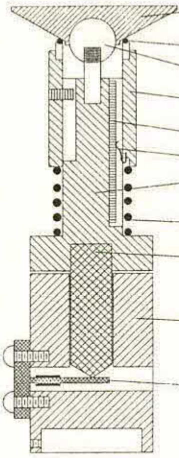

Figure 1. Typical probe with strain gage force sensor.

RATIONALE

Bonded foil strain gages are used in many commercially available load cells since they are simple in principle, reliable, and inexpensive. Accurate load cells which use bonded-foil strain gages to transduce strains due to applied loads into electrical signals are readily available, but prohibitively expensive for the system described. However, the individual parts which make up these force sensors are themselves fairly inexpensive. The strain gages, bonding materials, and protective coatings necessary for a moderately accurate (+/- 5% accuracy), moderate sensitivity (3 mV/V), temperature compensated, cantilever-beam force sensor can be purchased and installed for less than $25 each for quantities of fewer than 100 pieces. A strain gage is mounted onto a material, in the case of load cells it is called the "spring", which is expected to be strained when a stress is applied. Usually, the gages are designed so the resistance of the gage varies linearly with the strain. Ideally, as long as the strains are within the design range of the gage, and the gage is glued properly to the spring, and the spring is designed to strain elastically with the applied stress, then strain gages can be used for force measurements with accuracies better than 95% and lifetimes greater than 10^6 cycles.

DESIGN

Figure 2 illustrates the aluminum cantilever beam which acts as the load bearing surface (spring) the strain gages are bonded to. Four individual strain gages (350 ohms each) are used to complete a "full resistive bridge" network. It is possible to use fewer gages to measure the applied load, but the full bridge offers linearity, temperature compensation, maximum sensitivity, and increased noise immunity due to the differential output.

When designing a strain gage force sensor, a number of decisions have to be considered: type of material used, types of strains to be measured, manner of loading employed, etc. The spring material was chosen after reviewing [4, pg 37]. 2024-T351 aluminum alloy was considered a good, widely used material for transducers and was readily available.

The cantilever beam configuration was chosen mostly for its simplicity in construction, low profile, and high output sensitivity for small loads.
The sensitivity of the completed sensor is determined by a number of factors:

1. The cross-sectional area of the cantilever beam.
2. The cantilever beam material composition.
3. The strain gage sensitivity.
4. The manner in which the load is applied to the beam.

A cross sectional drawing of the final probe design that incorporates the cantilever strain gage sensor is shown in Fig. 1. The piston has been machined into a conical point at the end where it comes in contact with the cantilever beam to concentrate the load in approximately one point. An overload safety feature has been designed into the probe by allowing only a specific amount of deflection in the cantilever beam to occur before the sensor body comes in contact with the piston bearing. This deflection is set by adjusting the cantilever beam vertically with the use of two mounting screws and slotted holes in the vertical portion of the beam.

The no-load output of the strain gage force sensor depends on a number of factors: residual strains in the gages, the resistance variation of the individual gages, as well as temperature differences between the beam surfaces. For these reasons, the no-load output is often not exactly equal to 0 volts and was compensated for by the addition of a calibration circuit shown in Fig. 2. The potentiometer allows the no-load +Vout voltage to be varied so it is equal -Vout which produces a no-load differential output voltage near 0 volts.

DEVELOPMENT

Sixteen T-shaped springs were manufactured with a milling machine, thoroughly cleaned and the surfaces were prepared for gage mounting. Transducer quality epoxy glue (Micro Measurements AE-15) was used which required curing at 200 °F for 75 minutes. The gages were clamped to the spring with rubber pads during the curing to ensure uniform pressure distribution. The gages were wired together and the probe was assembled as in Fig. 1. The completed probes were then tested.

EVALUATION

The strain gage force sensors were tested for their load/voltage relationships. Theoretically, the output should be fairly linear, but certain nonlinearities always exist. Figure 3 shows the load response of a typical sensor with and without the overload protection. For the overload protected sensor, the output is fairly linear over a load range of 0 to 3600 grams (0 to 8 lbs), and then saturates for higher loads.

Figure 4 shows the resulting measured vs. applied load characteristic of a typical probe when loads from 0 to 5400 grams were applied to the sensor. A cubic approximation was used to calculate the applied load from the measured voltage. Various masses were stacked on top of each other one at a time then removed one at a time during the test to illustrate the hysteresis and the overall accuracy of the force sensor. The sensors were found to have percentage errors less than 5% for loads up to 4500 grams.

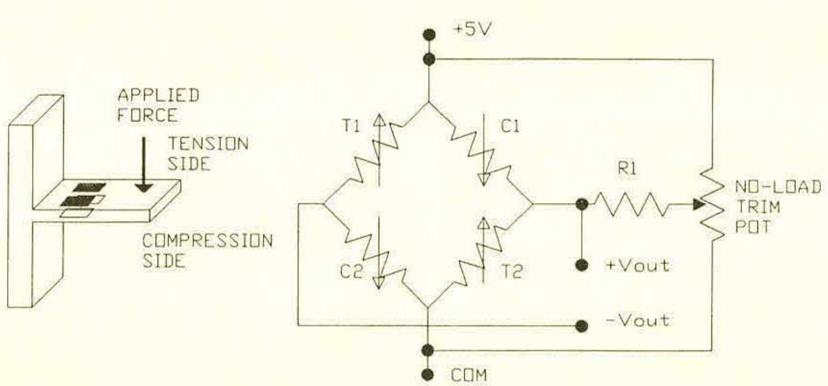

Figure 2. Strain gage cantilever beam.

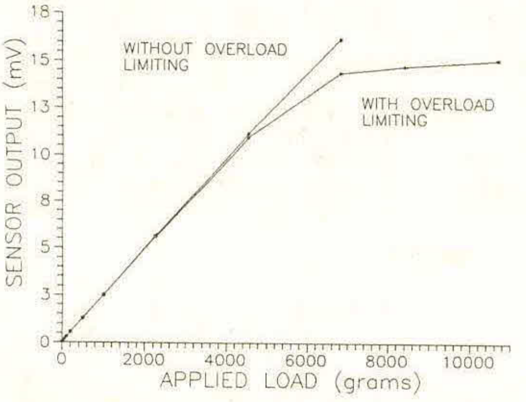

Figure 3. Typical sensor load/voltage curves.

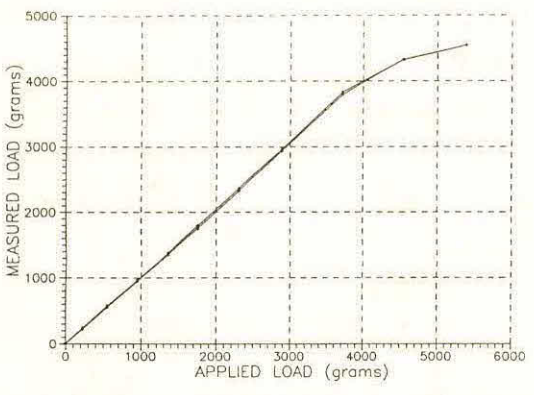

Figure 4. Typical sensor measured vs applied load.

When a person sits on the completed system, the swiveling probe heads will tilt and rotate with the seating surface. Tests were taken to determine how accurately the force sensor can detect loads applied at an off-axis direction. Loads were applied to a probe head which was permanently tilted at a known angle (15, 30 and 45 degrees). For the 15° tilt, the maximum percentage error was 10.7%. The absolute errors tended to increase with the tilt angle. The maximum percentage errors were 26.6% for 30° tilt and 72% for 45° tilt. Most of the errors were due to friction acting on the piston at the surface of the piston guide/bearing (see Fig. 1).

DISCUSSION

To reduce measurement errors due to friction at the piston, a vibration can be given to the probe by the probe's position actuator. This type of perturbation can easily be included in the actual use of the seating system. Before a force measurement is taken, a probe can be jogged up and down a sufficient amount. It was found that the percentage errors for the off-axis load measurements were significantly reduced by this method.

To compute the normal force, F_{normal}, from the measured vertical force, F_{sensor}, the following equation can be used:

$$F_{normal} = F_{sensor}/\cos\theta$$

where θ is the tilt angle measured by the linear potentiometer in Fig. 1. This equation is valid when there are no shear forces acting on the probe head. It is assumed that the normal force will be the largest component of the force acting on the probe head, and shear forces can be ignored. This assumption should be valid when the normal forces acting on the array of probes in the completed system are uniform.

The results from the testing of the strain gage based force sensor indicate that it should be acceptable for use in the closed loop seating system mentioned above. A 4x4 portion of the whole 128 probe system has been implemented and it was found possible to produce fairly uniform force distributions for soft hemispherical loads. Future goals of the project are to construct the remaining probes and to perform tests with seated humans. It is hoped that this system will increase our understanding of the way the human body reacts to various seating contours.

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A LEVERED DEVICE FOR INDEPENDENT LEGREST ELEVATION IN A MANUAL WHEELCHAIR

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ABSTRACT
A non-ambulatory, dependent transfer client, required an independent method to raise and lower elevating legrests on her manual wheelchair, while seated in the wheelchair and alone at home. No commercial device was found. A device was designed to modify the existing elevating legrest mechanism. The device allows independent and controlled movement, by the user, of standard, manual elevating legrests.

STATEMENT OF THE PROBLEM:
Mrs. P. is a 50 year old non-ambulatory woman diagnosed with multiple sclerosis in 1963. She is home alone during the day while her husband is at work. She stays in her manual wheelchair during her husband's absence, as she is a dependent transfer. She has had significant dependent edema in the lower extremities that has not responded well to compression pumping, stockings, and medications. She does find comfort and relief in having her legs partially elevated while sitting (hips flexed, knees extended) for intermittent, short periods, when someone has placed her in this position. Although not ideal for edema reduction, this has been condoned by her physician, in light of the caregiver burden to transfer her to a supine position multiple times throughout the day.

When Mrs. P.'s husband is not available to position her elevating legrests, her knees remain flexed in sitting. While in her wheelchair, she is unable to independently raise the standard elevating legrests. This prevents her from periodically raising and lowering the legrests throughout the day when she is alone. She has also been unsuccessful at attempts, despite Occupational Therapy, to place her feet up on a chair or couch, using her arm strength or adaptive devices to lift her legs.

DESIGN CRITERIA
To design a mechanism by which elevating legrests can be manually operated by the wheelchair user, within the following parameters:

User must be able to operate device while sitting in the wheelchair.

Device must be operable with Fair+ upper extremity strength.

Device needs to be able to lift the weight of an edematous paralyzed lower extremity, approximately 25 pounds.

User's position should not require more than 40-degrees hip flexion from upright sitting, to prevent loss of trunk balance, while operating the device.

Device must raise, as well as lower, the legrest in a controlled fashion, to prevent injury and spasms from an uncontrolled drop of the legrest.

Device should be no wider than the handrim diameter so as not to widen the chair any further.

Device design should be safely constructed, e.g., no sharp edges, no projections that could injure the user.

Device should be durable for daily use.

DEVICE DEVELOPMENT
The above criteria were conveyed to a Rehabilitation Technology Supplier with fabrication capabilities. A ratcheted mechanism was the first idea as this would allow the legrest to be moved with minimal strength. However, it was decided that the original elevating mechanism could be modified with a levered device.

Design

The device attaches to the pivot point of the elevating legrest mechanism, via an extended bolt. The bolt is secured through an L-shaped rod (5/16" in diameter). This rod extends 2-3/4" horizontally from the pivot point to provide clearance of the armrests. An 18" lever (1" wide and 3/8" thick) was heliarc welded to this rod. (See photo.)

The original 3-3/4" long legrest release lever was modified to extend 10" so that the user did not have to lean forward to lower the legrest.

The device is operated by downward force on the 18" extension lever. The long length allows this to be done with minimal strength. The legrest is lowered by pushing forward on the 10" release lever. The velocity that the legrest lowers can be controlled by the other hand applying counterpressure to the 18" elevation lever.

Materials

The first prototype was created out of aluminum. During the initial trial, the elevating lever and L-shaped connector rod bent, so a stronger material was sought. The final device was fabricated from 304 stainless steel that was brush finished (4130 chromoly steel that is subsequently chrome plated could also be used).

Cosmesis

Cosmesis was of concern to the therapist and fabricators, but was not an issue to the client. "I don't care what it looks like. I'll only be using it at home, alone." In the initial wheelchair prescription two sets of front riggings, standard and elevating, were prescribed. The standard front riggings are used by the client when out in the community.

DEVICE EVALUATION

All design criteria were met. Follow-up after one week found the client was able to operate the device.

Follow-up 6 months later found that the client was independently using the device, on a daily basis, to both raise and lower her legs at will. She especially liked the design feature that prevents the legrest from "crashing" when lowering the legrest.

Her home physical therapist was impressed that some stretch was being exerted on the hamstrings and gastrocs, in addition edema relief, in the elevated position. However, full stretch is not achieved due to the static length of the standard elevating legrest. An extended elevating legrest was added to provide the additional 2" needed for a better stretch. Although the footplate would now touch the floor, the client does not use or propel the chair with the elevating front rigging in the lowered position. An articulating legrest was not used as the existing mechanism was working and the client does not need to fully lower the legrests, as she uses her standard footrests at that point.

This current design is not transferable to articulating legrests as the elevation mechanism is entirely different device.

CONCLUSIONS

Elevating legrests can only be raised by someone else on manual wheelchairs, not by the person using the wheelchair. A levered device that allows the user to independently elevate and lower elevating legrests was designed and fabricated, and is in daily use by a client.

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A LIGHT-WEIGHT FOLDABLE PUSH-CART WITH SELF-LOCKING BRAKES

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ABSTRACT

A push-cart was designed and fabricated for a man suffering from severe ankylosing spondylitis. The push-cart is light-weight for easy handling by his wife, also a disabled person. It is foldable for convenient transportation using a taxi as well as storage in their very small apartment. Each rear wheel has its own built-in self-locking brake for safety especially on a slope.

BACKGROUND

The man has a rigid spine, hip, knee and ankle caused by ankylosing spondylitis. He can shuffle about slowly using two axilla crutches and some residual hip movement but since he cannot sit, a commercial attendant propelled wheelchair cannot be used.

As a member of a self-help group for the physically disabled with all limbs affected, he frequently visits other disabled members and actively participates in functions organized by the group. Because of his limited mobility, a standard 24" wide steel hand trolley is modified to allow able-bodied members of the group to cart him around. He gets on the trolley sometimes by shuffling up a heavy wooden ramp or more often, he is lifted up onto it by a strong volunteer. Besides the weight and size, which make the trolley hard to handle and not able to go through a lot of doors, it is not safe because it would run away on a slope unless held by an attendant.

He is married to a person with kyphosis and she finds the modified trolley hard to push and too heavy to lift. She is certainly not strong enough to lift her husband onto the trolley. The couple lives in a very small apartment and storage has been a problem with the trolley. They have the desire for a mobility aid that can be handled by the couple alone without help.

STATEMENT OF THE PROBLEM

Design a push-cart which allows the man to move up unaided. It has to be light enough to allow handling by the wife alone, narrow enough for easy access and compact enough to go into the trunk of a taxi as well as convenient storage in a very small apartment. It must be safe for use on a slope.

DESIGN

The push-cart has a detachable ramp which allows the man to shuffle up onto the platform unaided (Fig. 1).

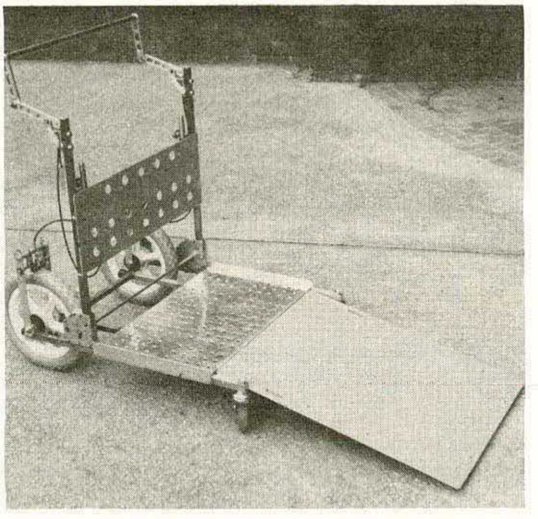

Fig. 1 Push-cart with ramp in position

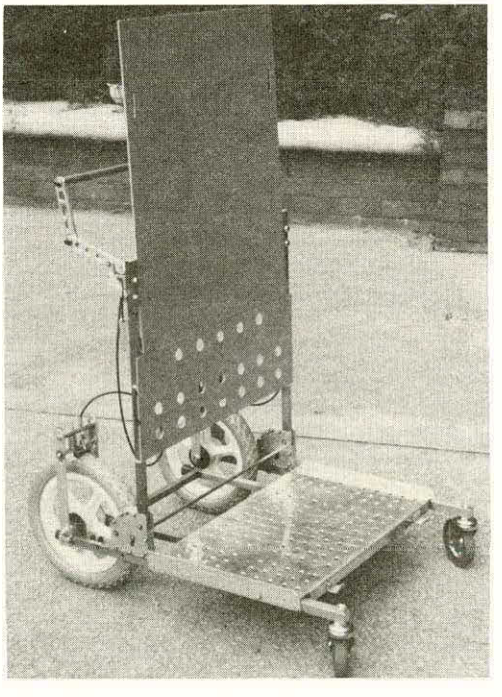

Fig. 2 Push-cart with ramp as trunk support

Afterwards, the ramp can be fastened on the back of the cart to serve as a trunk support (Fig.2). A wide chest belt loops through two slots on the trunk support for securing the man on the cart. Both rear wheels are normally self-braked to prevent run-away. The handle is a full-length bar which also serves as the brake release. The height of the handle, with the brakes released, is at elbow height of the wife.

Each solid synthetic rubber rear wheel has its own self-braking mechanism. A standard bicycle brake pad is normally driven by two adjacent springs to press down firmly on the wheel. The brake is released when it is pulled up by a cable connected to the handle assembly. For long trips on level ground, the brakes can be disabled by inserting two tapered aluminum flats in both hinges of the handle assembly. The rear wheels can be placed either in a wide position for added stability outdoors or narrow position for increased access indoors.

Non-rust material is used wherever possible because this city is hot and humid. PVC is used for the ramp and back and aluminium is used for the platform. Light-weight is achieved by using thin gauge materials reinforced by a welded stainless steel tube frame.

The folding mechanism is similar to a good quality steel trolley from hardware stores. A user steps on a horizontal bar with one foot to release a latch before pushing the handle forwards to fold the cart.

Specifications:

Carrying capacity:	40 kg
Platform:	337 mm x 545 mm
Ramp:	610 mm x 505 mm
Ground clearance:	127 mm
Maximum width:	
Wide position:	785 mm
Narrow position:	545 mm
Weight of ramp:	2.3 kg
Weight of main chassis:	8.5 kg

EVALUATION AND DEVELOPMENT

The couple was shown the cart and how it was to be used. The wife had no difficulty in removing the trunk support from the back and hooking it to platform to form a ramp. The man shuffled up the ramp without any problem. Removing the ramp, inserting and securing it on the back was also done with ease. After the man was secured with the chest belt, the cart was taken out by the wife for an outdoor trail. The first thing the wife reported was how light it was to push relative to the modified steel trolley. The cart locked positively on a 1:12 slope when suddenly let go at normal speed. On a rough road similar to that found in an unpaved path in a country park, the cart was stable enough with the rear wheels in the narrow position. The wife had no problem tilting the cart to climb a kerb. Folding the cart and lifting the two components, the ramp and the main chassis, one at a time into the trunk of a car also went smoothly.

After three weeks of use, the following minor modifications were made on the cart in response to reported problems and requests.

1. The cart was sometimes handled by persons other than the wife and the handle was found to be uncomfortably low. As a compromise, the handle was raised from 726mm to 840mm above ground.
2. Holes were drilled on the platform and back to decrease the total weight of the cart slightly.
3. The rear wheels were locked permanently in the narrow position because there is no need for the added sideways stability.

After 10 months of use, a pair of rear wheels was replaced because the threads were a bit worn down and there was loosening of one tire from its rim.

DISCUSSION

This cart was essentially a one-off design to increase the mobility of a person suffering from a rare condition. The self-locking brake design was, however, found to be generally useful in attendant propelled wheeled mobility aids.

ACKNOWLEDGEMENT

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BICYCLING MADE EASIER WITH A SIDECAR

Jody J. Whitmyer
Whitmyer Biomechanix, Inc.

ABSTRACT

Bicycling is an enjoyable experience for all ages but can prove to be a difficult maneuver for those with physical challenges. In this article a modification is described that allows a twelve year old boy with mild hemiparesis from birth, the ability to ride a bicycle independently for the first time thru the use of an age appropriate alternative to "training wheels".

BACKGROUND

The twelve year old child described also happens to be my step-son. Due to his hemiparesis, it was difficult for him to balance a standard bicycle. Several years earlier he had tried to learn to ride using training wheels but had difficulty because of his balance and lack of strength on his left side.

OBJECTIVE

In order to avoid the embarrassment of using training wheels, we explored other options such as a large "trike" or attaching a dual set of wheels on the front of his existing bicycle. The third option was to fabricate a framework and add a sidecar to the bike. This would certainly add stability to the frame and at the same time provide a unique look to the bike that might make it more attractive to other children his age. This would benefit him socially as well as functionally.

APPROACH

To do this, the framework was built from 1-1/4" steel tubing and then welded to the frame and reinforced at the attaching points. A 12-1/2" pneumatic wheel was then mounted to the framework thru an axle bushing. Because the bicycle was limited to one gear ratio, the front sprocket was replaced with a smaller unit to give it a lower gear ratio, thus making it easier to pedal with the increase in weight of the sidecar. To finish the bike off, a small plastic seat, footrest and handle were added for a passenger.

DISCUSSION

This modification proved to be an instant success as he was able to ride with stability and safety. Although he initially would sometimes tip far enough while riding, that the sidecar would raise off the ground, he quickly learned to control his balance. The additional weight caused by the sidecar may have worked slightly to his advantage in increasing strength in his left leg. Motorcycle enthusiasts have since pointed out that that the sidecar was placed on the wrong side of the bicycle, although this has not been a problem. His balance and strength are continually improving and it is anticipated that he will be able to ride a standard two wheel bicycle as his next bike.

ACKNOWLEDGEMENTS

Thanks to Christian Candal for his patience and perserverance.

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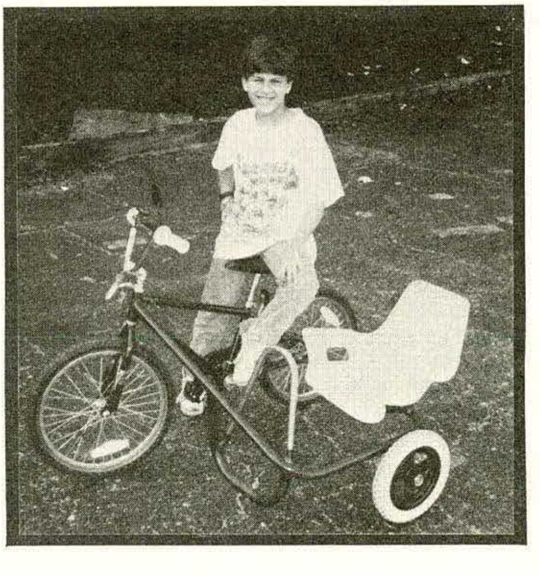

UPPER AND LOWER EXTREMITY POSITIONING CONSIDERATIONS FOR THE CLIENT WITH MUSCULAR DYSTROPHY

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ABSTRACT

As medical technology advances, the number and age of individuals living in advanced stages of Muscular Dystrophy increases. The desire to remain active, productive, and independent does not diminish as the disease progresses. Rehabilitation Engineering Specialists play a vital role in maintaining functional abilities in the young adult with Muscular Dystrophy. When evaluating seating and powered mobility, several problem areas can be identified as unique to this population. Precise upper extremity positioning is critical for function, particularly as it relates to access to control switches and comfort. Lower extremity positioning is frequently difficult due to deformity, and foot protection needs of the active young adult with Muscular Dystrophy. While solutions may necessitate custom design, concepts can be generalized to the population as a whole.

BACKGROUND

Duchenne's Muscular Dystrophy is the most well known type of progressive muscle disease affecting between 13 and 33 per 100,000 live male births (1). It is characterized by a progressive, and ultimately fatal, proximal to distal loss of muscular tissue and function. In the past, scales of functional ability described loss of ambulation by age 10 with dependence on power wheelchairs for mobility. Boys were often bed-bound by 20 due to respiratory compromise, with an overall life expectancy of 18-22 years (2).

Surgical intervention and improved medical care for respiratory and cardiac complications allows boys to stay up in their wheelchairs. The advent of night-time assisted ventilation increases life expectancy by an additional 5 to 10 years, and leads to longer and potentially more functional and productive lives (3). Although medical technology and specifically assisted ventilation is able to improve life expectancy, it has not yet been able to slow the loss of muscular tissue and function. The end result is a growing population of older boys and young men with rapidly changing and profoundly diminished physical abilities.

STATEMENT OF PROBLEM

A generally healthy, aging population of boys with Muscular Dystrophy presents a unique challenge to providers of Rehabilitation Technology services. The typical client at this residential facility is an active, social teenager who attends classes, enjoys rock concerts, and participates in high impact sports such as power wheelchair soccer. These clients require ongoing intervention as their disease progresses and physical abilities change. Clinicians must be sensitive to the fact that for these boys change is always negative as it is equated with further loss of function. Students often resist adjustment to their seating and mobility systems until they are completely unable to tolerate the current situation.

While overall positioning is vital to function, the techniques and solutions employed are similar to those of clients with other types of disabilities. The need for a stable, aligned pelvis and trunk can frequently be met with an appropriate combination of commercially available components. The focus of this article is on the upper and lower extremity positioning needs encountered in older boys with Muscular Dystrophy. These areas are

often best addressed by an integration of commercial and custom design to enhance function and provide a comfortable resting position. Custom solutions are frequently chosen for upper extremity positioning as it relates to joystick and recline-tilt unit access, and lower extremity protection and positioning.

Upper Extremity Positioning and Access to Control Devices

Loss of shoulder girdle musculature frequently leads to difficulty in maintaining hand position on standard power wheelchair joysticks. Students can typically operate the chair once their hand is placed on the control box. Bumps or irregular driving surfaces may be enough of a force to cause loss of contact with the joystick. Some students also experience difficulty with the amount of effort required to activate a standard joystick and drive effectively in all four directions.

The addition of recline or tilt mechanisms to aid respiratory functions and diminish pressure frequently causes loss of position due to the gravitational forces acting at the elbow. Additionally, the standard recline or tilt switch is often too difficult to activate, and once used, is no longer within reach to return to upright. Ulnar nerve compression is also reported by some individuals due to the inability to unweight an extremity. Contractures of upper extremity musculature can be severe and cause further limitation of functional range of motion.

Lower Extremity Positioning

In general, footrests tend to be rather unpopular with the majority of boys with Muscular Dystrophy in this residential facility due to social pressures. The need for an acceptable form of foot support and protection is evident. Students are active and involved in a variety of high impact sports activities which can easily result in bruising and injury to unprotected lower extremities and feet. This is especially true with this population as disuse results in osteoporosis and increased risk of fractures.

Severe, uncorrected equinovarus foot deformities are found in a number of clients with Muscular Dystrophy making shoes difficult, if not impossible to wear. Standard footrests are frequently inadequate due to both foot deformity and decreased hamstring range of motion. Commercially available angle adjustable hardware has not proven durable enough over time, requiring frequent repair or costly replacement.

APPROACH

The Rehabilitation Engineering Department relies strongly on an interdisciplinary team approach. Clients are frequently referred by their therapist following a report of discomfort or difficulty driving their power chair. Initial assessment looks at overall wheelchair positioning with modifications suggested as appropriate. Small changes often have great impact on functional abilities so each modification undergoes a lengthy trial period prior to final fabrication and upholstery. Clients need the opportunity to trial the equipment in all environments including school, home, and recreational settings prior to final construction and upholstery.

The design of equipment must be sensitive to the needs of the student for peer acceptance while providing the support needed to maintain function. Specific types of solutions for both upper and lower extremity positioning issues are presented as follows:

Upper Extremity Positioning

Initial solutions to problems of joystick access and control attempt to minimize the apparent visual impact of a modification while maintaining present functional level. Boys frequently resist any change in overall 'look' of their system at this stage. Clinicians start with sensitivity adjustments, then progress to a short throw joystick. Control boxes can be rotated to take advantage of relative strengths. Forward and reverse can be accomplished by medial and lateral wrist movements if that proves to be better maintained.

The next step is to alter upper extremity position to improve function. Some students will do well with custom designed arm troughs. These can be positioned in line with the standard armrest or mount in toward midline with swing-away hardware. Other students require the addition of a tray and midline control box. Control boxes may be dropped into the tray so that the student's forearms can rest on the tray surface. Elbow blocks are often required to prevent upper extremities from sliding out of position. Trays with midline control boxes must be designed with caretakers in mind. Joysticks should easily be removed and stored prior to tray removal, or wiring should be long enough to accomplish tray removal without damaging the control box in the process.

The majority of students seen for upper extremity positioning issues also operate either a tilt-in-space unit or a recliner. If a client is having difficulty with joystick operation, they are probably unable to independently operate a standard recline or tilt switch. In many cases, the power wheelchair can be reprogrammed to allow the recliner or tilt to run off the joystick. Custom light touch rocker switches have been extremely successful replacements for the standard control units as have switches with extra long lever arms. Clinicians should be aware that changing to a light touch switch will frequently require the addition of a relay box to reduce current.

Switches can be positioned wherever convenient and functional for the individual. Locations have included alongside the joystick, mounted on the tray, threaded through the seatbelt, and worn on a finger like a ring. The key point is to insure that the switch is available and operable at all points in the range of tilt or recline that the student utilizes.

Lower Extremity Positioning

Possibly unique to this setting is the need to provide impact protection for feet and lower legs. A foot bucket has been designed which is accepted by the majority of students. It provides both support and impact protection. This basic design is then customized to meet the specific needs of each client. In its simplest form, the bucket consists of a solid foot plate with sides to provide lateral protection and positioning of the lower leg. The front of the bucket can be left open or closed to provide even greater impact protection. This is particularly useful to students who use the front rigging of their wheelchair to push open non-electric doors.

Some students require removable padding inside the bucket to protect their feet when they are not wearing shoes. Buckets are often mounted in place using existing leg or footrest hardware. In this way, the foot bucket can be incorporated into the power tilt or recline as desired. However, in many cases students recline, but do not have sufficient hamstring range of motion to elevate their legs. In this case the back wall of the bucket provides the support and contact needed as they alter their position.

The majority of residential students are transferred using a mechanical lift, so swing away front riggings are not required. The needs of these students in their homes and other settings may be different and must be considered when designing foot buckets. Many students still require swing away hardware for transfers at home. Additional size constraints must also be taken into consideration when designing footbuckets including doorway width, van, and school bus clearance, and table access both at home and in the classroom setting.

SUMMARY

Older boys with Muscular Dystrophy have unique positioning needs due to the progressive nature of their disease and their desire to remain active. Although students at this residential facility may have a higher activity level than average, these designs can also have a significant impact on the quality of life of community or home based individuals. Rehabilitation Technology Specialists need to be sensitive to both the physical and psychological needs of this unique group. While medical technology has made it possible to extend the length of an individual's life, Rehabilitation Technology is vital to maintain the quality of that life.

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POSTURAL POSITIONING COUPLED WITH THERAPY
A LEUKODYSTROPHY CASE STUDY

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ABSTRACT

Three brothers lived with this genetically-linked disease. The two remaining brothers, ages 31 and 32, were fitted with custom-contoured linear positioning devices in December of 1990. In a home setting, these men received dedicated physical, occupational and communication therapy. RC showed remarkable and unexpected improvement. After observing improvement in tolerance of the postural positioning system and an increase in range of motion, the linear positioning device cushions were modified several times. This client now sits almost upright in a new Contour-U cushion positioning system mounted in a tilt-in-space wheelchair.

Figure #1. During evaluation almost all joints appeared to be fixed.

Figure #2. Custom-contoured linear positioning device designed after Bazata, Jones and Conyers was provided to client in December of 1990.

BACKGROUND

The three C brothers were born with leukodystrophy which is a genetically linked disability carried by females but affecting males only. This affects the brain and results in decreased muscle tone throughout the body. When the authors first evaluated RC for postural positioning, he was supine where he had been for almost 30 years. He demonstrated little response to people and virtually no understanding of cause-and-effect. His deformities appeared to be fixed.

OBJECTIVES

The general objective was to improve postural positioning by accommodating his "fixed" deformities. Specific objectives were as follows: 1) Improve respiratory function; 2) Improve eating/swallowing abilities; 3) Improve digestive function; 4) Prevent or slow progression of further deformities; 5) Improve spatial orientation and interaction; and 6) Provide opportunities for community access.

ACTION AND RESULTS

At the age of 29, RC was provided with a linear positioning device after Bazata, Jones and Conyers. See Photo #2 and Reference #1. After using this device and receiving physical and occupational therapy on a regular basis, the client demonstrated remarkable increase in range of motion, tolerance for the fixture and awareness of his environment. Approximately six months after receiving the linear positioning device, it was necessary to modify the cushions. See Photo #3. This was done several times.

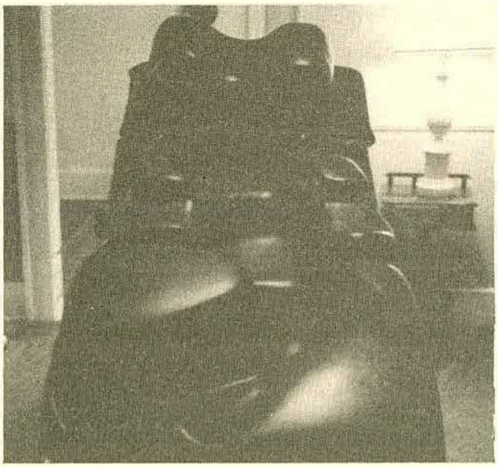

Photo #3. Linear positioning device was modified as client changed.

Photo #4. Mold was made for new Contour-U seating system in November 1992.

In November of 1992, RC was remolded in an upright seated position and provided with a tilt-in-space wheelchair. RC has begun to eat much better; he has gained seven pounds which is a remarkable achievement. His number of hospital visits and days of confinement have decreased significantly. Problems with intestinal gas distress have decreased. His interactions with people are much more positive.

Photo #5. New custom-contoured seating system in tilt-in-space wheelchair - December 1992.

DISCUSSION

Dramatic increases in range of motion were not expected. Successful transition from supine or linear positioning to upright seating is remarkable, indeed. It is believed that weight-bearing and warming of the joints provided by the linear positioning device contributed to this improvement. Clearly, appropriately aggressive physical therapy administered faithfully contributed most significantly. Communication therapy could be accelerated in the linear positioning device and even more so in the custom-contoured system mounted in the tilt-in-space wheelchair.

Provision of technical intervention and increased therapies for this man has been costly and time consuming. But this has resulted in improved health and quality of life for the individual. It has also made attendant care easier and more convenient. It has made life better for his caring family. A strong argument could be made that the cost savings in reduced medical expenses would dramatically exceed those for technical and therapeutic intervention.

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ACKNOWLEDGEMENT

Many therapists, care providers and other contributed to the improvement of this client. This may never have happened without the social action that resulted in a federal court order to serve and deinstitutionalize clients.

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SERIAL CUSTOM-CONTOURED SEATING FOR AN INDIVIDUAL WITH ATHETOID CEREBRAL PALSY

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ABSTRACT

The authors saw this woman for a seating evaluation May of 1990. She was in a planar system tilted 45°. She had no functional use of her hands and arms. In October 1990, she was provided a Contour-U seating system and a tilt-in-space wheelchair and ongoing physical therapy. Numerous, on-demand, changes were made to the seating system. After 18 months, a series of changes were made to the seat cushions due to changes in weight. After 24 months, a new seating system was made. The incredible results of serial development of postural positioning, coupled with therapy, have again been dramatically demonstrated.

BACKGROUND

This small, twenty-seven year-old woman has a sense of humor, is inquisitive and fun, but she is limited by severe athetoid type cerebral palsy and deformities. She spent much of her life on a mat on the floor in an institutional setting. She now lives in a special, modern home with two other young women where she receives regular therapy and ongoing intellectual stimulation. She has soft tissue contractures and severe scoliosis. She has shortened back muscles over stretched anterior trunk and abdominal muscles.

Three years ago her arms were virtually useless and severe spasticity caused pain and involuntary, uncontrolled body movements and positions. She was extremely frustrated, continually unhappy and usually ill-tempered. The advent of a federal court order in 1989 demanding provision of modern and appropriate services and equipment and a community living environment brought new hope for this person and her peers.

OBJECTIVES

The court order mandated return of individuals to the community, and services and equipment prior to this transition. Objectives of the rehabilitation team were as follows:

1) Improve spatial orientation; 2) Decrease scoliosis - (The spine remained somewhat flexible due to ongoing, involuntary movements); 3) Improve respiratory function; 4) Improve skin integrity; 5) Improve eating/swallowing abilities; and 6) Improve functional use of her arms and hands.

ACTION AND RESULTS

This client presented to the Postural Positioning Team in a planar seating system tilted at 45°. See Photo #1.

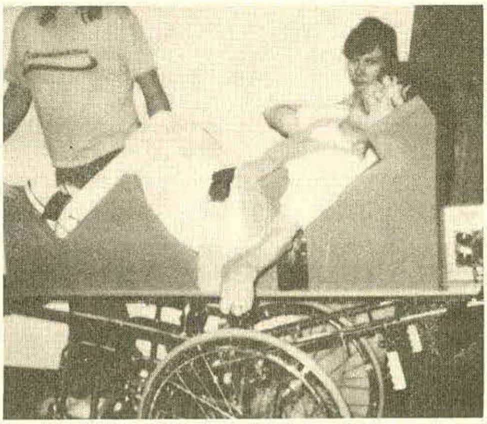

Photo #1. Planar postural positioning system fabricated in institutional setting.

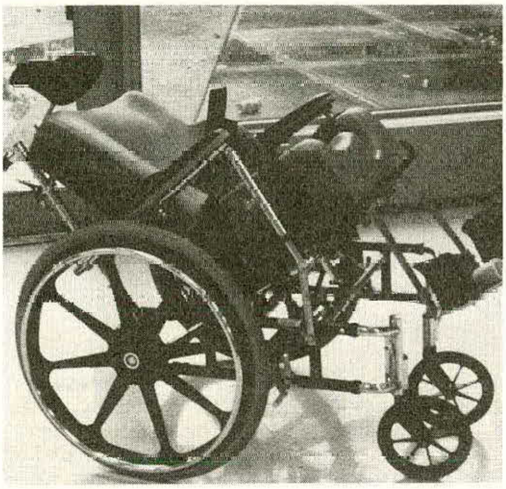

Photo #2. Contour-U seating system fabricated in October 1990.

In October 1990, a mold was made and a Contour-U seating system was mounted in a tilt-in-space wheelchair. See Photo #2. It was necessary to provide various headrests, a SUBASIS bar, double-velcro restraint belts, hand deflectors and thick padding on the footrests and other parts of the wheelchair. Many trials and modifications were made on an on-demand, quick-response basis in collaboration with institutional staff therapists and the director of the state institution. Over the course of three years, the weight of this young lady varied from 59 pounds to 83.5 pounds. The first modification of the Contour-U cushions were made in March of 1992. See Photo #3.

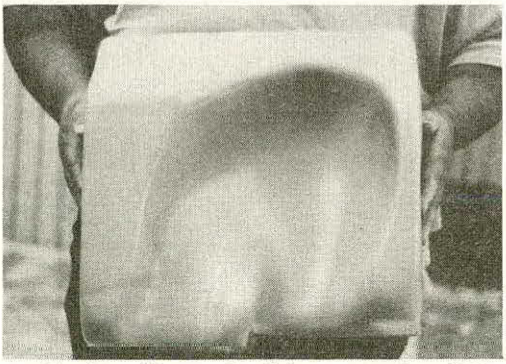

Photo #3. Cushion ready for modification.

Photo #4. Seat cushion was modified several times as individual changed.

In the ensuing 12 months, additional major modifications were made to the custom-contoured cushions. The cushions were reupholstered by vacuum forming with vinyl.

Then in December 1992, the individual was recast and an entirely new custom-contoured seating system was made. The seat-to-back angle is now 88°; a tilt-in-space wheelchair is still in use. The seating system can be conveniently transferred from the manual to a powered wheelchair.

Photo #5. New Contour-U cushions, January 1993.

Photo #6. Early trial of powered wheelchair.

The Postural Positioning Team tried the client in a battery powered wheelchair in August 1991 about 9 months after she received the first Contour-U seating system. She clearly understood the joystick control concept and was extremely excited about gaining independent mobility. But her spasticity made development of such capability doubtful. In September 1991, a temporary foam-in-place seating insert

Photo #7. Temporary FIP insert was used in powered wheelchair; Contour-U system remained in manual chair.

was made using the Contour-U seating system as a pattern. This was installed in an Invacare XT powered wheelchair to facilitate driving trials and to avoid transfer of the custom-contoured seating cushions from the manual to the powered wheelchair. Through approximately 12 months of intermittent trials in the powered wheelchair, coupled with dedicated physical and occupational therapy, and progressive changes of the seating system, this woman improved greatly. Initial postural positioning goals were met. Muscle tone and spasticity were reduced and head and hand control, as well as postural alignment, significantly improved. This young woman now has the ability to drive the powered wheelchair and her driving skills will undoubtedly improve even more.

DISCUSSION

Proper postural positioning and development of independent mobility for this young woman with a severe developmental disability woman has been difficult, costly and remarkable. This case again demonstrates the tremendous improvements that can be made in health, function and quality of life when adequate resources are available. Clearly, modern technology and ongoing therapy must be applied concomitantly to achieve best results.

ACKNOWLEDGEMENTS

Many therapists, care-providers and others deserve credit for the progress that this client has made. Deborah Rothe, superintendent of the host institution, gave relentless support to this effort. She encouraged the teams and fought for the funds.

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Electric Wheelchair Drive Train Efficiency

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Abstract

Laboratory tests of a typical drive train for an electric wheelchair consisting of a motor, wormgear, and belt give a low efficiency, ranging from 30% at .8 km/hr (1/2 mph) to 50% at 8 km/hr (5 mph). By changing the gear box from a wormgear to an EVOLOID gear box the efficiency of the drive train is increased by 10% for all speeds, which would result in an increase in wheelchair range by 10%. This study of drive train efficiency has also looked into changing the gear box lubricant, and it was determined that an additional 3% increase in efficiency of the drive train results from changing the lubricant from a grease with molybdenum disulfide to polytetrafluoroethylene (PTFE) grease.

Introduction

An efficient drive train in an electric wheelchair helps compensate for the limited supply of energy available from the lead-acid batteries. A drive train with improved efficiency will offer a greater range for the wheelchair. Improving the drive train efficiency will also increase the life of the batteries since the number of times a battery can be recharged is limited by depth of discharge, and with greater drive train efficiency the depth of discharge may be less on average.

The most common drive system for electric wheelchairs a 1/5 horsepower direct current permanent magnet motor, a gear box with a speed ratio of about 12 to 1, and a V-belt with a speed ratio of 3 to 1, which gives an overall speed ratio of around 36 to 1 between the motor speed and the rear wheel speed.

Two types of gear boxes are standard, with a worm gear box being more common than a spur gear box. Our tests examined the system with a worm gear box and also with a new EVOLOID gear box. The EVOLOID gear box is similar to a helical gear box, and we found that the theoretical equations for a helical gear box gave the proper trends for efficiency. See References 4 and 5.

Experimental Setup

A schematic of the test setup for the motors and gearboxes is shown in Figure 1. The power supply was set at the standard electric wheelchair voltage of 24 volts, and the current was controlled. The dynamometer measured the output power, and the efficiency is calculated by taking the ratio of the output power to the input power. Several motors were tested and one was selected that offered the average performance. Knowing the motor efficiency as a function of speed, it was then possible to measure the motor and gear box efficiency and compute the efficiency of the gear box.

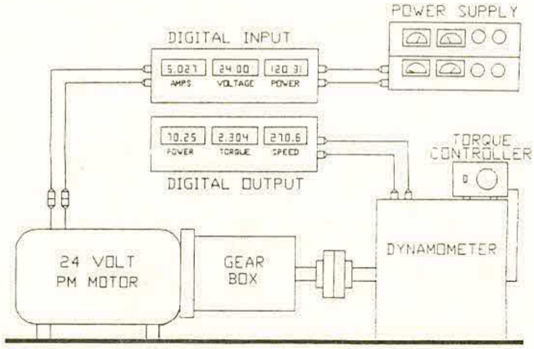

Fig 1: Gear Box and Motor Test Setup

A schematic diagram of the test set up for the V-belt and pulley part of the wheelchair drive system is shown in Figure 2. Again, the efficiency of the motor, gearbox, and V-belt & pulley system was measured. Knowing the efficiencies of the motor and the gear box system allowed the determination of the efficiency of the V-belt and pulley part of the system.

Test Results

All of the test results were based on a constant load of 120 Watts at 5 amperes, which is an approximate value for the output power of a wheelchair at full speed on a level road (see Ref. 1).

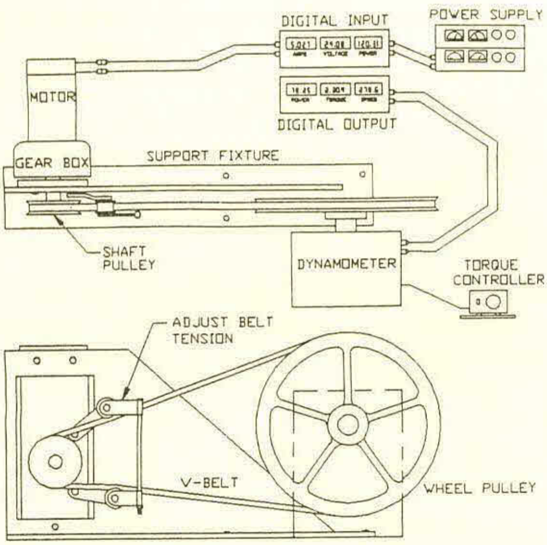

Fig. 2: V-Belt and Pulley Test Setup

Figure 3 gives the efficiencies of the individual gear train components. The V-belt and pulleys had a practically constant efficiency over the speed range tested of 90% as did the EVOLOID gear box. The wormgear box did much better than would be expected, and this is attributed to the fact that a grease lubricant is used rather than oil. The drop in efficiency of the motor at low speeds is characteristic of these permanent magnet motors (see Ref 3, p. 269), and suggests the need for an increased gear ratio at low speeds.

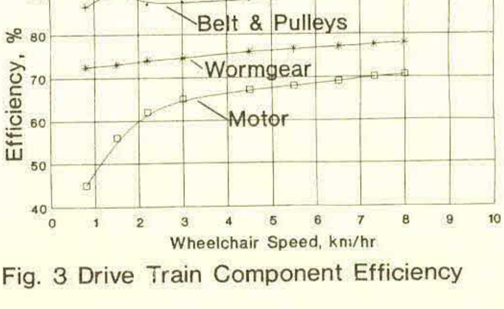

Fig. 3 Drive Train Component Efficiency

Figure 4 shows the experimental efficiency of the drive train with two different gear boxes (worm gear box or EVOLOID gear box), and with two types of lubricant in the gear boxes; a standard molybdenum disulfide augmented grease and a polytetrafluoroethylene (PTFE) grease. The overall efficiency of the gear train is calculated by multiplying the individual efficiencies of the components as reported in Fig. 3. In Fig. 4 we see that the wormgear drive train with grease is rather inefficient, especially at low speeds primarily due to the motor; the drive train efficiency was 30% at 1/2 mph (0.8 km/hr) and the maximum efficiency was about 50% at 5 mph (8 km/hr). For this same drive train with the grease replaced by a PTFE lubricant the test results show an average increase in efficiency of about 3%. However, if the worm gear is replaced by the much more efficient EVOLOID gear there is an increase of efficiency for the entire drive train of about 10% with a grease lubricant and about 13% with a PTFE lubricant. All of the test data had a standard deviation of about 5%.

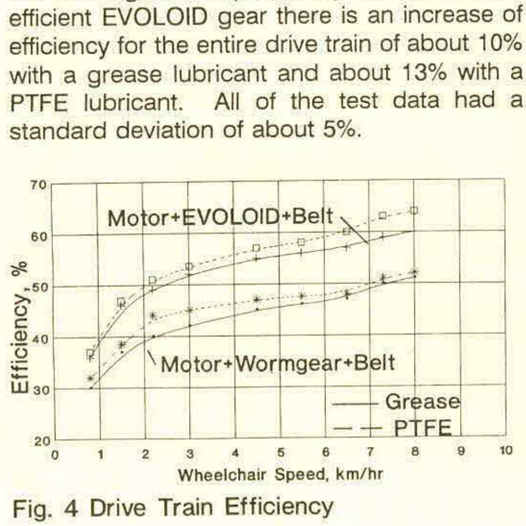

Fig. 4 Drive Train Efficiency

Discussion

One aspect for gear box selection concerns the fact that the worm gear input and output shafts are at a right angle while the EVOLOID gear box has its input and output shafts parallel. With right angle shafts for the worm gear the motor can be placed along the side of the frame, whereas the parallel shaft EVOLOID box means that the motors cross the frame. Motors that cross the frame do not permit a folding frame.

The test results show an improvement in efficiency by using a PTFE grease in place of the standard grease. However, the cost of the PTFE grease may prohibit changing grease. It was determined that the grease presently used in the gear box costs $25 per gallon, while the PTFE grease costs $40 per gallon. The PTFE grease consists of colloidal PTFE suspended in a phenolic resin. The resin adheres well to gear teeth surfaces, and a much smaller amount of PTFE grease may be needed to lubricate the gear box. No life tests for the PTFE grease have been carried out yet, but if a smaller amount of PTFE grease were found to be satisfactory the added cost would not be a problem.

In our testing we selected the permanent magnet motor whose efficiency is shown in Fig. 4. Measurement of the efficiency curve for 4 motors (not shown) gave a maximum deviation between motors of about 5%.

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EFFECT ON WHEELCHAIR STABILITY AND MANEUVERABILITY OF VARYING THE POSITION OF A REAR-ANTITIP DEVICE: A THEORETICAL MODEL

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ABSTRACT

The purpose of this study was to evaluate a theoretical model that we developed to estimate the effect of the position of antitip devices on rear stability and maneuverability. To validate the model we measured the static rear stability on a tilting platform of a representative manually propelled wheelchair, occupied by an test dummy and equipped with a customized antitip device that allowed us to test 68 combinations and permutations of vertical and horizontal positions. The relationships between the position of the antitip device and both the measured rear-stability and maneuverability values correlated highly ($r > 0.98$) with the values predicted by the theoretical model. These relationships should assist clinicians, users and wheelchair designers in finding appropriate compromises between safety and maneuverability.

BACKGROUND

Each year in the United States there are about 30,000 wheelchair-related accidents that are serious enough to result in a visit to an emergency room[6] and about 50 deaths.[1] Tips and falls account for two-thirds of these accidents. To limit the extent of rear tipping, many wheelchair manufacturers provide optional rear-antitip devices that extend backwards from the lower frame of the chair.

In spite of their presumed safety benefits, a recent study found that antitip devices were only used by 29.5% of 566 people who used manually propelled wheelchairs,[3] perhaps due to the adverse effect of such devices on maneuverability.

OBJECTIVE

The purpose of this study was to evaluate a theoretical model that we developed to estimate the effect of the position of antitip devices on rear stability and maneuverability.

METHODS

The model was developed to relate stability and maneuverability parameters to the following variables: A = radius of the antitipper wheel; B = height of the rear-wheel axle from the ground; E = diameter of caster; H = height of the center of gravity (of the wheelchair combination) above the rear-wheel axle; L = horizontal distance between the antitipper-wheel axle and the rear-wheel axle; P = the horizontal distance between the center of gravity and rear-wheel axle; Q = the distance from the rear-wheel axle to the caster axle; V = the height of the antitipper-wheel axle above the ground.

The stability parameter was the total-rear-stability angle (T), the angle of the wheelchair at which the chair tips backwards about the axis of the antitip-device axle. The maneuverability parameters were the departure angle[5] (D, the angle between the ground and a line connecting tangents of both the rear and antitipper wheels), and caster clearance (CC, the room beneath the casters that is available for clearing obstacles when the chair is tipped back on the rear wheels to the point of contact of the antitipper with the ground).

The theoretical relationships among these variables and parameters were determined by trigonometry. Using the model, we predicted the T, D and CC values corresponding to a set of horizontal (L) and vertical (V) coordinates describing the location of the antitipper axle. The actual values were measured on a tilting platform[2] using a representative wheelchair (an Invacare Ridelite 9000) occupied by a Hybrid II test dummy and customized antitip devices set in 68 combinations and permutations of vertical and horizontal positions.

We determined the correlation coefficients between the actual and predicted values.

RESULTS

The equations allowing the prediction of T, D and CC on the basis of measurable or derivable dimensions are:

$$T = \text{Arctan}[(P+L)/(H+B-V)]$$
$$D = \text{Arcsin}\,[(B-A)/(L^2+(B-V)^2)^{1/2}] - \text{Arctan}[(B-V)/L]$$
$$CC = B - E - Q*\sin[\text{Arcsin}[B-E)/Q] - \text{Arcsin}[(B-A)/(L^2+(B-V)^2)^{1/2}] + \text{Arctan}[(B-V)/L]]$$

The correlations between the predicted and actual values were highly significant: T ($r = 0.983$), D ($r = 1.000$) and CC ($r = 0.998$) (Figure 1).

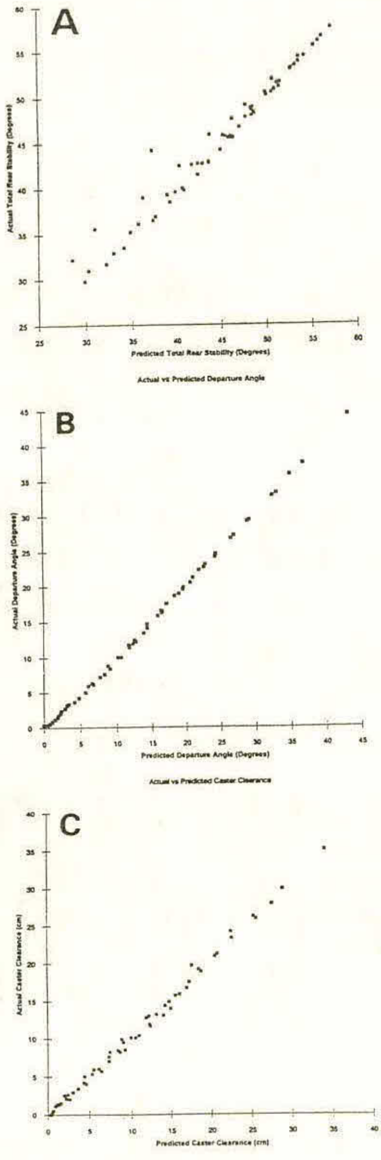

Figure 1. Theoretical vs actual values. A. Total rear stability. B. Departure angle. C. Caster clearance.

DISCUSSION

The development of an empirically validated theoretical model, relating the position of rear-antitip devices to stability and maneuverability measures, should be useful to those designing or carrying out research on antitip devices. We plan to incorporate the equations derived into a computer model of wheelchair stability that we have been developing.[4,7] Theoretical models may eventually also play a role in appropriately prescribing and fitting wheelchairs.

There are a number of implications that can be drawn from the model, including:

1. If the slope of an incline (IS) that one is attempting to ascend is > the stability without an antitip device (N), then the chair will tip over backwards (through the angle D) until the antitippers contact the ramp surface. If $IS + D > T$, then the chair will do a full tip backwards, pivoting around the antitipper axle. This is worse than tipping around the rear axle as the "fall" is from higher as R is > B. Also, on an incline the distance through which one falls is greater than it would be on the level.
2. If $D < N$, then no "wheelie" is possible. If $D >> N$, then the user could get stuck in the wheelie position and the force of dropping to D could be almost as dangerous as dropping to the ground.
3. If the antitipper clearance (AC) is less than the vertical height of an obstacle (OH), it may not be possible to clear the obstacle. If rolling forward over such an obstacle, the wheelchair may become suspended between the casters and the antitippers, with the rear wheels not touching and therefore with no rear-wheel traction.
4. If the $CC < OH$ (e.g. of a curb), it will not be possible to negotiate the obstacle by lifting the front wheels. If coming down over a curb backwards, the chair will be at risk of becoming "hung up", suspended tractionless between the casters and the antitippers.
5. Similarly, if one wishes to negotiate (in any direction) the lower transition of an incline, and the IS is > D, then the chair will be at risk of becoming hung up and tractionless.

There are some limitations to this study, including the single wheelchair studied, the use of an anthropomorphic test dummy rather than actual wheelchair users, and the use of static-stability considerations to help in predicting what will happen in dynamic situations. In the future, this work will need to be validated on a broader range of existing wheelchairs, extended to powered wheelchairs, to the problem of forward- and lateral-tipping accidents and to include dynamic-stability testing.

A well-designed chair, that has been properly prescribed and adjusted for the individual characteristics and the environment of the user, should be both safe and maneuverable. We hope that the relationships that we have demonstrated between the position of the rear antitipper and safety and maneuverability parameters will assist clinicians and users in finding an appropriate compromise between safety and maneuverability for individual users and will stimulate wheelchair designers to improve upon existing designs.

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THE KINEMATICS OF WHEELCHAIR PROPULSION IN ADULTS AND CHILDREN WITH SPINAL CORD INJURY

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ABSTRACT

There are few studies in the literature on wheelchair propulsion which have involved children and apparently none that have used kinematics to describe the wheeling style of the pediatric wheelchair user. Ten pediatric subjects were neurologically matched (by the ASIA scale) with ten adults subjects with spinal cord injury. The results of 3-D video analysis of wheeling at a steady speed, across a level runway showed that the pediatric group had significant absolute angular differences from the adult group. However, the angular changes over time and across the experimental conditions (own chair and test chair) were the same in both groups. The implications of this work for clinical practise are that the conclusions from previous adult studies on the biomechanics of wheelchair propulsion may be applied to the pediatric wheelchair user.

INTRODUCTION

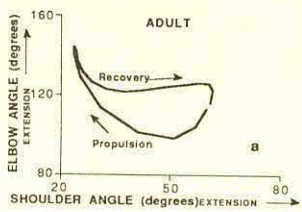
Wheelchair propulsion is a repetitive, cyclical movement which is the product of a user-machine interaction. For a child with a disability which makes mobility by way of the lower extremities impossible, the interaction with a machine is a life-long experience. The mass as well as the inertial force of the wheelchair that the user must overcome, are almost the same in pediatric and adult wheelchairs (1,2). There are very few studies that have involved children with disabilities and apparently none in the literature that have examined the kinematics of wheelchair propulsion by pediatric users. The consequence of the absence of such data means that clinicians have no objective data by which they can appropriately prescribe wheelchairs for children with disability. The purpose of this study was to determine if children with spinal cord injury would demonstrate similar kinematics of wheelchair propulsion to adults with spinal cord injury.

METHODS

The two subject groups were adults ($n = 10$) with spinal cord injury secondary to trauma and children ($n = 10$) with uncomplicated spinal cord injury secondary to congenital defects (Spina Bifida). The two groups were neurologically matched by motor assessment according to the American Spinal Injury Association (ASIA) scale. Steady state propulsion across a level runway at a velocity of about 2 m/s was recorded by two gen-locked video cameras. Each subject performed five trials for each of two test conditions: own chair and a test chair. The test chairs were new, identical low-mass test chairs (Kuschall, Champion 3000, mass = 9.3 kg) which were available in a variety of sizes to match the users. The three dimensional coordinates of 8 light reflective markers placed on the subjects' right side were determined by direct linear transformation after digitization and filtering (6 Hz). From these data, the movement of body segments (trunk, upper and lower arm) and angles between these segments (elbow, shoulder, trunk, and shoulder abduction) were determined. An electronic signal generated from a thumb switch was used to determine the timing of wheel contact (grab) and release from which the % propulsion of the wheeling cycle was determined. A single wheeling cycle was analyzed from the central portion of each trial and time normalized with grab being defined as 0% of the cycle and the subsequent grab being defined as 100% of the cycle. Within and between subject coefficients of variation (CVs) of the angular data were calculated in order to compare the variability of the angular data in the two groups. Statistical analysis were multiple univariate, repeated measures ANOVA and ANCOVA (BMDP) with significance levels set at $p < 0.05$.

RESULTS

The average mass of the pediatric group was much smaller than the adult user's mass (37.4 kg vs 68.5 kg). The mean age of the pediatric subjects was almost one third of the mean age of the adult subjects (11.3 years vs 33.5 years). The subjects were closely matched neurologically as evidenced by the mean ASIA scores in the two groups (pediatric = 56.1 ± 3.48, adults = 55.2 ± 4.73). There were 3 female and 7 male subjects in each of the two groups. The averaged group wheeling velocities were 2.26 ± 0.39 m/s for the pediatric group in their own chairs and 2.38 ± 0.31 m/s in the test chairs. The adult wheeling velocities velocities were 2.51 ± 0.18 m/s in the subjects' own chairs and 2.51 ± 0.17 m/s in the test chairs. A 2-(groups)-by-4-(conditions) ANOVA of the actual wheeling velocities showed a significant main-groups effect and a non significant interaction effect indicating that the pediatric group were wheeling their chairs at a significantly lower velocity than the adult group but that the response to the test chair condition was the same in both groups. The pediatric group spent 24.45 ± 7.29 % of the wheeling cycle in propulsion in their own chairs and 24.41 ± 7.61 % in propulsion in the test chairs. Comparable figures for the adult group were 25.20 ± 5.45 % in the own chair condition and 23.65 ± 4.87 % in the test chair. An ANOVA of the timing data showed that both the groups-main effect and the groups-by-condition interaction effect were not significantly different. The angular data showed that the pediatric group had greater shoulder extension (maximum pediatric group 66.6 °, adult group 60.3 °) and less elbow extension than the adult group (maximum pediatric group 138 °, adult group 144.7 °). A 2 (groups)-by-2-(conditions)-by-6 (time, first 25% of the wheeling cycle) ANCOVA of the angular data, correcting for wheeling velocity differences, showed significant differences for three (elbow, shoulder, and shoulder abduction) of the four angular parameters and non significant groups-by-conditions effects indicating that both groups responded in a similar manner to the different wheelchairs. The analysis was performed over the first 25% (propulsive phase) of the wheeling cycle because this was the portion of the cycle where force was being applied and therefore was the area of greatest clinical interest. The differences between the pediatric and adult group angular data are summarized in Figure 1.



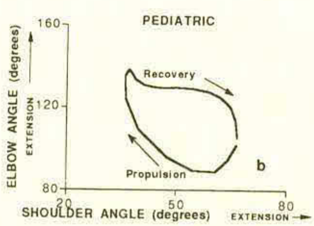


Figure 1: Shoulder angle/ elbow angle plots for the two groups (a= Adult and b=Pediatric) averaged across 5 trials and across 10 subjects/group over a normalized wheeling cycle.

These different wheeling styles are similar to those described by Sanderson & Sommer (3).

The within subjects coefficients of variation (CVs) average over the wheeling cycle and across subjects for the angular data were determined to be not significantly different between the adult and pediatric groups for the elbow (adult 5.24 ± 0.48, pediatric 7.09 ± 0.87) and shoulder (adult 9.93 ±1.61, pediatric 11.45 ± 1.51) angular data. The pediatric group showed significantly more within subject variability over the five trials than the adult group in the shoulder abduction (adult 6.34 ± 0.9, pediatric 16.87 ± 3.36) and trunk (adult 55.54 ± 7.72, pediatric 59.44 ± 8.59) angular CVs. The between subject CVs e found to be approximately 16% for both groups.

CONCLUSIONS

The adult and pediatric groups demonstrated significant differences in the angular and wheeling velocity data. However despite these differences, the two groups responded similarly to the test chair condition and showed similar variability and % propulsion. There is a need for further studies on the special needs of the pediatric wheelchair user.

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THREE vs. FOUR-WHEELED SCOOTERS: WHICH HAVE GREATER STABILITY?

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ABSTRACT

Four-wheeled scooters are purported to be more stable than their three-wheeled counterparts; however, the extent to which this is true is not generally known. The purpose of this paper is to quantify the characteristic differences between the two types of scooters, both in terms of static and dynamic stability. In conclusion, we found that four-wheeled scooters are generally more statically stable than three-wheeled scooters, however, the difference is marginal when dynamic stability is compared.

BACKGROUND

The four-wheeled scooter has, over the past several years, made significant inroads into the scooter market. In fact, during 1992, 56% of the new scooters entering the Ontario market were four-wheeled devices, compared with 25% in 1991 and 0% in 1990. Generally, the primary physical difference between the four-wheeled scooter and its three-wheeled counterpart is, as the name suggests, the replacement of the single front wheel with two separated front wheels. This design modification can be attributed to the demand for greater lateral stability than is inherently possible with a three-wheeled base. The *perceived* severity of this limitation is as much based on theory as it is on intuition and experience.

From a theoretical perspective, there are many ways of explaining the reduced lateral stability of a three-wheeled base. Figure 1 comparatively illustrates the stability conditions of the otherwise equivalent - centres of gravity included - three and four-wheeled bases. The centre of gravity of each illustration is represented by the quartered diamond. Essentially, the effect of wheel-base geometry on stability can be characterized by the line segment D; the shortest horizontal distance from the centre of gravity to the envelope formed by the wheel's geometry. The larger the magnitude of D, the better the wheelbase is at stabilizing the device. As depicted below, and can be shown mathematically, D_3 (D for the three-wheeled base) is shorter than D_4. Therefore, from a theoretical perspective, a four-wheeled base increases the lateral stability of an otherwise equivalent three-wheeled device.

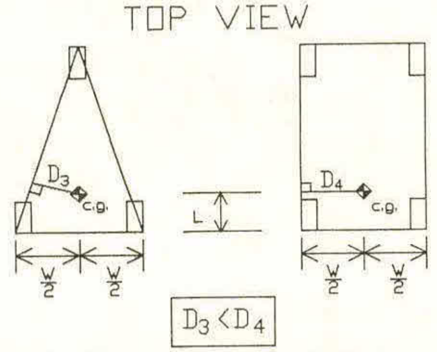

Figure 1: Comparison of the wheelbase characteristic length for stability of a three and four-wheeled scooter.

However, factors other than wheelbase geometry also greatly affect the stability of a scooter. Static stability is also a function of the centre of gravity position (operator included) and the frictional and pneumatic properties of the tires. Dynamic stability is yet more complex, as it is not only a function all of the above, but also a function of turning radius and velocity. Therefore, although the effect of a rectangular wheel-base is to increase stability, the influence of the above factors could possibly diminish the overall effect.

RESEARCH QUESTION

Essentially, we posed the question: are four wheeled scooters generally more stable than three-wheeled scooters? Before answering this question, the term stability, as we use it, must be defined. Two types of stability will be used to characterize a scooter's overall stability: static stability and dynamic stability. Static stability shall refer to the device's ability to maintain ground contact with all of its wheels while placed on inclines of increasing grades. Dynamic stability shall refer to the device's ability to maintain ground contact with all of its wheels when subjected to inertial forces; forward or lateral.

METHOD

Static Stability

The static stability of each device was measured using the ISO (International Organization for Standardization) standards for wheelchairs and the ISO standard 75 kg test dummy. Each device was placed on a variable incline ramp in each of three different orientations; fore (directed uphill), aft (directed downhill) and lateral (directed across hill). For each orientation, the ramp was inclined until the device either slipped, rolled, or tipped. In all cases, the devices were not prevented from rolling or slipping. However, only for those devices which tipped were results included. Also, three-wheeled devices were measured in the lateral-critical orientation (the orientation whereby an imaginary line connecting the front wheel to the left rear wheel is made parallel to ramp's axis of inclination).

Dynamic Stability

To measure dynamic lateral stability the device was driven over a flat hard surface by a 75 kg driver. Mounted with an accelerometer, the device was accelerated to full speed at which time the driver would execute the sharpest possible turn. Measurements of the lateral inertial acceleration necessary to cause impending tipping were then recorded.

RESULTS

Static Stability

The results for the static stability tests are shown in Table 1. In the fore orientation, results from eleven three-wheeled scooters indicate an overall average static stability of 17.1^0. Alternately, four-wheeled devices were, on average, stable to an angle of 20.2^0 in the fore orientation, an 18.1% relative increase in stability over three-wheeled devices. In the lateral orientation, the four-wheeled devices were, on average, 12.7% more stable (18.8^0 vs. 21.2^0). Comparing the lateral-critical orientation for three-wheeled devices with the lateral orientation for four-wheeled devices, four-wheeled devices exhibited an increase of 13.9% in stability. The aft orientation results have not been included, as they were all exceptionally large and, therefore, deemed irrelevant to the issue at hand.

	FORE	LATERAL	LATERAL CRITICAL
	Sample Size		
3-wheeled	11	12	6
4-wheeled	6	6	6
	Angle of Impending Tipping		
3-wheeled	17.1^0	18.8^0	18.6^0
4-wheeled	20.2^0	21.2^0	21.2^0
Relative Difference	18.1%	12.7%	13.9%

Table 1: Static stability test results in the fore, lateral and lateral-critical orientations

Dynamic Stability

Table 2 contains the results from the dynamic stability tests. On average, the four-wheeled devices tended to tip when exposed to a lateral inertial acceleration of 2.92 m/s^2. By comparison, the three-wheeled devices tended to tip, on average, when exposed to a lateral inertial acceleration of 2.86 m/s^2, a relative difference of 2.1%. Maximum lateral inertial accelerations for the three-wheeled devices ranged from 2.22 m/s^2 to 3.53 m/s^2. For the four-wheeled devices, maximum lateral inertial accelerations ranged from 2.65 m/s^2 to 3.14 m/s^2.

	Sample Size	Avg. Lateral Acceleration (m/s^2)
3-wheeled	7	2.86
4-wheeled	5	2.92
Relative Difference	N/A	2.1%

Table 2: Maximum lateral accelerations to cause impending dynamic instability.

DISCUSSION

From the results above, four-wheeled scooters do indeed appear, on average, to be more statically stable than their three-wheeled counterparts. The 18.1% increase in fore static stability, and the 12.7% increase in lateral static stability, indicate that wheel-base geometry does impact significantly on static stability. This increase in lateral stability is to be expected, however, it is difficult to attribute the increase in fore stability directly to wheel-base geometry. Most likely, since the frontal weight of a four-wheeled device is generally greater - a result of the increase in the number and size of components found in the front end - causing a favourable downward and forward shift in the device's centre of gravity.

Dynamic stability, however, is the more revealing stability characteristic for scooters. Experience would indicate that most mishaps occur while users attempt to negotiate turns at relatively high speeds (dynamic stability), not as a result of parking on inclines (static stability). From the results shown above, the four-wheeled scooter is only marginally more stable than the three-wheeled version. This indicates that lateral dynamic stability is not greatly affected by wheel-base geometry as is static stability. This is expected, as other physical factors also greatly influence dynamic stability (as mentioned previously), all of which may mitigate much of the desired effect of the expanded wheel-base.

Additionally, it is important to note that two of the seven three-wheeled devices were dynamically more stable than the most stable four-wheeled device; indicating that not all four wheeled devices are necessarily more stable than all three-wheeled devices. Therefore, care must be taken when prescribing or purchasing a scooter to ensure that the selected device, whether three or four-wheeled, provides sufficient stability for the intended user, perhaps with a user test through a slalom course. Concluding that a four-wheeled device guarantees increased dynamic stability could be a false and dangerous assumption.

Given that limited data is available regarding stability characteristics of scooters, individuals are often forced to make assumptions about a device's stability based on wheel-base geometry. Misguided assumptions could be preempted if consumers were provided the appropriate and standardized stability information from manufacturers/distributers. Voluntary disclosure by manufacturers/distributers of results obtained by testing to ISO/RESNA/CSA standards could alleviate much of this uncertainty.

CONCLUSIONS

Statically, four-wheeled devices are generally more stable than three-wheeled devices. Dynamically however, the increase in stability is marginal at best. Some three-wheeled devices were found to be more stable than some four-wheeled devices. Therefore, great care must be taken in the selection of a scooter to ensure that the system as a whole - device and user - is statically and dynamically stable.

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Stress Response of Wheelchair Frames to Front Caster Impact

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Abstract

Test results are reported for the stresses experienced in the frames of a manual and power wheelchair rolling over different size bumps on a treadmill. Both wheelchairs were folding design with cross tubes pinned at the center. On each wheelchair, one strain gage rosette was attached to the tube directly behind one of the front casters and the strains were recorded for one traverse of the bump. The strains were converted to von Mises stresses. Comparison of the stress variations indicate the response of both wheelchairs is very similar for a given size bump. Both wheelchair frames experienced large tensile stress spikes in response to the front caster impacts. The data show that the stresses developed at impact were in the range of two to four times the mean stress.

Introduction

A test program has been underway to investigate the dynamic response of wheelchair frames when operated over various terrains [1,2]. Earlier efforts [3,4] have tested wheelchairs in dynamic environments, however the strains were recorded by a storage oscilloscope. The data collection for this investigation was performed by a computer driven analog-to-digital data acquisition system. In addition to illuminating the nature of the time-varying responses, the test program has provided a body of strain data that can be used in future wheelchair frame fatigue analyses.

Two wheelchairs, an Invacare Rolls IV manual and an Invacare Rolls Arrow power, were used in the testing. The manual wheelchair frame was constructed of chrome plated steel tubes; the power wheelchair had painted steel tubes. These wheelchairs had very similar frame designs in that both were folding chairs with cross tubes pinned at the center pivot. The similarity extended to the structure supporting the front casters where both frames had a second vertical member connecting the top and bottom side frame tubes located behind the front vertical member. The second vertical member provided both a guide for the vertical seat rail tube and additional structural stiffness to the front of the wheelchair frame. Stress response data will be presented for a strain gage rosette located on the bottom horizontal tube between the two vertical members as shown in Figure 1. This rosette is designated CG1 for "caster gage 1". On both wheelchairs, the tube CG1 was attached to had an outside diameter of approximately 0.82 inches; the inside diameters were unknown. Note that the size of the strain gage rosette in Figure 1 is exaggerated for clarity. The terminal strip for the strain gage wires is also shown schematically.

The manual wheelchair had rigid steel caster forks and semi-solid tires. The manual wheelchair's front tires had a cross sectional height (radial thickness) of about 0.75 inches. The power wheelchair had steel caster forks mounted with a flexible rubber bushing between plates attaching to the frame. The front tires on the power wheelchair were semi-solid with a cross sectional height of about 1.5 inches. The power wheelchair was tested with a simulated battery load.

Test Methods and Computations

The wheelchair frames were instrumented with three-element rectangular strain gage rosettes with 0.06 inch gage length and grid width. The strain gage rosette installation was identical on both wheelchairs. The analog voltages output by the strain gage circuits were filtered with 30 Hertz low pass filters prior to sampling and digitization by the personal computer-based data acquisition board. The system was programmed to sample the strains at a rate of 512 samples per second from each strain gage element. The strain gage circuitry and data acquisition system has been described previously in Reference 2.

The wheelchair under test was tethered on a treadmill that provided a nominal relative velocity of 1 meter per second. The wheelchair was tested over three different terrains on the treadmill: no bump and wooden dowels of 0.375 inch and 0.625 inch diameter. The bumps were intended to simulate obstacles that might be encountered in daily operation of the wheelchairs. For the tests simulating bumps, a single dowel was placed across the treadmill belt perpendicular to the direction of the belt motion. Both front wheels impacted the bump simultaneously. For all of the tests reported here, a 150 lb. able-bodied male rode the wheelchair.

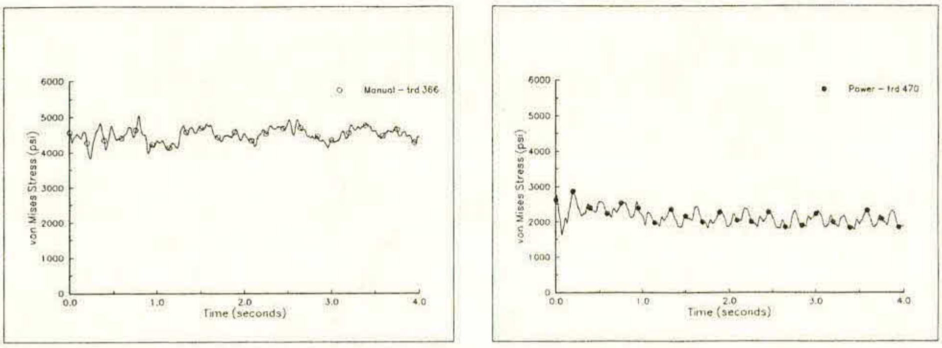
A single test consisted of rolling a wheelchair over a test terrain at constant speed and recording the strains as measured by the strain gage rosette for four seconds. The strain signals were sampled and digitized by the data acquisition system and stored as digital values. The von Mises stress at the rosette location was computed from the measured strains.

In this investigation, a test series consisted of a number of tests on a given wheelchair travelling over a given terrain. For each test series, thirty data sets were recorded.

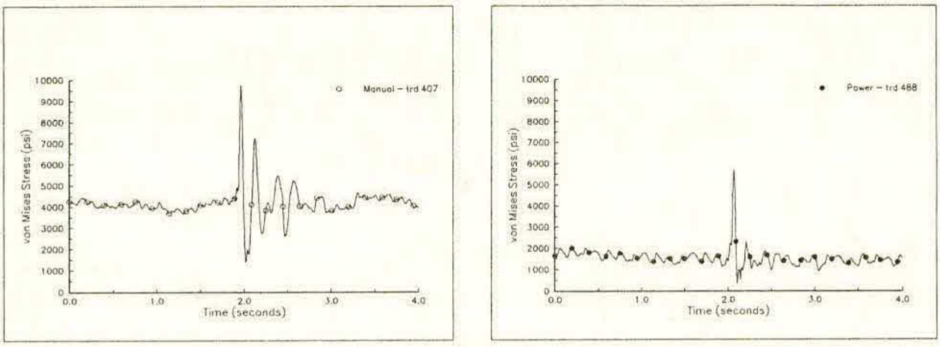
Results and Discussion

There were six test series recording strains from CG1 on

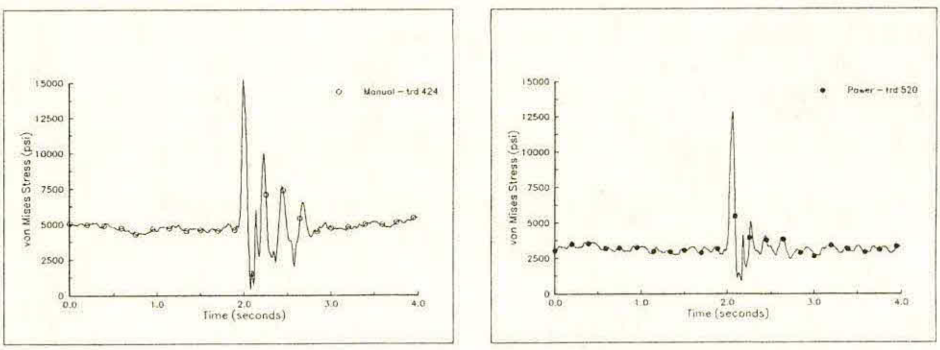
Front Caster Impact



No Bump



0.375 inch Bump



0.625 inch Bump

Figure 2: CG1 Stress vs. Time Plots

Bump Size	Whlchr.	Test ID	Max (1)	Mean (2)	Min (3)	(1)/(2)	(1)-(3)/(2)
No Bump	M	trd 366	-	4493 psi	-	-	-
	P	trd 470	-	2127	-	-	-
0.375 in.	M	trd 407	9739 psi	4174	1398 psi	2.3	2.0
	P	trd 488	5684	1537	344	3.7	3.5
0.625 in.	M	trd 424	15217	4884	410	3.1	3.0
	P	trd 520	12857	3229	890	4.0	3.7

Table 1: Summary von Mises Stresses for Sample Test Data

the two wheelchairs. One sample from each of the test series was selected to illustrate the stress response of the wheelchair frame to the front caster impact. These stress histories are representative of their respective test series, however it is acknowledged that no two stress histories from a given test series will be identical.

The von Mises stress versus time plots for the sample tests are shown in Figure 2. The manual wheelchair stress histories are on the left, the power wheelchair data is on the right. When crossing the bumps, the manual wheelchair responded with about 3½ cycles of larger than average variation. In contrast, the power wheelchair experienced about 1½ cycles of above average variation. It is apparent that the power wheelchair developed lower mean stresses than the manual wheelchair. A summary of the stress histories is given in Table 1.

It can be seen from the data in Table 1 that, although the manual wheelchair developed larger maximum stresses and larger ranges between the maximum and minimum stresses, the power wheelchair developed maximum stresses that were larger on a percentage basis when compared to the mean stress. The data show that for the power wheelchair, the maximum stress was between 3.7 and 4.0 times the mean stress when impacting the bump. The corresponding data for the manual wheelchair show that the maximum stress is between 2.3 and 3.1 times the mean stress. Another measure of the impact response is the ratio of the stress range (maximum - minimum) to the mean stress. Again the power wheelchair developed larger stress ranges compared to the mean with ratios between 3.5 and 3.7. Corresponding data for the manual wheelchair indicate ratios between 2.0 and 3.0.

Clearly the power wheelchair has a larger response, on a percentage of the mean basis, than the manual wheelchair even though the manual wheelchair has larger mean and maximum stresses.

Conclusions

Data has been presented that summarizes the von Mises stress response observed in the vicinity of the front caster on a manual and a power wheelchair frame. The test procedure consisted of rolling the wheelchairs over 0.375 and 0.625 inch dowels and recording the output of a rectangular strain gage rosette. The data shows that the manual wheelchair developed higher mean stresses and peak stresses in response to the impact. The power wheelchair, however, experienced stress maxima that were higher (as a percentage of the mean) than the manual wheelchair. The lower mean stress developed in the power wheelchair is perhaps due to the flexible caster connection transmitting less load to the frame than the stiffer caster connection on the manual wheelchair. For the this data, the peak von Mises stress experienced during a bump was between 2.3 and 4.0 times the mean stress.

The data presented here are applicable only the location on a given wheelchair frame where the strain gage rosette was attached and for the tire/caster fork combinations tested. It would be necessary to perform a more detailed structural analysis to relate the measured stresses to the stresses developed in the adjacent tube joints. Such a joint calibration would be used in a detailed fatigue analysis.

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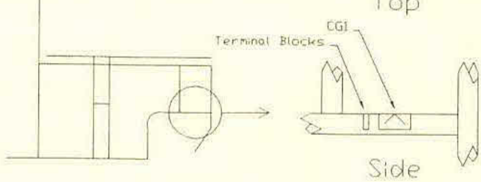

Figure 1: Strain Gage Installation

A 2-Dimensional Wheelchair Dynamic Load History using Accelerometers

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ABSTRACT

The introduction of new materials has mandated more stringent approaches to the determination of wheelchair dynamic loads. The use of accelerometers to determine these loads has a greater applicability than the use of strain gages because the data is more transportable from one design to another design. This should have the effect of encouraging new designs. The accelerations of several points along the surface of the wheelchair are needed and therefore, a technique was implemented to derive these accelerations from known accelerations at known locations on an ISO test dummy. A depot wheelchair and an ultralight wheelchair were both subjected to dynamic loading on an ISO curb-drop tester and an ISO two-drum tester. The data from the ultralight wheelchair is presented in a statistical format. The data from the ultralight and depot chairs are compared and some visual acceleration maps are presented as well. The results indicate that this method can be generalized to three dimensions and the two-dimensional data is useful for design purposes.

BACKGROUND

Many active wheelchair users subject their wheelchairs and themselves to frequent and severe shock loads. These loads can be detrimental to the long-term survivability of the wheelchair and to the comfort of the rider. Shock or dynamic loads occur when the kinetic energy of the chair in motion is absorbed by the chair and rider. This temporarily produces forces greater than is experienced when the wheelchair is loaded statically. In the past, wheelchair designers have commonly used a factor of safety approach to account for this increased load. The static load is simply multiplied by a fixed factor of safety (typically three) and it is hoped that the dynamic loads do not exceed this value. Furthermore, the wheelchair may fail by fatigue which is strictly a dynamic failure mode. A better approach would be to define a dynamic load history that is typical for many wheelchairs and then design new wheelchairs accordingly.

Attempts have been made to define the dynamic load history experienced by wheelchair. One such method uses strain gages placed on the cross members of a folding chair [1]. The data is converted to digital information and then stored on a computer. This method is limited. First, the data is only applicable to the area that directly surrounds the strain gages. Second, only one type of wheelchair design is considered, namely a folding tube frame wheelchair. The strain gage data can not be used directly to form the type of dynamic load history that is necessary to design a new type of wheelchair.

Another method is to derive the dynamic load history from a dynamic acceleration history. While accelerometers have been used in the past to determine rider comfort [3], a sufficient number of accelerometers has not been used to derive an acceleration history over the surface of the wheelchair. If the accelerations of all of the points along the loaded surface of the wheelchair (i.e. the seat, back, and footrest) are known, and furthermore the mass distribution of the load (i.e. an occupant or a load dummy) is known, then it is simple to calculate the forces acting on the wheelchair at all points along the loaded surface using Newton's 2nd Law. This data can then be used by wheelchair designers for a number of wheelchair designs. Using the dynamic load history, advanced design techniques such as finite element analysis can be used to produce lighter and more durable wheelchairs [6].

RESEARCH QUESTION

A dynamic load history was determined using an arrangement of four accelerometers. For all of the tests, both a folding ultralight wheelchair and a folding depot wheelchair were used. An ISO two-drum tester and an ISO curb-drop tester were used to produce the dynamic loads and the wheelchairs were loaded with a 100 Kg ISO dummy [2]. The head arms and trunk (HAT) of the dummy and the what represents the thighs of the dummy (LAP) were the instrumented segments.

METHOD

The accelerometers (ICSensors model 3031-050) were mounted in orthogonal pairs to aluminum blocks (1"x1"x2") which were then bolted to the surface of the ISO dummy. The accelerometer blocks were mounted at the extreme front and rear surface of the dummy segment that was being tested, figure 1. Analog devices 1B31AN signal conditioning chips were used to amplify and filter the signals which were subsequently sampled by a Data Translations DT2825 A/D converter board in a DOS computer (80486, 33 Mhz). The cutoff frequency of the analog filter in the 1B31AN was set at 1000 Hz and the signal was sampled at 2500 Hz per channel. The high cutoff frequency was chosen to allow for flexibility in designing a digital filter after the data had been collected. Since the sampling frequency was high, a special program had to be written which used the expanded memory capabilities of the computer.

The acceleration at an arbitrary point from one end of the dummy segment to the other end of the dummy segments can be derived with the following relation, (1).

$$A_C = A_A + r_{AC}(A_B - A_A) / r_{BA} \qquad (1)$$

Complex numbers are used to make the calculations easier to understand and manipulate. A_A and A_B correspond to the accelerations that are being directly measured by the accelerometers and A_C is the acceleration at an arbitrary point between point A and point B, figure 1. The components of the accelerations that are perpendicular to the dummy segment are defined as imaginary accelerations. The distance vectors r_{CA} and r_{BA} are defined in a similar manner, figure 1. This method does not imply a simple weighted average of the accelerations between point A and point B. The above method takes into account rotation of the dummy segment and the resulting centripetal acceleration if the r_{AC} is not parallel to r_{BA} [5]. This would be the case if the bottom surface of the dummy were not flat as in the case of a standard ISO test dummy [2].

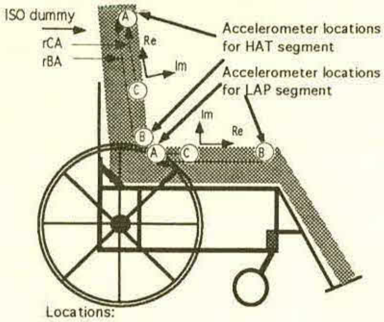

Figure 1: Diagram of accelerometer locations and definition of acceleration directions. The LAP segment is 11.5" from A to B and the HAT segment is 14.95" from A to B.

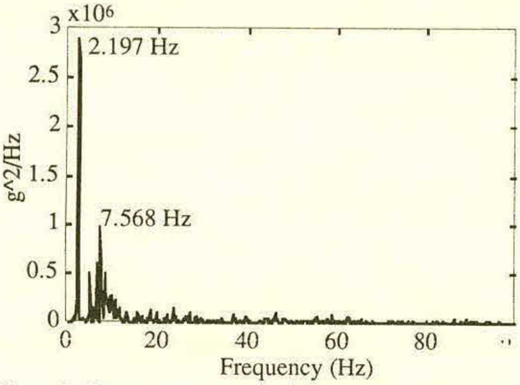

Figure 2: Power spectral density function for two-drum test (HAT, block B, perpendicular to dummy). DC power not displayed for clarity.

The data was filtered and analyzed with MATLAB. A MATLAB program was used to select characteristic data from the curb drop tests by rejecting the data 500 points (0.2 sec) before the value of any accelerometer reached a threshold value. The value chosen for threshold was 1 % of the maximum value under or over the first value. After windowing the data as described, the data was filtered using a Chebyshev type I filter of order 10 with a cutoff frequency of 25 Hz. Figure 2 shows a power spectral density function (g^2/Hz) for the two-drum tester (HAT, block B, perpendicular to dummy). Figure 2, shows that most of the unfiltered power lies below 25 Hz.

RESULTS

To help visualize the acceleration patterns that occur across the surface of the dummy segment, a mesh plot was generated using the digitally filtered sets of data, figure 3 and figure 4. These plots represent the accelerations of six points across the surface of the dummy segment (from A to B) as they vary with time. Each of the accelerations has been resolved into the vertical direction relative to the wheelchair.

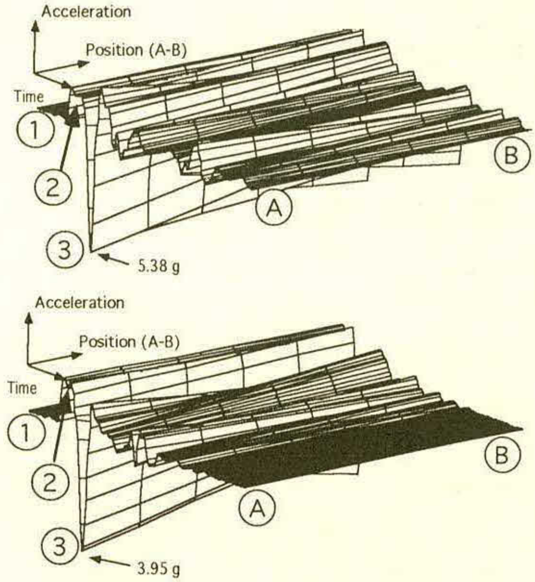

Figure 3: Vertical accelerations of the LAP segment during a curb-drop test. Ultralight above. Depot below.

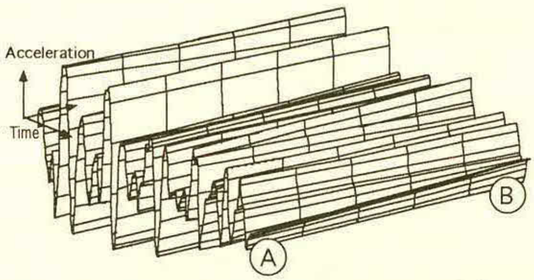

Figure 4: Vertical acceleration of the HAT segment during a two-drum test of the depot wheelchair. Maximum acceleration is 1.83 g.

The initial data shown in figure 3 (point 1), represents the wheelchair being supported by the curb-drop tester before being dropped. Just after release (point 2), the acceleration of the dummy with respect to the wheelchair is zero because they are in free fall. Upon contacting the ground (point 3), both chairs show sharp peaks of acceleration and then bounce in much the same manner. The bounce can be detected by the second period of reduced acceleration. Both acceleration maps in figure 3 are similar, but the ultralight wheelchair has a greater impact acceleration and takes longer to settle. These differences indicate that the ultralight wheelchair is stiffer than the depot wheelchair. The correlation coefficients between like accelerometers of the depot wheelchair and the ultralight wheelchair are shown below in table 1 (LAP, curb-drop).

Table 1: Correlation coefficients of like accelerometers, (N=170).

A(perpendicular)	.8834
A(parallel)	.6453
B(perpendicular)	.7095
B(parallel)	.6067

A statistical distribution of the accelerations at equally spaced points along the dummy are shown in table 2. The curb-drop data is normalized to 100 points per drop. Two-drum data is averaged for one point per second for 16.4 sec. The left column data is derived from the magnitude of accelerations at block A . The columns progress to the right as the location of the acceleration progresses from block A to block B.

Table 2: Normalized Statistical Distribution of Accelerations for the Ultralight Wheelchair.

	Two-Drum - HAT					
acc<0.5	0.2	0.1	0.1	0.2	0.1	0.2
1.0<acc<1.5	8.3	8.5	8.3	8.3	8.4	8.2
1.5<acc<2.0	7.5	7.5	7.6	7.6	7.6	7.8
2.0<acc<2.5	0.4	0.4	0.4	0.3	0.3	0.3
	Curb-Drop - HAT					
acc<0.5	14	13	3.6	1.2	0	0
1.0<acc<1.5	33	36	47	50	55	34
1.5<acc<2.0	47	47	45	45	43	68
2.0<acc<2.5	3	1.2	1.8	2.4	4.2	0
2.5<acc<3.0	0	1.8	1.8	1.2	0	0
3.0<acc<3.5	1.8	0.6	0	2.4	0	0
acc>3.5	0.6	0	2.4	0	0	0
	Two-Drum - LAP					
acc<0.5	0.2	0.1	0.1	0.1	0.1	0.1
1.0<acc<1.5	8.2	7.9	8	7.9	7.8	7.8
1.5<acc<2.0	7.7	8.1	8	8	7.7	7.6
2.0<acc<2.5	0.3	0.3	0.3	0.4	0.7	1
	Curb-Drop - LAP					
acc<0.5	13	11	9.6	9.6	9.6	9.6
1.0<acc<1.5	39	41	45	45	47	47
1.5<acc<2.0	42	40	38	38	36	35
2.0<acc<2.5	6	6	5.4	3.6	4.2	5.4
2.5<acc<3.0	0.6	0	0.6	2.4	1.2	0
3.0<acc<3.5	0	1.2	0.6	0.6	1.8	2.4
acc>3.5	0.6	0	0.6	0.6	0.6	0.6

DISCUSSION

The results of the accelerometer testing have shown that it is possible to generate two-dimensional acceleration load histories based on actual data. The technique used for finding accelerations at arbitrary points is robust and can be directly applied to cases where the bottom surface of the dummy (i.e. that part in contact with the wheelchair) is not flat (this adds the second dimension). With some modifications this basic method can be extended to the three-dimensional case where the load can vary from side to side as well as front to back across the surface of the dummy. The major obstacle to be overcome before the three dimensional model can be implemented is the development of faster software to process the increase in data from nine accelerometers.

The results shown in table 1 are encouraging. If a single set of data could be defined which represented a large class of wheelchairs, then a designer could use this standard data to design a new type of chair based on different materials or a different arrangement of common materials. This would provide an invaluable first step in the design process. If a single set of data could not be defined, then the worst acceleration profile could be used for initial designs. The windowing algorithm performed well enough that it could be used for signal averaging. This method could eliminate much of the noise in the audio frequency range present in the output. This would produce data more suitable for design use.

The curb-drop test is ideally suited for signal averaging because each drop is highly repeatable. The two-drum tester would have to be modified so that the both the front and rear drum rotated at the same rate to produce a repeatable cycle. The curb-drop results may be modeled as a second or third order impulse response which would make the data easier to use for design.

The reader should be cautioned when using the data presented in table 2. While the use of real statistical data is superior to simply assuming a normal distribution, it must be remembered that this system cannot be directly represented by a random process. However, the data does give an engineer a good first step in evaluating the feasibility of a particular design before having to collect data of his/her own.

It is interesting to note that the peak acceleration is considerably above 3 g at many locations. A safety factor of three is commonly used in the design of wheelchairs. This may not pose a problem for wheelchair designs made of metal because metals have the ability to deform plastically and absorb much of the excess energy. But, many new designs are based on composites or other materials [4]. Many of these materials experience brittle failure and cannot be loaded above their ultimate strength.

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To Integrate or Not? Findings from a Performance Study and a Retrospective Review

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ABSTRACT

Devices known as *integrated controllers* are now readily available to allow access to multiple assistive devices from a single input device. It is sometimes difficult to determine when these devices are appropriate for clients. Through a retrospective review and a performance study, information is being obtained to determine factors which suggest when integrated controls are and are not appropriate. Integrated controls appear to be appropriate when: 1) the "best" method for controlling each assistive device is the same; 2) the individual has a single, reliable access site; 3) performance on one or more devices is improved with integrated control; and 4) the individual prefers integrated controls for subjective reasons (e.g., aesthetics, minimizing fatigue). Integrated controls may not be appropriate when: 1) performance on one or more devices is degraded; 2) greater cognitive demands of integrated controllers make use difficult; 3) access to other devices is desired from a position other than from the wheelchair; and 4) additional cost (up to $3500) may not be justified.

BACKGROUND

Frequently, individuals who use more than one assistive device such as a wheelchair, communication device and environmental control unit (ECU) operate each piece of equipment using a separate input device (e.g., switches, joystick). In this type of system, access to each assistive device is *distributed* across several input devices, and often to more than one access site. While using several "distributed" controls is effective for some, it can be difficult or impossible for others, especially those with limited reliable access sites. Multiple input devices can also make a system more cumbersome to use, and less aesthetically pleasing.

In response to the specific needs of several people, customized systems were developed in the past decade to combine control of multiple assistive devices to a single input device (e.g., Braswell & Buckett, 1983; Romich, 1984; Trefler, Romich & Russell, 1985; Bresler, 1989). These customized systems demonstrated that "integrated" controls were both clinically and technically feasible.

Since that time, several integrated controllers have become commercially available. These integrated controllers offer therapists greater flexibility in making access recommendations to clients. For example, the same joystick or switches which are used to control a wheelchair can now also be used to control a communication device, a computer, a recliner, and an ECU. Caves, et. al. (1991) described an application of a commercially available integrated controller. An integrated controller allowed an individual with C1-C2 quadriplegia who had severely limited head range to access a wheelchair, computer, and communication device all through a single sip-and-puff device. Caves (1992) also demonstrated that other devices (e.g., a Nintendo game controller) could be modified to allow access from a wheelchair equipped with an integrated controller.

While integrated controls may be beneficial to some, they are not appropriate for all individuals. Two projects are currently underway to determine when the recommendation of integrated controls is appropriate. First, a retrospective review of all patient charts at the Center for Applied Rehabilitation Technology (CART) was conducted to determine the factors involved in recommending integrated controls. Second, a performance study is underway to compare access to various assistive devices using both integrated and distributed controls. The results of the retrospective study will be summarized briefly, and two case studies from the performance study will be presented.

RESEARCH QUESTION

Integration may be clinically advantageous in some cases. However, it is also possible that integrated controls may actually interfere with performance. The current project seeks to determine the factors which support integrating control of multiple assistive devices and those which suggest that control be distributed across multiple input devices.

METHOD

Retrospective Review. CART therapists were asked to identify the primary factors considered in determining allocation of control. Twelve primary factors were identified and were categorized into four domains: *performance* (speed, accuracy, ease of use), *functional abilities* (visual/perceptual, physical, cognitive), *subjective* (aesthetics, personal preference, independence achieved), and *external* (cost, technical limitations, other). Since the primary commercially available integrated controllers operate through the wheelchair input device, only those individuals receiving a recommendation for powered mobility were entered

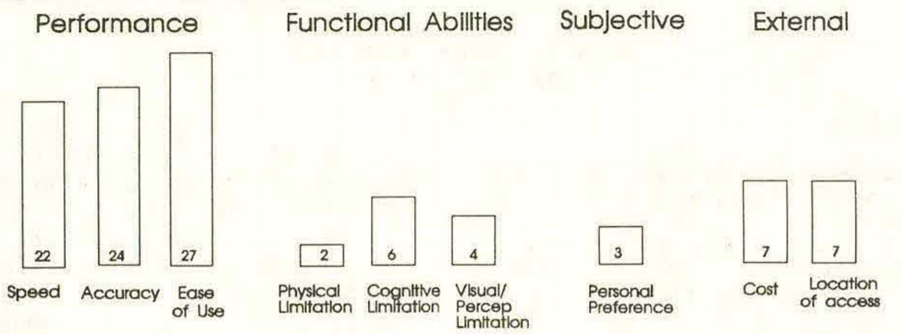

Figure 1. Frequencies of factors supporting the recommendation of distributed controls.

into the retrospective review. Information for each of these individuals was obtained regarding the specific disability, available access sites, clinically feasible access methods, and configuration of access methods recommended by CART therapists. Using this information, alternative feasible access methods (which included integrated controls if recommended systems were distributed, and vice versa) were considered, and reasons for recommending or not recommending an integrated system were determined for each individual.

Performance Study. Individuals who were able to operate both integrated and distributed controls were considered eligible to participate. To date, six of twelve individuals have completed the performance study. Participants were asked to perform a variety of simple exercises to access the devices recommended to them. For example, those who used a communication device were asked to access specific cells in various locations on the device. Participants performed exercises using the input device(s) recommended by therapists, and also using an "alternate" system, with input devices configured in the opposite manner (i.e., integrated if the recommended system was distributed & vice versa).

RESULTS

Retrospective Review. A total of 205 charts were reviewed. Of these, 65 met the study criteria and were entered into the retrospective review. Fifty-four (85%) received recommendations for systems with distributed controls. For many individuals, more than one reason for recommending a specific system type was noted. Therefore, the combined frequencies across all factors exceeds the total number of subjects. As can be seen in Figure 1 above, the primary reasons cited for recommending distributed controls rather than integrated controls were attributed to factors relating to performance (e.g., speed, accuracy).

Functional limitations and subjective factors were noted as the primary reason for distributing control for much fewer individuals. The additional cost of integrated controls was a factor for 7 people (14%), as was location from which access is desired, a factor not identified in the original list. This latter factor was important for individuals who wished to access equipment such as a computer or ECU from a position other than the powered wheelchair (e.g., couch or bed), thus precluding the possibility of integrating control through the wheelchair.

Eleven individuals (15%) received recommendations for systems with integrated controls. Limited functional abilities--primarily limitations in physical access--were the primary reasons for recommending integrated controls for four individuals. Superior performance was noted for four individuals when using integrated controls to operate other devices (i.e., computer, communication device) through the wheelchair controller.

Performance Study

Case Study #1 - *Integrated controls recommended.* This individual was a 16 year old female with congenital myopathy. She had extreme weakness in her upper extremities but had selective control of her arms and hands when using mobile arm supports. She wished to access a powered wheelchair and a computer. Wheelchair driving was accomplished through a proportional joystick operated by her left hand. During the performance study, computer access was compared using direct selection (pressing keys with her fingers) and using a scanning software program, accessed through the wheelchair joystick. While speed was only half as fast using the integrated system, error rates were comparable and were extremely low with both access methods. Furthermore, this person reported a strong preference for the integrated controls because she found them much less tiring to use and could use them for a much longer period of time.

Case Study #2 - *Distributed controls recommended.* This individual was a 25 year old male with spastic athetoid cerebral palsy. He desired access to a powered wheelchair, communication device, computer, and ECU. He accessed his wheelchair using a proportional joystick, and was also able to access large keys by touching them with his hands, although control was imprecise. During the performance study, access to the communication device was compared while using direct selection with his hand versus using directed scanning with the wheelchair joystick. To perform directed scanning, however, he required a four direction switch joystick rather than the proportional joystick used for wheelchair driving. While error rates on the communication device were 50% lower while scanning, time required was 3-4 times that of direct selection. In addition, in order to use the four-direction switch joystick to communicate, this joystick would also replace the proportional one for driving. In the driving exercises, driving performance was severely compromised with the four-direction joystick. Furthermore, this individual wished to access his computer and ECU from locations outside the wheelchair. For these reasons, integrating control of all devices to the wheelchair joystick was considered inappropriate.

DISCUSSION

From the information gathered in the retrospective review, as well as from preliminary findings from the performance study, several factors emerge as important in the recommendation of integrated controls. First, integrated controls appear to be appropriate for clients whose "best" method for controlling each individual assistive device is the same, and for individuals with functional limitations that result in a single, reliable access site. In addition, integrated controls may be preferable for individuals who experience fatigue using separate methods of access. Finally, integrated controls may be preferable for performance reasons. However, consideration should be given to the effects of integrating control on an individual's performance with each separate assistive device; integrating control often results in performance trade-offs, especially if an individual must use a less appropriate mode of access for one device in order to integrate control. The cognitive demands of integrated controllers appear to be greater than those involved in using dedicated controls for each device and thus should be taken into account. Finally, the additional cost of up to $3500 for integrated controls must also be considered.

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A LOW-COST SHAPE SENSING MACHINE FOR CUSTOM CONTOURED BODY-SUPPORTS

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ABSTRACT

A PC-based, 3-axis motorized movement with a working volume of 900mm x 480mm x 480mm (XYZ) has been constructed to automatically trace the shape of a moulding bag impressed with the contour of a client. The machine uses only one single commercial displacement sensor and is constructed with standard, non-precision materials for low-cost.

BACKGROUND

Various equipment have been devised to facilitate shape sensing for special seating. One approach uses 32 linear displacement sensors, 0.5" apart, to obtain the contour of the cast of a moulding bag at given intervals (1). The disadvantages are that a cast has to be made and that an operator has to move the sensor array at precise intervals to capture the shape of the cast. A more recent approach uses a number of spring loaded probes, each with a linear displacement sensor, arranged in a 11 x 12 matrix, to sense the shape of the buttock of a person sitting on the probes (2). The advantage is that buttock shape can be obtained almost instantaneously and that the springs can be adjusted independently to obtain a desirable normal pressure distribution profile. The main disadvantage is that the probes have to be custom made. A 1.5" probe spacing was used likely because of the large number of probes required for a finer spacing. This wide spacing may be inadequate for small users. The most recent technique uses a commercial electromagnetic 3-D space sensing equipment for shape sensing of a moulding bag. These ideas have resulted recently in three commercial products in North America and all rely on the commercial supplier to produce a contoured cushion which cost several hundred US dollars each.

RATIONALE

Contoured body support service in this city is not adequate mainly due to the lack of formal funding and expertise. A computer aided seating provision system which helps unskilled front-line workers to produce contoured body-supports at low-cost with little technical support may help to alleviate this problem. The first step is to design and construct a low cost shape sensing machine.

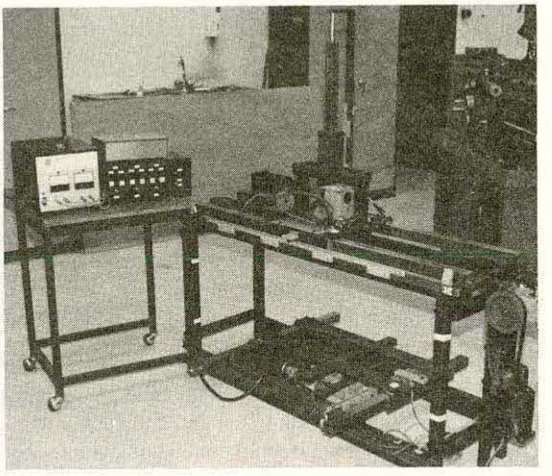

Fig. 1 3-axis shape sensing machine

STATEMENT OF THE PROBLEM

To design and construct a low-cost PC-based 3-axis machine large enough to trace out the body contour impressed on a moulding bag automatically.

DESIGN

The orthogonal 3-axis movement has a steel structure constructed with standard bars, channels and square tubes (Fig. 1). The moulding bag is supported on a plywood platform on the Y-axis assembly which is rack and pinion driven to travel on two stainless steel square tube tracks. A commercial 100mm LVDT, a displacement transducer which has a freely moving plunger, is attached on the rack and pinion driven Z-axis movement. The Z-axis assembly is chain driven to travel on two stainless steel square tube tracks along the X-axis.

The freely moving plunger of the LVDT has a 5mm diameter stylus at the end. It is driven by the 3-axis movement to travel along the moulding bag at fixed X-Y grid points and its 3-D coordinates is collected by a PC. Displacement on the X and Y axis are sensed with digital scales with a resolution of 5mm. Since the LVDT only has a range of 100mm, it is augmented by a 380mm digital scale with a resolution of 5mm. Z-axis displacement is determined by the output from the LVDT, which produces a continuous signal, plus an offset from the digital scale.

Small electric wheelchair DC geared motors are used on all 3 axis. Each motor is further geared down by a worm gear and the top speed for all axis is 20mm/sec. A block diagram of the shape sensing machine is shown in Fig. 2. The motors can be controlled either using push-buttons on the Motor Drive Module or under an IBM compatible PC.

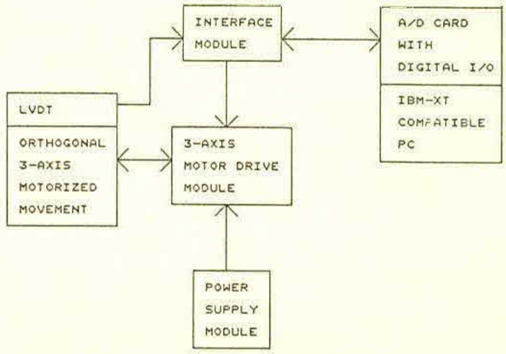

Fig. 2 Block diagram of shape sensing machine

EVALUATION

In operation, the machine is first driven manually to four points on the moulding bag to define the X-Y limits. Control is then passed over to the PC which will scan the moulding bag in the X direction for each 10mm step of travel in the Y-direction. When the LVDT is close to the limit of its measurement range, The Z-axis drive will automatically step to the next 50mm in a direction which brings the LVDT back towards its mid range. Tracing an adult size moulding bag takes about 1 hour. This apparent slow speed is caused by the fact that the maximum speed cannot be used throughout because the motors take time to decelerate and stop to get to known positions, a shortcoming of using a digital sensor with 5mm resolution and simple open-loop motor control.

DISCUSSION

The cost of this shape sensing machine is low because structural materials chosen are low-cost and only one commercial displacement sensor is used. Tracing a moulding bag is slow but it is possible to speed up this process with better motor control hardware and software.

With the collected data, software can be developed to generate paper patterns to facilitate manual construction of a foam body support. The second step of this project is to built a low-cost 3-axis foam milling machine similar in design to this shape sensing machine. These two machines together may be used to form a copying milling machine for quick production of a contoured body support.

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A BATTERY-POWERED URINARY LEG BAG EMPTIER

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ABSTRACT

The ability to empty one's urinary leg bag can give an individual who is quadriplegic great independence. None of the commercially-available electric leg bag emptiers are ideal. Design criteria for a better device were established. A new battery-powered device, the Freedom Flow leg bag emptier, was developed. Eight subjects participated in a two-month study to evaluate the Freedom Flow leg bag emptier, as well as several types of manual switches. Preliminary results show that the device is effective.

INTRODUCTION

Many quadriplegic individuals are independent throughout the day with the assistance of powered wheelchairs and accessories. One task that is difficult for most of these individuals is emptying their urinary leg bag. Often, this is the only hindrance to living independently during the day.

In 1977, Project Threshold, a rehabilitation service delivery program at Rancho Los Amigos Medical Center in Downey, California, developed a urinary drainage device. The device consists of a spring-loaded solenoid that is mounted on the wheelchair footplate. The device stops the flow of urine by pinching the leg bag drainage tube shut.

Although the device has been reliable, there have been several problems. For example, installation is quite complicated because it requires drilling into the wheelchair footplate and tying into the wheelchair battery. Also, it is too easy for the emptier to be accidentally activated by someone else because of the switch design.

Other devices have since become commercially available. None, however, seem to be ideal. Most control the flow of urine via an in-line valve. Such valves may increase the risk of a urinary tract infection. Furthermore, they can easily become clogged or, in some cases, corroded, because they are in direct contact with urine. Most of these devices are powered by the wheelchair battery and some also require drilling into the footplate.

Because the need is so great and the existing devices have shortcomings, we sought to develop a more effective urinary leg bag emptier.

DESIGN AND DEVELOPMENT

The first step was to meet with seven users of the Project Threshold device to develop design criteria. Some of the major goals were as follows (not necessarily listed in order of importance):

- Must not leak
- Must be reliable
- Must be easy to set up each day
- Must be able to remove footrest and/or swing footrest to the side
- Must allow normal positioning of the user and wheelchair
- Must accommodate leg muscle spasms
- Must have a manual back-up/override
- Must be easy to install on all major makes of wheelchairs
- Must be as cosmetically unobtrusive as possible
- Desire that it can easily be used on either leg

Also of importance was the design of the switch. The challenge was to design a switch that is easy to use but will also prevent accidental activation. Not only is the shape and size important but so is the switch type (latching or momentary). A momentary switch is on only while the user is activating it. It automatically turns off when released. An advantage of this type of switch is that the user doesn't have to remember to turn it off and if it is accidentally bumped on, it won't stay on. A latching switch locks in the ON or the OFF position. The advantage of this type of switch is that one can be very discrete when emptying one's legbag. A disadvantage is that more damage can be done if it is inadvertantly tripped. Of course, good placement of the switch is essential to success.

Our next step was to develop a working prototype for clinical testing. It was during this time that we were fortunate to meet Seyed, a client who was using a battery-powered leg bag emptier that his professor had designed and built for him. This device, called the Freedom Flow leg bag emptier, seemed promising because it already fulfilled many of the design requirements.

The inventor is an associate professor in the Industrial and Systems Engineering Department at the University of Southern California. He had custom-built a couple of units, but did not have plans for immediately proceeding to market the device. We collaborated to make several sample emptiers of his design and to evaluate them. We were also to provide all feedback and suggestions for improving the design.

The Freedom Flow leg bag emptier is a small box, 4"L x 1.25"W x 1"D. An extension flange and tubing guides bring the overall dimensions to 5"L x 1.25"W x 1.44"D. It weighs appoximately three ounces (93 grams). The device is molded of ABS plastic. It stops the flow of urine by pinching the leg bag drain tubing under a metal lever. The lever is kept in the closed position by a torsional spring.

The device is worn on the leg bag tubing as shown in Figure 1, concealed under a trouser leg. The leg bag tubing is cut long enough to end near and just below the heel, so urine can be emptied into a floor drain or urinal.

The mechanism and power source for the device are completely self-contained within the housing. The electric current, controlled by a simple switch, is supplied by rechargeable batteries sealed in the unit. When the current is applied, the lever lifts up far enough to allow the leg bag to drain. Once the electrical current is discontinued, the torsional spring returns the lever to the closed position and the tubing is clamped shut.

The lever can also be raised by pressing a manual release button (Figure 2). This is especially useful when inserting the tubing under the lever during daily set-up.

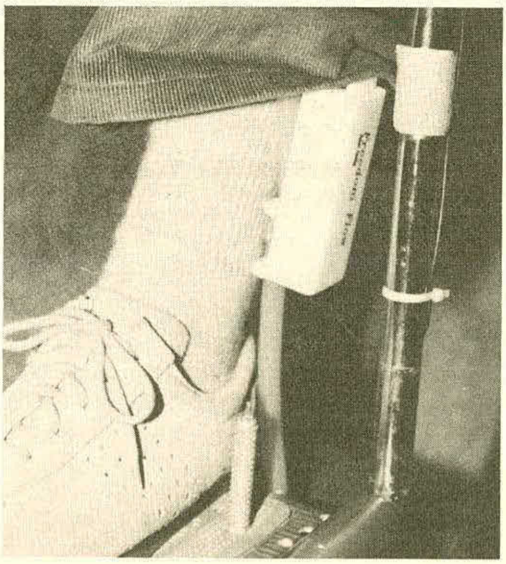

Figure 1. Leg Bag Emptier shown on left leg.

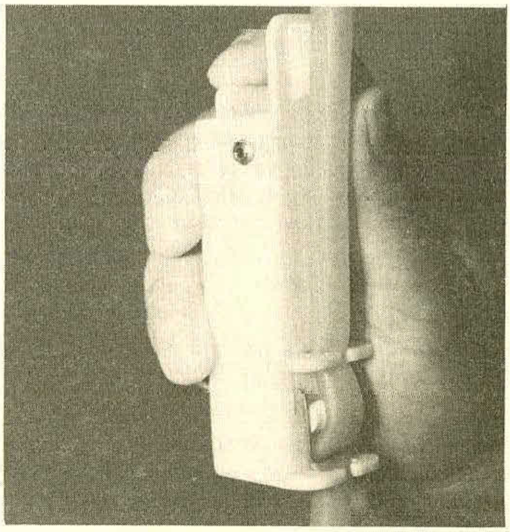

Figure 2. The manual release button.

A variety of manual switches can be plugged into a small port in the device. A switch is attached to the chair in a location that is easy for the user to reach but not likely to be accidentally activated by someone else. The wire is routed along the chair frame then up into the bottom of a trouser leg.

Because of individual abilities and preferences, several kinds of switches were provided. One type was a momentary pushbutton in a protective well. This switch can be mounted on any 7/8" round wheelchair tubing with a rubber band. The touch-sensitive button is set approximately 1/2" deep in the well to prevent accidental activation. An optional swiveling cover is provided.

Two types of latching switches were provided--a simple toggle switch and a rocker switch. The rocker switch is color coded so that, from any angle, it is easy to tell that is is on.

The emptier is recharged overnight every one to two weeks. The charger plugs into the same port as the switch.

CLINICAL EVALUATION

The objectives of the clinical evaluation were to evaluate the Freedom Flow leg bag emptier and the switches for effectiveness, ease of use, and satisfaction of design criteria. This information would allow us to make suggestions for improvement.

Eight subjects, all in powered wheelchairs, participated. Seven of the subjects have been diagnosed at a C4-C5 level of quadriplegia and have been using the Project Threshold emptier for several years. The remaining subject has muscular dystrophy and had no previous experience with a leg bag emptier.

Each subject was given an emptier, instructions, a charger, extra drain tubing, and up to three switches to try. We installed the switch(es) that each subject chose, and attached the emptier. Each subject was asked to try out the device for two months and then provide feedback.

RESULTS

Although we have not finished collecting all the data, we have the following preliminary results:

Several of the subjects experienced problems with leaking units; the lever did not pinch down on the tubing hard enough. However, all of those who had no problems with leaking liked the Freedom Flow device and most will continue to use it instead of the Project Threshold version.

The subjects were favorably impressed with how convenient the device was to use and how reliable it was. They liked the fact that the system was discrete because the device was concealed. They especially liked the fact that, other than the switch, the system was not attached to their wheelchair footplate or the battery. One subject reported using it on both his powered and his manual chair.

Aside from the leaking, there were few negative comments about the system. A few subjects noted that their attendants found the Freedom Flow emptier harder to set up in the morning than the Project Threshold solenoid emptier. This was due to having to fit the new device under a pant leg. To set up the solenoid emptier one just slips the leg bag tubing into a slot near the heel.

One subject rejected the device because it hung out of the bottom of his trouser leg. This problem can usually be corrected by wearing the leg bag higher up on the leg, but the subject strongly preferred to wear his bag low.

Most thought the device's physical appearance was acceptable, but a couple of subjects thought it should be smaller and less boxy.

Though there is no battery-charge indicator, no one had problems with running out of power.

Switch preference was spread over all three switches, with a very slight preference for the rocker switch. It was easy to use and the low profile minimized the chance of it being accidentally tripped.

DISCUSSION

In general, the Freedom Flow leg bag emptier proved to be an effective device that worked well for many of the subjects. It was easy to use, worked well, and satisfied most of design criteria. The most significant problem was that several of the units leaked. This must, of course, be corrected in future versions. Other than the leaking, there were no significant complaints about the system.

Another issue must be resolved. We must decide on the best type of switch(es) to provide. This may become more clear after we complete our surveys. Although, at this point, slightly more than one-half of the subjects preferred a latching switch, we must consider that they are accustomed to this type of switch since this is what accompanied the Project Threshold version. Perhaps other potential users should also be surveyed.

One last comment is that the evaluation units were tested for only two months; it would be beneficial to test for a longer term. It is worthwhile to note, however, that Seyed, the original client, has used his unit for over three years with no problems.

After improving the design, there are plans to market the Freedom Flow leg bag emptier. Definite dates for marketing are not available at this time.

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INCREASED REACH AND TRANSFER CAPABILITIES FOR WHEELCHAIR USERS

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ABSTRACT

Individuals with lower extremity paralyses have limited access to heights that are attainable to able-bodied individuals in a standing position. Because of their disability, some are also unable to transfer themselves to objects at heights greater than that of their wheelchairs. These two limiting factors affect their employment opportunities and independent living capabilities. Research is needed to improve the capability of motorized wheelchair transportation systems to improve the independent living and employability of wheelchair users. Described below is a system which will improve the vertical reach of the outstretched hand from the wheelchair seat by 24." The system can also be used by individuals with limited upper extremity strength to transfer themselves to alternative positions higher than the wheelchair seat height by 24."

BACKGROUND

The present motorized wheelchair design has not addressed the problems of (a) limited reach beyond the outstretched hands of wheelchair-dependent individuals from their wheelchair seats, and (b) their inability to transfer independently to positions higher than their wheelchair seat when the upper extremity of the individual is weak.

Literature from patents show proprietary artwork by Koeingkramer et al. [1], where a patient carriage has a base support mounted on castors with a patient supporting surface mounted on a hydraulic lift for vertical movement. The patient support can be moved around freely back and forth, side to side or rotated. This system is very large and expensive, and it cannot be turned into a chair for personal transportation. It cannot be used at a home or office. The system can only be moved side to side using the support castors which does not facilitate independent transfer. A second system was developed by Anderson et al. [2] which can be configured to support an individual either in a supine or a seated position. However, it does not have the capability to increase the reach of a seated individual, or to enable independent transfer. Additional devices other than these and commercially available wheelchairs include those by Kuhlman [3], Furniss [4], Weiner [5], Ooka et al, [6] and Plewright et al [7]. None of these devices used alone has the capability of providing the disabled individual access to greater heights, and the ability to improve independent transfer to heights greater than their wheelchair seats, while at the same time being used for transportation.

OBJECTIVE

The objective was to seek the answers to three key questions: (1) whether it is possible to develop a system that will enable individuals with lower extremity paralyses to overcome limitations of reach of 24" above their outstretched hands from their wheelchair seat, (2) whether the system could facilitate independent transfer to devices within this differential height safely; and (3) whether it is possible to develop a system to accomplish these functions and still be used as a motorized wheelchair in home and work environments.

APPROACH

The solution was to design a motorized wheelchair that has the following capabilities: (1) the seat designed to rotate 180^{o} on either side from its vertical axis to facilitate reach without mobility; (2) the pillar which supports the seat can extend 2 feet in a vertical plane; (3) the motion guide system upon which the pillar and seat are mounted facilitates side to side movement on the wheelchair base; (4) the system base withstands overturn tendency during side to side movement of the pillar and seat arrangement, and during transfer; (5) the finished product occupies and weighs no more than a regular motorized wheel chair, and is capable of being driven by a regular motorized wheelchair drive.

Figure 1 shows the illustration of the seat mounted on a pillar via a rotational drive system. In this design hinges were used to adjust the leg and back supports when the system is used in either the supine or sitting positions. In the supine position the back support rests on an aluminum stalk which telescopes in an aluminum tubing attached to the seat base. Self lubricating plastic sleeve rings were used to reduce the friction between the aluminum parts. In the sitting position, the aluminum stalk remains retracted in the seat base. The back and leg supports are padded with high density foam. The vertical height drive system consists of a three stage quiet DC driven telescoping pillar. It is made of high grade aluminum and is capable of withstanding a 400 LB load placed one meter off the center.

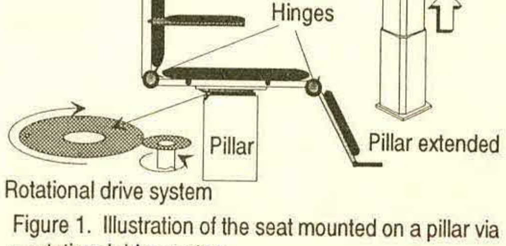

Figure 1. Illustration of the seat mounted on a pillar via a rotational drive system.

Figure 2 illustrates the arrangement for side-to-side movement of the pillar on the wheelchair base. The pillar is mounted on a linear motion guide system which is secured to the system base. The pillar is driven side-to-side by a DC motor attached to a ball screw drive system. Left or right travel is limited to 5 inches on either side of the center of the wheelchair base.

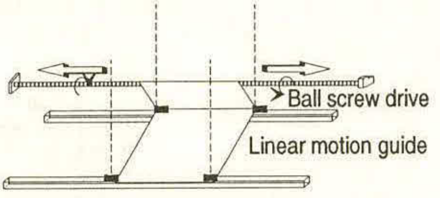

Figure 2. Illustration of the side-to-side movement of the pillar via linear motion guides and ball screws.

Figure 3 shows the illustration of the system base. The shape of the system base is crucial to the stability of the system during use and transfer. The front and the back wheels are located towards the farthest positions to the left and right of the system base. The base support has a small negative arch with the maximum deflection located at the center of the base. This design refers the center of mass of the system and the user to the center of the wheelchair base when the pillar is at the farthest position to left or right side of the wheelchair base. The control panel illustrated in Figure 3(b) is mounted on an adjustable stand off the base of the system along with the electrical connections. The system is driven with joystick control mechanism.

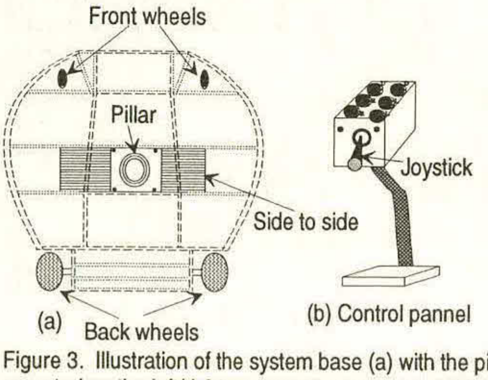

Figure 3. Illustration of the system base (a) with the pillar mounted on the left/right movement arrangement. Note the positions of the wheels. Figure 3 (b) shows the control pannel on a stand off.

Knowing the expected maximum load of 400 LB, an appropriate rear drive system and the front wheels have been selected from commercially available systems. The control circuitry has been developed to select the tasks of vertical drive, up or down, or the rotation of the seat base to the left or right, or to move the pillar support on the motion guide system to the left or right of the user. Feedback systems were used to limit rotational movements to a maximum of 180^{0} and the side-to-side movement to a maximum of 5 inches to the left or right of the user from the center.

TEST RESULTS AND DISCUSSION

Figure 4 illustrates the assembled system in the sitting position (a), and the optional use in supine position (b). Field testing of the system stability with a 400 LB able-bodied rider going up and down slopes; over small pavements; in and around office tight corners; and, retrieving files from shelves were very successful. Independent transfer when the seat base was moved to either the extreme right or left was also successful. While it was convenient for the user to get off the wheelchair independently, it was difficult for others to help the user get off the wheelchair by physical lifting. Although the system was designed for independent transfer, the assisted transfer test was conducted because in some real-life cases, the user may need help during medical emergencies. This difficulty was due to the physical size of the back support which was part of the design in order to turn the wheelchair seat into a bed as an optional use of the system. If this option is to be maintained, a new back support would be necessary.

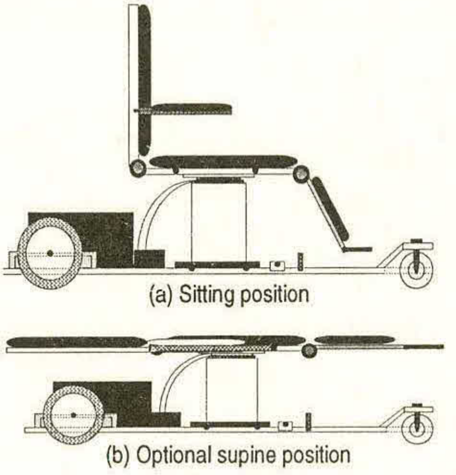

Figure 4. Illustration of the assembled system and the optional use in the sitting (a) and supine (b) positions.

During the field test, the control circuit was able to select and execute each of the assigned tasks exclusively. With the added reach and maneuverability, the new motorized wheelchair will make the work of getting into and out of bed easier for wheelchair dependent individuals. This is due to the fact that instead of working against gravity, they will be working with gravity during transfer. It may also enhance their employability. This is because the users of this system in a work environment will be able to retrieve items from shelves independently, and to turn 180^{0} towards the left or right of the work area without moving the wheels which could affect the flow of traffic.

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COGNITIVE READINESS FOR POWERED WHEELCHAIR MOBILITY IN THE YOUNG CHILD

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ABSTRACT

Few resources are available to therapists to assist in the decision to recommend a powered wheelchair to a young child. A five-year research project is currently seeking to identify the cognitive developmental skills and temperament factors that influence functional powered wheelchair mobility in young (18-36 months) children with physical disabilities. A case study comparison of two children who have completed a cognitive developmental assessment battery and powered wheelchair mobility program is presented and discussed. Information gained from the project will be used to assist professionals in determining cognitive readiness for powered wheelchair mobility, as well as to describe a program of mobility skills necessary for functional operation of a powered wheelchair.

BACKGROUND

Research has documented the developmental and psychosocial benefits of independent mobility for children with severe physical disabilities (1,2). At this time, provision of powered wheelchairs to young children continues to be infrequent due in part to professional biases and inexperience, the sparse and relatively recent nature of research studies, the difficulty in disseminating available information to care providers and professionals, and the lack of research that identifies the skills needed to operate a powered wheelchair functionally.

A child's ability to operate a powered wheelchair is influenced by a number of factors. Clinicians consider these factors to include physical access, cognitive developmental "readiness", temperament (e.g., attentiveness, persistence, motivation), and dynamic sensorimotor integration (e.g., perceiving and processing stimuli, motor planning, and reacting appropriately in a timely manner while moving in space). Apart from actually placing a child in a powered wheelchair or transitional powered mobility aid (TPMA) (3), it is often difficult for clinicians to determine whether a child has developed the cognitive skills and has the temperament necessary for functional powered mobility.

OBJECTIVE

This project focuses on identifying the extent to which specific cognitive developmental skills and temperament factors influence functional powered mobility skills in very young children. Results of two children who have completed a cognitive developmental assessment battery and a powered wheelchair mobility program will be compared.

METHOD

Forty-five children between the ages of 18 and 36 months will participate in the study over the next three years. All children will have severe physical disabilities that limit independent mobility but will demonstrate age appropriate cognition and learning abilities. Only children with *physical* disabilities (e.g., muscle disease, spinal cord injury, arthrogryposis or osteogenesis imperfecta) will participate to minimize the influence of sensorimotor integration problems which often result from central nervous system involvement (e.g., cerebral palsy, acquired brain injury).

To evaluate specific cognitive developmental skills, an assessment battery has been compiled with tasks grouped into five Piagetian-based hierarchial scales (4,5,6,7). The scales include eighty-three items evaluating cause/effect, object permanence, problem solving, spatial relations, and symbolic play. Because of the ordinal construction of the scales, it is possible to determine a child's stage of developmental thinking within each cognitive scale from their performance on the assessment battery. Characteristics of each specific stage of development are evaluated through individually modified activities. For example, a child's response to a solid ring stacking task can help differentiate between the stages of trial and error problem solving and foresight problem solving. The battery also includes a measurement of "temperament" which includes factors such as persistence, intensity of responses, and adaptability in new situations (8).

In addition, a program has been developed to introduce and evaluate powered wheelchair mobility skills through the child's exploration and play. The program includes nineteen basic mobility skills that demonstrate cause/effect association, directional control, and speed control. Sixteen more advanced tasks integrate these skills in different community environments. The child's ability to maneuver the powered wheelchair through the tasks is scored according to the amount of hands-on assistance and/or verbal cueing required, according to the following scale:

- 0 - Tasks not attempted;
- 1 - Maximal hands-on assistance of joystick with verbal cueing;
- 2 - Minimal hands-on assistance of joystick with verbal cueing;
- 3 - Direct stand-by guarding with verbal cueing;
- 4 - Verbal cueing only;
- 5 - Age-appropriate supervision.

Upon completion of all subjects, the cognitive developmental assessment results will be compared to the overall levels of assistance required on the powered mobility program to determine which cognitive and temperament factors influence functional powered mobility skills. Information gained from the project will be used to develop an assessment tool to evaluate cognitive and temperament factors that influence functional powered mobility in young children, and to document an age-appropriate powered mobility program.

RESULTS

Eight children have completed the study. Following is a brief comparative description of the performance of two of these subjects. Both subjects are male and chronologically 30 months of age. Developmental age ceilings (and range of scores) on each cognitive scale, as well as the scores on the powered wheelchair mobility program as shown in Table 1. Their performance on the cognitive developmental evaluation, temperament rating, and level of assistance required on the powered mobility program is described.

SUBJECT #1. Etiology; Spinal Muscular Atrophy (SMA)

COGNITIVE DEVELOPMENTAL EVALUATION

Cause/Effect: Able to infer the cause of something shown only its actions.
Object Permanence: Finds objects hidden through a series of *visible* displacements. Emerging ability with *invisible* displacements.
Problem Solving: Invents solutions through foresight. Emerging ability to generalize foresight in unfamiliar/abstract problems.
Spatial Relations: "Represents" relationships that exist between objects (matched parts to objects). Emerging ability to discriminate shapes.
Symbolic Play: Symbolic play with realistic toys. Short and self-limiting sequences. Parallel play emerging.

PARENTAL TEMPERAMENT RATING

Overall Score: Average temperament
Variable intensity of response; variable persistence and attention span; generally adapts easily in new situations.

POWERED WHEELCHAIR MOBILITY

Average Score = 1.4
Required maximal hands-on assistance of joystick with verbal cueing for completion of basic mobility skills (e.g. stop spontaneously to avoid a stationary object; turn wheelchair right/left).

SUBJECT #2. Etiology; Arthrogryposis.

COGNITIVE DEVELOPMENTAL EVALUATION

Cause/Effect: Able to infer the cause of something shown only its actions.
Object Permanence: Finds objects hidden through a series of *invisible* displacements.
Problem Solving: Invents solutions through foresight with familiar objects and with unfamiliar/abstract objects.
Spatial Relations: Emerging ability to copy shapes and sequence by toys by size. Can "represent" objects symbolically (e.g. 4 blocks are a train).
Symbolic Play: Short and self-limiting sequences with unfamiliar toys and miniature toys. Parallel play predominates.

PARENTAL TEMPERAMENT RATING

Overall Score: Easier than Average temperament
Mild intensity of responses, high persistence, generally adapts easily in new situations.

POWERED WHEELCHAIR MOBILITY

Average score = 3.7 points. Degree of assistance required to perform advanced integrated community tasks ranged from occasional direct stand-by guarding with verbal cueing to verbal cueing.

DISCUSSION

Although both boys are 30 months old, different stages of cognitive abilities emerge in the cognitive developmental evaluation using the Piagetian-based model. It is not unusual for a child to demonstrate different stages of development between the cognitive scales or for children the same age to demonstrate different cognitive abilities (9). From this comparison, it appears that certain stages of cognitive development and possibly certain cognitive scales do influence a child's readiness to learn powered wheelchair mobility skills. It is interesting to note the wide discrepancy between the two children's spatial abilities, a factor which would seem relevant to operating a powered wheelchair. Differences in performance are also apparent on the object permanence and symbolic play scales. The developmental differences between the two subjects are reflected in the amount of assistance required to functionally operate a powered wheelchair. Subject #1 requires maximal hands-on assistance. He is appropriate for a transitional powered mobility aid, but not yet ready for functional mobility in a powered wheelchair. In the case of Subject #2, factors such as his school/home environment settings and parental involvement need to be considered. He is appropriate for powered wheelchair mobility with additional training for him, his parents, and teachers in the recognition of potentially unsafe settings. As more children complete the study, we anticipate being able to further delineate specific cognitive abilities and temperament factors, and their influence on powered mobility.

TABLE 1

	COGNITIVE DEVELOPMENTAL EVALUATION *Ceiling Age in Months (Range)*					POWER MOBILITY *Scale range – 0 to 5*
	Cause/Effect*	Object Perm**	Problem Solve	Spatial Rel	Symbol Play	
Sub #1	21 (0)	15 (15–22)	26 (24–30)	22 (22–30)	24 (24–30)	1.4
Sub #2	21 (0)	23 (0)	26 (20–30)	36 (36–42)	30 (30–42)	3.7

**Scale ends at 21 mos **Scale ends at 23 mos All other scales end at 42 mos*

ACKNOWLEDGEMENTS

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A SURFACE ACCESSIBILITY MEASUREMENT DEVICE

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ABSTRACT

Our goal is to design and evaluate a device that can quantitatively measure characteristics of a suface that correlate with its degree of accessibility to wheelchairs. A wide range of test surfaces will be measured using four proposed and four existing devices. The device that best correlates with the resistance to wheelchair movement imposed by the surface will be identified.

INTRODUCTION

Persons with mobility limitations often encounter environments that are difficult or impossible to access due to the characteristics of the floor or ground surface. Unfortunately, none of the current accessibility standards regulate the physical properties of a surface, such as penetrability or sheer strength. The characteristics measured by existing surface measurement devices include the coefficient of friction, rolling resistance and sheer resistance. These devices only measure a limited range of surfaces and the data obtained with these devices has not been correlated to the degree of accessibility of the surface to wheelchair users.

Quantitative surface measurements would enable a person with mobility limitations to determine the degree of accessibility of indoor and outdoor environments. Such measurements would also facilitate the creation of standards for the usability of indoor carpeting and other surfaces by persons with mobility limitations.

BACKGROUND

Research on surface-wheelchair systems has focused mainly on the characteristics of the wheelchair and user, rather than the surface. The amount of metabolic energy required to travel a given distance in a wheelchair is greater on carpeting than on a concrete surface (Wolfe et al., 1977). Brubaker et al. (1988, 1989) has shown that propulsion efficiency is affected by several wheelchair parameters such as the speed of the wheelchair, the seat position, and the user/chair interface. Therefore, characterizing a surface in terms of the amount of metabolic energy expended would vary between different people using different wheelchairs. In addition, measuring metabolic energy requirements in outdoor environments would be extremely different.

The factors that affect the rolling resistance of a wheelchair are: wheelchair tire characteristics, wheel alignment and surface texture. Kauzlarich et al. (1985) found that the rolling resistance on carpet was three times that on concrete and that the differences among the various tires tested on carpet were not significant. This research indicates that the characteristics of the wheelchair system may be relatively insignificant compared to the characteristics of the surface in determining the wheelchair rolling resistance. Since the rolling resistance did not vary significantly with speed, an indirect method such as the proposed surface accessibility measurement devices would be the easiest way to measure the rolling resistance on various surfaces.

Analysis of terrain-vehicle systems can be broken down into two components: the terrain and the vehicle. The characteristics of a terrain that relate to its trafficability to vehicles include resistance to penetration, sheer strength, slipperiness, water content, and the presence of geometric obstacles (Hemstock et al., 1969). Data obtained with the cone penetrometer developed by the US Army Corps of Engineers has been correlated only to the trafficability of soils to military vehicles. Unfortunately, this device is incapable of measuring a variety of surface types.

Objective

The objective of this research is to develop a surface accessibility measurement device that can quantitatively measure a variety of indoor and outdoor surfaces. The data obtained with this device will correlate to the wheelchair rolling resistance measured, which gives an indication of the degree of accessibility of the surface. The surface accessibility measurement device will be cost effective, portable, easy to use and reliable on a wide range of surfaces.

Pilot Study

A pilot study was conducted to validate the need for a surface accessibility measurement device and to evaluate the feasibility of three prototype devices. Four devices were used to measure four test surfaces: concrete, carpet, packed granite and sand. The four devices included a tire penetrometer, a gimbaled pull-cart, a modified stimpmeter and a commercially available pocket penetrometer.

The results of the pilot study showed that the pocket penetrometer was capable of measuring only a limited range of surfaces. The repeatability of the device was poor, as indicated by the large standard deviations of the readings. All three proposed surface accessibility measurement devices were capable of measuring the wide range of test surfaces. From the pilot study, it was concluded that, with design modifications and a more precise data acquisition system, the three prototype devices could potentially measure the surface characteristics which correlate to the wheelchair rolling resistance and the degree of accessibility.

FUTURE WORK

Overview
A system for measuring surface resistance to wheelchair movement and four surface accessibility measurement devices will be designed, fabricated and tested. Proposed and existing devices will be used to measure a variety of test surfaces.

System for measuring surface resistance
The system for measuring surface resistance to wheelchair movement will measure the rolling resistance of a wheelchair pulled across a test surface. The components of the system include a manual wheelchair, a semi-anthropometric dummy, an electric winch, a linear force transducer and a data logger. The force required to pull the wheelchair system across the test surface at a constant velocity will be measured. The resistance the wheelchair encounters will be used as an indicator of the degree of accessibility of the surface.

Surface accessibility measurement devices
Gimbaled pull-cart
The gimbaled pull-cart device will consist of a mass, in a gimbaled box, suspended from a pair of 24-inch wheelchair wheels. The cart will be pulled at a constant velocity across the test surface, and the force required to pull the device will be measured. The device will be weighted such that 75 kg will be exerted on the two wheels.

Tire penetrometer
The tire penetrometer will consist of a section of wheelchair rim and tire with a vertical push handle. The device will be pushed into the test surface with a given force, and the amount of vertical displacement of the device will be measured.

Modified stimpmeter
The components of the modified stimpmeter will include a bar and a weighted object. The bar will be raised to a specified angle above the horizontal and the object will be rolled down the bar onto the test surface. The distance the object rolls on the test surface will be measured. Two objects, one spherical and one cylindrical in shape, will be fabricated and evaluated. The mass per unit of surface contact area of the objects will approximate that of a loaded wheelchair tire.

Modified coefficient of friction measuring device
The test apparatus for the modified coefficient of friction measuring device will include a 10 kg steel test block and a force gauge. The test block will contain two curved ribs protruding from the bottom surface, resembling two wheelchair wheels in parallel. The average force required to pull the device over the test surface at a constant velocity will be measured.

Optimization of parameters
In order to produce reliable and repeatable measurements on a wide range of surfaces, certain design parameters and testing procedures need to be optimized. These include: 1) the speed which the wheelchair system and the gimbaled pull-cart are pulled across the test surface; 2) the force applied to the tire penetrometer; 3) the weight and shape of the modified stimpmeter object; and 4) the slope of the inclined bar and the distance the object travels down the bar used in the modified stimpmeter. Each of these parameters will be varied and tested to determine the best design.

Existing surface measurement devices
Existing surface measurement devices will include a cone and a pocket penetrometer, a stimpmeter and a coefficient of friction measuring device which is currently used in ANSI/RESNA wheelchair standards test procedures.

Measurement of test surfaces
The surfaces that will be measured include a variety of carpets with various pile heights and padding thicknesses, and outdoor surfaces such as concrete, dirt, gravel, and sand. The system for measuring surface resistance to wheelchair movement will be used to measure the wheelchair rolling resistance on each test surface. Each of the test surfaces will be measured with the four existing surface measurement devices and the four proposed surface accessibility measurement devices.

Data analysis and interpretation
The mean values obtained with each device will be compared to the data obtained with the system for measuring surface resistance to wheelchair movement and the correlation coefficient will be calculated. A simple comparison of the correlation coefficients will determine which surface measurement device best correlates with the actual resistance to wheelchair movement measured. The reliability of each device will be evaluated by performing two-tailed t-tests to determine if the measurements obtained on different test surfaces are significantly different. The standard deviation of measurements obtained on each test surface will give an indication of the repeatability of each device. Inter-tester repeatability will be examined by performing paired t-tests on the data obtained by two different operators using the same surface measurement device to measure a given test surface. From the results of the statistical analysis, the surface measurement device that best correlates with the surface resistance measured and produces reliable and repeatable measurements over a wide range of surfaces will be identified.

CONCLUSION

The development of a surface accessibility measurement device will enable accessibility experts, park and recreation management authorities and others to quantitatively measure indoor and outdoor surfaces. The information obtained with the appropriate device would enable a person with mobility limitations to determine the degree of accessibility of the environment. The measurement device may also facilitate the development of standards for the use of indoor carpeting and other surfaces by persons with mobility limitations.

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KNEE BLOCK FITTING JIG

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ABSTRACT

Custom-contoured knee blocks are required for certain clients. Lack of immediate availability can delay the fitting process. Clearly, a knee block fitting jig can accelerate fitting and fabrication and performance of a custom-contoured postural positioning system.

The knee block fitting jig described herein fulfills two roles, (1) it serves as a temporary component during the fitting process and (2) it serves as an accurate pattern for fabricating the final knee blocks.

BACKGROUND

Symmetrical, commercially available, knee blocks seldom meet the needs of severely involved seating candidates.

It becomes necessary, therefore, to take measurements, fabricate a prototype, conduct a fitting with the prototype seating system, modify the prototype, and eventually fabricate and install the completed knee blocks. This results in long delivery times and increase in expense.

OBJECTIVE

The objective was to develop an accurate, quick and inexpensive device for making temporary knee blocks and a pattern for fabricating permanent knee blocks.

APPROACH

The framework of a knee block fitting jig was made with Kydex, a heat formable plastic sheet, with holes one-inch on center to permit adjustment of base width and depth. See Photos #1 AND #2.

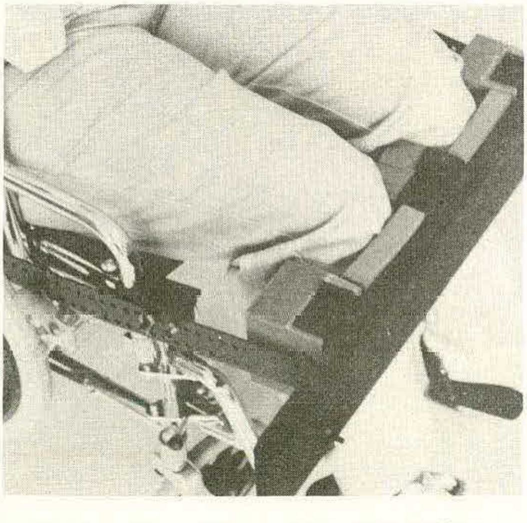

Photo #1. Wing nuts and holes one inch on-center facilitate adjustment of depth.

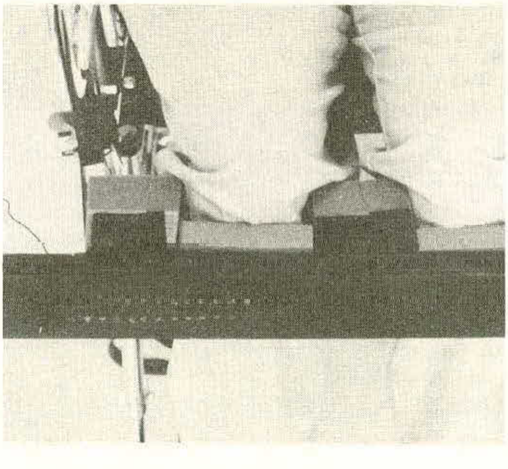

Photo #2. Overall width is readily adjusted.

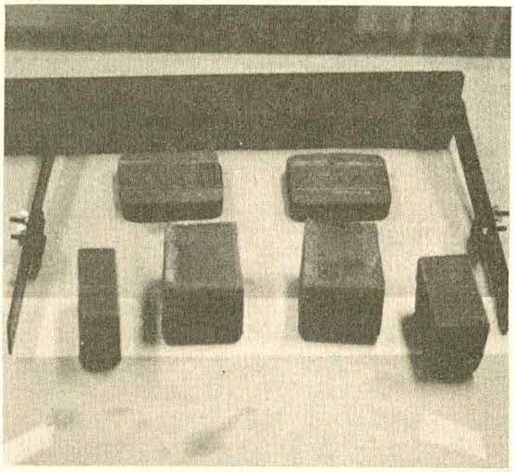

Photo #3. Foam blocks are interchanged to make and position abductor and knee slots.

A series of outboard and inboard plastic foam blocks with velcroed sides and of various sizes were fabricated for fitting purposes. See Photo #3. Trial and substitution of these blocks readily permitted mockup of knee blocks to, (1) compensate for leg length discrepancy, (2) properly size the abductor, (3) properly size the knee slots, (4) offset of abductor and knee slots if required, and (5) provide correct overall width. See Photo #4.

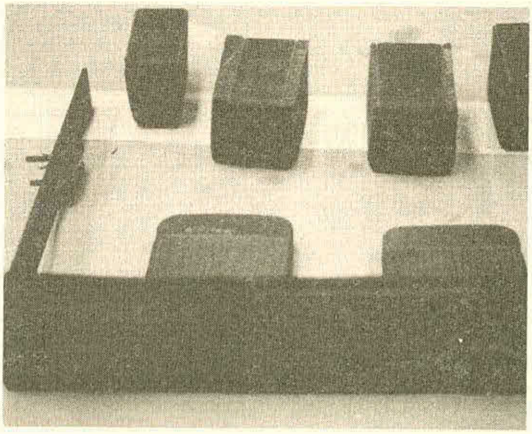

Photo #4. New foam blocks can readily be made and added to the kit.

Anterior-posterior adjustment members were made of sheet Kydex with adjustment holes and snap-in seat belt buckles. This permits quick and accurate adjustment relative to the back of the seat. Adjustment of elevation is accomplished by use of modified Enduro 6025 spring-loaded clamps.

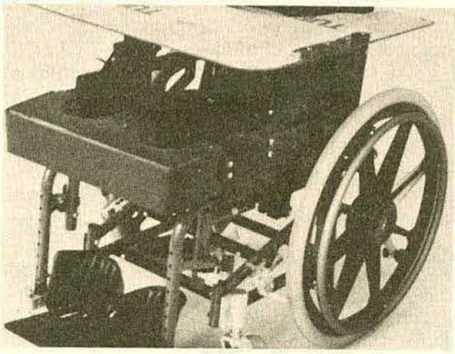

Photo #5. Knee block made using Knee Block Fitting Jig.

DISCUSSION

Five sets of custom knee blocks have been fabricated during the past year. This has resulted in accurate fits, reduced fitting and fabrication time, and a durable, adjustable product.

ACKNOWLEDGEMENTS

Development of improved postural positioning devices and methods have been funded by The Mervin Bovaird Foundation of Tulsa, Oklahoma for several years. KRC therapists, local therapists in private practice and Oklahoma Department of Human Services therapists have collaborated in much of this work.

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CUSTOM-CONTOURED ANTERIOR-LATERAL SUPPORTS

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ABSTRACT

Certain severely deformed clients require custom-contoured anterior-lateral supports. These can be made directly by using heat-formable plastics such as Kydex or with Beadseat components. Those made with Kydex can be padded, upholstered and fixed-mounted or mounted swing-away with Otto Bock hardware. The larger anterior-lateral supports, molded with Beadseat materials, must be reinforced. Methods for fabricating and mounting large custom-contoured anterior-lateral supports have been developed.

BACKGROUND

Clients with severe deformity and unusual muscle tone sometimes require support that cannot be provided with a molded back alone. Various approaches to this problem are available including the following: shoulder restraints, chest or "butterfly" vests, padded chest belts, flat supports, spherical thoracic supports (Otto Bock) and deeply custom-contoured backs. But if none of these suffice, a custom-contoured anterior-lateral support bears consideration.

Custom-molded anterior-lateral supports have been fabricated from sheet Kydex and applied very successfully. See Photo #1. These lend themselves to fixed or swingaway mounting. However, they are not readily applicable and adaptable to large, compound surfaces or significant pressures. In some instances, the fit achieved through vacuum-consolidation of plastic beads is indicated.

Photo #1. Swingaway anterior-lateral supports made from heat-formable plastic.

PROBLEMS

Commercially available anterior-lateral supports do not always provide sufficient contact area and support. Large, custom-contoured supports are difficult and inconvenient to mount on wheelchairs.

DESIGN APPROACH

It is well known that custom-contouring can be achieved through the use of vacuum consolidation of beads. Small Beadseat platilon bags can be hand-held in making supports that fit surfaces of unusual geometry. Strength of such supports can be achieved by providing enclosures that assure application of compressive forces. But both strength and mounting attachment can be achieved by installation of dowel pins after the Beadseat mold has been formed. The design approach is, (1) make a suitable molded support by

Photo #2. Fabricating a thoracic and arm support with hand-held platilon bag and vacuum consolidation method.

hand-holding a platilon bag, (2) reinforce the plastic bead and epoxy mold with dowel rods, (3) attach mounting hardware to the dowel rods, and (4) custom mount the assembly to the wheelchair.

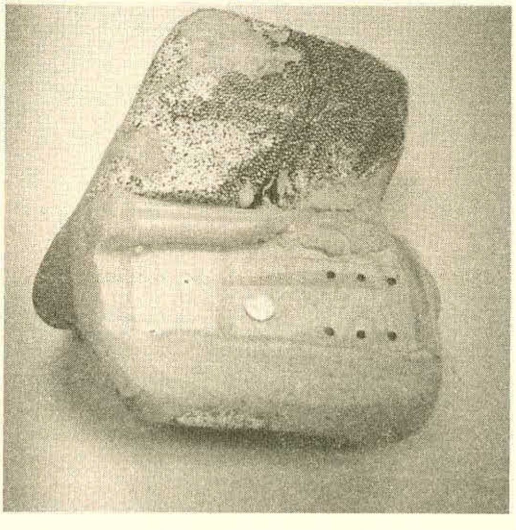

Photo #3. Support strength and mounting options can be achieved with dowel rods or plywood.

DEVELOPMENT

The need for a custom-contoured anterior-lateral support is determined collaboratively by therapists and a seating hardware specialist. Ordinarily a small Beadseat platilon bag is simply preshaped by using a partial vacuum. See Photos #2 and 3. With the client in the existing seating system, the bag is pressed against the body and shaped. Negative pump pressure is adjusted to facilitate shaping. The primary criterion is to shape and position the raw support fixture until the required support is achieved. This is, of course, determined by the participating therapist. Once the support shape is determined to be satisfactory, an appropriate negative pressure is applied and the raw mold is removed and permitted to cure.

A second criterion is to shape the support to facilitate attachment to the wheelchair structure and to "marry" the new support with existing seat and back cushions. The need and feasibility of making the new anterior-lateral support swingaway or quick-disconnect must be considered at this point.

The mounting method is a major factor in determining whether reinforcement is required. It also poses requirements for attachment hardware. Reinforcement is usually achieved by drilling the cured mold and installing wooden dowel rods. Obviously, large rods provide more strength and a larger "target" for screws that attach mounting hardware. An alternative is to epoxy a suitable board, with mounting nuts, to the Beadseat mold. See Photo #3.

The activity of the client, pressure applied, shape and fit of the existing back cushion and need for swingaway or

Photo #4. This support used 1" dowel rods and fixed mounting.

quick-release will dictate mounting method. Upholstery of the new anterior-lateral support is facilitated by vacuum-forming. Acceptable appearance can be achieved by attaching a plastic, metal or wood plate on the back side of the support to cover upholstery seams.

Photo #5. Client had used this anterior-lateral support for one year.

DISCUSSION

This center has fabricated four custom-contoured anterior-lateral supports using the heat-formable plastic method. All of these have swingaway mounts and have functioned most satisfactorily for two to three years.

This center has also fabricated five custom-contoured lateral-supports using Beadseat components and custom mounting. All of these have functioned satisfactorily for six to twelve months. One is presently being remade due to positive changes in the client. Three more units are under fabrication.

ACKNOWLEDGEMENTS

Funding for development of improved postural positioning devices and methods have been provided by The Mervin Bovaird Foundation of Tulsa, Oklahoma for several years. KRC therapists, local therapists in private practice and Oklahoma Department of Human Services therapists have collaborated in much of this work.

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AN ECONOMICAL SWING-AWAY AMPUTEE BOARD FOR THE WHEELCHAIR

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ABSTRACT

Proper positioning of the residual limb of the below the knee amputee is an essential part of an effective pre-prosthetic program. Sitting in a wheelchair with the limb flexed for prolonged periods of time promotes knee flexion contractures, and distal limb edema. This can result in increased discomfort for the amputee and a delay in prosthetic fitting. Criteria for an effective amputee board include: 1. ease of removal for transfers and standing up; 2. adjustability for individual limb size and comfort; 3. durability and 4. affordability. An amputee board which is easily mounted to the footrest hanger of the wheelchair and meets these criteria is described.

BACKGROUND

Although one of the primary rehabilitation goals for amputees is to have them be independent in ambulation with a prosthesis, the reality is that they often use a wheelchair for at least part of the day. A study was done at Guys Hospital in London, England on success rates for rehabilitation of vascular amputees. It was concluded that only 5 percent of the 440 patients studied became independent of their wheelchair and that more consideration should be given to surgery that will optimize wheelchair rehabilitation.[1]

Amputees often are referred to our seating and positioning service within the Applied Rehabilitation Technology (A.R.T.) Department for proper seating while they are inpatients, but also for their definitive wheelchairs. A Rehabilitation Technology Supplier (RTS) from a nearby company collaborated with the therapists in our department to develop a product which would adequately meet the seating needs of these clients with below the knee amputations.

STATEMENT OF THE PROBLEM

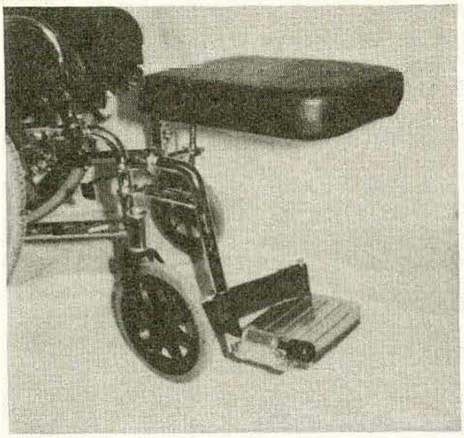
The primary task was to develop an amputee board with the following features:

1. Easy removal and replacement by the client, making transfers and coming to stand from the wheelchair as easy and as safe as possible.
2. A high degree of adjustability to accommodate the great variance in residual limb shape and length. The board could be angled slightly if needed to accommodate an existing knee flexion contracture, and to decrease pressure on the distal portion of the residual limb.
3. Durability to withstand everyday use, but the ability to be easily repaired by any RTS using commercially available hardware.
4. Availability to the client at a cost below the price of most commercially available boards as Medicare in Illinois does not reimburse for this item.

RATIONALE

Other amputee boards which had been assessed failed to meet the needs of the clients prompting the decision to explore other alternatives. The most commonly used board is the slide-in type which consists of a flat board that slides under the wheelchair cushion and a pad on the end that supports the residual limb. Clients often require assistance to slide the board under the cushion. Without a solid seat under the board it tends to angle down towards the center of the chair following the sling of the upholstery. Even with a solid seat under the cushion, having an additional board under one side can cause a pelvic obliquity. Another type of amputee board often used is hinged and attaches either to the wheelchair or to a wooden solid seat. By means of a release mechanism, it swings down out of the way for transfers. This type of board can usually be operated by the client and does not cause problems with the pelvis. However, it is not adjustable for height and angle and costs approximately fifty dollars more than the swingaway amputee board. The third type of board assessed is similar in concept to the swingaway amputee board in that it swings out of the way and is adjustable in angle and height. It attaches to the wheelchair with a footrest hanger to fit the client's own wheelchair. At this time it is available for a limited number of wheelchairs and the cost is ninety dollars more. If problems arise with this type of board, it must be returned to the manufacturer for repair.

DESIGN



The design of the amputee board pictured above consists of a padded board with a zippered vinyl cover and mounting hardware which attaches it to the footrest hanger of the wheelchair. The 1/2" plywood base of the pad is 7" wide and 9" long. (The dimensions can vary according to the size of the clients residual limb and the width of the wheelchair.) A 1 1/2" pad of medium density foam is attached to the base and covered with the vinyl cover. Two pieces of commercially available hardware by Millers[2] are used. The first piece is a 6" adjustment bar with a ball socket that is mounted to the base using T-nuts and screws. This controls the angle of the board. The entire board is attached to the upper most portion of the footrest hanger using a mounting base bracket. One end attaches to the adjustment bar and the other to the footrest hanger and is available to fit 3/4", 7/8" and 1" wheelchair tubing sizes. The adjustment bar slides up and down in the bracket, allowing for height adjustment.

DEVELOPMENT

The RTS originally designed this amputee board for a bilateral below knee amputee who was not a prosthetic candidate and needed to perform a transfer to her toilet independently. She was unable to maneuver the slide-in type of amputee board. The pad portion was originally the entire width of the wheelchair and was mounted to one footrest hanger. However, this was not sturdy enough to support both of her limbs, thus individual pads for the right and left limbs were fabricated and attached to the respective footrests. The original hardware used to attach the pad to the mounting bracket was an L-shaped bracket, but this was often not sturdy enough to support a heavy residual limb or a limb with a rigid dressing. As a result, the original bracket was changed to a ball socket or a heavy duty L-bracket.

EVALUATION/DISCUSSION

The swingaway amputee board meets all of the criteria for an effective residual limb support. It has been found that when a client is using the wheelchair and is wearing their prosthesis for a portion of the day it is more efficient for the amputee board to be mounted on a separate footrest hanger without a footplate. The amputee board and the standard footrest can be alternated as needed. The swingaway amputee board has been shown to be an important tool used for the rehabilitation of below the knee amputees.

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A COMPARISON OF SWING-AWAY LATERAL TRUNK SUPPORT FOR SEATING SYSTEMS

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ABSTRACT

The following is a review of commercial swing-away lateral trunk supports that can be used in the design of postural seating systems. Those utilized are manufactured by Advanced Engineering Labs, Freedom Designs, Mulholland, and Otto Bock. Each has a different approach to answering the need for lateral trunk supports that can be moved out of the way for client transfers. This study is based on extensive use of these four systems in service delivery. The conclusion reached is that each style of swing-away trunk lateral has its advantages and disadvantages. The selection of which system to use for a specific application depends on the individual merits of the application.

INTRODUCTION

There has been an increase in the number of commercially available lateral trunk supports with a swing-away function. At present there are 12 systems that we are aware of. This hardware provides client and caregivers with full clearance for transfers into and out of the seating system. Swing-away hardware allows the use of curved trunk laterals to provide anterior trunk control. This often reduces the need for extra strapping.

Adaptive Engineering Labs (AEL), Freedom Designs, Mulholland, and Otto Bock are four of the companies producing swing-away lateral trunk supports of which we have considerable experience in our service delivery program. Each has a different mechanism of locking the laterals in position. Operating under similar conditions, the hardware must address the same problems and constraints such as:

-wear on the locking mechanism,
-binding due to forces from the client,
-build up of residue,
-large forces on the locking mechanism due to considerable mechanical disadvantage,
-inappropriate use due to caregivers unfamiliar with their operation.

We are not aware of any published or unpublished reports addressing this issue.

METHOD / APPROACH

The analysis used was based on usage of the four systems in our service delivery program. Those included were the A.E.L "Quick Plus Lateral Brackets", Freedom Designs "Swing-away Trunk Supports", Otto Bock " Moss STS Supports", and Mulholland "Trunk Control Assemblies". There were other systems that are excluded for which it would be interesting to make similar comparisons but we thought it was appropriate to include only those systems with which we have sufficient experience.

A subjective analysis of the problems in design, ability to accomplish seating goals, and ease of use was utilized for 102 systems delivered. Feedback from the seating team, community professionals, clients, parents, and caregivers were taken into account as were the incidences of component failures or inadequacies. This analysis was affected by the availability of commercial swing-away supports and limited to those with dynamic and adjustable attributes.

RESULTS

-AEL or Freedom Design laterals allow greater offsets to midline from the mounting bracket. The AEL allowed an offset up to 2 1/2 " including the pad, while Freedom Designs has offset brackets allowing up to 4" including pad.
-When trunk supports are needed on a wheelchair the Otto Bock STS supports or clamp style AEL attach directly to the wheelchair canes.
-The pivot point on the AEL lateral is at the inside of the bracket. When the pad swings away it protects the client from the hardware but the lateral is still in front of the back. The Mulholland, Otto Bock, and Freedom Designs swing clear of the back. The pivot point of the Freedom Designs is at the side while the Mulholland lateral pivots behind the system.
-The locks of the AEL, Freedom Designs, and Mulholland laterals are positive pin locks while the Otto Bock lateral is positioned in a saddle.
-Freedom Designs and Otto Bock have exposed allen bolts where the pad attaches to the hardware. AEL bolts were countersunk and Mulholland bolts were partially covered by the naugahyde covering.

RESULTS -cont

	AEL Quick Plus Lateral Bracket	Freedom Designs Swing-away Trunk Supports	Otto Bock Moss S.T.S. Support	Mulholland Trunk Control Assemblies
Number	8 in last year	36 in last 2 years	38 in last 6 years	25 in last 2 years
Aesthetics	Anodized black, powder coated	Anodized black	Aluminum and steel	Anodized black, steel rods
Mechanism	covered, spring, locks intohardened steel post, push button to release,	open, spring, pin into steel strike plate, locks into bracket, lift 1/4" to release	open, rod sits in saddle, lift 1/2" to release	covered, spring pin locks into steel post, pull ring to release
Mounting Bracket	1/8 "x 1 1/2" steel bar	3/16" x 2 1/4" aluminum bar	clamp, aluminum bracket, 7/8" steel rod	aluminum blocks, track, steel post, steel rod
# of styles	4 (C,Z,L,Clamp)	4 (0, 1,2,3" offsets)	3	1 (are custom made)
adjustment with	allen key 1 size	allen keys 2 sizes	allen keys 2 sizes and Phillips screwdriver	allen keys 2 sizes
Weight (lbs) hardware - incl. pad - (4x5)	0.8 pair 6.4 pair	0.8 pair 6.4 pair	1.0 pair 7.2 pair	2.8 pair 8.0 pair
Lateral pads/ supports	abs / foam/ naugahyde	abs / foam/ naugahyde	molded polyurethane foam	abs / foam/ naugahyde
stock sizes	13	4	3	10
custom sizes	yes	yes	no	yes
thickness	3/4"	1 "	1 1/4"	3/4 "
adjustments	3 settings on front plate 1" /slide adj. on mounting plate 2 1/4"	slide adj. on lat. bracket 1 1/2" /slide adj. on mounting plate 3"	no	slide adj. on pad bracket /slide adj. on mounting bar/both limited by length of rods
angle adjustment (degrees)	laterally 30 in 10 out	horizontally 20 up 20 down	any angle to 90	no
Cost (Canadian $)	$225.00 pr	$300.00 pr	$260.00 pr	$565.00 pr

DISCUSSION

As with any component for positioning a client there are no absolute choices, each of the swing-away lateral supports are useful in their own right. Any of the swing-away lateral trunk support hardware may be more advantageous depending on the other factors affecting the prescribed seating system. Aesthetics, durability, ease of use, adjustability and the ability to be customized are factors to consider when making a choice. Often overriding some of these technical / therapeutic considerations are the necessities of cost, availability, and suitability to the seating system.

Aesthetics. Aesthetically all have been acceptable to the client, parents and caregivers. The AEL and Freedom Designs styles were perceived more favorably due to their slim lines and black coatings.

Ease of use. The ease of use of each system affected their acceptability. The AEL release mechanism was obvious and required little training. Freedom designs and Mulholland hardware needed demonstrations and often practice.

All of the laterals would bind when client pressure was applied laterally or lifting forces were applied to the distal pad. This would greatly impede the operation of the lateral and increase the frustration of the user. Wear and tear on parts was also accelerated. The Otto Bock STS support is easily used, however upward forces can cause these laterals to release unintentionally. AEL and Otto Bock are easily one handed operations while Freedom Designs and

Mulholland often needed two hands to release with one hand to relieve the lateral force while the other lifts or pulls the pin. All designs needed pressure to counter the forces from the client while the locks were released.

"T"and"I" Back. When "T" and "I" back seating systems are used the swing-away laterals are better utilized. This keeps the hardware offsets minimal while allowing a closer fit, greater adjustability, and less interference with arm function.

Offsets. The larger offset brackets of Freedom Designs are often required when not using a "T" or "I" back style seat system. These place an obstruction at the back of the elbow which could limit function or hurt the client. AEL maintains its flat profile to the back cushion in these circumstances. The Otto Bock allows a greater offset adjustment than the AEL but is less stable due to a long lever arm to the pivot point and places an obstruction behind the arm. All swing-away lateral supports except Otto Bock are limited as to degree they can open when a seating system is recessed between the canes.

A seating system that is recessed between the canes or has an open back readily lends itself to use of the Mulholland laterals. With open access behind the mobility base and the consideration of other components such as pelvic positioners, custom headrests, or switch mounts the bulk of hardware behind the seat poses few problems. Whether one component is behind the seat or many the attachment concerns are the same. There may be problems if the seating is to be used in other places.

Lateral pads. In the pediatric use of these laterals, all were felt to limit function due to the thickness of the pads. Customizing the pads was easily accomplished with AEL, Freedom Designs, and Mulholland due to their pad design. Customizing Otto Bock was not possible and was therefore limited to their three stock sizes. Customized lateral pads were made using ABS, a thin foam, and a neoprene covering. Custom neoprene sleeves were often made for all styles of pads to protect the clients arms from bolt heads or the edges of the bracket.

Durability. Durability would be major consideration when choosing a swing-away lateral support. AEL and Freedom Designs had only minor failures while Otto Bock shifted out of position and Mulholland locks sometimes failed. The Freedom Designs and Mulholland needed more maintenance in the form of frequent cleaning and oiling as their springs and contact surfaces tended to stick as the surfaces wore. The clamping of the Otto Bock laterals to the canes required regular tightening of bolts due to the clamps slipping on the round tubing of the wheelchairs.

Weight. Weight would rarely be a priority when selecting lateral swing-away hardware.

Cost. Cost of the components vary greatly as do supply and availability in Canada. Cost had little to with the durability, appearance, or ability of the lateral support to be customized.

SUMMARY

A comparison of Adaptive Engineering Labs, Freedom Designs, Mulholland, and Otto Bock swing-away lateral trunk supports has demonstrated all to be a great benefit in postural seating control. The major factors when deciding which device to use are aesthetics, durability and the interference of the pad or hardware with client function and other seat hardware.

When multiple caregivers were involved extra time was needed in demonstrating and practicing use of the swing-away lateral trunk supports. AEL were chosen most often when greater client independence was sought. Freedom Designs were preferred when custom pads were necessary due to their adjustability and ease of customization. While Mulholland laterals were utilized more often when other supports such as pelvic positioners or shoulder supports were to be used as well.

Failure of components was highest with the Mulholland locks while AEL and Freedom designs were felt to be the most positive locking. Otto Bock laterals were the most easily knocked out of adjustment and were also most likely to release unintentionally.

Availability of components was a more important factor than cost and all swing-away lateral supports were felt to be quite expensive.

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Remote Stop Switch for Power Wheelchairs

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Abstract

Advancements in technology and training methods have made it possible to provide power mobility to younger children. Here we describe a remote radio frequency (RF) wheelchair stop switch intended for use by parents in emergency safety situations or by clinicians during power mobility training. The system is based on a RF car alarm, modified to cut off power to the wheelchair control module.

Background

Many advances have been made in technology and training methods, which have enabled younger children to receive power mobility. Several studies have shown the importance of early power mobility for children (1,2), and manufacturers have developed pediatric size power wheelchairs.

While independent power mobility is very beneficial to children several factors combine to make it a dangerous proposition. Pediatric wheelchairs can weigh upwards of 150 pounds without the child in the chair and while these chairs are smaller, they often have the same motors and power as adult wheelchairs. This power can make these chairs climb an wall and flip rather than stopping. For a parent or trainer to manually stop such weight and power can be difficult or impossible. Also, children are curious. This curiosity can cause problems for adults because they can not simply grab a child who is in danger due to the size of the wheelchair.

Statement of Problem

Rehabilitation Engineering was contacted by the Pediatric Service to develop a remote emergency stop switch for power wheelchairs. This switch system could be used by parents in emergency safety situations or by rehabilitation professionals during power mobility training.

Design

There were several design criteria that were incorporated into the device.

1. The device must stop a power wheelchair on command from a distance of at least 25 feet.
2. Device should work with a variety of wheelchairs.
3. The device should have different channels to allow several wheelchairs to be independently stopped (during training sessions).
4. The device should not require modification to any of the wheelchair's wiring.

In order that the switch operate over a distance yet not be connected to the chair, it was decided that the device be radio frequency (RF) controlled. The system was designed to interrupt the power to the wheelchair's control module. This was to ensure that the device would work with different wheelchair systems and not require modification to wheelchair wiring. Taping into the control module or joystick could potentially void the manufacturer's warranty.

Development

A Ninja RF auto car alarm was modified to open a 60 amp, normally closed relay. The Ninja car alarm provided a small package, a keychain sized transmitter switch, and 512 possible digital codes. The car alarm was used to drive a NPN bipolar transistor which energized the relay, and cut off battery power to the wheelchair controller. The receiver board and relay are always powered. The system was packaged in a plastic enclosure.

A smaller RF transmission package has been identified as well as a physically smaller relay. This should reduce the overall size of the device. Future development plans include investigation of use with a variety wheelchair systems.

Evaluation

Testing found that cutting the power to the wheelchair at the battery worked well for wheelchairs at slow to moderate speeds. At high speeds the wheelchair module stores power which will cause the chair to coast to a stop. The distance the chair moves before it stops is a function of the speed and terrain. Our tests were on an Everest and Jennings Xcaliber with a Dufco Multimode. Top speed settings which allowed immediate cutoff were Outdoor-60% and Indoor-80%. In general these speeds are sufficient for the young or inexperienced driver population who would require such a device. Also, most of the power wheelchair manufacturers have systems of adjustment which prevent accidental modification, so that the performance parameters are protected. This will reduce the chance that the settings could be changed.

At the time of this paper, the device was scheduled for evaluation with a ten year old girl.

Discussion

As we look to provide independent mobility to younger children it is important to realize that though they can operate this sophisticated technology, they are still children. By providing power mobility we are expanding children's access to their environment. They are able to explore, interact and even get into trouble. It is our responsibility to ensure that the driving experience is a safe one.

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POWERED WHEELCHAIR MOBILITY SIMULATOR

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INTRODUCTION

Powered wheelchairs are an option of choice in providing a means of independent mobility to individuals who do not possess the physical capacity to propel a manual device. Providing powered mobility to persons with both physical and cognitive impairments has been a controversial issue among rehabilitation professionals as some people do not feel that individuals who fall into this category possess the skills necessary to operate and maintain a device safely or effectively[1] A powered mobility simulator was developed based on the concept and work of Mark Bresler and his Turtle Trainer[2]. Our design concept is a motorized platform to which an individual's manual wheelchair can be mounted and fastened to experience actual powered mobility. It serves as an assessment and training device to provide critical information on an individual's ability to operate a powered mobility device.

BACKGROUND

Evaluation and prescription of the optimal powered mobility device for an individual depends on several factors that includes a comprehensive interdisciplinary collaboration of rehabilitation professionals, the candidate, and significant family or caregivers[3]. Generally, the protocol for evaluation and prescription of these devices is as follows;

1) assessment of the individual's neuromuscular movement and tone as well as cognitive and perceptual capabilities that will affect the ability to use the device

2) assessment of the individual's level of ability to complete daily tasks

3) assessment of the individual's home, work/school, family, social, and community environments that will play a role in the ability to use the device

4) assessment of the individual's ability to access and operate an input device such as a switching system or joystick needed to control the wheelchair appropriately

5) assessment of the person's seating needs to determine what system will provide the most appropriate postural support for controlling the device

Evaluating a cognitively and physically impaired person's ability to operate a powered mobility device is often difficult as one can only speculate performance based on the individual's past performance at related tasks. Successful powered mobility is a complex integration of various skills that have perhaps only been observed in controlled isolated environments. For example, an individual may possess the capability to activate a switch for the cause-effect task of turning a radio on however, can the individual activate the same switch to propel a powered wheelchair through the doorway without striking an obstacle? Snell and Balfour[4] state that individuals who have long been dependent for mobility needs have never had the opportunity to develop the skills necessary for independent mobility. From this, one assumes that the training process for these individuals will involve significant remediation in skill development.

Traditionally, powered mobility training for the cognitively impaired involves a series of progressive training phases ranging from and starting with simple cause-effect understanding, to using a switch control interface in simulated activities related to powered mobility (such as a computer based simulation program), and finally to a trial phase of actual powered mobility in a trial chair. This method is by far not the most efficient as two documented case studies by Chase & Bailey[5] and Bailey & DeFelice[6] have reported that the entire process has taken up to five years. Another problem with this method relates to the fact that persons with significant cognitive problems may have difficulty with carry-over of skill from one activity, such as a computer simulated task, to control of an actual powered wheelchair.

Placing the candidate in a trial powered wheelchair often involves removing them from their familiar specialized seating environment. This takes away the postural support necessary for them to effectively access and control the interface needed to operate the mobility device therefore, is not a fair measure of their ability to use it.

Equipment vendors, who supply trial devices, are also limited in the availability of trial wheelchairs thus can only offer the equipment for a short time-span which is insufficient to provide enough information regarding an individual's ability to use it successfully.

There are also problems with the person's specialized interfacing control device being electronically incompatible with the trial chair since standardization of interfacing is nonexistant.

The above mentioned problems, input from therapist actively involved in the evaluation and prescription of powered mobility devices for people with cognitive and physical impairments, and our own experiences in providing the technology compelled us to design a device that will serve the following needs;

1) actual simulation of powered mobility

2) the ability for the user to remain in their own seating environment

3) compatibility with virtually any joystick or other switch interface device

4) continuous availability for long-term assessment and training protocols

5) universal accessibility by people with varying disabilities

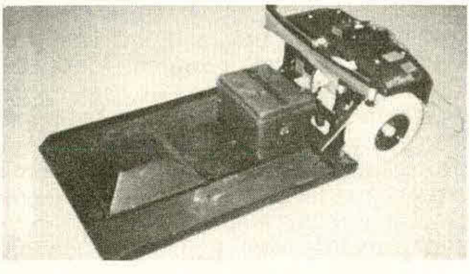

Photo 1: Powered Wheelchair Mobility Simulator

METHOD

Fabrication and design of the device involved taking the existing base of a powered wheelchair and modifying the chassis to fit a platform to which a manual wheelchair could be mounted. The Invacare Arrow XT was chosen as it is available with microcomputer controls that allows for electronic compatibility with a multitude of switch options. The on-board computer also allows for variabilitv in speed, turning, acceleration, and deceleration control. An attendant control is provided with the unit that enables the therapist to override the user's controls in hazardous situations.

The front end of the chassis was cut and removed leaving only the two motors, the drive system, and microcomputer. A 36" long and 25" wide frame was constructed out of steel and welded to the residual base. A housing unit was placed at the front of the frame to encase a four hundred pound industrial strength double caster that would support the device. Two 36" long and 6 3/4" wide plastic runners were cut and inserted on both sides of the frame to support the user's wheelchair. The battery box was attached behind the caster housing underneath the user. A steel bracket was mounted to the rear of the frame that prevents the rear wheels of the user,s chair from rubbing against the tires of the power base. This bracket is also fashioned with a nylon webbing strap that wraps around the user's wheelchair frame and is tightened with a ratchet to secure the chair safely in place. Two additional straps were provided at the front of the platform to anchor the casters in place.

Photo 2: Powered Wheelchair Mobility Simulator mounted with manual wheelchair. Also, switch control options are shown.

Once the user's manual wheelchair has been mounted and secured to the platform, the switch control system is connected to the power base and positioned in the most appropriate way for access. Switch controls can be placed on a lap tray or on a mounting arm that can be adjusted in various positions depending on the user's need. The parameters are entered into the microcomputer to adjust for control needs. The attendant control is plugged into the unit and used by the therapist to stop and redirect the user when necessary.

RESULTS

A prototype of the device has been in use for approximately six months by the therapy staff with several clients who were selected as potential users of powered mobility. The initial responses by the staff have been favorable. The simulator has been well received by a multitude of rehabilitation professionals at conferences and workshops. Demands for use of the device are continuously being received from other centers who wish to try it with their clients. As the demand cannot be met, plans are underway to construct additional prototypes and ultimately find a manufacturer who is willing to mass produce them.

CONCLUSION

A Powered wheelchair mobility simulator has been developed based on a previous design concept and existing technology. It serves as a tool to enhance the evaluation, training, and prescription process of providing powered mobility to individuals with physical and cognitive limitations. It should assist in providing vital information as to an individual's ability to successfully operate a powered mobility device. A prototype has been well received and used by therapist in the clinic. Plans are in place for a research study that will determine its efficacy in simulating actual powered wheelchair mobility as well as to develop appropriate protocols for maximum utilization.

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A MODIFICATION OF JOYSTICK ASSEMBLIES TO LIMIT THE EXCURSION AND FORCE APPLIED BY THE USER

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ABSTRACT

Proportional control joysticks are, by concensus, preferable to other types of input drive controls used on motorized wheelchairs because they provide the user with finely graded movement and enhance their maneuverability. These joysticks are frequently at risk of damage when used by individuals with high tone or spasticity due to the mechanism's inherently delicate design. Described in this article are two different types of linkage devices which have been retrofitted to interface with Invacare's proportional joysticks to prevent the mechanism from traveling past it's range of excursion, while also limiting the force applied to them.

BACKGROUND

Two client's, ages 31 and 33, both diagnosed with cerebral palsy, spastic quadraplegia, currently reside in a state residential care facility and had both been using Invacare Arrow conventional frame power chairs. Due to their extremely high tone, both clients had a history of damaging their joysticks thru their normal driving operations. Each client had required the replacement of their inductive joysticks numerous times in the course of a three year period. Besides the frustraton experienced by the clients during "down" time, the replacement costs for the joysticks and labor to install them was becoming an expensive reoccurence.

OBJECTIVE

Both clients were assessed for new powered mobility systems. Because both client's had become quite proficient at driving with proportional controls, alternatives were sought which would permit this. Invacare XT power bases were chosen and the objective was to build a type of force limiting device to protect the delicate joysticks from the movement of the clients.

APPROACH

Two different approaches were utilized. The first method (see figure 1) involved the fabrication of a metal housing constructed of aluminum channel that was bolted over the top of the factory joystick. A linkage assembly, made of a nylon material, was then added to the inside of the housing where one end slipped over the factory joystick and the other end was attached to a secondary joystick. Pivioting for the secondary joystick was accomplished using a spherical rod end coupler attached to the inside of the housing. The hole in the top side of the housing was cut to a diameter that would limit the amount of excursion on the secondary joystick, thus stopping the factory joystick before it reached it's full travel. Both of the left and right motor leads were then swapped to compensate for the action of the linkage assembly to reassign directional commands.

FIGURE 1

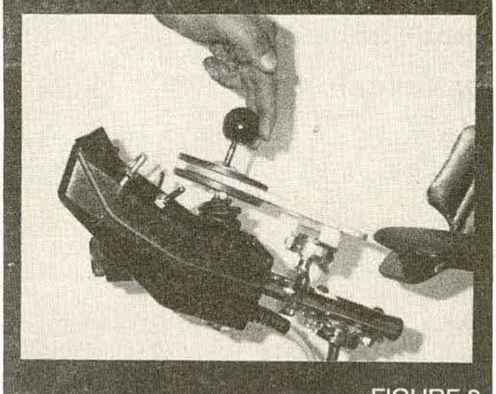

FIGURE 2

The second method employed a flat plate surface that was horizontally positioned above the factory joystick (see figure 2) using ball and socket hardware. A large diameter hole was cut directly over the joystick assembly. A pair of bushings were then fabricated to fit thru the hole and bolt together with a loose enough fit that they could easily slide within the full area of the circular hole. In the bottom of the paired bushings was a hole that was drilled to allow the joystick gimble to fit into. A secondary joystick that the user would grasp was then added to the top of the limiter. The size of the hole which the bushings moved within was critical in limiting the excursion of the factory joystick. Return to neutral in both of the methods described, relied on the spring tension in the factory joystick.

DISCUSSION

Both of these devices have been in use on a regular basis for more than a year without any damage occuring to the inductive joysticks. The few down times the clients have experienced have been caused by totally unrelated incidents such as battery charge and loose connections. Although both of these methods have been successful in protecting the factory joysticks, the team prefered the second method because of it's simplicity and it's easier fabricaton requirements.

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DEVELOPMENT OF A POWERED ELEVATING LEGREST SYSTEM (PELS)

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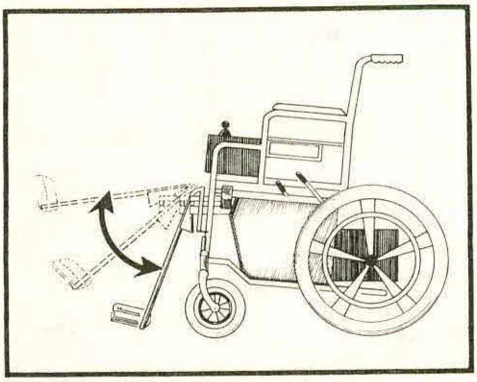
ABSTRACT

A powered elevating legrest system (PELS) was developed for wheelchair users who require elevating legrests but cannot manage the elevating task manually. One of two variations of the system can be installed on either a manual or powered wheelchair. The PELS uses switch controlled electric actuators to raise and lower the legrests. Initial review is positive. Benefits include increased independence for the wheelchair user and reduced incidence of back strain for the caregiver.



STATEMENT OF PROBLEM

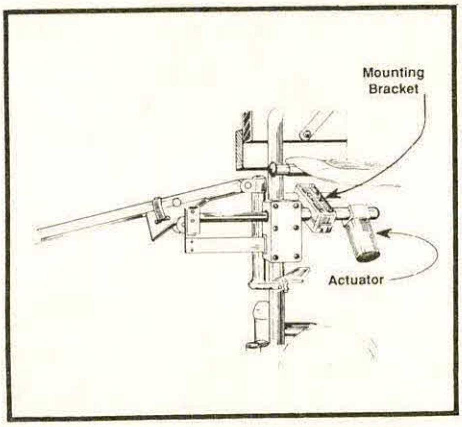
The ability to elevate the legrests on a standard powered or manual wheelchair is a necessity for some individuals. Elevating legrests are medically required for those with edema in the lower extremities or environmentally required because of obstacles such as unusually high door thresholds. When using a standard wheelchair, the legrest is elevated manually either by the wheelchair user or a caregiver. However, for some individuals, manually lifting the legrest is a difficult, if not impossible, task. Currently, commercial powered legrests elevate only in coordination with powered reclining backrests.

OBJECTIVE

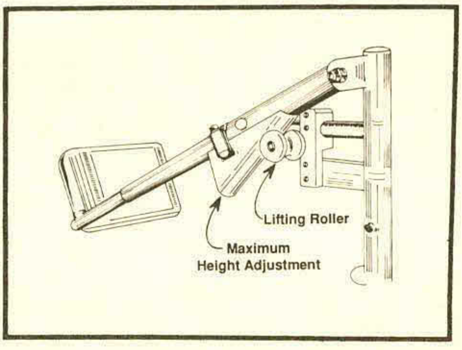
A PELS has been developed to provide an alternative for those wheelchair users who require elevating legrests, without a coordinated reclining back but who cannot manually elevate the legrests.

DESIGN/DEVELOPMENT

The PELS requires two 24 volt, 100 pound force actuators to raise and lower elevating legrests currently used on powered and manual wheelchairs. The entire system consists of two electric actuator assemblies with mounting clamps, two lift wedges, and a fused wiring harness with toggle switch controls. For manual wheelchair applications, two 6.5 amp-hour sealed lead-acid batteries, two battery holders, and a charger are also required. The mounting clamps which attach the actuators to the side of the wheelchair and the slide mechanisms which permit the actuators to elevate the legrests are composed of machined aluminum alloy. A separate actuator is used for each legrest. The stock manual elevating legrests are modified by removing the hardware that holds them in elevated positions and installing lift wedges which determine the maximum height to which the legrests will elevate. The wiring harness is connected to the existing battery system of a powered wheelchair or, in the case of a manual wheelchair, it is connected to the two small batteries added to the rear portion of the wheelchair frame. The double-pole, double-throw, momentary control switches, which are mounted in an accessible location on either the left or right side of the wheelchair, permit unilateral control of the legrests.



When either switch is pushed forward, the actuator assembly extends and elevates the respective legrest. When the switch is pushed rearward, the actuator assembly retracts allowing gravity to slowly return the legrest to the down position. With the actuator retracted and the legrest in the down position, the legrest can be rotated to the side and removed. The system is designed for easy removal to allow the wheelchair to be returned to its original condition. When installed on a manual wheelchair, limited folding capability still exists. The PELS adds approximately 8 pounds additional weight to a powered wheelchair and 20 pounds additional weight to a manual wheelchair. In either the powered or manual wheelchair versions, the mounting brackets may require customization depending upon the application and wheelchair model. It is not certain that either version will be compatible with all wheelchairs.



EVALUATION

Laboratory

The PELS was attached to a powered wheelchair, loaded, and subjected to some preliminary fatigue testing. No failures or adverse effects on the wheelchair frame or electrical system were noted. Additional testing is planned.

Clinical

The PELS has been reviewed and operated by clinicians and wheelchair users on a limited basis. Initial reaction to the PELS has been extremely positive. Powered operation of elevating legrests offers independence to the wheelchair user and reduced attendant care and back strain. Operation of the system is easily accomplished by accessible switches. Unilateral elevation of the is also beneficial. The additional weight of the power pack on manual wheelchairs appears to be negligible during wheelchair propulsion. However, it may be a factor when transporting the wheelchair. The batteries can be removed from their cases to reduce the additional weight during transport activities.

Additional clinical trials are planned with manual and power wheelchair users. It is believed that the powered elevating legrests can be beneficial to a variety of individuals with different disabilities who must elevate their lower extremities. The switch mechanism can be altered to enable operation by a variety of controls, e.g., pneumatic, chin.

DISCUSSION

Further evaluation is planned in order to obtain additional clinical information. It is believed that the PELS could be a viable alternative to existing elevating legrests. Due to the individual modifications necessary to attach the mounting brackets of the PELS onto specific wheelchairs, it may be necessary for the PELS to be offered by individual wheelchair manufacturers as an option.

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Evaluation of an Isometric Joystick For Power Wheelchair Control

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ABSTRACT

Many power wheelchair users with severe intention tremor, limited range of motion, or spastic hypertonia may benefit from a stationary joystick that uses force as the control signal. An isometric, force-sensing joystick has been designed for control of a power wheelchair. The joystick was compared with a standard displacement joystick in a wheelchair driving test using non-wheelchair users (n=18) and experienced power chair users (n=4). The subjects displayed increased, but not significant (p = 0.069), ability to control the wheelchair using the isometric joystick.

INTRODUCTION

Many preliminary studies have shown that people who exhibit intention tremor show some improvement in tracking tasks when using an isometrically restrained or damped controller (Repperger 1991, Durie 1980, McGill 1990, Bennett 1987). Other studies, however, conclude that isometric joysticks offer no advantage over displacement joysticks (Riley 1987, Stewart 1990, 1991, Sengupta 1974, Adelstein 1981). In each of these studies, the subjects were tested with a computer tracking test in which the subject used the joystick to move a cursor to a moving target. This kind of test does not accurately simulate the feedback one receives from controlling a wheelchair. Driving a wheelchair involves proprioceptive and vestibular feedback as well as visual cues. A computer tracking test only measures the subjects' visual ability and hand/eye coordination.

An isometric, force-sensing joystick was designed to directly replace an existing displacement joystick currently standard with Quickie Design's P100 and P300 model power wheelchairs. The joystick consists of a steel shaft instrumented with strain gauges in two full bridge configurations. One bridge supplies the directional signal and one bridge provides speed information for forward and reverse. The electronics are designed so that the output mimics the output of the displacement joystick so no modifications to the motor controller circuitry are required. The sensitivity of each bridge can be set independently as well as the damping cutoff frequency.

TESTING

The purpose of the testing was to investigate whether users were able to control a power wheelchair with the isometric joystick better than or as well as with a conventional displacement joystick.

The subject pool consisted of 18 ambulatory novice power wheelchair users (4 female and 14 male) with no upper physical impairment and 4 experienced power wheelchair users (2 female and 2 male).

Novice wheelchair users were used to minimize the probability of a subject having a preconceived preference for or experience with either type of joystick. Experienced power wheelchair users were included to provide qualitative information and to validate the feasibility of an isometric joystick.

TABLE 1 - Subject Data

	Mean
Age	34.6 ± 10.2 years
Weight	171.9 ± 46.0 pounds
Height	68.0 ± 4.0 inches
Years of wheelchair use*	13.8 ± 5.2 years

* Experienced wheelchair user subjects, n = 4.

EQUIPMENT

A Quickie Designs, model P300, power wheelchair was used as the test chair. It was equipped with a padded, planar seating system (16" wide, 16" deep, 21" back height), removable/adjustable arm rests, and removable (non adjustable) footrests on an adult-sized rigid frame, total weight of the chair was 180 pounds. The rear wheels were 20" in diameter and the pneumatic front casters were 10" in diameter. The maximum speed attainable was 6 mph. The chair was equipped with a microcontroller-based control system (Dynamic, New Zealand).

The power wheelchair was equipped with a chalk holder constructed from aluminum to mark the path. The holder was clamped to a horizontal cross brace on the wheelchair frame. The arm of the holder was allowed to pivot freely. The weight of the arm placed sufficient pressure on the chalk to mark a path. The chalk, a piece of 1" diameter colored sidewalk chalk, was positioned between the axles of the front casters. The chalk was encased in a block of foam, to absorb the shock due to the rough surface, and held in place with duct tape.

A inductive joystick (Flightlinks) and an isometric joystick prototype were used in the testing. The handle for the isometric joystick was a dome-shaped knob, approximately 3" in diameter, 1/2" thick in the center tapering to 1/8" thick at the outer edge, and was turned on a lathe from 6061T6 aluminum (Figure 1).

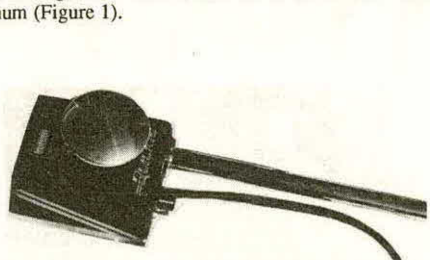

FIGURE 1 - Isometric Joystick

The test course (Figure 2) was designed as a continuous set of tasks that modeled tasks performed on an everyday basis by power wheelchair users. The overall length of the course was 190 feet and was marked with duct tape on a level asphalt surface. The tasks were:

TABLE 2 - Tasks

Task 1	180 degree left turn (10' radius)
Task 2	180 degree right turn (10' radius)
Task 3	straight path (25' length)
Task 4	90 degree left turn (13' radius)
Task 5	90 degree right turn (13' radius)
Task 6	360 degree left circle (16' circumference)
Task 7	90 degree turn while in reverse (5.5' radius)
Task 8	straight path in reverse (18' length)

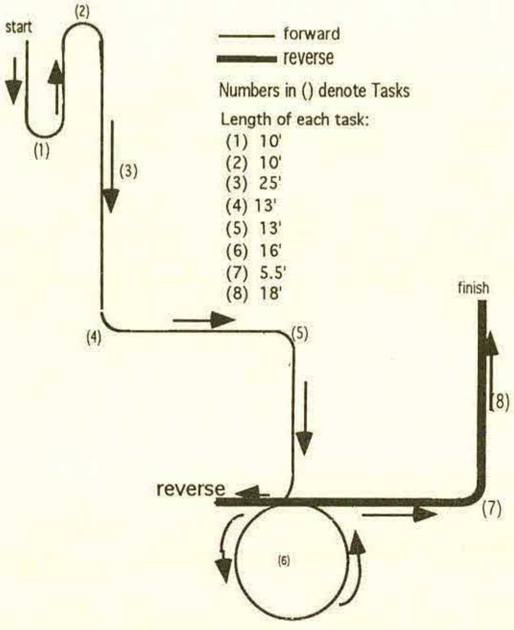

FIGURE 2 - Test Course

Prior to testing, a person traversed the test course multiple times to determine approximately how many trials would be needed to establish a steady-state value for completion time. Steady state was reached when the subject's completion time differed by less than 10% from the previous trial. It was determined that a subject could reach a steady completion time in approximately 5 trials.

Each subject was asked to maneuver the test chair using one of the two joysticks along the test course. Each joystick was mounted on the armrest using the mounting arm standard with the P300. It was positioned on the right side for right-handed subject and on the left for left-handed subjects. Fore/aft placement was per the subject's preference. Subjects were randomly assigned to use the isometric joystick first or the displacement joystick first. Each subject was instructed to travel at the fastest speed that was comfortable and to keep the chair centered on the tape. Subjects were not allowed any trial runs or practice with either joystick. The time required for the subject to complete the course was recorded for each trial. When the subject's time from one trial to the next differed by less than 10%, the chalk holder on the chair was allowed to drag, marking the course of the chair. The other joystick was then installed on the chair and the test was repeated. Each subject was then asked to complete a survey regarding their assessment of the isometric joystick.

DATA COLLECTION

Five equidistant points for each of the 8 tasks were marked. The lateral distance from the center of the tape at each mark to the chalk line created by the chair was measured and recorded at each point for each task.

STATISTICAL ANALYSIS

Two-way ANOVA's were performed on the data for each task, each joystick, each subject group (experienced and novice wheelchair users). Learning effects were also explored for each joystick by analyzing the completion times for each trial.

STATISTICAL ANALYSIS RESULTS

The results of the ANOVA analysis comparing the overall average deviation for all subjects for the displacement joystick (DJ) and the isometric joystick indicate that the subjects' performance with the isometric joystick, while not significantly better ($p \leq 0.05$), was slightly better for all the tasks combined ($p = 0.069$). The non-wheelchair user subjects had a significantly lower mean path deviation ($p = 0.0001$) than the experienced wheelchair users. This could be attributed to the small sample size for the experienced wheelchair users. The tasks where the mean path deviation was significantly ($p \leq 0.05$) greater for the isometric joystick were the left and right 90 degree turns for all subjects, the reverse turn for the novice wheelchair subjects, and the left 180 degree turns for the experienced wheelchair users. For the straight reverse task the mean deviation for the isometric joystick was significantly lower than the DJ ($p = 0.05$). The differences in the mean deviation for the straight forward and the circle tasks were substantial but not significant ($p = 0.062$ and $p = 0.065$ respectively).

The order with which the subjects performed the tests did have a significant ($p = 0.04$) effect on mean path deviation. All subjects performed better with the second joystick with one exception. The experienced wheelchair user subjects that started with the isometric joystick had a lower mean path deviation for the isometric joystick ($m = 4.525$) than for the DJ ($m = 5.181$). The subjects' completion times also improved with the second joystick but by the fifth trial the times were similar for both joysticks and regardless of which joystick was used first. There was a more dramatic decrease in the mean times from the first trial to the second for the isometric joystick (-19.7 seconds for the isometric joystick and -2.5 seconds for the displacement joystick, a decrease of 21.1% and 3.05% respectively) but the mean times between the two joysticks for the third, fourth, and fifth trials were within 3%.

SURVEY RESULTS

Of the ambulatory subjects, 12 out of 18 favored the isometric joystick while none of the four wheelchair user subjects preferred the isometric joystick even though statistically they performed equally as well with the isometric joystick. Of the 6 ambulatory subjects who chose the DJ, most indicated that they would have preferred the isometric joystick if it were more sensitive and required less effort or if the handle was more comfortable. The 4 ambulatory women subjects were included in those 6 who chose the DJ. 36% of the subjects reported some fatigue (including 3 of the 4 wheelchair-using subjects), 50% of the subjects reported some soreness in the hand or wrist, and 32% of the subjects experienced frustration while using the isometric joystick.

Although none of the wheelchair-user subjects chose the isometric joystick as a preference, all were enthusiastic about the concept and felt if given a sufficient amount of time to adjust to it, they might be better able to make a fair assessment of the isometric joystick. Also, experienced users tend to travel at top speed for longer periods of time and might fatigue faster with the isometric joystick at its current sensitivity.

Some of the comments made by the subjects on the survey form stated that the isometric joystick was not sensitive enough and required too much force for full speed. Many negative comments were also made about the shape and size of the handle. Some subjects also felt that the chair slowed down, specifically on the straight forward task, and that the isometric joystick should somehow incorporate a "cruise control". Some subjects felt that changing directions was much smoother with the isometric joystick. Those subjects who preferred the DJ commented that they felt more comfortable with the feedback of the positional joystick.

On the survey, the subjects were asked to rate six characteristics of the isometric joystick on a scale of 1 to 5 with 1 being poor and 5 being excellent. The following table lists the average value of the responses.

Table 3 - Survey Responses

Category	Mean	Std. Dev.	Std. Error
Appearance	4.182	.853	.182
Ease of Use	3.273	1.241	.265
Maneuverability	3.818	1.006	.215
Control	3.409	1.054	.225
Acceleration	3.591	1.098	.234
Comfort	3.409	1.098	.234

DISCUSSION

The statistical results lend mild support to the hypothesis that power wheelchair users would have better chair control with an isometric joystick even though the difference between the joysticks was not significant. The significant difference in the time decrease from trial one to trial two for the isometric joystick compared with that for the DJ implies that the learning curve for the isometric joystick has a much steeper slope. One subject who was having a lot of difficulty using the isometric joystick was instructed to not concentrate on what his hand was doing, he immediately relaxed and gained full control over the chair. This incident shows that a lack of feedback can sometimes increase performance by relegating the task to a more intuitive level. This is consistent with the significant decrease noted in the average time for the first trial to the second; the subject is no longer focusing on the mechanics of using the isometric joystick.

The slowing down of the chair when using the isometric joystick that some subjects mentioned in the survey was most likely due to the relaxation of the arm muscles after the initial thrust against the joystick. This type of muscle activity is consistent with a displacement joystick where only an initial movement is necessary to activate the joystick. The isometric joystick requires a sustained muscle contraction. The subjects that complained of fatigue and soreness may have been pushing harder than necessary for full speed. Because the isometric joystick gave no feedback or indication when full scale output was reached, the subjects may have continued to increase the force in an attempt to go faster than the controller allowed, resulting in wasted energy and muscle fatigue. This condition would probably diminish after the user became familiar with the isometric joystick and how much force is required to maintain full speed.

CONCLUSION

The isometric joystick design principle developed here can also be extended to other applications as well; chin controls, foot controls, possibly even a proportional switch. The prototype isometric joystick produced in this project has been demonstrated to be functionally and economically viable as a control interface for a power wheelchair. Further development and refinement is necessary to improve the design and prepare it as a commercially available product.

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Improving Wheelchair Efficiency through Intelligent Diagnostics

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ABSTRACT

This paper describes the design and implementation of a highly reliable wheelchair and proposes intelligent diagnostics for improved efficiency. This improved efficiency is achieved by automatically detecting degradations in performance and recommending preventative maintenance to increase the useful lifetime of the wheelchair. Artificial neural networks can be used to check for degradations in critical component performance, such as tire pressure, frame degradation, and motor performance. Also, faults in the controller electronics, motor drives, and interconnected wiring can be detected, located, and reconfigured around.

MOTIVATION

Preliminary investigations have shown that increases in wheelchair reliability have come by either the addition of diagnostic sensors or incorporating the increased durability of individual components. Diagnostic sensors include such things as watchdog timers and battery monitors. Increased durability includes using a better or stronger grade of material for belts or gears, and placing more frame members or stronger frame joints in a wheelchair frame. Both of these methods have proven highly effective in increasing wheelchair reliability. However, the wheelchair industry has incorporated the use of these features in only the most rudimentary way. Most systems incorporating these features do so only on the simplest of components and assume perfect operation of sensors and other more complicated components. Invacare's Action Arrow line of powered wheelchairs are arguably the state-of-the-art with respect to diagnostic capabilities (along with E&J's Excalibur), and it falls well short of its potential with respect to diagnostic and efficiency improvement. There is also a limit on the level of reliability that can be cost effectively achieved by using more durable components. Two recent surveys [1,2] indicate that wheelchair components still fail quite frequently.

Motivated by the need to take full advantage of the capabilities of this and other commercially available platforms, this work attempts to extend wheelchair diagnostics to include motors, tires, and frame members. By detecting degradations in component performance, preventative maintenance can be performed and the useful lifetime of wheelchairs can be increased.

APPROACH

The next two sub-section describe the design and implementation of a highly available microprocessor-based controller for a powered wheelchair. By using the capabilities of the controller to detect and locate faulty components, and reconfigure itself around these components, this controller can continue to operate in the presence of failed components. Then a description of how these capabilities can be extended to include improved efficiency will be presented.

Design

A diagram of the system is shown in Figure 1. The command sensor or joystick module consists of two Hewlett-Packard (HP) HRPG miniature optical encoders and four HP HCTL-2016 counter single chip integrated circuits. The optical encoders produce pulses which are transmitted to the counter chips as the joystick is moved along either of two axis, forward-reverse and left-right. Each of two counter chips records the current position of the joystick along that axis. These counters have an eight bit interface to the controller modules so that it can be read at any instant. This arrangement is duplicated for the redundant system, therefore using four counters.

The controller module consists of a single Motorola MC68HC11 microcontroller, local memory and two HP HCTL-1100 pulse width modulated (PWM) motor controller chips. The 68HC11 periodically reads the joystick values and updates the command register of the HCTL-1100. The local memory is used to store the control and diagnostics routines. The HCTL-1100 receives an eight bit command velocity from the 68HC11 and generates a PWM signal to the interface and bridge modules. It also receives feedback from the motor module tachometer and updates the PWM signals based on its own integral velocity control algorithm. The gain coefficients for the control algorithm in the HCTL-1100 are initially supplied by the user via the 68HC11.

The interface and bridge module consists of four International Rectifiers IR2110 level shift and bootstrap interface chips and eight IRFZ42 high current power MOSFETs arranged in two H-bridge configurations. The PWM signals must be level shifted from 0-5 volts to 0-15 volts to drive the gates of the MOSFETs and bootstrapping must be performed since all nFETs are used. This can be accomplished by using a single IR2110 integrated circuit. The outputs of a single IR2110 go to the gates of two nFETs, therefore only four are needed

The motor module consists of a relay, two permanent magnetic DC motors, and HP HEDS-5500 shaft optical encoders. Velocity feedback is achieved by sending the pulses from the optical encoder to the HCTL-1100 of the controller module. The relay is used to control which complete system is driving the motors. The motors are 24 volt DC permanent magnetic motors and are not duplicated. The global memory consists of a dual ported RAM which allows both system's microcontrollers to communicate. Specific locations are reserved for known variables and an interrupt from one controller to the other can be generated.

Operation

The microprocessors of the two independent systems periodically synchronize themselves to simultaneously read from the command sensor. This is initiated by one of the processors (the master) handling an internal real time interrupt. The master synchronizes itself to the slave by writing to the dual ported memory which interrupts the slave. The slave responds by acknowledging the synchronization request and reads the command sensor. If either system has failed, the other system operates in stand alone mode and reads from the command sensor by processing its real time interrupt without trying to communicate with the failed system. Having read the command sensor, the two systems independently calculate the motor speeds to be written to the motor controllers. Again, the master prompts the slave to exchange their calculated motor speeds and to decide on their validity. They exchange their respective decisions via the dual ported memory. If both microprocessors agree that the motor speeds are

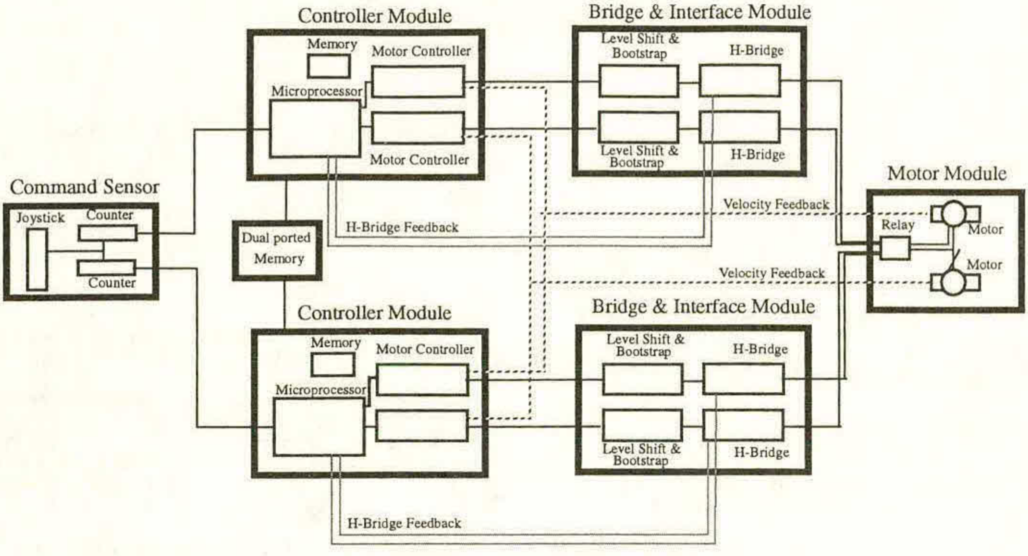

Figure 1

equivalent, within some degree of accuracy, both will write to their respective motor controllers and no other action will be taken. Even though both systems initiate drive signals to the motor, only one actually controls the motors at any instant.

If either system detects a miscompare, both systems initiate a comprehensive series of fault location routines to determine which is faulty. They exchange their command sensor values and other intermediate values and try to determine where the error occurred. Self diagnostic routines are run by each processor to see if the fault can be located. If either system can determine that it is the faulty one, it notifies the other, notifies the user that it needs to be replaced, and shuts itself down until it is replaced or prompted to return to action. A failed controller, which has turned itself off, can be brought back into operation by the currently running system to see if its previous fault was transient or permanent. If the same fault can still be detected, the failed system again shuts itself down and will not be prompted to return to action until it has been replaced and the controllers are reset by the user.

If neither system is able to locate the fault, both are inhibited and this information is relayed to the user. The user may then select either system to get him home if necessary and override the mutual inhibition. This is known as "failed safe" in that the system has failed, by not knowing which system to let operate the motors, but failed in such a manner that is safe.

If the communication mechanism breaks down or the slave system does not respond as expected, the master will notify the user, take control and merely act in stand alone mode until reset. If the master system fails, it relinquishes control to the slave. This passing of control is usually achieved by communication through the dual ported memory, but if this is not possible, both systems monitor the control signal and can tell if they have been passed control from the other without warning. In addition, both systems will periodically switch control back and forth to allow testing of their bridge and interface modules.

As long as the processors are able to run their control and diagnostics routines, no unsafe failures will occur in the controller. However, it is difficult to predict the effects that a runaway processor will have on the system. Therefore, a watchdog timer is used to prevent the processor from getting out of control. This watchdog timer allows the processors and the motor controls to gracefully die.

The wheelchair can detect faults in the command sensor counter circuitry, by utilizing a custom integrated circuit [3], all of the individual components of the control module and the MOSFETs of the H-bridge. Faults in the command sensors are detected by comparing the values read in from the two processors. Faults in the control module components are detected by traditional means of detecting faults in digital circuits. These include memory checks, address and data bus checks, ALU checks and register checks. The MOSFETS in the H-bridges can be tested by alternately energizing and de-energizing the terminals that feed into the relay and verifying their operation via feedback to the processor. Faulty interconnections between modules and components can be detected and, more importantly located to specific faults.

EFFICIENCY IMPROVEMENT

This section describes how this controller is able to perform intelligent diagnostics for improved efficiency. This work extends the detection capabilities of the controller to include non-electronic components of the wheelchair and those that have not been replicated. This wheelchair not only achieves a high degree of reliability, but is also able to monitor its performance and detect and classify any degradations in performance.

This research uses intelligent diagnostics based on model-based fault detection for improved efficiency. These techniques will enable a microprocessor based wheelchair controller to monitor system parameters (motor armature current and actual velocity) and to automatically diagnose potential critical component performance degradations. In addition, maintenance facilitating routines will be implemented to aid the user in replacing failed components. These components consist of modular, easily replaceable units that can be pulled out and a replacement plugged in without ever needing the services of a technician.

The aim of model-based fault detection for improved efficiency is to find degraded components in the model of a system using parameter observations. This involves identifying component failures which are responsible for discrepancies between observed and predicted system behavior. Once these discrepancies have been detected, they must be classified in order to distinguish between individual faults, multiple simultaneous faults, or false alarms. This predicted system behavior of a continuous dynamic system is based on a mathematical model expressed in terms of many non-linear differential equations and affords an analytical redundancy of the system. As previously mentioned, most existing self-diagnosing wheelchair systems address only the most trivial issues. This is because failure detection, in the presence of noise and modelling errors, fault classification (using signal processing, pattern recognition, or expert systems techniques), sensor failure isolation, and system failure detection often involve very complex models of ill-defined processes.

This work proposes to circumvent these complexities by using artificial neural networks to detect and classify degraded performance. In the past, expert systems have been used to successfully diagnose component failures in electromechanical systems. However, they suffer in their ability to handle unanticipated situations. Also, the causal relationship between symptoms and disorders do not need to be clearly defined for an artificial neural network. This method resolves the fundamental computational complexity problem which has previously limited the usefulness of model-based fault detection techniques. Fault detection is accomplished by training an artificial neural network to recognize the signature of respective inefficiencies.

Model-based fault detection has been shown to achieve good diagnostic capabilities in a wide range of applications, including aerospace [4], industrial robotics [5], and process control [6]. Examples range from diagnostic systems for the Space Shuttle main engine [7] to small squirrel cage electric motors [8]. Detroit Diesel Corporation's engine monitoring system uses a redundant microprocessor-based controller to perform on-line diagnostics and, with the aid of a hand held diagnostic unit and a modem, can perform troubleshooting for its marine engines anywhere in the world [9]. Work is currently being performed on an artificial intelligence version of this engine monitoring system. The technology for model-based fault detection and neural network-based classification already exists and only needs to be incorporated into wheelchair design.

This intelligent diagnostics enables the user to feel confident that not only is the controller able to withstand failed components and continue to operate, but is also performing on-line diagnostics of the wheelchair itself to determine if and when maintenance should be performed. Thus preventative maintenance will help avoid system failures outside of the controller loop.

These goals will be achieved by using redundancy where applicable, recognizing trends toward failure, before an actual failure occurs, and classifying these trends. This classification involves discrepancies between actual and predicated motor responses and deviations between right and left motors.

CURRENT STATUS

The redundant microprocessor-based controller, including the joystick module and bridge and interface modules, has been completed and tested. The control and diagnostics software has been written and tested. Currently work is being performed on developing an artificial neural network that can detect degradations in wheelchair performance and methods are being developed to incorporate these findings into increasing wheelchair efficiency.

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SHARED CONTROL OF THE NAVCHAIR OBSTACLE AVOIDING WHEELCHAIR

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ABSTRACT:

The NavChair assistive navigation system [1, 2] is being developed to meet the needs of multiply handicapped people who are unable to operate available wheelchair systems. The NavChair shares control with users by allowing them to achieve desired behavior while overriding unsafe maneuvers. Issues related to this shared control are being investigated.

An outgrowth of this project is an investigation into new methods for autonomously switching between different NavChair operating modes such as wall following, close approach and obstacle avoidance. Autonomous mode determination, the assignment of control responsibility between internal control modules, is discussed within the context of the NavChair control system and ongoing research into its solution is outlined. In particular, this paper suggests that human modeling is a promising approach for autonomous mode determination and adaptive shared control of the NavChair.

INTRODUCTION:

The NavChair assistive navigation system is being developed to meet the needs of multiply handicapped wheelchair users [1, 2]. In particular, the goal of the NavChair Project is to provide increased mobility and safety for people who have impairments that limit their ability to operate a power wheelchair. The NavChair control system is designed to use sonar range detectors to avoid obstacles, follow walls and travel safely in cluttered environments. This paper outlines research into shared control systems that is an outgrowth of the NavChair Project.

The NavChair is a human-machine system in which the machine must share control with the user. In other words, the control system must allow the user functional control while overriding unsafe commands. Two aspects of real-time shared control are of particular interest: autonomous task allocation and mode determination. Task allocation is the problem of assigning control between the human and the computer. This kind of decision is illustrated by the obstacle avoidance control mode: in most circumstances, the human user exercises direct manual control over the wheelchair; however, if an obstacle is present the control system must allocate itself enough control to prevent a collision. This decision is not necessarily binary; the system must be able to adjust the allocation of control along a continuum from direct manual control to autonomous wheelchair control. The NavChair control system allocates control based upon the presence of obstacles in the direction of motion.

The NavChair control system consists of separate control modules corresponding to different behaviors: obstacle avoidance, wall following, close approach, etc. These control modules may act independently or in unison. Not only must the NavChair allocate control between itself and the human user, but also between these internal control modules. This decision is called mode determination and can be either continuous or discrete. For example, wall following has only two activation states, on and off, while obstacle avoidance can share control with wall following, from having no influence to completely overriding the wall following command.

Task allocation and mode determination are important aspects of human-machine system adaptability — a crucial characteristic of any system that will be used in a variety of environmental conditions by people of different and varying abilities. However, autonomous mode determination for human-machine systems is not readily achieved using current control techniques; mode determination is typically performed manually by a human user.

The purpose of this paper is to present an approach to developing methods of autonomous mode determination specifically for the NavChair wheelchair control system. The first section outlines the NavChair control system. Next, the shared control of the NavChair is discussed and an example of a mode determination problem is presented. Finally, an approach to the solution of autonomous mode determination in the NavChair is proposed and discussed along with a brief description of ongoing experiments.

THE NAVCHAIR CONTROL SYSTEM:

The NavChair system consists of an Everest and Jennings Lancer power base equipped with a portable computer and Polaroid ultrasonic range detectors. Detailed descriptions of the NavChair hardware and low-level software can be found elsewhere [3]. The following paragraphs outline the functions of the primary control modules: close approach, wall following and obstacle avoidance.

Close approach mode enables a user to enjoy fine manual control in tight spaces. It imposes strict limits on the velocity of the chair and the scaling of the joystick based upon the proximity of obstacles.

Wall following mode drives the wheelchair smoothly parallel to a wall even if the user's joystick command is unsteady. Wall following must be either on or off. It functions well in conjunction with other modes such as obstacle avoidance.

Obstacle avoidance mode is an application of a system developed by Borenstein and Koren. This system consists of two components: Vector Field Histogram (VFH) obstacle avoidance [4] and sonar error rejection [5]. Application of the VFH to a human-machine system has been studied in the context of teleautonomous systems [6], but this is its first application to a system in which the human user is onboard the vehicle. The advantage of the VFH method, robust, high-speed obstacle avoidance [7] in a cluttered environment, has been demonstrated [8]. Figure 1 illustrates the operation of the VFH obstacle avoidance method.

SHARED CONTROL OF THE NAVCHAIR:

As previously discussed, the NavChair control system must be able to perform task allocation and mode determination in order to achieve effective shared control. Autonomous task allocation is based upon an unambiguous environmental cue: the presence of obstacles in the direction of motion.

Autonomous mode determination, while desirable, can be more difficult since sometimes it must be performed in the absence of environmental cues, as the following example illustrates.

Consider the scenario shown in Figure 2 in which the NavChair is approaching an obstacle head-on. The control system must make a discrete mode decision based upon user intention: either approach the desk (close approach mode) or avoid it (obstacle avoidance mode). Typically, this sort of problem is solved in one of two ways: either 1) the system has only one control mode and therefore has no decision to make or 2) users indicate their intentions explicitly, such as with switches. For this and other analogous situations, autonomous mode determination may be of value.

One broad class of approaches to autonomous mode determination is based upon the use of human decision models of the user. These approaches rely upon the idea of goal inferencing — determining the intention of the user. These methods have not been shown to improve system performance in shared tasks at all [9]. This failure is at least partly due to the rudimentary state of current integrated models of human cognitive behavior.

We propose a new approach to mode determination based upon control theoretic models of human tracking behavior. We hypothesize that human driving can be classified into a few basic control behaviors, such as high-speed forward travel and narrow-space passage, and that these behaviors can be identified in real time to estimate the intention of the user.

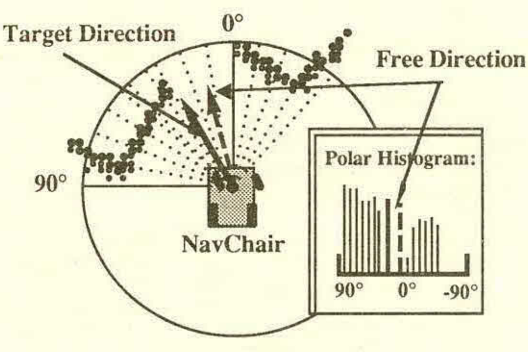

Figure 1: The Vector Field Histogram Obstacle Avoidance Method: Sonar readings are used to update a map of obstacles in the form of a *certainty grid*. Obstacles are represented as areas of high obstacle certainty. New readings are used to increment the certainty value at the location of the reading and decrement areas thought to be obstacle-free. The certainty grid is used to calculate a *polar histogram* of obstacle densities in each direction. This histogram gives the approximate risk of collision for motion in any given direction. In obstacle avoidance mode, the *target direction* specified by the joystick (solid arrow) is modified to a *free direction* (dotted arrow) to avoid areas of high obstacle density while staying as close as possible to the direction specified by the user. This system allows the NavChair to steer automatically around obstacles with only a marginal decrease in speed.

MODE DETERMINATION: This new approach is based upon the idea of using identified human tracking models to estimate user intention in real time. The modeling of instrument-based human manual tracking is well-understood, but little is known about actual driving behavior under real-world conditions. The primary difficulty with modeling real-world human tracking behavior is that the mechanisms by which humans extract control variables from sensory perceptions are not well understood [10]. This approach attempts to bypass these difficulties by searching for predictable human control patterns based upon measurable variables. We make analogy to engineering control theory but do not necessarily claim to accurately reflect the internal workings of neurological control processes. Our goal is to perceive patterns in human tracking behavior and use them to control the wheelchair, not to explain those patterns theoretically. This approach to modeling the human is called *control theoretic modeling* to reflect the fact that it is a control- rather than decision-oriented approach.

Experiments are currently underway to investigate the application of this approach to mode determination in the NavChair. In particular, the mode determination problem illustrated in Figure 2 is being studied. Standard system identification techniques are being used to find linear models of the human operator in real time [12]. Figure 3 depicts the schematic diagram of the human-machine system on which modeling effort are based. Patterns of behavior, such as "fast forward travel," and "door passage" are being identified and compared. Characteristics of these behaviors are being sought that would allow real time categorization of human driving behavior. Preliminary results indicate that in at least some circumstances, human behavioral patterns exist and can be determined in real time.

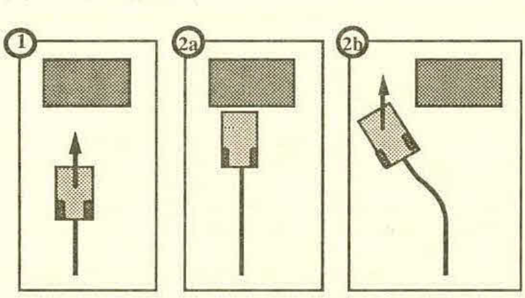

Figure 2: Mode Determination for the NavChair. An obstacle avoiding wheelchair is an example of a shared control system that must perform mode determination in an absence of environmental cues. Frame (1) shows the NavChair approaching a desk. One of two outcomes is possible: either (2a) the NavChair 'docks,' allowing the user to access the desk, or (2b) the NavChair performs an avoidance maneuver and continues to move forward. These two behaviors correspond to two different modes of operation, close approach and obstacle avoidance, that cannot be performed simultaneously.

This approach could be applied in the following manner in the situation depicted in Figure 2: As the desk is approached, system identification determines that the person is controlling the motion of the chair to achieve a specified heading (zero) and a desired velocity. The NavChair system will react to the desk by slowing the wheelchair in anticipation of either turning or stopping. If the person is trying to continue in the current direction and is unaware of or unconcerned with the desk, their reflexive control response will be to increase the joystick command in response to the undesirable decrease in speed. On the other hand, a desire to approach the desk could be signaled by an acceptance of the lower speed or a command to fine-tune the orientation of the chair. We hypothesize that measurable human control characteristics can be used to make the mode determination decision in many such situations.

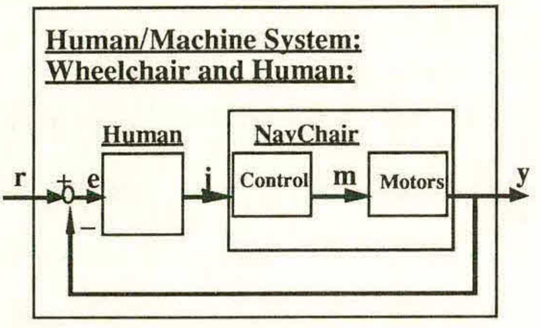

Figure 3: ***Overview of the wheelchair system:*** The human, wheelchair and environment together make up the wheelchair system. The "input" and "output" variables, *r* and *y*, represent the path the user is attempting to follow and the actual path of the chair, respectively. A control theoretic model of the human is a relationship between *e* and *j* that describes how the human translates the perceived path error into joystick position.

DISCUSSION:

This method of using identified human tracking models for mode determination takes advantage of an important attribute of control models: rather than merely measuring the *result* of human control behavior, we suggest attempting to estimate the *process* of human control in real time.

Human tracking models provide information useful in many aspects of adaptive shared control besides autonomous mode determination. For example, since human behavior models reflect the human's performance capabilities, such as fundamental frequencies, time delay and gain, these parameters could be used to adapt joystick characteristics, such as gain and tremor damping bandwidth, in real time.

CONCLUSION:

Important changes are occurring in the way human-machine systems are designed. Computers are sharing more high-level control tasks with humans, such as the resolution of instructional conflicts and ambiguity. This paper presents ongoing research into the design of an advanced assistive navigation system that dynamically shares control tasks with the user.

The development of effective assistive technologies will require advances in our ability to estimate and react to the intentions of users in the absence of explicit instructions and environmental cues. An improved ability to perform autonomous mode determination potentially would allow a broader range of multiply handicapped people to use assistive technologies. It is our hope that the solutions developed will also have application to numerous other human-machine systems.

ACKNOWLEDGMENTS:

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A DIRECT CURRENT TO THREE-PHASE INVERTER FOR ELECTRIC WHEELCHAIR PROPULSION

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ABSTRACT

New high performance, reliable and inexpensive propulsion systems have been designed for electric automobiles using new types of motors. On the other hand, electric wheelchairs still rely on commutator type direct current motors, a motor that has been in use for more than 100 years. In this paper we describe an "inverter", i.e. a circuit that transforms the battery direct current voltage to a three-phase sinusoidal voltage. This is required when induction squirrel cage motors are used for propulsion. This is the type of motor most used in electric automobiles. The inverter is designed using integrated circuits, thus it is reliable and inexpensive. An induction motor adequate for wheelchair propulsiuon has been tested using the inverter with excellent results.

BACKGROUND

Electric propulsion systems requiring variable speed have been implemented, until quite recently, by means of direct current (dc) servomotors. This was due to the good torque-speed characteristics plus the easiness of speed control of commutator type dc motors [1,2]. Commercially available electric wheelchairs (EWC) use this type of motors exclusively. In spite of its many advantages, dc servomotors also present significant disadvantages [3] such as the use of a mechanical commutator and brushes, which produce strong electrical and acoustic noise and decrease efficiency. In addition, maintenance is required to replace worn out brushes.

Other types of electric motors are being considered and used for electric vehicle propulsion, paramount among them the squirrel-cage induction motor (SCIM), [4]. The SCIM is extremely reliable due to its lack of contacts between stator and rotor, very inexpensive, because it does require permanent magnets, and smaller in size for a given power than a dc machine. It also has good efficiency over a wide range of operation and torque/speed characteristic [5]. The reason why SCIMs have not been used for EWC is that they require a three phase sinusoidal power supply with variable frequency and voltage. This voltage has to be obtained from the dc 24 volts battery and, until quite recently, this was not an easy proposition. However, the availability of powerful integrated signal conditioning circuits has simplified the task considerably in addition to making it economically attractive [6].

In a previous paper [7] we reported a preliminary version of a dc to 3phase ac inverter. This inverter was designed, constructed and tested with a 24 volts ac, 3/4 hp SCIM with good results. However, the inverter's voltage was square wave and constant amplitude, thus producing a decreased motor performance because of the high harmnic contents of a square wave and the non constant iron gap magnetic flux due to the constant voltage amplitude.

OBJECTIVE

The objective of the project reported here was to design, construct and test a sine wave variable frequency, variable voltage inverter to be used as a controller for two SCIM motors for EWC propulsion. This controller should be competitive in price and comparable in performance with existing dc controller-motor systems. SCIMs are maintenance free and should last as long (or longer) than the EWC mechanical structure. All the conmponents of the inverter are integrated circuits (IC), except the power transistors. The number of ICs is minimum, thus making the device low cost and highly reliable. A SCIM adequate for EWC propulsion shows excellent performance when driven by the new inverter.

The power part of the inverter consists of power transistors (MOSFETS) in a bridge configuration. For efficient inverter operation, the MOSFETS must operate in "ON" (saturated) of "OFF" (cut off) mode. This is achieved by controlling the gate voltage.

METHOD

PWM signals are derived by a comparison process. In this case, a variable-frequency, variable-amplitude modulating sine wave is compared to a (constant) high-frequency, constant-amplitude triangular carrier wave. The result is a series of pulses that approximate a sinusoid and that can be used to control the power inverter. Figure 1 shows the comparison.

Both of the major problems of the square-wave system are addressed by the PWM controller. The harmonics of the PWM signal occur at high frequencies, around multiples of the carrier frequency. These frequencies have little effect on motor performance, so loss of efficiency is minimized. In addition, the amplitude voltage applied to the motor is proportional to the ratio of the amplitudes of the modulating and carrier waves, so the motor voltage amplitude can be controlled along with its frequency. Therefore, in order to produce a variable frequency three phase voltage with an amplitude proportional to the frequency, a pulse-width modulated (PWM) system was used. A variable frequency, variable amplitude modulating sine wave is compared to a constant amplitude constant high frequency triangular wave carrier. This results in a series of pulses which approximate the sinusoide with the desired frequency and voltage characteristics and is used to control the power transistors, Fig.2 .

Notice that the PWM waveform turns the MOSFETs "ON" or "OFF" as required for efficient operation.

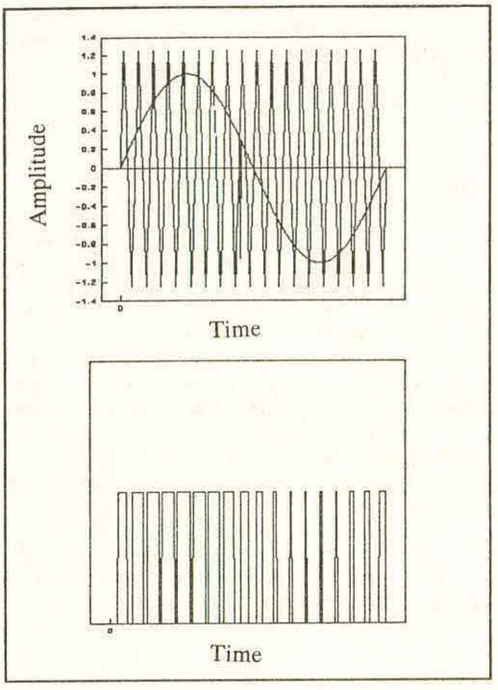

Figure 1. Sine and triangular wave comparison and resulting PWM with variable width.

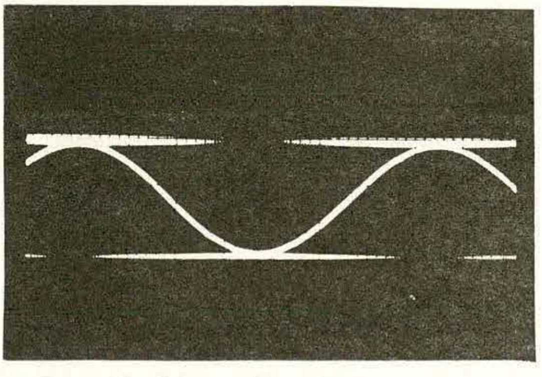

Figure 2. Sine wave obtained from the PWM waveform

Figure 3 is a block diagram of the complete inverter. Three programmable-read-only-memories (PROM) contain each one period of the three-phase sine wave. These are accessed through the PROM address bits usingan 8-bit counter. The speed of the counter is determined by a voltage controlled oscillator (VCO). The dc voltage input to the VCO is also the reference voltage for D/A converters which create continuous sinusoidal signals from the PROMs digital data. A fourth PROM contains data representing one period of a triangular wave. For this signal the oscillator setting counter speed runs at a fixed high frequency and the reference voltage input to the D/A converter is also constant. Further processing by means of operational amplifiers and voltage comparators finally generate the three-phase sinusoidal signal used to control the inverter's power transistors.

RESULTS

The PWM inverter described above was tested to verify the hypothesis that the performance of PWM induction motor control would greatly surpass that of a square-wave controller. Tested in a laboratory setting, the output of the PWM controller was used to drive a 24V-24A three-phase induction motor at variable speed from a constant DC voltage source.

In initial no-load tests, the PWM controller was capable of maintaining a fairly constant air gap flux, evident by the constant current requirement of the motor over a wide range of frequencies, from 10 to 120 Hertz. Below 10Hz, the air gap flux becomes a non- linear function of voltage and frequency. This series of tests showed, as demonstrated in theory, that the proportional volts- frequency ratio produced by the PWM controller successfully held the motor flux constant at variable frequency.

In the most recent tests, the PWM controller has been used with the motor under load. Utilizing a dynamometer and power analyzer, it has been found from this initial series of trials that pulse-width-modulation control of three-phase induction motors greatly increases the torque capacity and the efficiency of the induction motor over the more naive square-wave approach to motor

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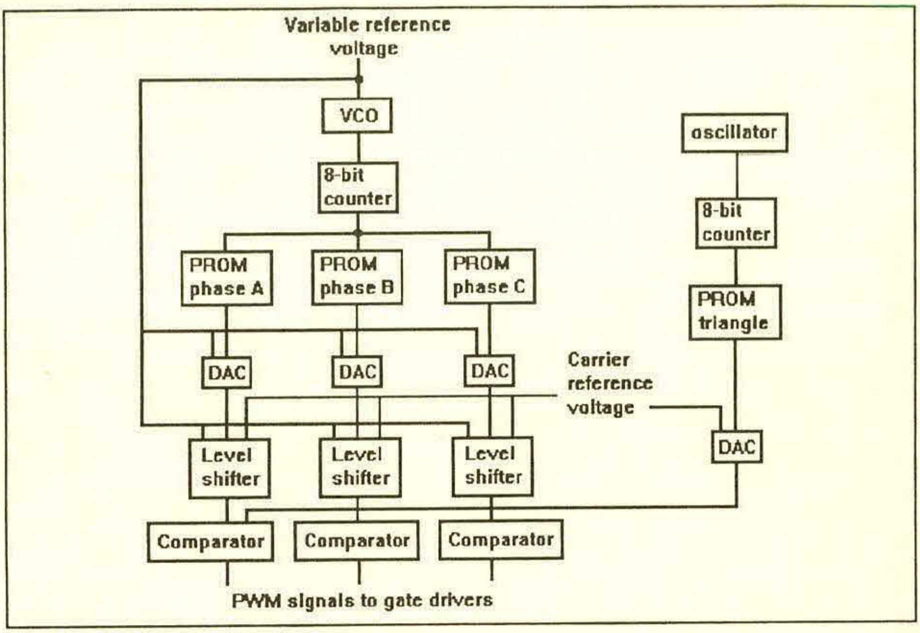

Figure 3. Inverter block diagram

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MORE PATTERNS IN POWER MOBILITY REPAIRS

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ABSTRACT

The viability of any company that markets assistive and rehabilitation technology is based on the selection of cost effective product lines. Power mobility systems comprise one high expense category of assistive and rehabilitation technology devices. To gather information necessary to determine which power mobility product lines to carry, a company owned by three rehabilitation technology suppliers collected data on the types of repairs needed by manufacturer and by type of power unit. This paper discusses the patterns in power mobility breakdown gained from the study of 136 power mobility system repairs completed between July 1991 and November 1992.

BACKGROUND

Rehabilitation technology suppliers (RTSs) have become essential to teams making decisions regarding the provision of assistive and rehabilitation technology devices to persons with disabilities. In addition to providing general information about the variety of equipment commercially available, the RTS is in a primary position to offer options, specific product specifications, characteristics, and performance capabilities. To remain viable in a competitive marketplace, the selection of cost effective product lines is crucial to the RTS who works for or owns a business in the private sector. Power mobility systems comprise one high expense category of assistive and rehabilitation technology devices.

To determine whether there was a pattern to power mobility system repair, a preliminary study was conducted in an RTS owned company (1). For each power mobility unit brought into the shop for repair, the *Power Wheelchair Repair Survey* was completed by the electronics repair supervisor. The survey included six sections: specific information about the power system (manufacturer, type, serial number, and age), user's description of the problem, other problems found during servicing (if applicable), length of time needed to complete repairs, retail cost of replacement parts, and time and materials (if any) covered by warranty. In this earlier study, electronics repairs occurred significantly more frequently than either battery related repairs or mechanical repairs; however, a repair pattern did not emerge among manufacturers nor among mobility types with the sample size of 36 power mobility units.

A significant problem that emerged from the earlier investigation was the incidence of torn joystick boots. Once inexpensive parts to replace, when left unrepaired, the boots either directly or indirectly caused the more costly electronics problems in 25% of power mobility systems (1). The need to replace the boot was found for one manufacturer: Invacare. The earlier study proposed using a replacement boot from Production Research Corporation (PRC) that was noticeably thicker than the original factory boot and also featured a wider flange at the base.

A second investigation in this ongoing series of studies looked at the expected and actual repair rates of power mobility systems by manufacturer and also by type of power unit (2). This study showed the power mobility product lines from ABEC, Amigo, Damaco, E&J, Orthokinetics, Pace Saver (Leisure Lift), and Shuttle (Pride) performing at or above expectations while the combined performance of Fortress, Invacare, and Quickie was below expectations. For the power unit types, the power bases, three-wheelers, and add-ons performed at or above expectations, but the conventional power system performed below expectations.

RESEARCH QUESTIONS

The purpose of this study was to determine whether there is a pattern to power mobility repairs. Three research questions were investigated:

1. Which power mobility systems by unit type and by manufacturer have repair rates that were higher than expected.
2. Which power mobility systems by unit type and by manufacturer have repair rates that were lower than expected.
3. Which power mobility systems by unit type and by manufacturer have repair rates that were expected.

METHOD

From November 1991 to November 1992, the electronics repair supervisor continued to complete the six part intake questionnaire, *Power Wheelchair Repair Survey*, for each power mobility unit brought into the shop for repair. Data collected during this time were added to the information gained between July and November 1991. Concurrently with survey completion, an examination of the records of RTS owned business was performed to ascertain the numbers and percentages of power mobility systems sold by power mobility unit type and by manufacturer. Chi-square tests were conducted to determine if there were differences between the expected (calculated from the examination of records) and actual repair rates (calculated from the surveys) among manufacturers and among types of power units.

RESULTS

In the 16 months from July 1991 through November 1992, four types of power mobility units (conventional, power base, three wheeler, and add-on power unit) from 10 manufacturers [ABEC, Amigo, Damaco, E&J, Fortress, Invacare, Orthokinetics, Pace Saver (Leisure Lift), Quickie, and Shuttle (Pride)] were included in the total of 136 power mobility repairs. The repairs were divided into three categories: electronics, boots, and mechanics. The actual and expected repair rates for mobility unit types are depicted in Figure 1 and for manufacturers of mobility systems are illustrated in Figures 2.1 and 2.2 (listed in alphabetical order).

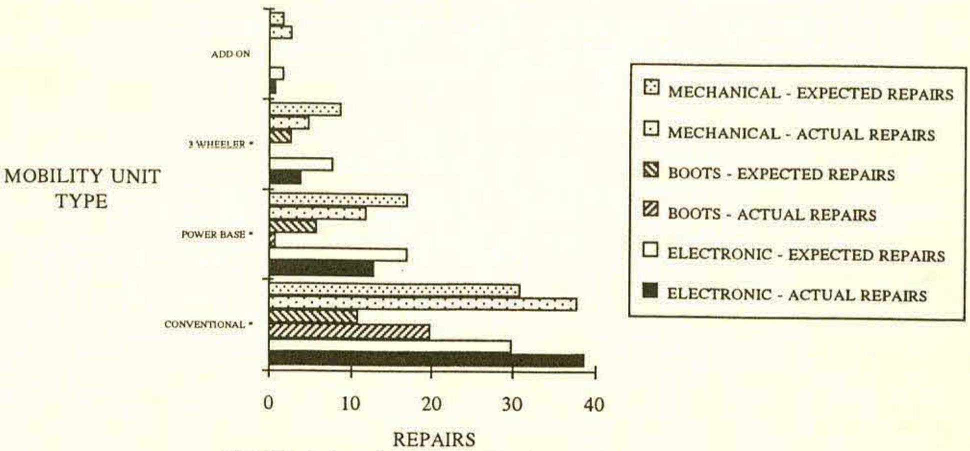

FIGURE 1: Actual and expected repair rates by power mobility unit type (*$p < .05$).

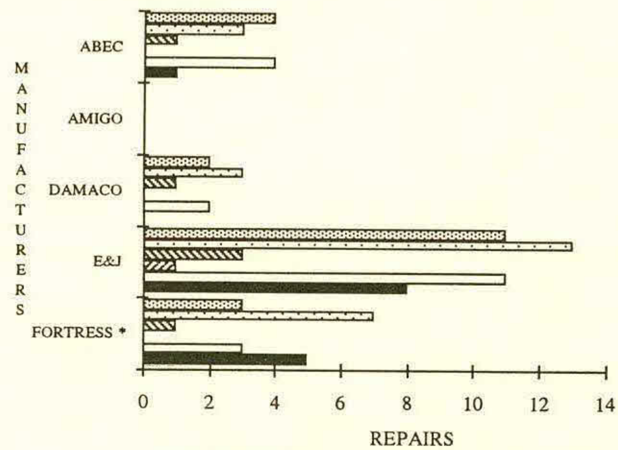

FIGURE 2.1: Actual and expected repair rates by power mobility manufacturer (*$p < .05$).

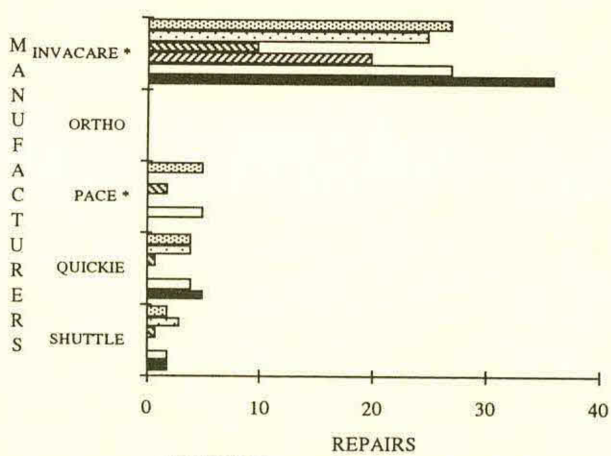

FIGURE 2.2: Actual and expected repair rates by power mobility manufacturer (*$p < .05$).

Repairs were needed significantly more frequently than expected in all three categories (electronics, boots, and mechanics) for conventional mobility systems, $\chi^2(2, N=97)=11.644$, $p<.05$; in the electronics and mechanics categories for systems manufactured by Fortress, $\chi^2(2, N=12)=7.666$, $p<.05$; and in the boots and electronics categories for systems manufactured by Invacare, $\chi^2(2, N=26)=6.578$, $p<.05$.

In the electronic, boots, and mechanics categories, there were significantly fewer repairs for power bases, $\chi^2(2, N=26)=6.578$, $p<.05$; and three wheelers, $\chi^2(2, N=81)=213.148$ $p<.05$; and for systems manufactured by Pace Saver (Leisure Lift) systems, $\chi^2(2, N=0)=12.00, p<.05$. The number of actual repairs equaled the expected number of repairs for add-on units, $\chi^2(2, N=4)=1.00$, n.s., and systems manufactured by ABEC, $\chi^2(2, N=4)=3.5$, n.s.; Amigo, $\chi^2(0, N=4)=0.00$, n.s.; Damaco, $\chi^2(2, N=3)=3.5$, n.s.; E&J, $\chi^2(2, N=22)=2.5$, n.s.; Orthokinetics, $\chi^2(2, N=0)=0.00$, n.s.; Quickie, $\chi^2(2, N=9)=1.25$, n.s.; and Shuttle (Pride) $\chi^2(2, N=5)=1.50$, n.s.

DISCUSSION

With lower than expected repair rates, power bases, three wheel mobility units and systems manufactured by Pace Saver (Leisure Lift) appear to be cost effective lines to carry in this assistive and rehabilitation technology company. Add-on mobility units and systems manufactured by ABEC, Amigo, Damaco, E&J, Orthokinetics, Quickie, and Shuttle (Pride) are product lines that will be kept as these systems performed as expected. One mobility unit type (conventional) and the systems of two manufacturers (Fortress and Invacare) will be watched more carefully as these mobility systems seem to have more frequent repairs than expected.

Similar to the finding of the earlier study (1), boot repairs were found in the current study to occur more frequently than expected for systems manufactured by Invacare. While the earlier study had no data on the success rate of the proposed PRC replacement boot, subsequent long term use of the PRC boot has proven to be a poor alternative as these thicker boots were brittle and tended to break apart at the folds after a few months of use. A simple solution to the joystick boot problem, proposed in the earlier study, was the redesign of the original product to eliminate tearing and to prevent subsequent electronics difficulties. After contact regarding the frequency of the boot problem of the current study, Hymie Pogir of Invacare found that the easiest solution would be to place an extra boot over the standard boot. This extra boot would be retrofitted and could be installed at the dealer level. Invacare is now researching and testing various materials for effectiveness. With a change in boot design, systems manufactured by Invacare will be cost effective units.

To collect more data for the determination of cost effective product lines, the electronics repair supervisor will continue to complete the six part questionnaire, *Power Wheelchair Repair Survey*, for each power mobility system brought into the shop for repair. An update on the continued effort to investigate power mobility repair patterns will be available in the future.

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NAVCHAIR: DESIGN OF AN ASSISTIVE NAVIGATION SYSTEM FOR WHEELCHAIRS

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ABSTRACT

The design of the NavChair system for assistive wheelchair navigation is described. The system utilizes a commercial powered wheelchair which has been enhanced to sense its environment so that it can assist the chair user in safe navigation. Enhancements include an array of Polaroid ultrasonic sensors to detect obstacles, a portable IBM-PC compatible computer, interface circuitry to monitor and control the wheelchair itself and software. This design provides the basic capabilities for a *shared control* system which can augment the limited capabilities of a wheelchair user to permit functional mobility and increased independence.

BACKGROUND

The development of mobility aids for persons with disabilities has followed a logical progression mirroring the pace of technology. In particular, the powered wheelchair has evolved into a range of products which offer a wide variety of interfaces and control features. Nevertheless, persons with a variety of motor, sensory, and/or cognitive impairments find it difficult or impossible to drive a wheelchair.

Many potential users would benefit from a wheelchair control system which assists in making control decisions related to avoiding obstacles, following a straight path, or safely approaching objects. An assistive navigation system for wheelchair control called NavChair is being developed to meet these objectives (3).

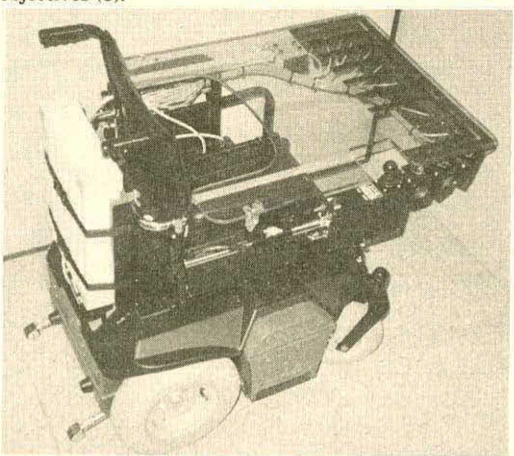

Figure 1. NavChair Prototype

STATEMENT OF THE PROBLEM

The ultimate goal of the NavChair project is to create a wheelchair control system which reduces the motor coordination and cognitive effort required from the user. There are a number of ways to decrease the control demands on the driver. The most important of these methods is automatic obstacle avoidance, which provides the central design goal of the NavChair system. Other features of the NavChair include a wall following mode and a close approach mode. NavChair is based on an ultrasonic mapping and navigation system developed for autonomous mobile robots (2). This technology allows a robot to move smoothly through an environment filled with both moving and stationary obstacles. Avoidance maneuvers are automatic, and occur in real time, without significant slowing of the robot.

NavChair employs these navigation techniques to assist the wheelchair operator. The user indicates desired direction and velocity of travel using the joystick in the normal way. NavChair monitors the joystick and also obstacles in the wheelchair's immediate environment. As long as the user's commands move the chair through clear space, the joystick commands are merely echoed to the power module. When an obstacle appears in the desired path, the NavChair computer will alter the joystick command enough to miss the obstacle, whether this requires a slight steering change for small obstacles, or a full stop when a dead end is encountered.

To provide these navigation capabilities, several features must be added to a standard wheelchair. First, significant computational power is necessary, in the form of one or more computers. The system must have an interface which allows it to read the user joystick and send its own commands to the wheelchair motors. It must have sensors which can detect obstacles around the chair, and finally, it must be able to measure the actual movement of the chair.

This last requirement presents a challenge to wheelchair implementation. In order to maintain a map of the environment, the robot or wheelchair must know when it has moved, so that its internal map can be altered to reflect that change. Mobile robot drive systems are designed with close attention to this requirement. Wheelchairs are quite different. Most make no provision for feedback about wheel movement, as this is normally unnecessary. While pneumatic tires cushion the ride for the user, they slide across the ground easily and move differently at different internal pressures.

DESIGN

The NavChair prototype is constructed on an standard Everest & Jennings Lancer[a] powered wheelchair. Modifications made to the chair, itself, are minor and are described below. The Lancer (Figure 1) is a robust, powerful base with an accurate and responsive control system. It is functionally divided into a joystick module which produces the proportional control signals and a power module which converts these controls into appropriate motor current (Figure 2). This separation of functions allows the NavChair module to intercept control signals from the joystick, modify them and then pass them on the power module.

In standard operation, the joystick module translates the position of the joystick into two output voltages, one for the right wheel and one for the left wheel. The transfer function employed by the joystick module can be customized by the user. A series of 9 potentiometers allow the user to specify individual characteristics such as maximum forward velocity and maximum turning velocity.

The Lancer has one unusual feature which benefits the NavChair project: closed-loop velocity feedback control. This chair is designed to monitor the actual motion of the wheels. This allows it to compensate automatically for unusual terrain such as inclines. To provide this capability, wheel rotation sensors are built in to the motors. These sensors are used by the NavChair system, as explained below.

The components of the NavChair module are mounted on the Lancer and powered by the chair batteries, making the system completely mobile. The NavChair module consists of three subsystems (Figure 2):

Onboard *Master Control* Computer This is a 33 MHz PC-compatible 80486-based computer manufactured by Ergo Computing. Designed as a portable computer, it is small and rugged. It has an aluminum case, internal space for two expansion circuit boards and takes DC power from an external source. The computer reads joystick voltages and produces output control voltages through an internal analog interface board made by Real Time Devices[c]. The computer is visible as the light-colored box behind the chair back in Figure 1.

Ultrasonic Sensor Array A semi-circular array of 12 Polaroid ultrasonic transducers is mounted across the front of a standard-size lap tray. The sensors are aimed in a radial pattern with an interval of 15°. Each sensor can be fired individually, and provides information about the distance to the nearest obstacle in the direction the sensor is facing.

Interface Module All necessary interface circuits are combined in one box, located between the *Master Control* computer and the back of the chair. This box provides voltage conversion for computer power, a multiplexor to fire and read ultrasonic sensors and a set of wheel position pulse counters to track wheelchair movement.

When it is active, the NavChair module interrupts the direct connection of the joystick module to the power module. Joystick signals are read by the A/D board in the computer. In this way the computer can monitor what the user wants the chair to do. The joystick signals can then be modified by the computer (if necessary) before being passed on to the chair power module through the D/A converters in the computer.

Information used by the Master Computer to make decisions about editing the user's joystick commands comes from several sources. The most important of these is the ultrasonic obstacle detection system. The Master Computer can trigger individual sonar transducers to produce a short ultrasonic click (this is called *firing* a sensor). That burst of sound travels away from the sensor, bounces off the closest obstacle and returns. The sonar transducer functions as a microphone to detect this returning echo and the time from trigger to echo is directly proportional to the distance the sound waves have to travel. NavChair uses this method to assemble data about its immediate environment.

While the sonar sensor is attractive due to its simplicity and low cost, individual sonar distance readings are often erroneous. There are several sources for these errors. The sound wave travels out in a 30° cone, and can reflect off anything in that area. Sound from one sensor can reflect back to another sensor. A pulse can bounce off a series of object in a round-about path, before returning to the transducer. A smooth, hard surface oriented at an oblique angle to the sensor may reflect enough of the sound energy away so that not enough returns to trigger the transducer. To extract useful information, sonar readings must clearly be acquired and evaluated under carefully controlled conditions.

The sonar mapping method currently used with NavChair is the result of substantial research in

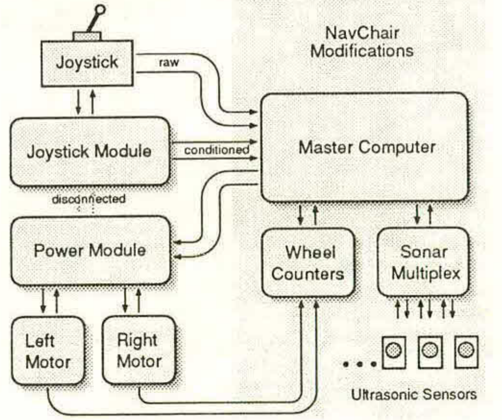

Figure 2. NavChair Block Diagram

controlling autonomous mobile robots. It is called the Error Eliminating Rapid Ultrasonic Firing (EERUF) method (2). The mapping process is performed by the Master Computer. The computer fires all the transducers in the array approximately 10 times each second. By varying the order and timing of individual sensor readings, the EERUF algorithm is able to detect and reject a large proportion of erroneous readings. This correction, combined with large numbers of separate readings, allows the computer to assemble an accurate two-dimensional grid map of obstacles around the wheelchair.

The Master Computer has one other important source of data about the environment. To keep the grid map of obstacles accurate, the computer tracks when and how far the chair moves. This is accomplished using binary counters to track the motion of the two driven wheels, right and left. The counters tally tach pulses produced by the rotation sensors on the wheelchair's motors. Each time a wheel moves one millimeter forward or backward, one tach pulse is produced. To complete the system, the motor circuits also provide a forward-backward signal which tells the counter whether tach pulses should be added (forward motion) or subtracted (backward motion). The Master Computer can read these two counters at any time to find out the current position of the chair.

DEVELOPMENT

During development, the joystick interface had to be redesigned. Initially, it was to use only the control signals coming out of the joystick module. These signals are already modified by the joystick module to limit velocity and acceleration (as dictated by the potentiometer settings). This signal conditioning causes an unacceptable delay between actual joystick motion by the user and output voltage change. The interface had to be altered to give the NavChair system access to both these conditioned signals and the raw position signal coming straight from the joystick.

Another area which had to be reworked was the motion control software. As noted above, the Lancer monitors the actual motion of its wheels and alters motor current automatically to maintain velocity. Thus, a given control voltage produces the same chair velocity whether the chair is going uphill or downhill. The initial NavChair plan was to rely on this built-in velocity control. Experimentation showed that this did not give the NavChair software accurate enough control. The software now monitors wheel motion and implements its own closed-loop feedback control.

DISCUSSION

The hardware of the basic NavChair system is complete. The functions of ultrasonic mapping, obstacle detection, path planning and motor control operate as planned. The software can be configured to make the wheelchair function much as the robot from which it is copied. In fact, one of the system tests used was to run the wheelchair as an autonomous robot, without a driver.

However, this represents the completion of only the first phase of the NavChair project. Current efforts are focused on refinement of navigation routines and optimizing performance. This includes the development of methods for a user to manually choose between various control modes (wall following, close approach, etc.). Next will come testing with users to investigate the functional effectiveness of the NavChair system as well as to establish optimal system configuration for varying user capabilities.

One offshoot of this research has been the use of the NavChair for investigating issues related to *shared control* systems (3). *Shared control* describes systems where both human and machine participate in the control process. Study includes the development of methods for automatic mode selection based on prediction of human intention.

ACKNOWLEDGEMENTS

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COMPUTER AIDED DESIGN OF INDUCTION MOTORS FOR ELECTRIC WHEELCHAIR PROPULSION

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ABSTRACT

Many of the electric automobiles now being introduced use induction motors (IM) because of their outstanding characteristics for vehicle propulsion. This also makes IM an attractive alternative for electric wheelchairs. Commercially available IM can not be used in this application because they require 120 or 240 volts power supplies. The source of energy in an EWC is a 24 volt battery. This voltage is converted to three phase alternating current by means of an inverter, but only a maximum of 24 volts is easily attainable. This paper describes a computer program developed at the UVA Rehabilitation Engineering Center, that allows for easy and fast design of an induction motor when key performance parameters, such as rated power, maximum torque, maximum and minimum frequency and voltage, are entered by the designer. If an existing frame is available, the program specifies the windings. If no frame is available, the program provides a complete design, including frame specifications.

BACKGROUND

Alternating current three phase squirrel cage induction motors (SCIM) are inexpensive, efficient, highly reliable and have a torque/speed characteristic very adequate for vehicle propulsion [1,2]. These characteristics have made SCIM the motor of choice for many of the new electric automobiles [3,4]. SCIM should also be a very attractive alternative for electric wheelchair (EWC) propulsion [5]. Commercial SCIMs, however, can not be used for this application because the available power supply in an EWC is a 24 volts battery, and commercial SCIMs are available for much higher voltages only. Practical inverters (the device used to transform 24 volts dc to three phase sine voltages) have a maximum voltage amplitude equal to the dc voltage. SCIMs for EWC need to operate at variable frequencies and corresponding variable voltages [6]. This makes the motor design different from commercial, constant frequency, constant voltage motors. This motivated the development of a program to design SCIMs specifically for EWC propulsion.

OBJECTIVE

The primary objective of this project was to develop a practical computer aided design method for SCIM intended for EWC propulsion. The design required low operating voltage with variable amplitude and variable frequency. The program, however, can also be used for more general purposes, i.e. motors with higher voltages and different frequency ranges, adequate for other industrial applications.

DESIGN

The heart of the program consists of an analysis routine which is used to obtain the operating characteristics of a motor such as its output torque and efficiency. This routine is based on the equivalent circuit model of an SCIM [7]. In order to accurately take into account the effects of a variable frequency, variable voltage power supply the model was modified to include frequency dependent losses, and reduced voltage operations. In addition, a graphics routine has been added to enable the motor's operating characteristics to be viewed on the screen if desired. The analysis routine is used as the basis of several other portions of the program.

The remaining sections of the program include routines for rewinding an existing SCIM frame and designing a motor from scratch as well as some user interface considerations. The winding of the motor (used in both the rewinding and motor design sections) is handled by an optimization algorithm which finds the "best" winding available in much less time than an exhaustive search would. The program can be set to optimize the motor's efficiency, power consumption, or torque output depending on what the user feels is most important.

In designing the entire motor there are no hard and fast rules which can be used. Instead there are many "rules of thumb" which are used by designers to obtain the frame dimensions of the motor [8,9]. These rules of thumb have been automated in the program and are used to design the frame of the motor. The frame is then rewound by the optimization algorithm.

One of the primary user interface considerations is the ability of the program to use either metric or English units. This is desirable since many people are much more familiar with the use of English units. An attempt has also been made to reduce the amount of data which is entered by the user by including look-up tables within the program of the most commonly used information.

The various interactions within the program can be most easily visualized from the flow chart given in Figure 1. The initial call of the UNITS block determines whether the program will prompt for English or metric units during the program run. This can easily be changed while the program is running by another call of the UNITS block. The ANALYSIS block computes the equivalent circuit for a given motor frame and stator winding and can display graphs of the resulting operating characteristics. This block is also used by the optimization routine during the design of the motor windings. If a motor or winding is to be designed by the program the MOTOR SPECS block is used to obtain information about the desired operating parameters of the motor such as the torque needed and the speeds at which the motor will be run. Once these are obtained, the motor frame dimensions will either be designed by the program in the STATOR DESIGN and ROTOR DESIGN blocks or, if just the windings are to be determined, input by the user in the FRAME INPUT block. In either case the OPTIMIZATION block is used to design the motor windings. Once this is done the frame, windings, and operating parameters are displayed or sent to a file by a call of the DISPLAY MOTOR block. The program is then ready to run again.

DISCUSSION

The portion of the program which is expected to be of greatest use in the area of wheelchair propulsion is the motor rewinding routine. This is because it is generally much cheaper, given the lack of an appropriate SCIM, to have existing motor frames rewound than to specially order a unique motor.

As a verification of the program's techniques the results of a simulated rewinding compared well to that of a motor rewound by other methods. Work is continuing in this area in an effort to guarantee the accuracy of the program's results.

ACKNOWLEDGMENTS

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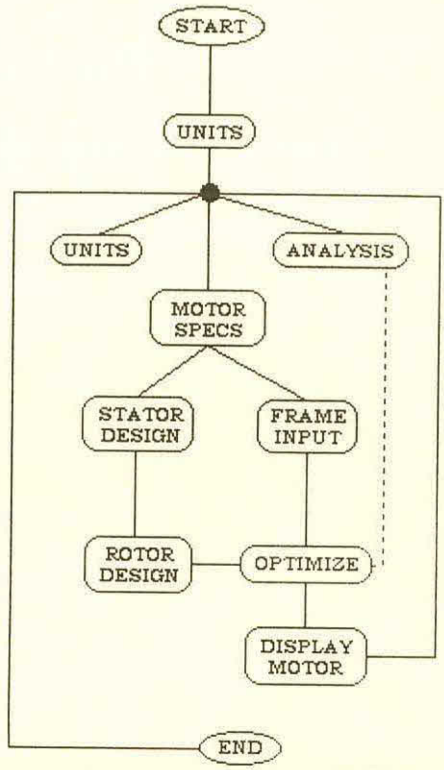

Figure 1 . Flow chart of SCIM design program

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SIG-10
Electrical Stimulation

Functional Neuromuscular Stimulation: At the Crossroads

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ABSTRACT

FNS research has reached a critical point in its development in the United States. While great progress and significant advances have occurred in basic science and application of electrical stimulation in the neurologically impaired or disabled population, future research in FNS is at risk of substantially reduced support. This is due to a number of factors and responsible parties for the current state of affairs include not only researchers and grant funding agencies, but also Congress, clinicians, the public and the media. The effect of this situation and our response to it may have profound effects on the realization of benefits to mankind unless concerted and substantial efforts are made to support new and continued research and development in this important field.

INTRODUCTION

Functional Neuromuscular Stimulation (FNS) is one of the most interesting and potentially beneficial areas of investigation in clinical research. It combines the fields of electronics, computer science, medicine, physical therapy, mechanics and a host of other related fields. The combined talents of engineers, physical therapists and physicians are all integral to the design and successful research and implementation of techniques and devices in this fascinating field. Over the last thirty years FNS has grown tremendously with clinical impact being felt in clinically useful applications of electrical stimulation. Patients suffering the effects of a multitude of neurological impairments, both temporary and permanent, have been able to realize relief from limited joint range of motion, spasticity, inappropriate muscle timing during function, contracture, weakness, joint subluxation and lack of neurological control to name but a few of the areas in which electrical stimulation has played a significant role.

FNS RESEARCH AND ITS APPEAL

Electrical stimulation has the potential to achieve far greater benefits for mankind than those mentioned above. Perhaps it is because of the awareness of this potential that FNS research has been subjected to exaggerated and unfair expectations beyond its current potential. To date, FNS research has concentrated on the complete spinal cord injured individual as the most appropriate model for study. This is in many ways appropriate in that it provides researchers with a study situation in which there is a clear distinction between the physiological actuators and the artificial control systems and their agents. This model has been the guiding foundation for a number of granting agencies under the premise of studying the basic and well defined principals of FNS and creating a total solution, even if it takes decades to accomplish the ultimate desired outcome. The most common form of spinal cord injury and other forms of neurological impairment, however, is that of the incomplete loss of central control. This population of patients (incomplete SCI, stroke, brain injury, cerebral palsy, multiple sclerosis, etc.) has been avoided for a number of reasons, including the number of research variables to be controlled and the inability to adequately simulate these human disorders in an animal model. In terms of clinical application however, incompletely paralyzed patients comprise the vast majority of potential FNS consumers and have the most to gain from FNS applications.

Complicating success in FNS research applications are the myriad of difficult issues to solve in even the complete spinal cord injured population. The physical properties of human motor systems are those of highly non-linear, time variant systems, and cannot be favorably compared to the those of the usual tools of engineering research such as DC servomotors. Multi-joint biomechanics is an exceedingly difficult area of study and has defied all but the most simplistic applications in FNS research. The unavailability of accurate and readily applied sensors to detect motion, force, and intent of neurologically impaired research subjects has greatly limited the success rate of FNS. Yet despite all of these and other difficulties we have seen electrical stimulation become commonplace in physical therapy patient management as well as impressive demonstrations of the potential application of FNS to replace function in the patient who has lost voluntary control.

FNS RESEARCH FUNDING

FNS research has enjoyed the funding support of a number of federal and private organizations for the last several decades but is currently receiving fewer research dollars than in recent years. The most significant reduction has been in federal grants. Primary supporters have included the National Institute of Handicapped Research (NIHR) (now the National Institute on Disability and Rehabilitation Research (NIDRR)), the Veterans Administration (VA), the National Institutes of Health (NIH), and the National Science Foundation (NSF). Recently, however, NIDRR has dropped the Rehabilitation Engineering Center on Functional Electrical Stimulation (REC) as one of its core research areas. The REC structure has provided major funding on a five year basis and its loss will have a significant impact on FES research to come.

NIH has recently formed the National Center for Medical Rehabilitation Research (NCMRR) with the intention of funding research into the more applied arenas of medical science. While this agency will undoubtedly prove to be a key funding source for FNS research, it is not yet funding at levels commensurate with its potential. This is due to a number of factors, including its recent organization, the fact that a standing study section has not yet been formed and will not be formed until more proposals are received, and that it is not yet receiving many proposals. Since applications to this center will be significantly different from those submitted to other centers it can be expected that other study sections temporarily responsible for review of proposals submitted to NCMRR may not be prepared to give priority to the proposals over proposals more in line with their own research interests. This transitory period will potentially be difficult for new applicants to NIH under the auspices of the NCMRR.

EXPECTATIONS OF FNS RESEARCH

The ultimate result of any medical research is that it either results in the development of a commercial product or that it affects the delivery or practice of medicine to the benefit of mankind. Has progress in FNS been fast enough, or has Congress, the funding agencies and the public had expectations of FNS research that have been unrealistic? Or both? In many areas of medicine the research and delivery of devices or techniques has been readily observable. References have been made to the development of the cardiac pacer as an example of how medical devices can evolve from research curiosities to medical commonplace. Not to make light of the requirements of cardiac pacing, but it is a far different situation to supply regular stimulation pulses to a single muscle as opposed to controlling multiple muscles and joints and maintain dynamic stability in the neurologically involved patient.

Despite this inherent complexity, expectations have been raised in the public and patient communities that FNS is ready to be fully transferred to commercial availability. This false expectation has been generated in part because of a number of ambitious investigators, media who fail to distinguish fact from fiction utilize sensationalism. The result is that the public has clamored for quick research results and investigators have failed to deliver the desired results to the medical community, however well-intentioned the effort.

Despite these difficult times, dramatic results have been achieved. Credible researchers have made substantial progress in recent years. Commercial entities are poised to test and deliver exciting new technologies. The possibilities paved by past research are close to fruition with continued support. Now is not the time to restrict research funding, it is the time to maintain and expand, to encourage commercialization and to facilitate the delivery of systems to the medical community which can now enhance, at least in small part, the lives of the neurologically impaired.

REALIZATION OF FNS BENEFITS

What can be done to encourage and enhance the delivery of FNS's tremendous potential in the future? A better understanding by the public of the difficulties of this very integrated area of research is important. The recognition by the reimbursement community that FNS treatments, or for that matter many other treatments relevant to neurological impairment, are not cured in fixed number of treatment visits or limited dollar amounts will greatly help to increase the understanding of FNS applications and foster more realistic levels the expectations and timely arrival of FNS solutions to neurological impairments. A goal-oriented approach to allocation of research and clinical dollars would improve quality of patient care as well as FNS applications.

In as much the media often views the medical and scientific community as the gold standard for reliable information it is imperative that all researchers and clinicians in FNS help by tempering their discussions with the media and with patients, by refraining from promises or predictions that exceed reasonable expectations in the foreseeable future. Funding agencies need to be encouraged to maintain and expand programs in FNS research and to keep in mind the complexities of this field when setting clinical goals for research programs. Consumers need to be careful not to believe everything that is cast in their direction, to place as much skepticism in the analysis of medical and clinical claims as they do in any other purchase of services or goods.

The future potential patient benefits from continued FNS research are most promising. The responsibility for the direction and well-being of that research is mutually shared among researchers, clinicians, funding agents and recipients.

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EFFECTS OF LEG FNS UPON WHEELCHAIR LOCOMOTION EFFORT

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ABSTRACT

The efficacy of functional neuromuscular stimulation (FNS) during wheelchair locomotion was evaluated using 8 male spinal cord injured (SCI) subjects (6 quadriplegics and 2 paraplegics). Two randomly assigned tests were performed, one with and one without FNS applied to the musculature of the lower extremities. The functional locomotion range consisted of self-selected "slow", "fast" and two interpolated velocities, each performed for 4-min stages. Heart rate (HR) was recorded each min via an earlobe pulse meter. Ratings of perceived exertion (RPE) were solicited at rest and following each 4-min stage. The results showed that HR increased linearly with increased locomotive velocity, analogous to a graded intensity arm crank exercise stress test. HR was consistently lower during FNS application at each velocity than without FNS. RPEs were consistently lower during FNS. FNS application during wheelchair locomotion may have important clinical implications for enhancing wheelchair mobility and improving rehabilitation potential in SCI individuals.

INTRODUCTION

Individuals with lower-limb paralysis due to SCI often experience pooling of venous blood in the lower limbs secondary to inactivity of the skeletal muscle venous pump and vasomotor dysfunction (5). This condition has been shown to induce "hypokinetic circulation", i.e., marked reduced central circulatory responses such as stroke volume (SV) and cardiac output ($\dot{Q}$) at rest (9) and during upper-body exercise in SCI individuals (8). Excessive venous pooling and diminished venous return may predispose these individuals to medical complications such as edema and venous thrombosis, as well as reduced arm and wheelchair exercise capacity (5).

FNS has been used to induce contraction of paralyzed muscles and increase circulation from the legs by activating the muscle pump (1,10). Glaser et al. (9) reported a 12-30% increase in SV and $\dot{Q}$ at rest during FNS-activation of paralyzed thigh and calf musculature. In addition, Davis et al. (2) used FNS to induce contractions of similar musculature in paraplegics and found cardiac output to be significantly augmented at rest (by 30%), as well as during several submaximal intensities of arm cranking (by 18-28%). In contrast, neither rest nor exercise HR was significantly influenced by the lower-limb FNS application. Therefore, the FNS-induced increases in SV and $\dot{Q}$ strongly suggest enhancement of venous return during rest and exercise in the upright posture.

Wheelchair propulsion has been shown to be mechanically inefficient compared to arm cranking and leg locomotion (i.e., walking and cycling) (6). As such, upright wheelchair locomotion, which requires relatively high energy expenditure, may be even more encumbered in the presence of hypokinetic circulation. Whether lower-limb FNS could enhance wheelchair locomotion capability by facilitating peripheral and central circulatory responses has not been reported previously. Thus, the purpose of this pilot study was to determine the effects of leg FNS upon the wheelchair locomotive effort in SCI individuals.

PROCEDURES

__Subjects__:
Eight male SCI subjects (6 quadriplegic and 2 paraplegic) participated in this study. Physical characteristics, including lesion level and time since injury are presented in Table 1. Prior to testing, subjects were medically screened, and signed a statement of informed consent in accordance with the Institutional Review Board of our University.

Table 1. Subject Characteristics.

Subject	Age (yr)	Height (cm)	Weight (kg)	Level	TSI (yr)
1	51	172.7	84.1	C7	1.0
2	30	190.5	60.1	$C7_i$	5.0
3	32	188.0	79.5	C8	10.0
4	37	182.9	67.8	C7	14.0
5	51	170.0	56.2	T6	5.5
6	39	183.0	82.6	$C6_i$	7.0
7	26	170.2	61.0	T4-6	2.5
8	16	177.8	59.1	$C6_i$	1.0
Mean (±SD)	35 (11)	179.4 (7.4)	68.8 (10.8)		5.8 (4.2)

i - incomplete
TSI - time since injury

__Wheelchair Field Test__:
To determine the range of functional wheelchair propulsion velocities, each subject was asked to operate his wheelchair at a self-selected "slow" velocity and at a self-selected "fast" velocity while the absolute speed was monitored. Based upon these two endpoints, two additional intermediate velocities were interpolated, resulting in a total of four test velocities. During testing, the velocity for each stage was set and maintained via a speedometer-wheel that was pushed in front of the subject by a technician. An illustration of this procedure is presented in Figure 1. Subjects propelled their own wheelchairs indoors, over a low-pile carpeted hallway of a modern research facility. On two separate occasions, each subject performed a wheelchair test in a counterbalanced order during which FNS was or was not applied to the muscles of the lower extremities.

A continuous, graded-velocity test protocol was used. Following a 5-min rest period, the subject was paced by the speedometer-wheel at the slowest velocity for 4 min. The velocity was then increased by the pre-determined increment for the next 4-min stage, followed by a second 4-min intermediate stage and a final 4-min "fast" stage. The test was terminated upon completion of the final "fast" stage or upon volitional exhaustion, indicated by the subject's inability to maintain the pre-determined, paced velocity.

FNS Application:
For FNS application, a specially constructed 8-channel neuromuscular stimulator, which was similar to one previously described (7), was used. This device was battery powered and provided FNS parameters as follows: rectangular biphasic asymmetrical waves, 35 Hz frequency, 300 μsec duration with a current output of 10-150 mA. This device was secured to the back of the wheelchair during both test to equalize weight. During the FNS test, skin surface electrodes were placed bilaterally over the motor points of the thigh (quadriceps, hamstrings) and the calf (tibialis anterior and gastroc-soleus) musculature. Current level (up to 150 mA) for each muscle was adjusted independently to obtain moderately intense contractions without causing the subject discomfort. The FNS application pattern caused the calf muscles to co-contract for 1.5 sec followed by a 1.5-sec relaxation. At 1.0 sec into this contraction, the thigh muscles were induced to co-contract for 1.5 sec followed by a 1.5-sec relaxation. Thus, there was a 0.5-sec overlap where the calf and thigh muscles were contracted simultaneously. The rationale for this FNS pattern was that venous return to the heart would be facilitated due to the upward "milking action" of the muscles on the veins, and back flow into the calf veins would be minimized if there was valvular insufficiency.

Figure 1. SCI subject paced by technician during wheelchair locomotion field test with FNS applied to the calf and thigh muscles.

Monitored Variables:
The relative stress of the wheelchair locomotive effort was evaluated from HR and RPE responses. HR was determined using an infrared earlobe digital pulse monitor (Schwinn PulseMeter Model SPM 150) and recorded each minute. RPE was recorded by use of the Borg Scale which was printed on a placard and presented to the subject during the final 10 sec of each velocity stage. Category-ratio ratings (0-10) were obtained in the categories of *central* (heart-lungs), *peripheral* (arm muscles), and *integrated* (overall).

Statistical Analysis:
A 2 x 4 repeated measures analysis of variance was used to examine differences between the two test conditions (i.e., FNS v no FNS) at rest and the four locomotive velocities. The *post hoc* Duncan Multiple Range test was utilized to determine interactions between test conditions of rest and the four stages of locomotion. Significance level was maintained at .05.

RESULTS

It was found that mean velocities for the slow stage, first and second intermediate stages, and the fast stage were 6.5, 7.8, 9.7, and 11.3 km/hr, respectively. Six of the subjects were able to complete all four stages of both field tests, whereas two of the subjects were unable to complete the fast stage. HR responses at each velocity of both tests, (i.e., with and without FNS) are presented in Table 2. It was found that HR increased progressively (i.e., linearly) as locomotive velocity increased. In addition, during FNS application, HR was consistently lower at each stage (2-7%), with a mean difference of 3% between the FNS and non-FNS conditions. However, the differences in HR between test conditions were not significant ($p > .05$).

Table 2. Mean ($\pm$SE) HR response at rest and four locomotive velocities with and without FNS.

Stage	rest	1	2	3	4
FNS	71.6 (6.8)	84.5 (4.4)	91.1 (5.7)	96.3 (6.2)	100.6 (7.1)
No-FNS	67.3 (4.0)	85.9 (7.8)	92.6 (8.1)	98.5 (7.3)	108.0 (7.9)

Table 3 presents the Borg Scale ratings of perceived exertion for *central, peripheral* and *integrated* categories. These data show a consistent pattern of lower perceived effort in all categories during the tests in which FNS was applied. The observed differences between conditions were not significant ($p > .05$).

Table 3. Mean ($\pm$SE) RPE for central, peripheral, and integrated categories of perceived effort.

Stage	rest	1	2	3	4
RPEC					
FNS	0.0 (0.0)	0.8 (0.2)	1.8 (0.4)	4.4 (0.8)	5.9 (1.3)
No-FNS	0.0 (0.0)	1.2 (0.3)	3.1 (0.6)	4.9 (0.7)	6.6 (0.9)
RPEP					
FNS	0.0 (0.0)	1.0 (0.4)	2.8 (0.6)	4.4 (0.8)	7.1 (7.1)
No-FNS	0.0 (0.0)	1.6 (0.5)	3.6 (0.6)	5.9 (0.9)	7.4 (1.0)
RPEI					
FNS	0.0 (0.0)	0.9 (0.3)	2.1 (0.5)	4.1 (0.8)	6.4 (1.1)
No-FNS	0.0 (0.0)	1.6 (0.5)	3.5 (0.5)	5.9 (0.7)	6.9 (0.7)

DISCUSSION

In this pilot investigation, there was a strong trend toward reducing the stressfulness of wheelchair locomotion at given velocities when rhythmic, static FNS-induced contractions were induced in the paralyzed muscles. This was indicated by the consistently lower HR and RPE responses at each velocity when FNS was applied. Although these differences were not statistically significant, there appeared to be definite advantages of using FNS with some of our subjects. This was especially true of those individuals who tended to be hypotensive. This FNS technique had been previously reported to markedly facilitate venous return reflected in greater SV, $\dot{Q}$, and the maintenance of mean arterial blood

mean arterial blood pressure (4). Therefore, FNS may reduce the incidence of orthostatic and exercise hypotension in susceptible SCI individuals. This may reduce the incidence of presyncopal symptoms and improve wheelchair locomotive performance.
Laboratory studies which have utilized arm crank ergometer exercise in SCI individuals indicated that performance was improved and cardiopulmonary responses were enhanced when methods to increase venous return were incorporated. For instance, Figoni et al. (3) demonstrated higher maximal power output when arm exercise was performed in a supine vs sitting posture. This was primarily attributed to a reduction of gravitational effects on the columns of blood in the lower body. Pitetti et al. (11) found improved arm exercise capacity when a G-suit was used to apply lower body positive pressure to facilitate venous return. Davis et al. (2) reported greater SV and Q when FNS was applied during submaximal levels of arm crank ergometer exercise. Therefore, it appears feasible that improved venous return during wheelchair locomotion could translate into improved performance. Of the methods employed in the laboratory settings, FNS appears to be the most favorable technique due to its small size and portability. An additional benefit from activation of the skeletal muscle pump may be improved limb integrity (i.e., bone and muscle).

Heart Rate:
The application of FNS to the musculature of the lower extremities appeared to have only a slight effect upon lowering HR. Previous investigations have not reported significant HR effects of static pulsatile FNS, but have reported marked increases in both SV and Q. It may be physiologically significant that the added muscular "work" of the FNS-induced contractions did not increase HR due to the larger active muscle mass during FNS. In contrast, the tendency of the larger active muscle mass during FNS to increase HR appeared to have been counterbalanced by the increased vagal tone from the FNS-induced increase in venous return via the baroreceptor reflex.

Perceived Exertion:
The Borg Scale of perceived exertion may offer a sensitive, albeit global, indication of underlying physiological responses to FNS. In this study, ratings related to local arm muscle stress were *21%* lower during FNS application. Similarly, mean central ratings, (i.e., a reflection of central cardiopulmonary responses) were *31%* lower during FNS application than without the FNS. Overall ratings were also *27%* lower when FNS was applied during wheelchair locomotion. During FNS, the decreased central ratings of perceived exertion may have partially resulted from the reduced HR, thus suggesting decreased cardiovascular stress. The consistently striking reduction in these subjects' perceived level of stress during FNS-applied locomotion is clearly deserving of further investigation.

Methodological Considerations:
The process of developing this protocol provides a valuable source of information for future investigations. First, in our protocol the subject self-selected the *slowest* and *fastest* velocities, with two intermediate velocities interpolated. The successful completion of the four incremental stages was partially dependent upon the subjects' ability to gauge their endurance capabilities. For an inexperienced or sedentary individual this may be difficult and result in premature local muscle fatigue before test termination. Therefore, it may be helpful to allow several practice habituation trials prior to actual testing. Second, in contrast to the present test conditions, this test would be better performed on a non-carpeted surface within a large enough area to eliminate unnecessary turns. This latter factor may be difficult for quadriplegics and require additional energy not related directly to locomotive performance. Inclusion of these modifications could improve efforts to simulate physiologic requirements of daily wheelchair locomotion further enabling the evaluation of FNS application in this environment.

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CARDIOVASCULAR RESPONSES OF GERIATRIC MEN TO ELECTRICALLY STIMULATED AND VOLUNTARY LEG MUSCLE CONTRACTIONS

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ABSTRACT

Ten geriatric mobility-impaired men participated in this study to compare cardiovascular responses during rest, voluntary bilateral repetitive ankle plantar/dorsiflexion (VOL), and electrically stimulated pulsatile contractions of bilateral calf and thigh muscles (ES) while sitting upright. VOL and ES were performed for 1-min periods to activate the skeletal muscle pump and assist venous return. Only VOL increased heart rate (HR) significantly above rest, whereas only ES increased stroke volume (SV) above rest. Both VOL and ES increased cardiac output ($\dot{Q}$) above rest, with ES eliciting a greater $\dot{Q}$ than VOL. Neither VOL nor ES produced a significant change in mean arterial pressure (MAP). Both VOL and ES decreased total peripheral resistance (TPR) below rest, with ES eliciting a greater decrease than VOL. Only ES increased thoracic fluid volume (TFV) above rest, whereas both VOL and ES decreased calf fluid volume (CFV). These results suggest that, while both VOL and ES reduced calf venous pooling, ES-induced contractions of calf and thigh musculature enhanced venous return *twice* as much as calf VOL in the upright sitting posture. Therefore, with this geriatric population, ES may produce greater clinical circulatory benefits than VOL. ES was tolerated well and would not require patient compliance since it can be applied automatically.

INTRODUCTION

Electrical stimulation (ES)-induced contractions of the lower-extremities of spinal cord injured individuals have been shown to activate the skeletal muscle venous pump and facilitate venous return during orthostatic and exercise stress (1,2). This application of ES may be clinically useful since paralysis of leg muscles and sympathetic autonomic dysfunction predispose these individuals to excessive venous pooling and its medical complications. ES may also have applications for use with other clinical populations who are at risk for lower-extremity circulatory problems. In particular, institutionalized geriatric patients are at high risk due to their advanced age, multiple chronic medical conditions, and sedentary lifestyle. Some spend long periods sitting immobilized in chairs which tend to encourage venous pooling and lower-extremity edema. Thus, physical inactivity may predispose these individuals to potentially life-threatening vascular problems such as varicose veins, venous stasis ulcers, venous thrombosis, and thromboembolism.

To aid circulation in sedentary geriatric patients, it is recommended that a simple exercise consisting of bilateral ankle movements (alternately raising and lowering the heels and toes) be performed at regular intervals. These movements require voluntary cooperation/compliance and neuromuscular coordination of opposing muscle groups bilaterally (gastroc-soleus and tibialis anterior muscles). Due to the impaired ability to perform/coordinate the required movements, such voluntary exercise is often ineffective for patients with neuromuscular, neurological, or psychiatric disorders. However, ES-induced contractions may offer advantages over voluntary exercise since it can be automatically applied at specified intervals and provide contraction of multiple muscle groups in more complex patterns.

To date, no studies have been published which compare the effectiveness of voluntary ankle exercise with ES-induced leg muscle contractions for

METHOD

Subjects:
Ten men volunteered to serve as subjects. Mean ± SD age, height and weight were 64 ± 8 years, 180 ± 5 cm, and 84 ± 10 kg, respectively. All subjects were mobility-impaired but functionally independent with assistive devices such as a manual wheelchair or cane, resided at home, and participated in the Adult Day Health Care program at a large urban VA Medical Center. Each subject had at least one physical disability resulting from stroke, brain injury, diabetic complications (excluding amputation), hypertension, coronary artery disease, etc. All subjects were medically stable at the time of testing. Subjects took a variety of prescribed medications for their chronic conditions. Although several subjects were hemiparetic, all subjects had sufficient ankle plantar and dorsiflexion strength to move their ankle through part of the range of motion against gravity. All subjects were cooperative and seemed to understood instructions without difficulty.

Procedures:
The chair used in this study was a "Three-Position Recliner" (Model 574, Lumex, Div. of Lumex Inc., Bay Shore, NY). This chair permitted the subject to be placed in a nearly supine position, or a seated position. In the seated position, the subject's back was was reclined 25° from the vertical, and the seat was reclined 10° from the horizontal. The leg rest of the chair remained vertical for this study (although it was capable of elevating the legs toward the horizontal position). The subject's feet rested flat on the floor, with his arms supported by arm rests.

All subjects participated in a single testing session, the protocol for which is illustrated in **Figure 1**. During an initial 10-min period, where they were placed in a nearly supine posture, the subjects sequentially rested, performed VOL, and had ES applied. Then, the subjects were seated upright in the padded chair. In this position, two cycles (trials 1 and 2) were conducted, each consisting of 6-min periods of rest that were alternated with 1-min periods of VOL and ES. These duplicate trials allowed estimation of the trial-to-trial reliability of the data within one testing session.

VOL consisted of bilateral active ankle plantar and dorsiflexion. Thus, contractions of gastroc-soleus and tibialis anterior muscles alternated every second, verbally paced ("up"-"down") by the technician who used the sweep second hand of a clock. Subjects were requested to voluntarily contract the ankle musculature with moderate vigor through their maximum range of motion. ES consisted of bilateral isometric co-contractions of the calf (gastroc-soleus, tibialis anterior) and co-contractions of the thigh (quadriceps, and hamstring) muscle groups. VOL and ES contractions were intended to activate the skeletal muscle pump, assist venous return, and move venous blood from the legs to the thorax.

ES was applied via skin surface electrodes using a specially constructed neuromuscular stimulator similar to one previously described (3). ES parameters were

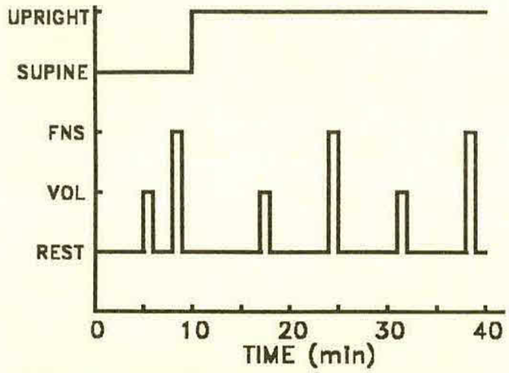

Figure 1. Testing protocol.

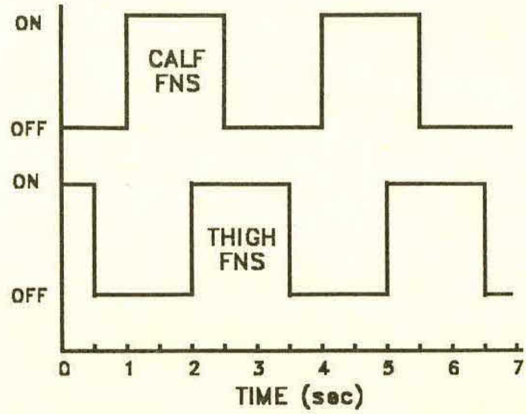

Figure 2. Timing pattern for ES-induced contractions of calf and thigh musculature.

as follows: rectangular-wave biphasic asymmetrical pulses, 35 Hz frequency, 300 µsec duration, with an ES current output range of 0-150 mA. The calf and thigh muscle groups were stimulated for 1.5 sec each, with 0.5 sec overlap and 1.0 sec of rest between pairs of contractions. **Figure 2** illustrates the timing pattern for ES-induced contractions of the calf and thigh muscle groups.

Cardiovascular responses were monitored before, during and after each VOL and ES period with computerized impedance cardiography, impedance plethysmography, ECG, phonocardiography, and auscultation. Cardiovascular variables included heart rate (HR, beat·min^{-1}, computed from the R-R intervals of the ECG), left ventricular stroke volume (SV, mL·beat^{-1}), cardiac output ($\dot{Q}$ = HR·SV·1000^{-1}), mean arterial blood pressure (MAP = DBP + [SBP-DBP]·3^{-1}), and total peripheral vascular resistance (TPR = MAP·$\dot{Q}^{-1}$). Segmental fluid volumes were calculated for the thorax (TFV = $\rho \cdot L^2 \cdot Z_0^{-1}$) and the right calf-segment (CFV = $\rho \cdot L^2 \cdot Z_0^{-1}$), where ρ was the blood resistivity, computed from hematocrit (Hct, %): $\rho = 53.2e^{0.022 \cdot Hct}$, L = lengths of thoracic and calf segments (constants 25.0 and 15.0 cm, respectively), and Z_0 = mean baseline impedance (Ω) of each segment. A specially constructed multi-segmental impedance device utilizing an IBM-type microcomputer was used to collect data simultaneously from the thoracic and calf segments.

Data Analysis:
Two-factor (trial x condition) and one-factor (condition) repeated measures analyses of variance and post hoc Tukey tests were used to statistically analyze the data. Intraclass correlations were used to estimate trial-to-trial reliability of the data. The 5% significance level was used for all hypothesis testing.

RESULTS

Between trials 1 and 2, no statistically significant differences ($p < .05$) were found for all variables at the rest, VOL and ES test conditions. Therefore, data from the two trials were averaged for reporting purposes. Intraclass correlation coefficients calculated for each dependent variable under each condition ranged from 0.899 to 0.999 (mean ± SD: 0.978 ± 0.022), indicating very high trial-to-trial reliability within a single testing session. Similarly, no differences were found between the resting baseline data before VOL and ES within each trial, indicating no order effects; therefore, these data were averaged to represent the resting condition.

Subjects were cooperative and learned VOL after a brief practice session before testing. The subjects were habituated to ES for at least two sessions before testing. The small and nonsignificant increases HR and BP suggest that ES did not elicit strong sympathetic nervous system responses and, therefore, was tolerated well. It was found that mean current amplitudes for ES were adjusted to 46-60 mA to induce moderate-intensity contractions of stimulated muscle groups. **Table 1** shows the mean, SD, and range of the current levels for each stimulated muscle group.

Table 1. Current amplitudes (mA) for each stimulated muscle group.

	Current (mA)		
Muscle Group	Mean	SD	Range
Right Quadriceps	53	10	35-75
Left Quadriceps	56	12	30-70
Right Hamstrings	57	15	36-90
Left Hamstrings	56	12	35-70
Right Gastroc-soleus	46	9	26-60
Left Gastroc-soleus	54	16	25-85
Right Tibialis Anterior	59	12	45-80
Left Tibialis Anterior	60	12	44-80

Cardiovascular responses (mean ± SD) during rest, VOL, and ES are summarized in **Table 2**. Only VOL increased HR significantly ($p < .05$) above rest (by 1%, 4 beat·min^{-1}), whweras only ES increased SV above rest (by 16%, 8 mL·beat^{-1}). Both VOL and ES increased $\dot{Q}$ above rest (by 10%, 0.35 and 20%, 0.69 L·min^{-1}, respectively), with ES eliciting a greater $\dot{Q}$ than VOL (by 9%, 0.34 L·min^{-1}). Neither VOL nor ES produced a significant change in MAP. Both VOL and ES decreased TPR below rest (by 7%, 2 PRU; and 16%, 5 PRU, with ES eliciting a greater decrease than VOL (by 9%, 3 PRU). Only ES increased TFV above rest (by 0.7%, 21 mL), whereas both VOL and ES decreased CFV (by 3%, 37 mL and 4%, 50 mL , respectively).

DISCUSSION

Fluid Shifts:
Both VOL exercise and ES-induced pulsatile contractions of gastroc-soleus and tibialis anterior muscles are presumed to mechanically squeeze venous blood away from the calf and toward the heart. Both methods were found to measureably reduce venous pooling in the calf segment (by 37-50 mL per calf segment), but only ES was found to have

Table 2. **Cardiovascular Responses of Mobility-Impaired Geriatric Subjects (N = 10) during Rest, Voluntary Exercise (VOL), and Electrically Stimulated Exercise (ES) in the Upright Sitting Posture.**

	Rest	VOL	ES	
HR (beat·min^{-1})	70 ± 13	74 ± 14	73 ± 13	
SV (mL·beat^{-1})	50 ± 16	52 ± 17	58 ± 19	*
$\dot{Q}$ (L·min^{-1})	3.37 ±.79	3.72 ±.88	4.06 ±.94	*
MAP (mmHg)	109 ± 20	111 ± 22	111 ± 22	
TPR (PRU)	34 ± 10	32 ± 11	29 ± 9	*
TFV (mL)	2867 ± 254	2874 ± 248	2888 ± 266	
CFV (mL)	1170 ± 87	1133 ± 192	1120 ± 195	

Values are mean ± SD.
Underlined means are nonsignificantly different.
* ES is significantly different from VOL and Rest.
PRU (peripheral resistance units) = mmHg·L^{-1}·min^{-1}

moved fluid from the calf against gravity to the thorax. Although ES appeared to be the superior method to reduce venous pooling, not all of the fluid removed from the calf segment by either method was relocated to the thorax. Since the thorax gained only 21 mL, the majority of the fluid may have been moved to veins (capacitance vessels) between the calf and thorax (i.e., organs of the hips, pelvis and abdomen, and inferior vena cava). But, the precise distribution of venous blood is not well understood. Furthermore, some of this discrepancy may be due to the imprecise nature of the impedance technique for determining *absolute* fluid volume values.

Hemodynamics:
Some of the blood that was shifted to the thorax by ES appeared to have entered the central circulation as venous return. Thus, ES simultaneously reduced venous pooling and increased cardiac preload, SV and $\dot{Q}$ without a change in HR. In contrast, VOL also increased $\dot{Q}$, but via a different mechanism where HR increased without a change in SV. Both VOL and ES did not increase MAP, but they did lower TPR, thus, increasing total vascular conductance, presumably from active legs muscles. These changes in TPR seemed to be in proportion to the active muscle mass and vasodilation during VOL and ES activities. Since ES involved both the calf and thigh muscle groups compared with only the calf during VOL, the greater muscle mass used during ES may account for the approximately two-fold reduction in TPR.

A previous investigation (4) had indicated that simultaneous or alterating contractions of both calf and thigh muscle groups improved venous return (SV and $\dot{Q}$) in younger able-bodied men more than contraction of the calf or thigh muscles alone. Similarly, this present study has found that both calf and thigh muscles appear necessary to elicit the best skeletal muscle pump effect, whether activated voluntarily or via ES.

Conclusion:
All of our physiologic data indicated that ES-induced contractions of four (bilateral calf and thigh) muscle groups is superior to voluntary contractions of two (bilateral calf) muscle groups in terms of reducing venous pooling and enhancing venous return in sitting geriatric subjects. Many institutionalized mobility-impaired geratric patients spend a considerable amount of time assuming this sedentary posture. Therefore, potential clinically important benefits of using ES technique may include prevention of excessive venous pooling, orthostatic hypotension, edema of the lower extremities, and complications of venous stasis such as varicose veins, venous stasis ulcers, venous thrombosis, and thromboembolism. The ES current levels used to induce the required contractions was well tolerated by the subjects and produced no discomfort despite their sensate skin. It is apparent that ES may have an additional advantage over VOL since it does not require patient compliance and it can be applied automatically at specific time intervals.

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Afferent Stimulation of the S1, S2 Dermatomes for Calf Spasticity in Hemiparetic Patients

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ABSTRACT

Afferent cutaneous stimulation was applied for 20 min. to the dermatomes belonging to the same spinal cord level as the triceps surae (S1, S2) in six hemiparetic patients with calf spasticity. Resistance, expressed as work of the plantarflexors (Nm·deg) to passive dorsiflexion, was assessed in both ankles of subjects pre and post-stimulation on an isokinetic dynamometer. There was a significant decrease in the work (Nm·deg) of the plantarflexors on the involved side during passive dorsiflexion following stimulation. In a subsequent session, temporal distance parameters, ankle motion and electromyographic (EMG) activity of the pretibial and triceps surae muscle groups were assessed pre and post-stimulation. There were no significant differences in temporal distance factors, ankle dorsiflexion or timing of the EMG activity of either the pretibial or triceps surae muscle groups during the gait cycle pre and post-stimulation.

INTRODUCTION

Electrical stimulation is one of the strategies currently employed in the treatment of spasticity. Various stimulation regimens have been described in the literature with varying degrees of success. Many of these regimens involve stimulation of the peripheral nerve of the spastic (Lee et al., 1950) or antagonistic muscles (Levine et al., 1952). All of these programs of stimulation involved efferent stimulation of the peripheral nerve to produce a contraction of the muscle. Alternatively, afferent stimulation has been described by Dimitrijevic´ and colleagues (1968) as "stimulation of the afferent sensory limb of the spinal reflex arcs". Afferent programs of stimulation have been used successfully for excitation and facilitation as well as inhibition. Ankle clonus has been shown to be suppressed with afferent stimulation to the anterior tibialis muscle in hemiplegic patients (Dimitrijevic´ et al., 1970) or with submotor stimulation to the radial and median nerves in patients with multiple sclerosis (Walker, 1982). Bajd and coworkers (1989) applied stimulation to the dermatomes belonging to the same spinal cord level as the spastic quadriceps muscle in five spinal cord injured patients and all demonstrated a decrease in knee extensor spasticity following stimulation.

One explanation for variability in the success rate of electrical stimulation programs for reducing tone, is difficulty in the objective measurement of spasticity. Stefanovska and colleagues (1989) characterized ankle spasticity in hemiplegic patients using a combination of torque and EMG during passive range of motion. Torque was reported as the average peak torque over 10 repetitions. Gottlieb and coworkers (1978) used joint compliance as an index of spasticity by measuring the ankle angle in response to a sinusoidally applied torque. Knutssen (1983) has suggested that an isokinetic dynamometer could be used to measure spasticity, since torque measurements during passive motion may correlate with increased resistance.

Based upon the results of Bajd and colleagues (1989), this study was undertaken to determine whether afferent cutaneous stimulation of the S1, S2 dermatomes would reduce spasticity of the triceps surae muscle group in hemiparetic subjects. Isokinetic testing was used to measure spasticity as work output produced during passive motion of the ankle. Total work output was used instead of torque since it represents resistance over the entire range of motion. Temporal distance parameters, ankle motion and muscle activity during gait were also measured following a brief period of afferent stimulation to determine if there was carry-over during walking.

METHODS

Subjects: Six hemiplegic individuals participated in this study. Criteria for participation included hemiparesis secondary to a cerebral vascular accident (CVA) or a traumatic brain injury (TBI), primarily unilateral involvement, and increased tone in the plantarflexors. All subjects could ambulate independently without assistive devices for a minimum of 80 m before resting. All subjects read and signed the informed consent form approved by the Institutional Review Board at the University of Texas Southwestern Medical Center.

Laboratory Instrumentation: An isokinetic exercise and testing device (KinCom™) measured the resistance to passive motion of the ankle between 10° of dorsiflexion and 30° of plantarflexion. Total work of the plantarflexors was expressed as Nm·deg generated in ten repetitions of passive dorsiflexion of the ankle at 30° /sec. This speed was chosen since it did not elicit clonus in any of the subjects. A neuromuscular stimulator (Select™, Medtronics) was used to deliver biphasic symmetrical pulses (300µsec) at a rate of 50 Hz at a submotor level for 20 min. These stimulation parameters were chosen based upon those reported by Bajd and Krajl (1989). Temporal distance measurements were collected as a measure of overall gait performance. Thin flexible footswitches were attached to the heel, fifth metatarsal, first metatarsal, and great toe of both feet for temporal distance recordings. Temporal distance parameters included velocity, cadence, stride length, double limb support time (DLS), and a ratio of the involved to uninvolved single limb support time (SLS). Simple two axis electrogoniometers (Penny & Giles™) were secured to both ankles for measuring sagittal ankle motion during gait. EMG activity of the pretibial and triceps surae muscle groups was recorded during gait using infant size EKG electrodes arranged in a bipolar pair. Inter-electrode distance was less than 2 cm and skin impedance was less than 50K ohms. Miniature amplifiers/transmitters were secured to the limbs for wireless transmission of EMG to the recording equipment, as previously described (Carollo, 1992).

Procedure: The subjects were scheduled for two appointments within one week. During the first appointment resistance to passive motion of both ankles was assessed pre and post-stimulation. Subjects were positioned supine on the isokinetic table with both legs in extension and neutral rotation. The subjects were asked to relax for 10 min. to control for changes in spasticity associated with positional changes. The uninvolved ankle was first secured in the ankle piece and following a 5 min. rest, resistance to passive motion was recorded during ten repetitions of 10° dorsiflexion to 30° plantarflexion at 30° per sec. This was repeated on the involved ankle. Before each assessment of each ankle, the subject was asked to relax for 5 min. to control for changes in tone following limb movement. Stimulation was delivered to the S1, S2 dermatomes of the involved limb using 1"x 2" surface electrodes. Amplitude was set at a submotor level and continuous stimulation was delivered for 20 min. Following stimulation, resistance to passive motion was reassessed in both ankles.

During the second appointment temporal distance parameters, sagittal motion of ankle, and the EMG activities of the pretibial and triceps surae muscle groups during gait were assessed pre and post-stimulation. The subject was instructed to walk at a free, comfortable velocity down a 20 m gait lane while anterior-posterior and lateral views were recorded on video. Footswitch and goniometer readings were collected in the middle 8 m of the gait lane using photocells. EMG activity was synchronized to the video. Four passes down the gait lane were recorded for each subject. With the subject in a comfortable supine position, stimulation was delivered as described above and the gait assessment was repeated.

Data Analysis: A two-way ANOVA was used to determine if there were significant differences in the work output during passive motion pre and post-stimulation and between the involved and uninvolved sides. A multivariate ANOVA was used to determine if there were significant differences in the temporal distance parameters or ankle motion during gait pre and post-stimulation. The timing of the EMG activity of the pretibial and triceps surae muscle groups was expressed as a percentage of the total gait cycle and was compared pre and post-stimulation.

RESULTS

The average age of the six subjects was 23.3 ± 8.4 years (range: 17-38). Five of the subjects had sustained TBI, and one had suffered a CVA. The average time since onset was 17.0 ± 19.9 months (range: 1-54).

Plantarflexion spasticity expressed as the amount of work (Nm·deg) during 10 repetitions of passive dorsiflexion is given for the uninvolved and involved ankle for each subject pre and post-stimulation.

	Uninvolved		Involved	
Subject	Pre Nm·deg	Post Nm·deg	Pre Nm·deg	Post Nm·deg
1	51.7	26.6	138.3	50.2
2	20.0	26.0	34.5	20.0
3	76.0	74.7	154.1	138.4
4	109.7	87.9	95.6	87.1
5	42.3	31.3	80.7	59.7
6	21.0	24.9	57.9	56.9

There was a significant decrease in the work output of the plantarflexors on the involved side during 10 repetitions of passive dorsiflexion following 20 min. of stimulation ($P<0.05$). Four of the subjects demonstrated a decline in the work of the plantarflexors on the uninvolved side following stimulation, however, this was not statistically significant. The mean ± SD for the percent change in work performed by the plantarflexors during passive dorsiflexion was 23.0±22.4% and 7.9±29.3% in the involved and uninvolved ankle, respectively. The amount of work performed by the plantarflexors during passive dorsiflexion was significantly greater on the involved side compared to the uninvolved side both pre and post-stimulation ($P<0.05$). The work performed by the plantarflexors on the involved side during passive dorsiflexion averaged 99.4±69.1% and 64.8±54.4% greater compared to the uninvolved ankle pre and post-stimulation, respectively.

There were no significant differences in any of the temporal distance parameters pre and post-stimulation. The mean ± SD are given below for the temporal distance parameters before and after stimulation.

Stim	velocity m/min.	cadence steps/ min.	stride length m	DLS time %GC	SLS ratio
pre	34.6 ± 27.1	69.1 ± 36.7	0.91 ± 0.31	46.4 ± 17.8	0.69 ± 0.20
post	35.2 ± 26.0	72.8 ± 35.5	0.88 ± 0.30	46.0 ± 18.4	0.72 ± 0.15

There was no significant differences in ankle dorsiflexion during the gait cycle before and after stimulation. There was no difference in the timing of the EMG activity of either the pretibial or triceps surae muscle groups during the gait cycle pre and post-stimulation.

DISCUSSION

Despite a small sample size, this study demonstrated that a brief period of afferent stimulation to the S1, S2 dermatomes decreased the work output of spastic plantarflexors during passive dorsiflexion. All of the subjects demonstrated a decrease in their resistance to passive motion following stimulation. Although not statistically significant, a decrease in the resistance to passive dorsiflexion was also observed in four of the subjects' uninvolved ankles. This may be due to crossed inhibitory influences on the contralateral side or due to the influence of inactivity during the tests. Although this study attempted to control for the influence of inactivity by having the subject relax for 10 min. prior to any testing, future studies should include a test of spasticity following 20 min. of inactivity without stimulation.

A joint will resist movement as a result of inertia, viscoelastic properties of the muscle and joint structures, and the reflex muscle contraction (Stefanovska et al., 1988). Since the speed of ankle rotation was held constant in this study (30°/sec), then any change in work output was secondary to a change in the reflex muscle activity. The work performed by the plantarflexors on the involved side during passive dorsiflexion was greater compared to the uninvolved ankle both before and after stimulation. This is evidence that isokinetic work output measures can be used as a quantitative index of spasticity over the entire range of passive motion.

There was no significant differences in any of the measurements made during gait following stimulation in this study. The length of stimulation (20 min.) was brief and may require longer durations of stimulation before a change could be observed in gait. The decrease in spasticity observed in this study may not have been sufficient to affect ankle motion or muscle activity during gait, since extensor tone increases when upright. Bajd and Krajl (1989) reported that 20 min. of afferent stimulation only reduced spasticity for 30 min. and have suggested that increasing the daily time of stimulation will increase the carry-over time.

Since the motoneurons for the triceps surae lie in the S1, S2 segments of the spinal cord, sensory stimulation of the large diameter afferent fibers in the S1, S2 dermatome should be the optimal peripheral location to affect a change in the information sent to the spinal cord. Vodovnik and colleagues (1988) have speculated that afferent stimulation facilitates the inactive inhibitory synapses but has no effect on the excitatory synapses. This improves the excitatory-inhibitory balance and reduces the spasticity. Regardless of the proposed neurophysiological mechanism, afferent stimulation to the dermatome at the spinal level of the spastic muscle may prove useful clinically in decreasing spasticity.

CONCLUSION

A 20 min. period of afferent electrical stimulation to the S1, S2 dermatomes of hemiparetic subjects with plantarflexor spasticity significantly decreased the resistance to passive dorsiflexion. Electrical stimulation did not improve the degree of dorsiflexion or the phasic timing of the pretibial and triceps surae muscle groups during gait. Gait performance, as measured with temporal distance factors did not change following a brief period of stimulation to the S1, S2 dermatomes. Future studies should evaluate gait performance following stimulation periods longer than 20 min.

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Voluntary Versus Electrically Stimulated Knee Extension Exercise: Differences Between Isometric and Isokinetic Expectations

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ABSTRACT

The purpose of this paper is to present a comparison of volitional [VOL] and ES (electrically stimulated) knee extension [KE]. 20 normal subjects attended 4 exercise sessions. A 40 repetition, maximal KE protocol was performed each time. MVE (maximum voluntary effort) was documented isometrically and at 60 deg/S. One and two channel ES recruitment curves established the maximum tolerable KE force prior to the ES protocols. Skin electrodes were used for open loop ES exercise (asymmetrical biphasic, 300 uS, 33 pps). Analog signals from an isokinetic system were sampled by an IBM PC/AT. Peak moment and work performed were plotted. ANOVA revealed differences ($p<.01$) between VOL and ES, as well as isometric and isokinetic exercise (ie peak KE moment: MVE-isometric > MVE-60 > ES-isometric > ES-60). Contrary to some previous reports, ES did not produce muscle performance equivalent to MVE. These findings have direct application to goal setting and patient management.

BACKGROUND

Neuromuscular electrical stimulation (NMES) can be used to augment muscle performance in patients with musculoskeletal and neuromuscular disorders. There is confusion in the literature, however, in regard to the amount of force and work that can be generated when NMES is employed. Previous reports on the percent of maximum voluntary contraction (MVC) that can be obtained with NMES in normal individuals varies from 11 to 133% of MVC. The study protocols, stimulation characteristics and methods of measurement have been varied among these reports.

A better understanding of the effectiveness of NMES on muscle performance in normal, healthy individuals is important to the physical therapy management of patients with intact or impaired sensation and to the physical therapist's ability to critically read the literature.

PURPOSE

The purpose of this poster is to present the differences in muscle performance between volitional and electrically stimulated (NMES) knee extension (KE) performed under isometric and isokinetic (60 deg/S) conditions.

METHODS

Subjects: Twenty normal, healthy subjects participated in the study. The 13 women and 7 men ranged in age from 21 to 44 years and were free of previous musculoskeletal pathology. None of the subjects were users of NMES.

Instrumentation: Cutaneous electrodes (3x4 inch, PALS FLEX, Axelgaard Mfg., Fallbrook, CA) were used for open loop NMES exercise (asymmetrical biphasic, 300 uS, 33 pps). Electrical stimulation was provided by a modular stimulator plug-in board in an IBM PC/AT. KE exercise (concentric isokinetic and isometric) was controlled by the LidoActive dynamometer (Loredan Biomedical, Davis, CA). Analog signals from the LidoActive system were sampled by an IBM PC/AT for angular position, velocity and moment. Calibration, gravity compensation and all data acquisition were performed by the IBM system. An auditory beep was provided through headphones to cue the subject to perform the next KE repetition. The electrical stimulator was programmed to allow the limb to return to 80 degrees of flexion and then immediately stimulate again. There was no rest interval between repetitions in either volitional or NMES exercise. The LidoActive isometric measurement mode was not used, and instead the system was held in a "ready" state and isometric data was gathered by the IBM system. Peak moment and work performed were documented for each KE repetition and performance data were plotted by a custom software protocol.

Procedure: Each subject attended four KE exercise sessions. During each session, a 40 repetition, maximal KE protocol was performed. Maximal voluntary effort was documented isometrically and at 60 deg/S. Single and dual channel NMES recruitment curves established the maximum tolerable KE force (isometrically and at 60 deg/S), prior to the 40 repetition NMES protocols. Subjects exercised volitionally at 60 deg/S during the first session and then the order of testing was randomized. The knee angle at which peak KE moment was generated by isokinetic volitional effort was used for both isometric exercise modes (voluntary and NMES). Subjects were not permitted to use their hands or arms during the test sessions.

Data Analysis: A repeated measures ANOVA was performed to detect differences among the four test sessions in peak KE moment (Nm), work performed (Nm-deg),and several indices of fatigue (decrement in moment from peak to end, decrement of the peak moment in the first seven repetitions after the peak and number of repetitions to 50% decrement in peak moment). The recruitment curve characteristics (peak moment produced versus the stimulus amplitude) were compared for single and dual channel stimulation. A Bonferonni adjustment of the alpha level was employed when differences among the sessions were identified.

RESULTS

Voluntary effort produced significantly greater peak moment and work than NMES exercise ($p<.01$ to $p<.0001$ across all comparisons). Isometric voluntary MVC produced 194.2 Nm in comparison to an isokinetic peak moment of 169.9 Nm ($p=.001$). Isometric NMES KE (88.8

Nm) was greater than isokinetic NMES (59.7 Nm) ($p<.01$). (Fig. 1) Fatigue rates were greater in NMES KE exercise than in volitional exercise. Isometric volitional fatigue (indicated by the 40th peak moment as a percent of the maximum KE peak moment) was less than volitional isokinetic fatigue (16.8% versus 39.6%) ($p<.0001$). NMES KE fatigue was significantly greater than in voluntary isometric exercise but NMES isometric fatigue was not statistically greater than NMES isokinetic KE (38.2% vs 41.2%). (Fig 2). The total work performed during the NMES 40 repetition test was approximately one third of that performed during the voluntary isokinetic test (Fig. 3). The addition of a second channel of stimulation resulted in significant gains in peak KE moment in both the isometric and isokinetic exercise modes (Fig. 4).

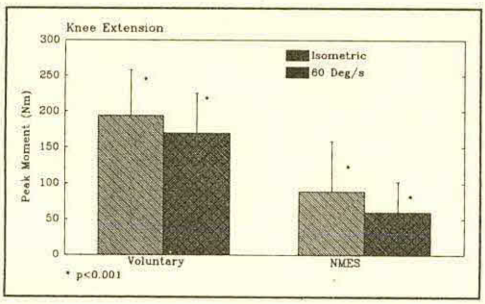

Fig 1. Peak KE moment for voluntary and NMES activation of the quadriceps. Significant differences were documented between isometric and isokinetic peak moments in both volitional and NMES exercise. The maximum tolerated NMES moments were 46% (isometric) and 35% (60 deg/S) of peak volitional contractions.

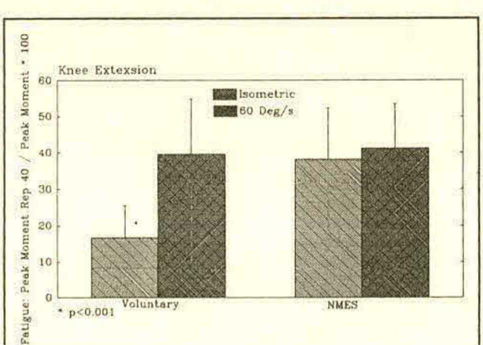

Fig 2. Decrement in peak KE moment, or fatigue, over 40 maximum volitional and 40 maximally tolerated NMES contractions. As expected, volitional fatigue was greater in isokinetic than isometric exercise. Despite the lower peak moments, fatigue was significantly greater than in isometric volitional effort.

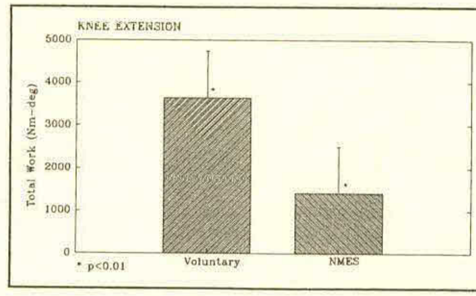

Fig 3. The total work performed over 40 maximal voluntary knee extensions was significantly greater than the work performed with NMES (60 deg/S).

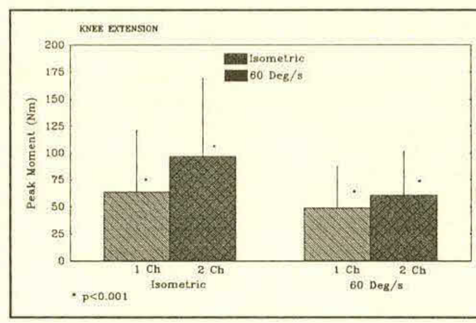

Fig 4. Employment of two channels, rather than one channel, of NMES resulted in significantly greater peak KE moment in both isometric and isokinetic exercise.

DISCUSSION

The differences between isometric and isokinetic muscle performance in volitional exercise were consistent with previous reports. NMES did produce functional muscle contractions (46% of isometric MVC and 35% of isokinetic MVC) in these normal subjects with intact sensation. This would be equivalent to a Good (4) or Fair+ (3+) manual muscle test grade. This report is especially valuable because of the accurate documentation of both stimulus parameters and instrumented indices of muscle performance (peak moment, work performed and fatigue rates). In contrast to some previous reports, the maximum tolerated NMES contractions here were certainly not of the quality that would support the use of NMES for muscle strengthening, a passive therapy aimed at hypertrophy, in normal individuals.

The reduced force production in isokinetic NMES KE, when compared to isometric NMES KE, is important when setting goals for patients who will require NMES to produce a functional force through a range of knee movement.

The reduced peak KE moments, work performed and increased rates of fatigue documented here for NMES exercise when compared to volitional effort, are not surprising in view of the differences between volitional and NMES exercise. These differences include: altered recruitment of muscle; motor unit firing rates in excess of normal; altered geographical location of the contracting fibers within a muscle; the potential for greater ischemia in muscle during exercise; and the bombardment of sensory receptors in the skin with a stimulus that is perceived as noxious when forceful muscle contractions are required. Each individual has their own discrete sensory tolerance level which limits the NMES muscle performance, especially when skin, or cutaneous, electrodes are used.

The use of 2 channels of stimulation permitted activation of more motor units at the same or lower stimulus amplitude. Two channels would be expected to be more effective in activating a large muscle group with multiple "motor points" or locations of motor innervation. When a symmetrical biphasic waveform is not available, 2 channels of asymmetrical biphasic stimulation can be effective. Adequate recruitment of the vastus lateralis is essential to produce force throughout the range of knee motion. Care must be taken to incorporate the vastus medialis to prevent undesirable patellar tracking during forceful vastus lateralis contraction.

CONCLUSION

NMES can be used to produce useful, potentially functional, contractions of the quadriceps. For the patient with an inadequate quadriceps, NMES may prove to be a useful substitute on a short-term or long-term basis depending on the amount of volitional recovery that occurs. NMES also may activate reflexes and provide timing cues for the neurologically disabled patient.

NMES cannot produce normal KE in people with sensation, despite the use of the most comfortable stimulus characteristics and dual channel stimulation. Peak KE moments, work performance were significantly reduced and fatigue rates increased when compared to voluntary KE.

NMES KE exercise cannot be considered equivalent to voluntary exercise in any way. It is inappropriate to claim that NMES KE is a passive exercise modality that provides all the benefits of regular exercise.

It is hoped that this presentation will help physical therapists as well as other medical care providers in the credible prescription of NMES and point out the need to clarify NMES issues so that the unfounded "salon prescription" of NMES exercise (and the billing of this passive exercise by non-physical therapists as a physical rehabilitation procedure [ie P.T.]) can be eradicated.

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HYBRID FES ORTHOSIS FOR PARAPLEGIC LOCOMOTION

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INTRODUCTION

People with paraplegia often require orthotic systems (used with or without FES) that encompass the hip, knee and ankle joints HKAFO's. Braces that extend above the level of the hip are usually inconvenient to don and doff and are encumbering for many activities of daily living. In an attempt to minimise the encumbrance of such bracing particularly when used in hybrid FES systems, the author previously proposed the following two part concept [Andrews 1990]. One part, a means of stabilising the knees, can be implemented using either a KAFO or an AFO used in conjunction with FES. This can be designed to be relatively unencumbering and worn throughout the day to assist with sit to stand type transfers, prolonged standing and short range ambulation. The other subsystem, the hip and trunk stabilising component, comprises a hip/trunk brace that can be put on whilst in the wheelchair and used to further improve ambulatory function. Being easily removed when not required for ambulation ensures minimal ADL encumbrance.

A new prototype hybrid FES orthosis based on this concept is described.

Knee Stabilising Component The anterior floor reaction orthosis (FRO) can conditionally stabilise the paralysed leg without mechanically locking the knee joint [Saltiel 1969]. This permits flexion during the swing phase with improved ground clearance and dynamic cosmesis. The condition for knee stability is that the ground reaction force (GRF) must be directed ahead of the knee axis. A FES feedback loop based on sensing the action of the GRF has previously been described [Andrews 1989]. A force sensing resistor (FSR) (supplied by Interlink Electronics Inc USA) was used to detect incipient buckling of the knee and, in response, the knee extensors were automatically stimulated. Stimulation was removed after the GRF was reestablished in the stable position. The GRF is mainly oriented ahead of the knee during standing and the stance phase of walking. The activation of extensor muscles can be reduced to levels that avoid FES induced muscle fatigue [Mayagoita-Hill 1990]. The range of ambulation can be extended if periodic short rest stops are taken. To avoid having to locate appropriate seating, rest stops are best taken in the standing position without fear of collapse due to FES induced fatigue.

An improved FRO was developed for this application and is shown in figure 1. This brace is much stiffer in dorsiflexion than conventional posteriorly moulded designs and fits the patients normal shoe size. The elasticated calf band controls plantarflexion during the heel contact to foot flat phase of gait. As the elastic calf band stretches the anterior of the brace lifts off the shank to allow ankle plantarflexion. This action avoids the "rigid boot" feel of previous solid ankle designs. A similar FRO-FES system has been used by paraplegic individuals for FES assisted stand-sit manoeuvres [Andrews 1990] using phase plane switching control; prolonged standing [Mayagoita-Hill 1990] reciprocal [Andrews 1989] and swing-through gait [Heller 1989].

Hip & Trunk Stabilising Component An earlier prototype of this component incorporated modified Durr-Fillauer RGO hip joints and a push pull mechanical linkage (flexible linear bearing BowdenFlex 55 supplied by Bowden Controls Ltd UK) in place of the usual Bowden cables [Andrews 1990]. These preliminary trials also revealed problems with the hip/trunk brace hip joints and linkage including:

- Awkward to disengage the linkage.
- Difficult to engage with hip flexion spasticity.
- Serial adjustment required with hip contractures.
- 1:1 ext/flex may reduce gait efficiency.
- Swing-through gait [Granat 1991] requires the linkage to be disengaged.
- Difficult to lean forward and pick up something.

A "smart" hip joint motion control mechanism was designed based on the wrapped spring principle [Kaplan 1991] shown schematically for the right hip in figure 2. A helical drive spring is wrapped around two hubs to form the joint. One hub is fixed to the pelvic band the other to the thigh cuff. One end of the drive spring is fixed and the other can be displaced by a small servomotor. On the "engaged" state the joint is free to rotate in extension but flexion is resisted by a torque determined by small anticlockwise displacements of the servo. If the applied torque is exceeds the set torque the joint will slip (flex) whilst holding the set torque. In the "free" state a small clockwise displacement of the servo unraps the spring and the joint is free to rotate in either direction. A prototype was constructed with drive spring 54 mm diameter, 30mm length formed from 2.2mm wound square drawn wire. The set torque can be varied up to a maximum of 140Nm. In the "engaged" state the holding torque can be set by pulse width control of anticlockwise servo displacement as shown in figure 2. In "free" state the frictional drag is less than 0.02Nm. Once positioned, the servo [Futaba model S148] output can hold its output position even if the battery power is switched off. This is a useful for saving battery power between state changes and was used to reduce the average consumption to less than 50 mW. The weight of the hip joint and servo components approximately 0.2Kg. The joint can switch between states in less than 50ms. The complete 2-part system is shown schematically in figure 3.

Typically the joint is "engaged" with preset slip torque during stance phases and is "free" during the swing phases. To stand up, the user first positions the body centre of gravity over the feet. Then with the hands on the support the joints are switched to engaged throughout the standup movement and whilst standing. Any difficulty in immediately attaining full upright hip extension is automatically accommodated since both joints allow progressive extension with the user held in the maximum extension attained.

DISCUSSION

Preliminary lab tests with three users having motor complete thoracic lesions for sit-stand transfer using surface electrodes indicated suggest that: no manual interaction with the joint mechanisms is required; standing for periods in excess of one hour is

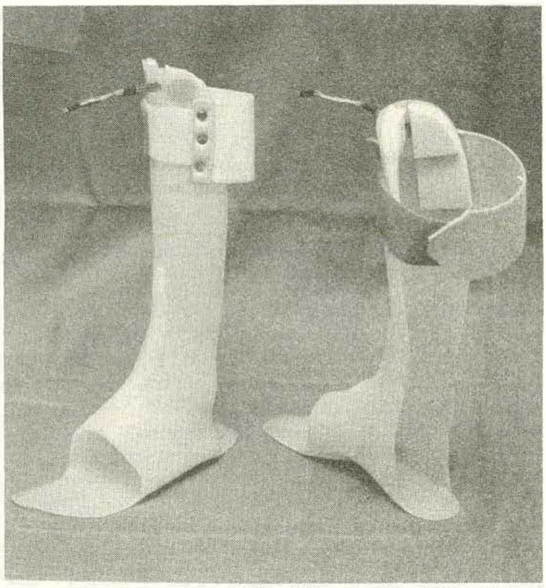

Figure 1 The anterior floor reaction orthoses.

possible; the hip/trunk component can be donned and doffed in less than 30 seconds. Further tests are required to assess the value of the hip/trunk brace during ambulation.

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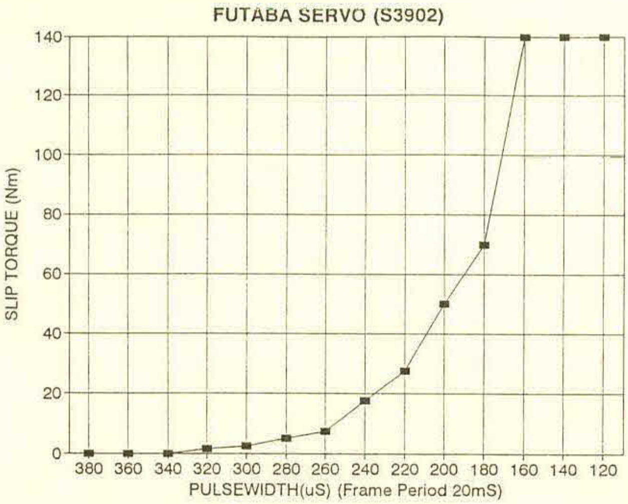

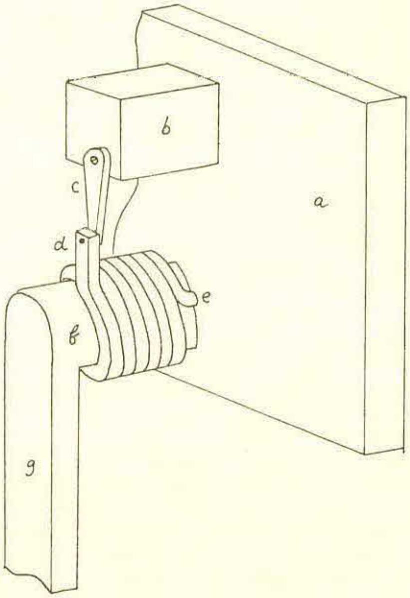

Figure 2. Schematic diagram of the right wrapped spring hip joint. Showing a) pelvic band, b) servo d) drive spring, e) spring connected to pelvic band.

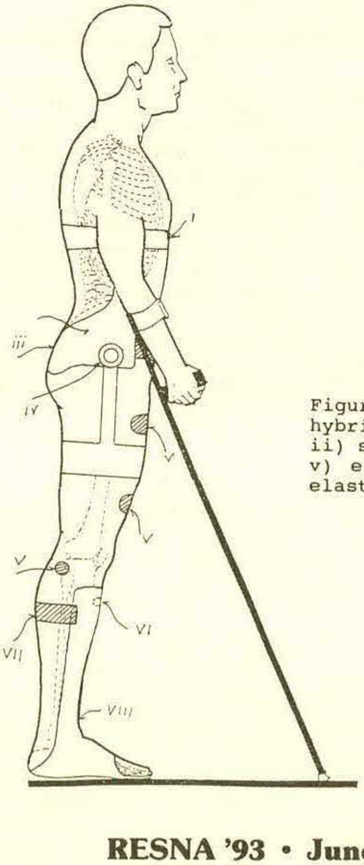

Figure 3. Schematic diagram of the two part hybrid FES HKAFO system showing i) chest band, ii) servo, iii) pelvic band, iv) WS hip joint, v) electrode, vi) FSR pressure sensor, vii) elastic calf band, viii) anterior molded FRO.

An Implanted Upper Extremity Neuroprosthesis

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ABSTRACT
Surgical implantation of a multichannel receiver-stimulator to provide grasp function has been performed in six quadriplegic individuals and has been operational in one subject for six and a half years. Surgical alterations have also been performed with each subject in order to enhance grasp function. All six subjects have demonstrated functional grasp patterns.

BACKGROUND

Functional electrical stimulation (FES) has been used to provide grasp and release in quadriplegic individuals for many years (1,2,3,4). Early neuroprosthetic systems consisted of a few percutaneous electrodes and provided one grasp pattern. More recently, we have used percutaneous systems with as many as 16 electrodes, providing both palmar and lateral grasp patterns. Proportional control of grasp opening and closing is obtained using some remaining voluntary movement, typically shoulder movement (5), although wrist movement is also used as a command source. A switch, usually mounted on the chest, is used to turn the system on and off and to select grasp patterns. A mechanism for locking the hand is also provided. These systems have been successfully implemented with more than 40 subjects and have provided them with the ability to perform many activities of daily living.

OBJECTIVE

As a result of the success of the percutaneous neuroprosthetic systems, we have proceeded to the implementation of an implantable neuroprosthesis. The goals in advancing to the implanted neuroprosthesis are: 1) to reduce the maintenance complexity, 2) to improve system reliability and 3) to improve function. The maintenance complexity is reduced by eliminating the percutaneous skin interface. This interface requires cleaning and upkeep by the subject and attendant. In addition, the external wiring necessary to connect the electrodes to the stimulator can get snagged during functional tasks. The implantable stimulator removes the need for external wiring along the patient's arm. The reliability of the system is improved through improved lead and electrode design. Function is improved by better electrode placement and by surgical alterations to the upper extremity anatomy that are performed in conjunction with surgical placement of the stimulator.

METHOD

The implanted neuroprosthetic system is shown in Figure 1. The implanted components currently consist of an eight channel receiver-stimulator and epimysial electrodes (6,7). The external components are an external control unit, an RF transmitting coil and a shoulder control unit. The subject is provided proportional control of lateral and palmar grasp patterns.

Candidate selection:

The candidates selected for implantation must be C5 or weak C6 level and must be at least one year post injury. The candidate must develop a grade 3 or better stimulated muscle contraction of each of the following key muscles:

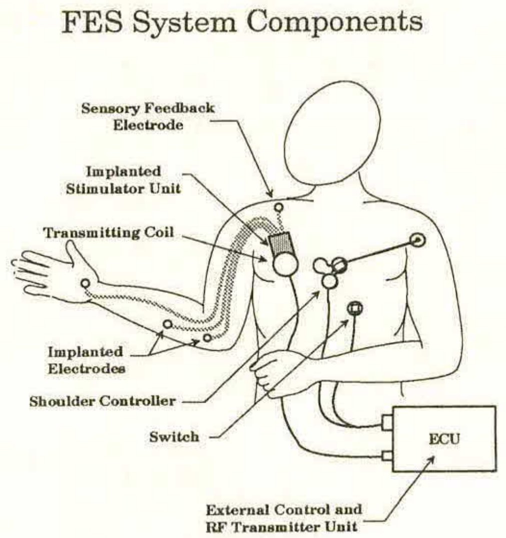

Figure 1. Components of the implanted upper extremity neuroprosthesis.

extensor pollicis longus (EPL), extensor digitorum communis (EDC), adductor pollicis (AdP), abductor pollicis brevis (AbPB), flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP). If one or more of these muscles is weak or denervated, augmentative surgical procedures may be required to achieve both palmar and lateral grasp patterns.

Candidates undergo a muscle conditioning period prior to implantation. This serves to build the muscle strength for better electrode placement in surgery, and allows the surgical plan to be formulated.

Surgical placement:

The stimulator unit is implanted in the pectoral region with the leads traveling down the arm. Epimysial electrodes are sewn on the muscles in an open surgical procedure. Leads are tunneled from the electrodes up the arm to the stimulator unit. A spring connector is used to connect the proximal implant lead to the distal electrode lead (8). Post-operatively the subject is placed in a long arm cast for three weeks so that the electrodes can stabilize. Electrical stimulation exercise is used to rebuild the muscle strength after the casts have been removed, and continues for at least a month prior to implementation of a functional system.

Surgical alterations:

The surgical alterations that are performed in addition to placement of the receiver-stimulator and electrodes are: 1) cross anastomoses of finger tendons, 2) Zancolli-lasso procedure, 3) arthrodesis of the thumb interphalangeal (IP) joint, 4) radial osteotomy and 5) tendon

	International Classification		Time Between Injury and Beginning of Stimulation	Initial Implementation	Time With Implanted Stimulator
	FES Side	Non-FES Side			
JJ	Group 2	Group 1	8 weeks	Percutaneous	6 1/2 yrs.
KT	Group 0	Group 0	3 yrs.	Percutaneous	1 1/2 yrs.
RZ	Group 1	Group 0	3 1/2 yrs.	Surface	1 1/2 yrs.
NM	Group 2	Group 1	1 1/2 yrs.	Percutaneous	6 mos.
KB	Group 1	Group 1	2 yrs.	Surface	5 mos.
JG	Group 3	Group 3	5 yrs.	Surface	3 mos.

TABLE 1.

transfer of a paralyzed muscle powered by electrical stimulation. These procedures are described in the paragraphs that follow:

Cross-Anastomoses of Tendons. The objectives of this procedure are to provide more uniform motion of the fingers when a single electrode is used to activate the muscle, to compensate for denervation (particularly of the flexor digitorum profundus of the index finger), and to provide uniform force distribution in flexion across the digits. The procedure is performed by suturing the four tendons of each finger extrinsic muscle so that they move as a unit. This procedure is most often performed with the FDS and FDP muscles, and occasionally the EDC.

Zancolli-Lasso Procedures. This procedure was performed as originally described (9). The tendon of the FDS is detached from its distal insertion, looped over the A1 pulley and then sutured to itself. The modified FDS then flexes only the metacarpal-phalangeal (MP) joint but not the PIP joint. As a result, the FDS acts as an MP block in conjunction with the EDC, allowing the EDC to provide better extension of the IP joints.

Arthrodesis of the Thumb Interphalangeal Joint. Fusion of the interphalangeal (IP) joint of the thumb was performed to allow improved transmission of thumb pinch force onto an object. The particular importance of this procedure is that it allows the FPL to be used in the functional grasp, since without IP stabilization, stimulation of the FPL will result in flexion of the thumb IP joint into the palm, a non-functional position.

Rotational Osteotomy of the Radius. This procedure involves rotation and fixation of the radius to correct a forearm that is too supinated for functional use.

Grasp and control setup:

The grasp patterns are customized for each subject by analyzing the recruitment properties of each electrode (10). The shoulder control is also customized to match each subject's shoulder range of motion and speed of movement. Subjects are trained in the use of the neuroprosthesis and participate in a series of functional evaluations (11).

RESULTS

Six quadriplegic individuals have received implanted stimulators at the date of this abstract. Table 1 shows the injury level for these six subjects. All subjects were classified as either C5 or C6 according to the ASIA classification (12), or groups 0, 1, 2 or 3 according to the International Society for Hand Surgery (13). The time between injury and implementation with an electrical stimulation system varied from 8 months to 5 years. Two subjects began with a functional percutaneous system and one subject began with a percutaneous system for exercise only. The remaining three subjects received exercise surface stimulation prior to surgical placement of the stimulator.

There have been no failures of the electrodes or leads with any subjects. To date, the cumulative time without failure is over ten years, and the longest for any one subject is six and a half years. The stimulator receiver unit was replaced in subject JJ after two years due to increased power consumption. To date, the maximum functioning time for the stimulator receiver is four and a half years.

The surgical alterations that have been performed are shown in Table 2. Each subject has had a minimum of three procedures performed to enhance his/her grasp patterns. All six subjects have had side-to-side anastomoses of the FDP tendons and five have had side-to-side anastomoses of the FDS. Thumb IP arthrodesis has been performed in two subjects. Five subjects have had at least one tendon transfer of a paralyzed muscle to augment a weak or denervated muscle group.

SURGICAL ALTERATIONS PERFORMED

PROCEDURE	JJ	KT	NM	RZ	KB	JG
FDP Synchronization	■	■	■	■	■	■
FDS Synchronization	■	■	■	■		■
EDC Synchronization	■					
IP Arthrodesis	■			■		
FDS Zancolli-Lasso	■	■				■
Radial Osteotomy					■	
Tendon Transfers + FNS	■	■	■	■	■	

TABLE 2.

All subjects can generate at least a grade 3 out of 5 muscle grade with electrical stimulation with their thumb flexors, extensors and abductors. Five of the six subjects were able to achieve grade 4 muscle strength from the finger flexors. One subject has very weak finger flexors, although that subject is still undergoing the muscle conditioning phase.

Four of the six subjects can achieve a grade 4 muscle contraction in their finger extensors. Two subjects have trace contractions of the finger extensors. In both cases, paralyzed muscles were transferred to the finger extensors in an attempt to provide finger extension, but in both cases the finger extension is too weak to use functionally. The most likely cause of this weakness is tendon adhesions to the surrounding tissue. However, both subjects are able to use their grasp patterns functionally either by dropping their wrist to get passive hand opening, or by using their opposite hand to push objects into their grasp.

Four subjects use their contralateral shoulder to control their hand neuroprosthesis and one subject uses ipsilateral wrist control. The sixth subject has used both types of control and is currently utilizing shoulder control.

All subjects have been provided with both lateral and palmar grasp patterns. Table 3 shows the pinch forces developed for each subject (two of the subjects are still undergoing the muscle conditioning phase and are likely to increase in muscle strength). The force levels are sufficient to perform many activities of daily living.

	Group 3	Group 2		Group 1		Group 0
	JG	JJ	HM	RZ	KB	KT
Pinch	8*N	15 N	11 N	13 N	5*N	26 N
Grasp	9*N	8 N	6 N	3 N	2*N	9 N

Group 3 Patient - No voluntary T.T.
Group 2 Patients - No voluntary T.T.
Group 1 Patients - BR voluntary -> ECRB
Group 0 Patient - ECU stimulated -> ECRB

N = Newtons

* Patient in muscle conditioning period

TABLE 3.

CONCLUSION

Six quadriplegic individuals have undergone surgical implantation of a receiver-stimulator to provide grasp and release. Each of the six subjects entered the study with an absence of voluntary thumb pinch force or grasp force. The implanted neuroprosthesis has provided each subject with two functional grasp patterns. There have been no problems with infection or device rejection. The implanted stimulator and electrodes have demonstrated excellent reliability.

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A Hand Grasp and Release Test for Tetraplegic Patients Using a Hand Neuroprosthesis

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ABSTRACT

We have developed a quantitative grasp and release test for assessing a hand neuroprosthesis used by C5 and C6 level tetraplegic patients. The objectives were: (1) to determine if a patient's hand performance with the neuroprosthesis exceeded a defined, clinically-acceptable baseline, (2) to compare differences in performance with and without the neuroprosthesis, (3) to determine the consistency of performance over time, and (4) to compare performance differences among patients. Patients are instructed to grasp, move, and release one of six different objects as many times as possible in five 30-second trials for each object, with and without the neuroprosthesis. Unlike other hand function tests, the objects and the task were chosen to span a range of difficulties appropriate for C5 and C6 tetraplegic patients using a hand neuroprosthesis. The data from five patients presented below showed that performance with the neuroprosthesis was above the baseline and that performance improved with the neuroprosthesis.

BACKGROUND

Over the past twelve years, fifty tetraplegic patients have been implemented with the Case Western Reserve University - Veterans Administration Medical Center portable hand neuroprosthesis. These persons have injuries at the C5 or C6 motor level according to American Spinal Injury Association guidelines; Groups 0, 1 or 2 (O or Cu) according to the international classification for surgery of the hand in tetraplegia. The neuroprosthesis enhances independence in activities of daily living (ADL) by giving users unimanual control of lateral and palmar grasp and release. Paralyzed hand and forearm muscles are stimulated electrically via percutaneous or implanted electrodes. The stimulation is controlled typically by movement of the contralateral shoulder using an external shoulder angle transducer and associated electronics. Elevating the shoulder closes the hand by increasing flexor stimulation, and depressing the shoulder stimulates extensors to open the hand.

Assessment of function is essential in determining the potential benefit of the neuroprosthesis or any other assistive device. We have reviewed and tried using several tests to evaluate hand function with and without the neuroprosthesis, but found the tests were inappropriate for this application and patient population. The main problems with applying these tests to tetraplegic patients include: (1) most tests do not specifically test lateral and palmar grasp (2) they are insensitive to small but important changes in hand function, (3) they are sensitive to additional variables other than those directly related to hand function, (4) they are affected by learning, (5) many tasks tested are not representative of actual ADL for tetraplegic patients, (6) the results are inconsistent since many task are only performed once, and (6) many tests have inadequate instructions for application to tetraplegic patients.

METHODS

The test is a variant of earlier "pick-and-place" tests, but the objects tested, the manipulation of the objects, the test structure, and the scoring methods were tailored to our tetraplegic population. Six objects were manipulated, three with lateral prehension (peg, paperweight, and fork) and three with palmar prehension (block, can and videotape). Nominal grasp patterns were specified for each object, but certain substitution patterns (with or without the neuroprosthesis) were defined and permitted. The objects were chosen or designed to span a range of weight, size, and difficulty representing a spectrum of objects and unimanual activities appropriate for our patient population. The peg and block represented small, light objects such as pens or finger foods. The paperweight, can, and videotape represented larger, medium weight objects such as a glass or a book. The "fork" represented stabbing food or writing, and had a cylindrical nylon handle connected to a spring-loaded piston. A vertical force of 4.4 N was required to depress the handle to the indicator line. Preliminary tests showed that a force of 4.4 N applied to a real fork is sufficient to stab pieces of fruit, cooked vegetables, and meats.

In addition to using simple, standardized objects, the test reduced "manipulation" to a standard sequence of movements appropriate for tetraplegic patients. Generally an object was grasped in the starting area of the test board, lifted and moved over a barrier and released in the target area. The sequence was completed as many times as possible in 30 seconds. The position of the patient, the position of the test board, and the location and orientation of each object were set according to written instructions, and were reproduced from session to session.

A preliminary test ("pretest") for each object was administered at the beginning of each session to determine if the patient understood the instructions and could manipulate the object. Patients practiced with each object for at least 30 seconds, and continued to practice until they developed a successful strategy.

The results of the pretest were important for two reasons. First, they identified and eliminated those objects that were impossible for the patient to manipulate, resulting in a shorter, less fatiguing test. Second, we defined "baseline performance" as successful manipulation of each object at least once during the pretest. In clinical practice, failing the pretest when using the neuroprosthesis would lead to re-examination of the patient and adjustment of the muscle stimulation levels.

The main part of the test followed the pretest, and consisted of testing each object, first with the neuroprosthesis and then without the neuroprosthesis, five times. Patients were instructed to complete each task as many times as possible in a 30-second trial, and the number of completions and failures were counted in each trial.

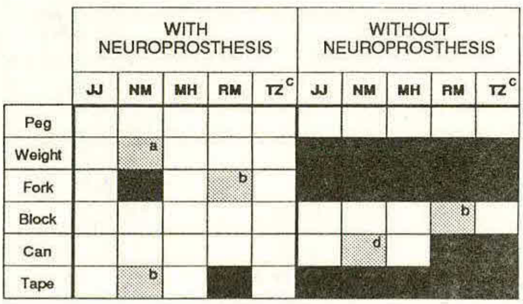
Five patients were tested, two individuals with injuries at the C6 level and three at the C5 level. Each patient was tested (nominally) once per week for five weeks with an average interval between testing of 8 days with a range from 4 to 16 days. The location, home or hospital, and time of testing were chosen by the patient. Test sessions were videotaped, and the videotapes were reviewed to corroborate the scores recorded during the test. The length of each test session depended on the number of objects the patient could manipulate in the pretest, and varied from 90 to 150 minutes.

RESULTS

Four hypothesis were tested: (1) performance with the neuroprosthesis will meet or exceed a predefined baseline for all patients that indicates a clinically acceptable grasp, (2) the number of completions will increase and the number of failures will decrease when the neuroprosthesis is used, (3) the number of failures and completions with the neuroprosthesis will be consistent across time (i.e., across sessions), and (4) the effectiveness of the neuroprosthesis will depend on injury level. The neuroprosthesis should help C5 patients manipulate all of the objects, and should help C6 users with more difficult objects. The data used to test the first two hypothesis are presented below.

Hypothesis 1 - Baseline Performance

The results of the pretest with and without the neuroprosthesis are shown in Fig. 1 (white cell = pass, black cell = fail, gray cell = variable result). Three of the five patients (JJ, MH, TZ) successfully manipulated all six objects with the neuroprosthesis in the pretest, and were judged to have satisfactory grasps. The other two patients failed with one or more objects in at least one session, which led to revisions of their grasps. These two patients passed the pretest in subsequent testing.



a Passed pretest in last two sessions
b Passed pretest in four sessions
c Tested only twice
d Passed pretest in one session

Fig. 1 Pretest results for each patient, with and without the neuroprosthesis. The white cells represent a minimum of one successful completion in all pretest sessions, the black cells represent failures in all sessions, and the gray cells represent variable results across sessions.

The pretest scores without the neuroprosthesis are shown for comparison purposes. Most patients could not manipulate the heavier, more difficult objects without using the neuroprosthesis. Patients RM and NM had inconsistent results with one of the six objects, probably due to small session-to-session changes in passive finger flexion tension.

Hypothesis 2 - Differences with and without the neuroprosthesis.

The difference in the number of completions or failures for each object was calculated for all five trials in all five test sessions. The results of the comparisons with and without the neuroprosthesis are summarized in Fig. 2. Each column gives the median of twenty-five trials. Median differences of zero are indicated by the circles on the axis. The white columns (and circles) represent statistically significant improvements in performance with the neuroprosthesis ($p \le 0.05$); defined here as significant increases in completions, significant decreases in failures, or any number of failures with the neuroprosthesis when the patient could not complete the task without the neuroprosthesis. In this last situation, we assert that performing the task with the neuroprosthesis, albeit with errors, is still an improvement over not being able to do the task without the neuroprosthesis. The gray columns and circles represent equivocal cases where the differences are not statistically significant ($p > 0.05$). The black columns are cases where the neuroprosthesis degraded performance by significantly reducing completions. The asterisks represent cases where the patient failed the task both with and without the neuroprosthesis. Using the neuroprosthesis increased the number of completions significantly in 16 of 24 cases. In 11 of these cases, the patients could not perform the task without the neuroprosthesis. In only four cases did the neuroprosthesis impede performance, and the decrease was statistically significant for two of these cases - for C6 patient JJ with the peg and block. This patient could manipulate the lightest objects more quickly with his active tenodesis grasp than with the neuroprosthesis. The neuroprosthesis also decreased the number of failures significantly in 7 cases. In 8 other cases the number of failures increased, but the task could only be performed with the neuroprosthesis. If a patient could perform a task with and without the neuroprosthesis, there were always fewer failures with the neuroprosthesis than without.

DISCUSSION

A test for assessing hand grasp and release in C5 and C6 tetraplegic individuals, with and without the hand neuroprosthesis has been developed. The test includes a selection of tasks appropriate for C5 and C6 tetraplegic individuals. The reliability of the test was maximized by choosing a robust, quantitative scoring method and standardized equipment, procedures and instructions. The fixed trial duration also set a maximum testing time for the patient.

The test was applied to five neuroprosthesis users to investigate four specific hypotheses about hand performance with and without the neuroprosthesis. The data from two were presented. Performance with the neuroprosthesis exceeded a baseline indicative of a "clinically-acceptable" hand grasp for three patients (Fig. 1). The other two patients passed with at least three objects in every session, and passed with most other objects in all but one session. Though patients failed a few times in the pretest, all of the problems have been corrected to give clinically-acceptable grasps. In contrast, none of the patients could perform at an equivalent level without the neuroprosthesis.

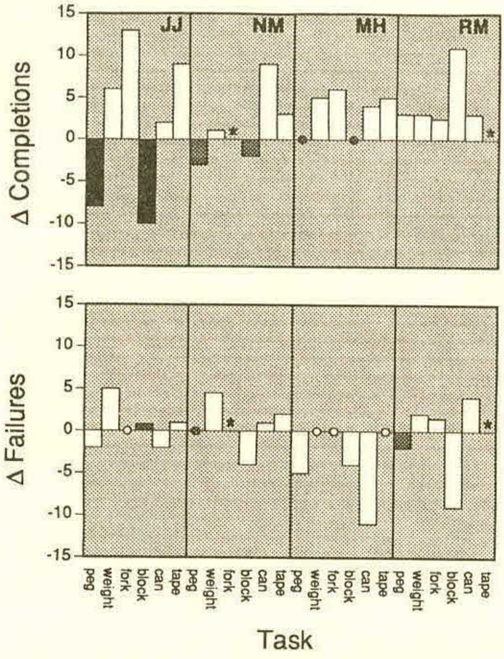


Fig. 2 Differences in the number of completions or failures for each object (i.e., count with the neuroprosthesis minus count without the neuroprosthesis). Data from subject TZ were omitted since he had only two test sessions for comparison. The columns give the grand median across all 5 trials in each of 5 sessions. The white columns and circles represent conditions where performance improved ($p \leq 0.05$) with the neuroprosthesis, i.e., where: (1) the number of completions increased, (2) the number of failures decreased, or (3) there were failures with the neuroprosthesis but the patient could not do the task without the neuroprosthesis. The gray columns and circles represent insignificant differences, and the black columns represent cases where performance declined with the neuroprosthesis (fewer completions with the neuroprosthesis than without it). The asterisks represent those cases where the patient failed the pretest.

The improvements provided by the neuroprosthesis were substantiated further, in accord with our second hypothesis, by analyzing the differences in the number of completions and failures with and without the neuroprosthesis. The performance differences (Fig. 2) indicate that for most objects, the patients had more completions with the neuroprosthesis than without it. The neuroprosthesis almost always enhanced performance with more difficult objects, and in many cases made the task possible. For the two easiest objects (pegs and blocks), one C5 patient (MH) showed no difference in completions (though he had fewer failures). The other C5 patient (RM) had significantly more completions with the neuroprosthesis. Both C6 patients (NM and JJ) had fewer completions with the neuroprosthesis with these two objects because operating the neuroprosthesis was slower than using unassisted, active tenodesis grasp.

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EFFECTS OF FES ON SHOULDER MUSCLE TONE, EMG ACTIVITY AND FUNCTION IN ACUTE HEMIPLEGIA

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ABSTRACT

The purpose of this study was to evaluate the effectiveness of a Functional Electrical Stimulation (FES) treatment program on the facilitation of shoulder muscle recovery in hemiplegics. Twenty-six recent hemiplegic stroke patients with shoulder muscle flaccidity were randomly assigned to either a control group (n=13; 5 female & 8 male) or experimental group (n=13; 6 female & 7 male). Both groups received the conventional physical therapy, but the experimental group received additional FES therapy where their flaccid/paralyzed supraspinatus and posterior deltoid muscles were induced to contract repetitively up to 6 hour/day for 6 weeks. Duration of both the FES session and muscle contraction/relaxation ratio were progressively increased as performance improved. Weekly evaluation of shoulder muscle function (i.e., active range of motion), tone, and posterior deltoid posterior deltoid muscle electromyographic (EMG) activity showed significant improvements in the experimental group compared to the control group over the 6-week period. These advantages for the experimental group were maintained after six weeks of FES termination. It was concluded that the FES program could facilitate the recovery of shoulder muscle function and increased range of motion.

INTRODUCTION

Hemiplegic patients typically have flaccid shoulder muscles for several weeks following the stroke. This can lead to muscle deterioration, loss of range of motion, and contracture. Additionally, stretching of the shoulder joint capsule can lead to chronic subluxation and pain. Traditional therapies for the upper extremity of hemiplegic patients typically include passive range of motion, progressive resistive exercise of paretic muscles, and neuromuscular facilitation techniques (1-3). However, it appears feasible that the addition of functional electrical stimulation (FES)-induced contractions to exercise the shoulder muscles could serve as a prophylactic measure against these problems and facilitate recovery following the flaccid stage (4-7) This is because the active contractions produced can reduce deterioration and maintain muscle readiness to return to function if and when neuromuscular pathways become operational in the latter stages of recovery. Thus, appropriate FES therapy may potentially enhance the rate and completeness of recovery, and improve rehabilitation outcome.

The clinical use and therapeutic effects of FES on lower extremity paralyzed/paretic muscles of neuromuscularly impaired patients are well documented (8,9). However, little is currently known about the therapeutic benefits of using FES on the upper extremity muscles of hemiplegics patients. Recent research studies indicated the potential of using FES exercise of shoulder muscle for the prevention and/or reduction of shoulder subluxation (6,7). But, no data have been reported on the effects of the rate of muscle recovery. Therefore, the purpose of this project was to determine the effects of a six-week FES program on the functional recovery of shoulder muscles in acute hemiplegics.

METHODS

Subjects. Twenty six recent hemiplegic stroke patients with shoulder muscle flaccidity/paralysis were randomly assigned to either a control group (n=13, 5 female, and 8 male) or experimental group (n=13, 6 female, and 7 male). Informed consent was obtained in accordance with the Wright State University Institutional Review Board procedure. The mean ($\pm$ SD) height, weight, and age for the experimental group were 174$\pm$7 cm, 76$\pm$12 kg, 65$\pm$13 yr; and for the control group were 166$\pm$10 cm, 78$\pm$11 kg, and 69$\pm$12 yr, respectively. A preliminary medical evaluation was used to derive information regarding the cardiac and medical history for each individual participating in this study. For the safety of the FES group, a baseline ECG, as well as a detailed cardiac history review was completed. Individuals with cardiac pacemakers were excluded from this study. Patients with cardiac deficits, especially conduction problems, were monitored closely by ECG during the initial trials of the FES program.

Treatment. Both the control and experimental groups received conventional physical therapy as part of their treatment program. However, the experimental group received additional FES therapy as provided by a commercially available stimulator (Respond II; Medtronic, Minneapolis, MN) and two surface electrodes. This device has adjustments for the on-off stimulation cycle and the intensity of stimulation, as well as having a timer to start and stop the stimulation. The active electrode was placed over the posterior deltoid muscle and the passive electrode was placed over the supraspinatus muscle utilizing a configuration which minimizes activation of the upper trapezius muscle (which can cause shoulder shrugging). Stimulation frequency was set at 35 Hz to create a tetanized muscle contraction. FES intensity was set to obtain the desired motion of humeral elevation with some abduction and extension to pull the head of the humerus into the glenoid cavity. To provide consistent position and shoulder joint protection, all subjects were asked to use their wheelchair arm support whenever sitting, both between and during the FES sessions. These FES sessions were conducted seven days/week for a total of six weeks.

Weekly Evaluations. All subjects were evaluated each week for shoulder muscle function, active joint range of motion using modified Bobath technique (2), shoulder muscle tone, as well as surface electromyographic (EMG) of the posterior deltoid muscle. A follow up evaluation was also performed six week after discontinuation of the FES program. The posterior deltoid muscle was chosen for EMG measurements because of easy access by surface electrodes. An increase in the EMG activity of the posterior deltoid muscle could indicate the recovery of muscle function from flaccidity in this muscle, and possibly other shoulder muscles as well.

To evaluate shoulder muscle function, active range of motion tests were performed with the patient in supine, sitting, and standing positions (2). These tests were divided into three grades according to their degree of difficulty, with tasks for grade 1 being the easiest and those for grade 3 being the most difficult. This grading system limited the number of tasks required for severely affected patients. Those less severely affected performed more tasks.

Shoulder muscle tone was evaluated using modified Gross clinical scale (10) from 0 to 4, where 0 was considered no tone and 4 as the affected part being rigid in flexion or extension. The shoulder muscle tone evaluations were performed to evaluate the subjects recovery process from the flaccid to the spastic stage where, normal tone was considered to be between 2 and 3. EMG activity of the posterior deltoid muscle was evaluated with surface electrodes, and were rated from 0 (no EMG activity) to 3 (normal EMG activity).

Statistical Analysis. Multivariate repeated measures analysis of variance was used to compare the experimental and control groups, and the 7 measurement periods during weeks 1 to 6, and during week 12 (follow-up evaluation). Before performing the analysis, formal diagnostic procedures were followed. No serious departures from the assumptions necessary for the analysis were found. For all statistical testing, the .05 level of probability was required for significance.

RESULTS

The results of the shoulder muscle function, muscle tone, and posterior deltoid EMG activity measurements for the involved shoulder of both groups are shown in Figures 1, 2, and 3, respectively. The shoulder muscle function testing (Figure 1) demonstrated that both groups had continuous and spontaneous improvements in their muscle function during the six week period following stroke. However, the experimental group showed significantly higher improvement in their shoulder muscle function (i.e., range of motion) at week 4 compared to the control group. This significantly higher improvement was maintained during weeks 4-6 of the FES treatment period and at the follow-up evaluation at week 12. The results of the muscle tone tests (Figure 2) showed continued improvement for both groups. However, the muscle tone was significantly higher in the experimental group at weeks 2-4 and 6, as well as at the 12-week follow-up evaluation. The EMG activity of the posterior deltoid muscle (Figure 3) also showed greater improvement in the experimental group. These differences were significant at weeks 5 and 6, and at the 12-week follow-up evaluation.

DISCUSSION

Early facilitation of activity in muscle groups producing protraction and upward rotation of the scapula and flexion-abduction of the shoulder (i.e., posterior deltoid and supraspinatus) is essential during the acute and flaccid phase of neural recovery from stroke (11). Different methods have been studied for facilitation of recovery in hemiplegics, including biofeedback, low voltage electrical stimulation, specific positioning of the shoulder and passive range of motion (2,12). Although the discussion of these methods is beyond the scope of this paper, it is unfortunate that little controlled research data are available to verify the relative efficacy of these

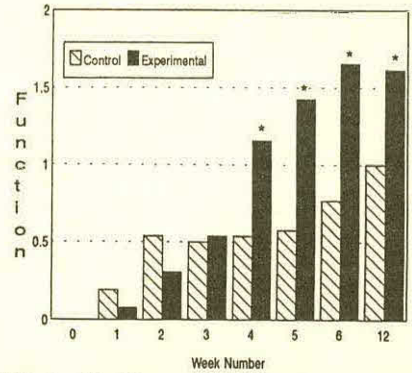

FIGURE 1. Weekly grade of the shoulder muscle function (i.e., active range of motion) for the experimental (FES) and control (non-FES) groups during the six-week treatment program and at the 12-week follow-up evaluation (* = $p<0.05$).

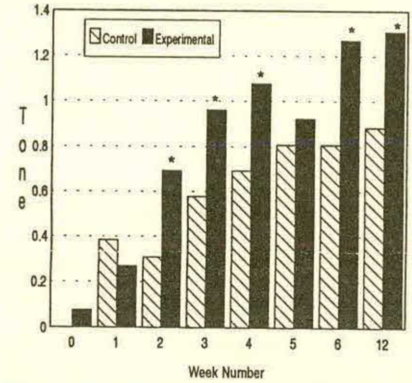

FIGURE 2. Weekly scale of the shoulder muscle tone for the experimental (FES) and control (non-FES) groups during the six-week treatment program and at the 12-week follow-up evaluation (* = $p<0.05$).

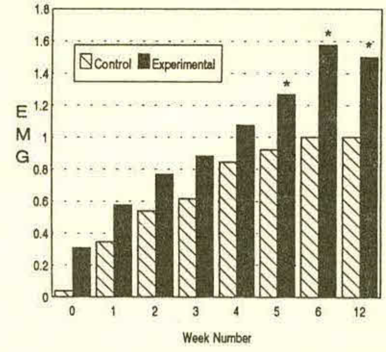

FIGURE 3. Weekly grade of the posterior deltoid EMG activity for the experimental (FES) and control (non-FES) groups during the six-week treatment program and at the 12-week follow-up evaluation (* = $p<0.05$).

methods. FES of the affected muscles has emerged as a promising therapeutic adjunct in the facilitation of voluntary motion.(13,14). Most of the studies relating to the efficacy of FES, however, have been on distal extremity function such as facilitation of ankle dorsiflexion and wrist finger extension (13,14). There are only a few research studies published relating to the effects of FES on the proximal (i.e., shoulder) muscles. However, these studies were primarily focused upon the effects of FES for prevention and/or reduction of shoulder subluxation in stroke patients (6,7). Results indicated that FES is effective in reducing and/or preventing shoulder subluxation, but the mechanism of these effects have not been clearly elucidated.

The result of our study demonstrated that the specific type of FES therapy tested can improve the voluntary function of shoulder muscles and active range of motion. Furthermore, these experimental subjects not only showed a greater rate of improvement during the FES treatment, but they also demonstrated maintenance of these improvements during the 12-week follow-up period. The supraspinatus and posterior deltoid muscle are the two most important muscles protecting the shoulder from subluxation. The faster and more complete these muscles recover, the better would be the rehabilitation outcome for the hemiplegic stroke patients .

When applying FES to these muscles, the shoulder was positioned in less adduction and internal rotation, thereby decreasing the risk of contracture. Patients without muscle contracture tend to have a more rapid recovery when participating in physical therapy programs. The weekly evaluations of our subjects also showed that, although both groups had spontaneous neurological improvement after stroke, these improvements were enhanced by the FES treatment as evident by the results of shoulder muscle function/range of motion, tone, and EMG activity of posterior deltoid. Increased EMG activities of the posterior deltoid muscle could be an indication of increased activity of other shoulder muscles as well. The active contractions induced by the FES may prevent the marked deterioration of muscles affected by hemiplegia. Thus, the primary mechanism for the greater recovery of our experimental subjects may be explained by the maintenance of muscle integrity, rather than neurologic recovery.

Conclusion. The FES therapy program used during this study exercise trained the supraspinatus and posterior deltoid muscles. Therefore, there was less disuse deterioration, and faster functional recovery of these shoulder muscles. Since the experimental group maintained the results following six weeks of FES termination, it appeared that the shoulder muscles acquired sufficient voluntary strength to maintain joint stability and alleviate the need for additional FES therapy. Further studies are necessary to investigate the use of longer periods of FES, different FES protocols, and the use of additional muscles for greater improvements in shoulder and arm function, and to accelerate recovery.

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EFFECT OF MUSCLE LENGTH AND ELECTRICALLY-INDUCED CONTRACTION ON *IN VIVO* TENDON TENSION

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ABSTRACT

The purpose of this study was to determine the effect of muscle length and electrically-induced contraction on *in vivo* tendon tensions in selected wrist muscles utilizing a computerized system for real-time evaluation of tendon tension and wrist range of motion during surgery. A computerized system was used for real time evaluation of tendon tension and wrist range of motion during three tendon transfer surgeries. Tension values were higher for flexor vs extensor muscles, and were highest at the most lengthened position. Stimulated tension values were 8% to 1130% higher than passive values. Eccentric tensions were 25% to 183% higher than concentric tensions. Tension values are consistent with the literature, and results demonstrate the usefulness of the *in vivo* real-time measurements for the surgeon performing tendon transfer surgery. These measurements may improve surgical outcome and enhance wrist function, as well as decrease the need for repeat surgeries.

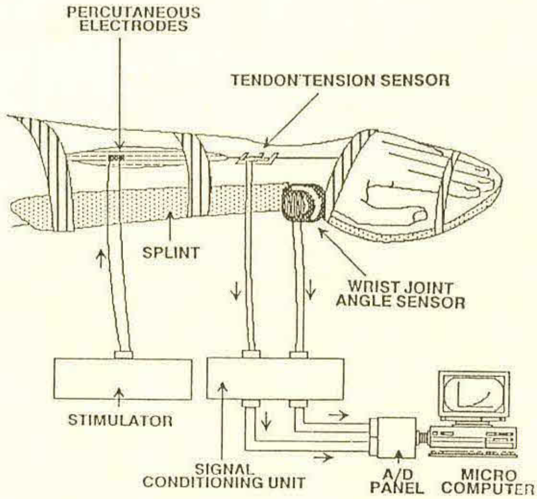

Figure 1. Experimental set-up for intraoperative measurement of muscle performance. In this example, the extensor tendons are exposed. The splint stabilizes the forearm and hand, and is instrumented with an electrogoniometer to monitor wrist angle.

INTRODUCTION

Various pathological conditions such as rheumatoid arthritis, peripheral nerve and spinal cord injury, and cerebral palsy often require wrist tendon transfer. One problem which affects the success of this procedure is the adjustment of tendon tension (i.e., muscle length) during surgery. The application of intraoperative tendon tension measurement techniques is of interest to both the surgeons and the biomechanists who study the function of the wrist muscles. The tension placed on tendons at different muscle lengths and under electrically stimulated conditions has not been investigated *in vivo*. The objective of this study was to determine the effect of muscle length and electrically-induced contraction on specific tendon tensions *in vivo*. Three surgical cases illustrated preliminary findings with the tendon tension measurement system.

METHODS

A computerized system, developed in this laboratory, was utilized for real-time evaluation of tendon tension and wrist range of motion during tendon transfer surgery[1]. A diagram of the tendon tension measurement system is shown in Fig. 1. It consists of an s-shaped buckle instrumented with strain gauges (NK Biotechnical Eng. Co., Minneapolis, MN) for tendon tension measurement, a stimulator to electrically induce muscle contractions, a flexible electrogoniometer for wrist angle measurement (Penny & Giles, Inc., Santa Monica, CA), an IBM PC with A/D converter for data acquisition and analysis, and software for real-time display of tendon tension and wrist angle during tendon transfer surgery. Instrumentation amplifiers were used to provide calibrated wrist angle readings of +40 to -40 deg. All data were conditioned and isolated for computer interface. The electrical stimulator provided adjustable frequency (5-50 Hz) biphasic pulses with an adjustable pulse width of 10-100 *u*sec. Coiled fine wire intramuscular electrodes (Case Western Reserve U., Cleveland, OH) were inserted into the wrist muscles for inducing contractions via electrical stimulation.

Procedures during surgery included measurement of tendon tension during three dynamic conditions: 1) pre-transfer passive movement, 2) pre-transfer stimulated movement, and 3) post-transfer passive movement. Muscles were not stimulated following transfer to minimize stress at the transfer site and possible tendon rupture. Each measurement was performed while the wrist was manually moved through a range of 80 deg using a template to ensure consistent timing (6 sec time period) of the movement from the most lengthened (-40 deg) to the most shortened (+40 deg) muscle position. Electrical stimulation was applied using fine wire electrodes to elicit a maximum stimulated contraction (the current level at which no further increase in tension was measured which provided maximum recruitment of muscle fibers). Tensions for both concentric (shortening) and eccentric (lengthening) muscle actions were measured during stimulated and passive conditions. Following informed consent, intraoperative tendon tension measurements were performed during wrist tendon transfer surgery for three patients who represented different tendon rupture cases. The tendons measured included third extensor digitorum communis (EDC), extensor indicis proprius (EIP), and third flexor digitorum superficialis (FDS). Three trials for each condition were averaged for data analysis.

RESULTS

Maximum tendon tension values for the three muscles tested during each of the three conditions (pre-transfer passive, stimulated, and post-transfer passive) are shown in Fig. 2. These values were highest for the flexor muscle (FDS) compared to the two extensor tendon measurements (EIP and EDC). The pre-transfer passive tension values showed a ratio of 1:1.9:28 for EIP, EDC, and FDS, respectively. Stimulated tension values were 8% to 1130% higher than pre-transfer passive measurements.

Fig. 3 shows an example of stimulated tendon tension (eccentric and concentric) for the FDS from 40 deg of wrist extension (the most lengthened position for the tendon) to 40 deg of wrist flexion (the most shortened tendon position). Eccentric values over all trials and tendons were 25% to 183% higher than concentric values. Tension measurements for all tendons tested were highest at the most lengthened position of the muscle regardless of the condition. Most variability within the three trials for each condition occurred when the muscle was at its most shortened position.

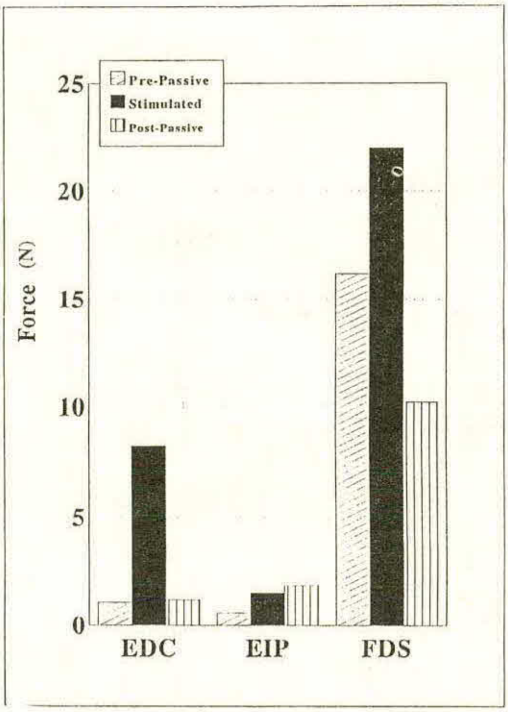

Figure 2. Maximum tension (force) values during three conditions (pre-transfer passive and stimulated, and post-transfer passive) for three wrist tendons (third extensor digitorum communis (EDC), extensor indicis proprius (EIP), and third flexor digitorum superficialis (FDS).

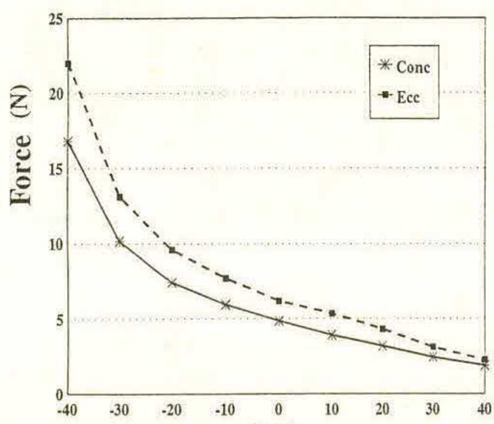

Figure 3. Stimulated tension values (force) from the third flexor digitorum superficialis tendon plotted against wrist angle for both shortening or concentric (conc) and lengthening or eccentric (ecc) muscle actions.

DISCUSSION

Relative pre-transfer passive tension values between the two extensor muscles were similar to those calculated by Brand *et al.*[2] The increase in tension with increasing muscle length suggests that the use of wrist movement to change tendon length during surgery is feasible for these muscles. The higher eccentric as opposed to concentric tension values is consistent with muscle strength literature[3]. The present study demonstrates the characteristics of tendon tension at different lengths (i.e. wrist angles) and with electrical stimulation induced contractions. The intraoperative tendon tension measurement system utilized in this research allows the measurement of absolute passive tensions and stimulated contraction tensions during surgery, and can be applied to either flexor or extensor wrist muscle groups. The variety of medical conditions requiring tendon transfer which confront the surgeon necessitate the ability to differentially evaluate tendon tension during surgery. This may improve surgical outcome and enhance wrist function, as well as decrease the need for repeat surgeries.

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USE OF LOWER-LIMB FNS TO IMPROVE ARM EXERCISE PERFORMANCE OF SCI INDIVIDUALS

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ABSTRACT

The purpose of this study was to determine if arm exercise performance of spinal cord injured (SCI) individuals can be improved by enhancing venous return and cardiac output via rhythmic functional neuromuscular stimulation (FNS)-induced contractions of the paralyzed leg musculature. For this, 10 SCI subjects underwent two progressive intensity arm crank ergometer (ACE) exercise tests to maximal effort on separate days. One test used FNS of the calf and thigh muscles (1.5 sec contractions in an alternating pattern), whereas the other did not. Test order was counterbalanced. Metabolic and cardiopulmonary responses were monitored via noninvasive means. At maximal effort ACE, the FNS condition elicited significantly ($p<0.05$) higher power output (+9%), peak oxygen uptake (+19%), pulmonary ventilation (+10%), stroke volume (+26%), and cardiac output (+37%). These results suggest that such FNS application may be clinically useful for improving arm exercise performance during activities of daily living, as well as exercise training to improve cardiopulmonary fitness and rehabilitation outcome of SCI patients.

INTRODUCTION

Spinal cord injured (SCI) individuals typically use their arms for performing activities of daily living including wheelchair locomotion and exercise training. However, arm exercise performance of SCI individuals may in part be limited by inadequate blood flow to the active upper-body muscles. This may be secondary to blood pooling in the legs, reduced venous return, and deficient cardiac output (1). Therefore, it appears possible that arm exercise capability can be improved in these patients by utilizing methods to increase venous return from the legs and make more blood available for the active muscles.

Indeed, Figoni, *et al.* (2) performed a study on arm crank ergometer (ACE) exercise capability of quadriplegics while cranking in the sitting and supine positions. They demonstrated that maximal power output (PO), peak oxygen uptake ($\dot{V}O_2$), ventricular stroke volume (SV), cardiac output ($\dot{Q}$), as well as other monitored cardiopulmonary responses were significantly higher during supine ACE exercise. The improved arm exercise capability and higher physiologic responses were primarily attributed to the reduction in the effects of gravity on the blood in the venous columns which facilitated venous return. Similarly, Pitetti, *et al.* (3) found improved ACE performance and cardiovascular capacities by SCI individuals when they used a G-suit to pump additional blood back to the heart via positive pressure on the legs. In contrast, Davis, *et al.* (4) used lower-limb functional neuromuscular stimulation (FNS) to induce rhythmic calf and thigh muscle contractions during ACE exercise by SCI subjects. They showed improved venous return as indicated by the higher SV and Q values which would possibly enhance exercise capability. However, the exercise protocol used was submaximal in intensity so information as to how these favorable central hemodynamic responses would affect maximal arm muscle performance was not ascertained.

Therefore, the purpose of this study was to determine if arm exercise performance of SCI individuals can be improved by enhancing venous return and Q via pulsatile, static FNS-induced contractions of the paralyzed leg musculature.

METHODS

Subjects:
Ten SCI men volunteered to serve as subjects. Mean $\pm$ SD age, height and weight were 33 $\pm$ 6 years, 182 $\pm$ 9 cm, and 74 $\pm$ 16 kg, respectively. Five were quadriplegic and five were paraplegic. All used manual wheelchairs. Prior to testing, subjects were medically screened, and signed a statement of informed consent in accordance with the Institutional Review Board of our University.

Procedures:
Arm Crank Ergometry. ACE exercise was performed on a Mijnhardt KEM-3 Cycle Ergometer which was equipped with handgrips and securely mounted on a table. Specially designed gloves were used to secure the hands of the quadriplegic subjects to the handgrips. The chair was mounted on a board to permit adjustment of the distance to the ACE, and to prevent sliding on the floor. Velcro straps were used to secure the subject to the chair to provide trunk stability. The subject's legs were strapped together and placed upon a cushion that was located on the floor in front of the subject. This was done to prevent injury that may be caused by movements induced by FNS, and to eliminate any assistance that the legs may offer to the performance of arm cranking.

Functional Neuromuscular Stimulation. The FNS application pattern caused bilateral isometric co-contractions of the calf (gastroc-soleus, tibialis anterior) and co-contractions of the thigh (quadriceps, hamstring) muscle groups. First, the calf muscles were induced to contract for 1.5 sec followed by a 1.5-sec relaxation. At 1.0 sec into this contraction, the thigh muscles were induced to contract for 1.5 sec followed by a 1.5-sec relaxation. Thus, there was a 0.5-sec overlap where the calf and thigh muscles were contracted simultaneously. The rationale for this FNS pattern was that venous return to the heart would be facilitated due to the upward "milking action" on the veins, and backflow into the calf veins would be minimized if there was valvular insufficiency. FNS was applied via skin surface electrodes placed over motor points of the muscles. A specially constructed 8-channel neuromuscular stimulator, which was similar to one previously described (5), was used. This device was battery powered and provided FNS parameters as follows: rectangular biphasic asymmetrical waves, 35 Hz frequency, 300 μsec duration with a current output range of 0-150 mA.

Physiologic Variables. To determine VO_2 ($L \cdot min^{-1}$) and pulmonary ventilation (V_E; $L \cdot min^{-1}$), subjects breathed through a 2-way valve and expired gases were analyzed by a metabolic cart (Medical Graphics System 2001). Cardiovascular responses were monitored with computerized impedance cardiography, ECG, phonocardiography, and auscultation. Cardiovascular variables included heart rate (HR, $beat \cdot min^{-1}$, computed from the R-R intervals of the ECG), left ventricular stroke volume (SV, $mL \cdot beat^{-1}$), cardiac output ($Q = HR \cdot SV \cdot 1000^{-1}$), mean arterial blood pressure ($MAP = DBP + [SBP-DBP] \cdot 3^{-1}$), and total peripheral vascular resistance ($TPR = MAP \cdot Q^{-1}$). Figure 1 illustrates physiologic data collection during ACE exercise with FNS application.

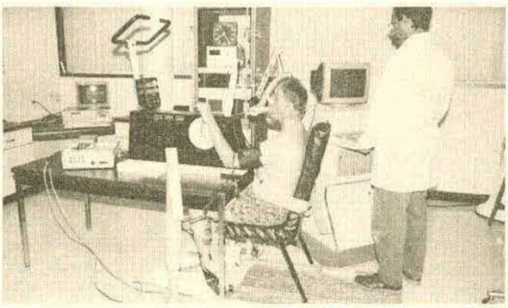

Figure 1. Physiologic data collection during ACE exercise with FNS application.

Protocol. A progressive intensity, discontinuous ACE exercise test to maximal effort was used. Subjects were administered this test twice on separate days: one where no FNS was applied, and one where FNS was applied. A counterbalanced order of presentation was used to prevent test interaction. Subjects first rested for 9 min and then performed submaximal ACE exercise (mean PO = 18.5 W) for 9 min. Following this warm-up, there was a 5-min rest, after which progressive intensity ACE exercise was performed until maximal effort was achieved.

Data Analysis:
Mean values for the collected data and the standard error of the mean are reported. Paired *t* tests were used to determine significant differences between the means of each variable at maximal effort ACE exercise when FNS was, or was not applied. The 5% significance level was used for all hypothesis testing.

RESULTS

At rest and during submaximal ACE exercise, it was found that the FNS-induced calf-thigh muscle contractions increased VO_2 about 0.11 $L \cdot min^{-1}$. Table 1 provides the mean PO, metabolic and cardiopulmonary data obtained for maximal-effort ACE exercise with and without FNS application. It was found that PO, VO_2, V_E, SV and Q were significantly higher with the application of FNS. HR and MAP were also higher, although TPR was lower, during this condition; but these differences were not significant. Subjects reported no discomfort for the FNS-induced contractions. Furthermore, some subjects indicated that the FNS improved their trunk stability, gave them more energy, and alleviated the dizziness that they usually experienced with high intensities of arm exercise. It was apparent that MAP was better maintained in quadriplegic subjects which helped alleviate exercise hypotension.

DISCUSSION

Today, more attention is being paid to improving the health, fitness and rehabilitation outcome of SCI individuals through increased participation in societal activities and specialized exercise training programs. However, arm activities performed in the upright posture, such as wheelchair locomotion and ACE exercise, can result in marked blood pooling in the lower-body. This is due to diminished sympathetic tone to the arterioles and veins which leads to dilatation, the effects of gravity on the columns of blood, and inactivity of the skeletal muscle pump. Thus, it is apparent that impaired venous return can cause low SV and Q which, in turn, can reduce blood flow to the active arm muscles (i.e., "circulatory hypokinesis"). This can result in the early onset of fatigue, limited wheelchair locomotion capability, and reduced therapeutic exercise tolerance, thereby hindering rehabilitation efforts. As previously indicated, ACE exercise performance of quadriplegics was found to be superior in the supine vs sitting position (2); and that positive pressure applied to the legs of SCI individuals by a G-suit improved ACE exercise performance (3). These studies demonstrated that the utilization of methods to facilitate venous return in SCI individuals can enhance their capability for arm activity.

For almost 50 years, the use of electrically stimulated leg muscle contractions has been investigated for reducing venous pooling and stasis in surgical and mobility-impaired patients. Data suggest that this

Table 1. Mean ± SE power output, metabolic and cardiopulmonary data for maximal-effort arm crank ergometer exercise with and without FNS application.

	No FNS Mean ± SE	FNS Mean ± SE	% diff.	*p*
PO (W)	76.5 ± 10.5	83.2 ± 10.4	+9	.014 *
VO_2 ($L \cdot min^{-1}$)	1.25 ± 0.14	1.49 ± 0.14	+19	.002 *
V_E ($L \cdot min^{-1}$)	57.8 ± 7.9	63.6 ± 8.2	+10	.042 *
HR ($beat \cdot min^{-1}$)	147 ± 12	156 ± 10	+6	.220
SV ($mL \cdot min^{-1}$)	51.8 ± 3.5	65.4 ± 4.4	+26	.004 *
Q ($L \cdot min^{-1}$)	7.4 ± 0.6	10.2 ± 0.9	+37	.001 *
MAP (mmHg)	70.7 ± 2.7	78.1 ± 6.6	+10	.306
TPR ($mmHg \cdot L \cdot min^{-1}$)	9.6 ± 0.8	8.5 ± 1.0	−12	.288

* indicates $p < 0.05$

technique has the potential for alleviating several serious medical complications that are secondary to impeded lower-limb blood flow including deep venous thrombosis, pulmonary embolism, and orthostatic hypotension. Although many of these prior studies reported moderately successful results, most used contractions of *only* the calf muscles. More recently, it was demonstrated by Glaser, *et al.* (6) that electrically-induced contractions of *both* the calf and thigh muscles are required in order to better activate the skeletal muscle pump, and facilitate venous return as indicated by markedly increased SV and Q. Therefore, it is feasible that the results of previous clinical studies may be improved by incorporating rhythmic, pulsatile FNS-induced contractions of the calf and thigh musculature.

Davis, *et al.* (4) reported that FNS-induced pulsatile, static calf-thigh muscle contractions during submaximal ACE exercise can enhance venous return, SV and Q. It was hypothesized that this technique could potentially increase ACE capability; but, maximal effort exercise tests were not conducted. The present study primarily focused upon addressing this important question. Our results indicated that the application of FNS during maximal-effort ACE exercise by SCI individuals can increase their PO capability, as well as their peak VO_2, V_E, SV and Q. The mechanism for these findings is apparently related to improved peripheral and central hemodynamic responses. Thus, it is apparent that the exercise capability gained by the improved circulation outbalance the 0.11 $L \cdot min^{-1}$ additional VO_2 caused by the FNS.

Exercise hypotension is a problem encountered by many SCI individuals (especially quadriplegics) during upright arm activity. This is where there is vasodilation of the vessels in the active muscles which lowers TPR, and Q is insufficient to maintain MAP. Orthostasis exacerbates this condition by increasing pooling in the legs. The hypokinetic circulation results in muscle fatigue, dizziness and the potential loss of consciousness. Several of our subjects reported feeling more energetic and less dizzy, where FNS enabled better maintenance of MAP, as the TPR decreased, through higher Q.

The higher Q during FNS is primarily due to the elevated SV rather than HR. This is most likely due to the Frank-Starling "Law of the Heart" where the facilitated venous return increases the ventricular preload (i.e., end diastolic volume) which in turn increases the force and velocity of the ventricular contractions. Therefore, this FNS technique appears to be advantageous for cardiopulmonary (aerobic) exercise training programs for several reasons including: 1- more efficient and safer cardiac function; 2- greater stimulus for metabolic, cardiovascular and pulmonary training adaptations; 3- greater stimulus for skeletal muscle training adaptations; and, 4- better tolerance of the exercise session.

Conclusions:

It is concluded that this FNS technique may have far reaching clinical applications for the rehabilitation of SCI patients. FNS appears to be advantageous over other clinically used techniques to alleviate venous pooling and stasis (e.g., elastic hose and pneumatic boots) since the active contractions of the paralyzed lower-limb muscles also may enhance their integrity. Our data demonstrated that FNS use could improve arm exercise performance, which may translate into more effective training programs, and enhanced wheelchair locomotion capability. Furthermore, its effects on promoting peripheral and central circulation may improve orthostatic tolerance training, as well as decrease the risks for medical complications in surgical and immobilized patients.

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SIG-11
Computer Applications

A SYSTEM FOR CREATING COMPUTER MUSIC AS AN OCCUPATIONAL THERAPY TREATMENT MEDIUM

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ABSTRACT

This paper describes a computer application in which therapist-prescribed muscle exercises allow an individual to control the notes that a music synthesizer plays. The system is designed for use in settings where therapists design physical activities to help clients achieve rehabilitation goals. A microcomputer detects limb movement through electro-mechanical input devices and commands the synthesizer to produce musical notes. The current system's three input devices detect the degree of flexion and extension in the elbow, wrist, and digits, respectively. To the client, the input devices become musical instruments with specific, learnable rules for producing music. Up to eight devices can be played simultaneously, each with a different synthesizer voice, which permits group practice and performance. To date, a total of ten clients with quadriplegia have used the system in programs of several months duration.

PROBLEM

Physical exercise is a common means of achieving functional goals in occupational therapy. The purpose of this project is to add a new purposeful activity to certain exercises by making exercise devices behave like musical instruments. For example, a user might wear a device that detects flexion of the elbow. Through the device, the user would play different notes by moving his or her elbow into different positions (i.e. degrees of flexion).

A system to support this activity is technically practical (Apkarian, 1991) because computers and music synthesizers can communicate with each other through the well-established Musical Instrument Digital Interface (MIDI) standard (International MIDI Association, 1983). When they are connected via MIDI, the synthesizer becomes another output device for the computer, playing the notes that the computer commands it to play. The computer can control various synthesizer settings as well, such as the "voice" in which the notes are played. Furthermore, most synthesizers can play more than one voice at the same time under computer control.

The design approach taken was to have the computer detect the position of the exercise device, map that position onto a musical note or chord, and instruct the synthesizer to play the indicated notes. A block diagram of this process is shown in Figure 1. It was decided that the system would provide graphical feedback of the device's position relative to the positions of playable notes so that users would always be aware of what notes they are about to play. With these additional system components, the exercise device would behave like a musical instrument with specific operating rules.

Two additional functional requirements were identified in order to make the system more useful in the occupational therapy setting. First, we decided to take advantage of the multiple voice capabilities of the synthesizer so that several exercise devices could be played at the same time. This would permit clients to work in groups and develop musical projects together. Second, it was decided that the software controlling the system should be flexible enough to allow different posi-

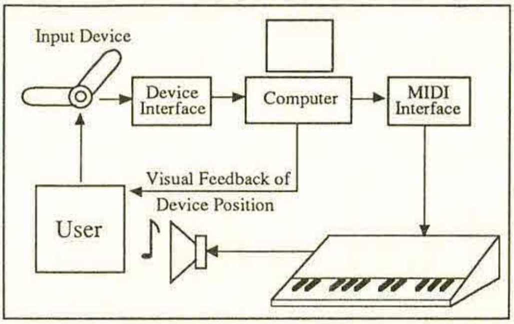

Figure 1: Current system for converting movement into music. Up to eight input devices can be used simultaneously.

tion/note mappings to be programmed easily. In this way, individual songs chosen by the group could be assigned their own mappings, which would enable the therapists to control how physically difficult each song is to play.

RATIONALE

The system's purpose was to provide a challenging and motivating method for clients with quadriplegia to strengthen upper extremity muscles, improve control of movement, and by so doing, enhance function in daily living tasks. This objective is consistent with the occupational therapist's role in providing purposeful activities that support the client's rehabilitation goals.

The use of purposeful activities that promote the practice of some desired movement is an essential component of occupational therapy in physical rehabilitation (Trombly & Scott, 1977, pp. 2-9). The process of choosing activities for a client starts with identifying problems and establishing long term functional goals. A functional goal is broken down into short term "sub-goals" which are often physical in nature (e.g. building strength). Activities are then chosen to support these short term goals. The value of a particular activity depends on both the qualities of the motions involved with respect to the client's goals, and the significance of the activity itself to the client (Hopkins et al., 1978, p. 100). This latter point, the consideration of how the client perceives the worth of doing the activity for its own sake, is what makes the occupational therapy approach to physical rehabilitation unique (Health and Welfare Canada, 1983).

Even though the client is made aware of the physical benefits of performing the motions associated with the specified activity, therapists downplay the exercise aspect relative to the activity as a whole. An activity is "...presented to the person in such a way that he can concentrate on the process and goal of the activity and not the specific movements or muscle contractions desired. The activity should be one, whether adapted or not, that automatically calls forth the correct response of the person." (Trombly & Scott, 1977, p. 6) Since the "correct response" is the desired outcome of the activity, therapists must also analyze the activity's underlying motions in terms of their physical value to the client.

Practising and performing music is consistent with the motivational characteristics that occupational therapy activities typically provide (Hopkins et al., 1978, p. 100). The following four points summarize the reasons for considering this activity in occupational therapy:

1. Music is a common leisure pursuit. The activity has the potential to capture the interest of a variety of clients. Playing music appeals equally to people of different ages and cultural backgrounds.

2. Playing music can be goal directed. Setting additional goals such as public performance could cause less attention to be paid to the exercise aspect of the process, and make practice sessions more purposeful.

3. It is possible to practise in a group. Being able to socialize and have fun with the activity offers obvious motivational benefits.

4. The program is client-driven as the participants have frequent choices to make. Decisions about songs to be practised and performed belong to the clients. The versatility of the synthesizer provides additional choices to make regarding sounds and special effects.

DESIGN

The mechanical design of the input devices impacts on the type of motion that the client performs to produce music. The current devices (Figure 2) are designed to monitor flexion and extension of the elbow (Figure 2a), wrist (Figure 2b), and digits (Figure 2c). The elbow input device is a goniometer that attaches to the user's arm with velcro bands. To use the wrist device, the user's forearm rests on a raised platform and the back of his or her hand slides under a hinged cylindrical handle. In this position, no active hand grasp is required to exercise the wrist extensors. The therapist can grade the difficulty of the elbow and wrist exercises by putting different weights on the client's wrist and hand, respectively. The hand grasp exerciser (Figure 2c) consists of a handle that slides horizontally inside a frame. The user's fingers wrap around the handle, and finger flexion causes it to slide. A variable number of elastics resist the movement.

A potentiometer is attached to each input device in such a way that its position changes as the device moves. Thus, the potentiometer produces an electrical signal which is proportional to the device position. The computer detects this signal through an analog to digital converter (Data Translation Inc., Model DT2801A) and calculates the device position. Positions are updated at a rate of 20 samples per second.

All three devices can measure positions beyond the range of motion of the user's joint. Therefore, the software includes a calibration procedure which allows the therapist to match the range of useful device movement to the client's active range of motion. The software only uses this specified range of positions to produce music. The calibration procedure is also useful when the goal of the exercise is to increase the client's active range of motion. The therapist can use the procedure to progressively increase the range that the client must move through to play a song successfully.

DEVELOPMENT

This section describes the use of the system for arranging and playing songs. A musical arrangement consists of all of the parts that will be played by the members of the group. Although the system can theoretically accommodate eight parts simultaneously, we have been arranging songs for three instruments only: one that plays the melody and two others that play rhythm. One of the rhythm parts typically provides the bass line and the other provides chords.

When the group decides on a new song, it is arranged and programmed into the system for playing. Songs are arranged by transcribing the three parts onto paper and listing the different notes or chords required for each part. An instrument is then programmed for that song by assigning each note or chord to a section of the input device's range. Typically, a maximum of eight input device positions can be targeted reliably, which means that each instrument in a song must have no more than eight different notes or chords. Although this is not a serious limitation for most pop music, some melody parts need to be simplified.

When the new song's arrangement is loaded into the system for playing, the note/chord mapping for each instrument appears in its own window (Figure 3, on the next page). This window is the graphical feedback represented by the line between the computer and the user in the block diagram in Figure 1. Each window is divided horizontally into numbered regions corresponding to the sections of the input device's range that were assigned to different notes or chords. While playing, the client can determine which numbered region the input device is currently in because a marker moves horizontally across the screen as the input device moves. The sheet

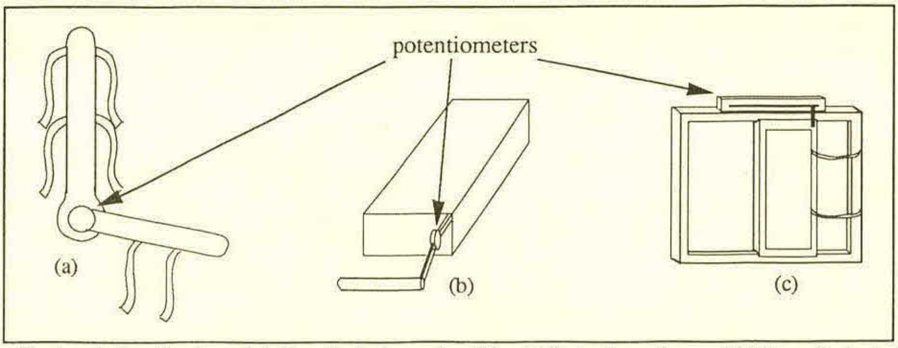

Figure 2: Input Devices designed to detect (a) elbow flexion/extension, (b) wrist flexion/extension, and (c) finger flexion/extension. Each device has a potentiometer which detects its position.

music for each part contains region numbers beside each note or chord. Therefore, playing a song involves finding the next note in the sheet music and moving the input device to the corresponding numbered region to play the note at the correct time.

The "correct time" depends on whether the part is a rhythm part or a melody part. The person playing the melody part has a pneumatic switch through which he or she explicitly controls when a note plays. The rhythm instruments play automatically according to a fixed rhythm at a settable tempo. If a rhythm device is held in some region, the system will repeat the same note or chord on every beat. To change the note or chord, the rhythm players move from region to region between beats. The input device must arrive in the new region before the beat.

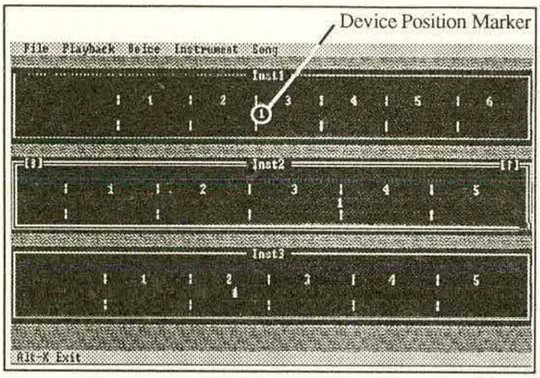

Figure 3: Screen image of music system software. Each of the three devices has its own window on the screen.

EVALUATION

Over the past eight months, ten individuals with quadriplegia have used the system as part of their occupational therapy program. Songs that were arranged for the program included: "I Get By with a Little Help from my Friends," "Smoke on the Water," "Hold On," "Lean on Me," "More than a Feeling," and "Janie's Got a Gun." There have been six opportunities for public performance, with a positive response from both the participants and the audience in each case. Performing music as described above appears to be a successful method of motivating exercise.

A pilot study is underway to examine the effect of the music activity on the quantity of exercise performed. The music activity is being compared with a rote exercise activity using the same input devices. The computer records the amount of device movement observed in each session. Subjective impressions will be collected from the participants at the end of the study.

DISCUSSION

In this project, a system was designed to convert abstract joint motions into music. The motions that control the music need not bear a physical relationship to the music produced. The system illustrates the usefulness of the computer as an activity design tool in occupational therapy. Its flexibility in interpreting and producing signals enables therapists to set up activities in which the computer-generated results do not require a physical relationship with the motions that cause them. This flexibility is consistent with the two different sets of objectives that exist in activity design in occupational therapy. The activity must have a purpose of its own, apart from the exercise, that captures the client's interest. At the same time, the associated exercise must be integral to the rehabilitation process. Computers with appropriately adapted input devices may broaden the range of activities that meet these two sets of objectives. The qualities of the input device determine many of the physical aspects of the exercise. The qualities of the software determine the appeal that the activity will have with the client. Music is not the only possibility. Any number of computer-based activities could be designed for use with the same input devices. Further therapist-driven explorations may result in a variety of new purposeful activities for use in physical rehabilitation.

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EVALUATION OF A SYNTAX-DRIVEN WORD PREDICTOR FOR CHILDREN WITH LANGUAGE IMPAIRMENTS

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ABSTRACT

A computer program has been developed to assist young people who have moderate language impairments with their writing. This writing aid predicts words in a syntactically correct order, and predicts the correct forms of words to fit the sentence being constructed. The program has been tested by 10 young people, and found to be of considerable benefit to some of them. This paper reports the results of these tests.

BACKGROUND

PAL[1], a word and phrase predictor, was developed to assist people with motor impairments with the physical task of typing. When the program was tested by children in local schools[2], it was found that PAL was also useful for children with spelling problems. Some of these, both motor-impaired and non motor-impaired, however also had difficulty with written grammar; Syntax PAL[3] utilised syntactic knowledge with the predictive mechanism. It was hypothesised that such a system would provide further help to these children.

OBJECTIVE

Due to funding constraints it was necessary to develop Syntax PAL, test it for errors, and evaluate its usefulness within a two year period. The evaluation phase also needed to fit in with the academic year, which seriously limited the time available for this phase.

Our objective in the evaluation was thus to do as much evaluation as time allowed, improving the program as ideas arose from the evaluation, and to attempt to obtain an initial idea of how effective the program was likely to be. Subject to funding, this phase would be followed by a rigorous and exhaustive evaluation of the final product.

METHOD

After an initial working version of Syntax PAL was constructed, an initial phase of testing with two children was undertaken. These children were selected partly on the basis that the children and their teachers were willing to test the program although it might still contain errors. One of the children was motor-impaired, the other had no physical difficulty with using the keyboard.

When an initial case study with these two children had been completed and the program was assessed as being reasonably error-free, short case studies with a further eight children were carried out. To give a baseline of each child's initial writing ability, the child was given PAL to write with, and was asked to provide copies of all the free writing done using the program. This was any unstructured writing done without the teacher's aid, and in practice was mostly the child's daily news. Some stories, or summaries of books read, or projects were also produced.

The child was then given Syntax PAL, and asked to use it just as they had been using PAL. The free writing being done was collected and evaluated again. Thus the evaluation was measuring the impact of syntactic prediction, over and above the impact of using a computer or using a word predictor. Simply using PAL was found to improve the grammaticality of some children's writing, presumably as a result of improved motivation and/or reduction in the physical and mental effort involved in writing. But what we were interested in was whether Syntax PAL would provide an additional improvement.

Ideally, Syntax PAL should have then been withdrawn, and the children asked to use PAL for a further period. However, time only allowed this ABA approach with one of the children.

The children's writing was evaluated for errors manually, with each omission of a word or part-word, each inclusion of an extraneous word, and each incorrect choice of a word or a tense counting as one error. For example, ***I will am going to shops*** contains an omission error (***the*** missing before ***shops***) and an overinsertion error (***will*** is extraneous).

RESULTS FOR EACH CLIENT

Client #1

Client #1 was a 17-year-old young woman with spina bifida and hydrocephalus. She participated in our first set of trials, during which the program was being tested for errors as well as evaluated. Her work deteriorated using Syntax PAL, her error rate increasing from .119 errors per word with PAL to .131 with Syntax PAL. This is attributed to two factors: firstly the high incidence of word-use errors in her work with which Syntax PAL is not expected to help, secondly personal factors.

Her level of interest in reading and writing had been greatly stimulated by the introduction of PAL. This effect, however, decreased towards the end of the trial period, such that the only reading or writing her teacher could persuade her to do was keeping her journal with Syntax PAL, and the amount she wrote decreased. This may have been related to her preparing to leave school, or to a shunt operation which was performed to relieve her hydrocephalus about this time.

Client #2 (ABA trial)

The work of client #2, a 15-year-old nonspeaking girl with cerebral palsy, improved dramatically using Syntax PAL. She wrote more, her sentences became more complex, and she made many fewer errors. The average number of words she wrote in a session increased by 41%, from 41 to 58. This dropped to 31 in the final trial period when Syntax PAL was taken away and she used PAL again.

Her grammatical error rate had not been decreasing over the baseline period of 11 weeks using PAL; it averaged .180 errors/word. This dropped to .089 when Syntax PAL was used, a statistically significant decrease at the 1% level. During the later period of using PAL again, her average error rate returned to .163 errors/word.

Her teacher commented that her work had increased in length and she had extended her sentences further using Syntax PAL, and the added keysaving it provided seemed to be what was prompting these changes. A detailed examination of her work revealed that she was using more complex language in at least two respects: she was using longer sentences, more often joining ideas together with conjunctions rather than expressing each in a separate sentence; and she used more secondary verbs (.034 per clause using PAL, .131 using Syntax PAL, reverting to .033 during the later period of PAL use).

As it would be expected that Syntax PAL would help more with some types of error than others, it is instructive to examine the types of error which contributed most to the reduction in overall error in client #2's work in more detail. Three specific types of error were very frequent when PAL was used, and substantially less frequent with Syntax PAL. These were:

	PAL	Syntax PAL	PAL(2)
- omissions of forms of *to be*	43%	18%	40%
- omissions of other main verbs	10%	6%	1.6%
- omissions of the past tense	15%	5.8%	7.0%

Client #3
Client #3, a 12-year-old boy with cerebral palsy, reduced his error rate dramatically using Syntax PAL. With PAL, he made .336 errors per word; with Syntax PAL, .104. Most of this reduction was in omission errors; for example, his omissions of past tenses in verbs decreased from 25% to 7%.

Hence, being prompted with correct words appeared to be successful in reducing the number he omitted. At the same time, it seemed to occasionally encourage him to choose these words from the prediction list when they weren't needed. Thus, his overuses of determiners increased from 1.7% (PAL) to 4.2% (Syntax PAL); but because of the massive decrease in his omissions of determiners, the net determiner errors decreased from 45% to 17%.

While using PAL, client #3's error rate was not improving: he made .317 errors/word during the first month of the PAL trial, and .382 errors/word during the second month. Thus, his considerable improvement is likely to be attributable to Syntax PAL, and this is reinforced by his improvements in the specific areas of tense and determiner omissions.

The quantity client #3 wrote per session remained more or less the same with Syntax PAL (40.80 words/session with PAL, 40.30 words with Syntax PAL); the complexity appeared to increase slightly, as his clauses lengthened from an average of 5.30 words to 6.50 words.

Client #4
Client #4 was a 21-year-old nonspeaking young man with cerebral palsy. His average error rate using Syntax PAL was very similar to his error rate using PAL. However, the type of errors he was making shifted markedly: his omissions increased substantially, while his overinsertions of words or parts of words decreased substantially. This is the reverse of the shift in errors of client #3 and others who were helped by Syntax PAL. Perhaps the range of potentially correct words the program presents confused this particular client, and he left out function words altogether when presented with too many choices.

On the plus side, the program appeared to help client #4 with using the correct form of verbs following forms of *be* (errors decreased from 67% to 33%), and with using tensed forms of verbs (errors decreased from 32% to 26%).

Client #4's complexity of language use didn't alter much between PAL and Syntax PAL, but the amount he wrote did. He is motor impaired, and with the increased keysaving and reduced effort possible with Syntax PAL, the average number of words he wrote per session increased from 58 to 69.

Client #5
Client #5 was a 13-year-old boy with learning difficulties and telegrammatic speech due to minimal cerebral dysfunction. He was an extremely poor writer at the start of the trial with PAL, and improved dramatically during the period he used PAL, and this dramatic improvement continued using Syntax PAL. Using PAL, he made .506 errors per word, and using Syntax PAL, he made .145 errors per word. In absolute terms, he decreased his error rate more during his use of PAL than with Syntax PAL. But in terms of proportion of errors eliminated, he cut his error rate by 45% using PAL, and by a further 60% of the remaining errors using Syntax PAL.

Similarly, the amount written and complexity of language used increased substantially both with PAL use and Syntax PAL use.

Client #6
Client #6 was an 8-year-old boy with cerebral palsy. His writing initially improved dramatically using Syntax PAL, with his error rate decreasing from .269 errors per word using PAL to .066 in the first month of using Syntax PAL. However, during each subsequent month with Syntax PAL, his error rate worsened again, first to .250 and then to .490, worse than the rate using PAL. In the second month with Syntax PAL, he wrote less per session and used simpler language, but in the third month the complexity and quantity written recovered somewhat. It is not clear what was happening with client #6, unless his teacher was assisting him some of the time.

Client #7
Client #7 was a 13-year-old girl with learning difficulties due to long periods of absence of school as a result of ill-health. Her omission errors decreased from .071 per word with PAL to .036 with Syntax PAL; rates of the other main types of error she made changed very little. Her number of words written per session also increased from 45 to 57. These improvements are surprising, given her teacher's comments that she did not pay close attention to predictions and typed faster than the program could respond. The complexity and quantity she wrote did not change greatly, which supports this observation. Not until the final session did the teacher comment that client #7 was concentrating well and taking her time. The improvement could be due to external factors, or the slowing-down forced on her by the program's speed of

response. The fact that the improvement consists of decreased omission errors, and the disappearance of tense omissions from her writing, suggests that she may sometimes have paid attention to the predictions and been helped by them.

Client #8
Client #8 was an 11-year-old nonspeaking girl with cerebral palsy. Her overall errors decreased substantially over the trial period, from .230 errors per word using PAL to .095 using Syntax PAL. Part of this decrease occurred during the 8 months she used PAL: over the first half of her PAL trial, she made on average .275 errors per word, which decreased to .177 errors per word in the second half. During the trial with Syntax PAL, her error rate did not change significantly: over the first half, she made .095 errors per word, and over the second half, she made .097 errors per word.

If we look at specific areas of error, the impact of Syntax PAL becomes clearer. Client #8's omissions of tenses, auxiliaries and copulas decreased substantially. These improvements did not begin occurring during her use of PAL, they rather appear to be a result of the assistance provided by Syntax PAL.

	PAL			Syntax PAL
	1st half	2nd half	Overall	
Tense omissions:	10%	14%	12.5%	0.67%
Aux/cop omissions:	41%	44%	42%	7.4%

Client #8's determiner errors also point to her deriving some benefit from Syntax PAL. Although her omissions of determiners decreased while she was using PAL (from 46% to 33%), the rate of decrease accelerated while she was using Syntax PAL (to 11%). She made more overinsertions and lexical errors with determiners while using Syntax PAL than while using PAL, but the net impact of the program in this area was positive.

Client #8's average clause length increased from 6.8 words using PAL to 8.0 words using Syntax PAL, an improvement associated with Syntax PAL, not with PAL. The number of words she wrote per session increased from 37 using PAL to 45 using Syntax PAL. She is motor impaired, thus the improved predictions presumably enabled her to write more with less effort.

Client #9
Client #9 was an 11-year-old dyspraxic boy with delayed expressive language due to minimal cerebral dysfunction. The frequency of errors he made decreased from .146 per word with PAL to .110 per word with Syntax PAL, most of the decrease being due to reduced omission errors. Much of this improvement lies in improved punctuation: his punctuation errors decreased from .029 per word to .006. In none of the other areas where Syntax PAL might be expected to help did he make a significant improvement. For example, he omitted the past tense transformation of the verb 32.5% of the time using PAL, and 31.2% of the time using Syntax PAL. The complexity and quantity of his writing did not change much from PAL to Syntax PAL.

Client #10
Client #10 was a 13-year-old boy with a language disorder and nonfluency due to minimal cerebral dysfunction. His experience with Syntax PAL was quite similar to client #9's. His overall errors decreased significantly using Syntax PAL, from .146 errors per word to .109 errors per word. A lot of this improvement was due to his forgetting periods less often: his punctuation errors decreased from .098 per word to .067 per word. His non punctuation errors also decreased slightly from .049 to .041, but no one type occurred often enough for the change to be significant.

Client #10 wrote less per session using Syntax PAL than with PAL (64.67 words versus 89.86), but his clauses were slightly longer (average length of 6.93 words, as opposed to 6.55 words with PAL).

SUMMARY

Syntax PAL assisted different clients in different ways. It has been shown to have helped two of our clients (#2 and #3) a great deal with their written grammar; it appeared to help #8, and possibly #7, #4 and #5, somewhat. No evidence was found of it helping clients #1 and #6; and it seemed to help #9 and #10 largely with remembering to use periods between sentences. (Syntax PAL predicts periods and other punctuation as well as words.)

In general, Syntax PAL helped the children most with remembering to include words and tenses they tended to omit. It was too slow for one client, and the prediction of several determiners (*the*, *a*, etc.) at the start of every noun phrase encouraged some people to put one in where it wasn't needed, or to use the wrong one.

In addition, the improved prediction offered by Syntax PAL decreased the effort involved for the clients with severe cerebral palsy (#2, #4 and #8), and thus assisted them to write more.

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DESIGN PARAMETERS AND OUTCOMES FOR COGNITIVE PROSTHETIC SOFTWARE WITH BRAIN INJURY PATIENTS

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Abstract

Three traumatic brain injury patients achieved a significant increase in level of function in a relatively short period of time using highly customized computer-based cognitive prosthetic software. Study objectives involved determining the kinds of interface and application design parameters and requirements for prosthetic software with brain injury patients. Research subjects were between 1 and 5 years post injury. Increases in level of functioning were seen both in everyday activities targeted for the intervention as well as generalized increase neurobehavioral and psychological dimensions.

Introduction

Enduring cognitive deficits from traumatic brain injury interfere with people's ability to return to pre-morbid functioning, and have been remarkably resistant to remediation by manual systems. The rehabilitation of higher level cognitive functioning using computer-based technology has received considerable attention, and applied a variety of approaches (Kirsch, Simon, & Horstmann, 1992; Vanderheiden, 1992; Gunderson, 1991; Prevey et al., 1991; Henry & Friedman, 1989; Steele et al., 1989; and Kirsch & Levine et al, 1988). Our previous work (Cole and Dehdashti, 1992, 1991, 1990a, 1990b) has shown that brain injury survivors with residual cognitive disabilities have achieved a higher level of functioning with extensively customized computer software as an assistive device. Performance is enhanced when the patient can gain access to their abilities, and at the same time, have the computer be a bridge over the deficits; all this within the context of the patient's life situations.

Research Objectives

The principal goal of this study was to develop an understanding of interface and application features which are modified in the customization process and thus contribute to successful cognitive prosthetic software. The goal was approached through two major objectives. First is to identify the software features which need to be manipulated as part of an authoring system for therapists working with brain injury patients. The second is to track changes in level of functioning in cognitive areas of patients who are using prosthetic software. Both interface and application functionality -- which need previous research has shown that highly customized software lead to increases in patient functioning. This study explores the kinds of features which are customized in designing successful prostheses. The outcome of the study can be applied to design authoring systems which can be used to highly customize systems for brain injury patients. Specifically, the study explores the kinds of interface features and application features which are modified over a 2 month period in prosthetic software interventions.

Methods

The study design is a quasi-experiment single-subject study with three subjects, each as a replicate; each subject is able to act as its own control. The study population were outpatients with a diagnosis of traumatic brain injury and who were at least 1 year post injury. In addition, conventional techniques needed to have failed to remediate a functional problem which could be a candidate for this study.

The study design called for 1 intervention to last approximately 6 weeks, with the hope that measurable progress toward the intervention goal might be achieved in that time. When intervention goals were fully achieved earlier than anticipated, the design was expanded to add an intervention goal when one was achieved.

To make the study population more homogeneous, it was decided to specify that the intervention consist of "daily schedule" or "To Do List" software. However it was recognized that additional software modules may be needed, depending on the needs of the patient.

Subjects were recruited from the outpatient population of a research oriented rehabilitation hospital. Therapists evaluated their patients on six items, including failure of traditional compensatory strategies to achieve restoration of function for specific activities, and likelihood that an increase in level of functioning could be achieved using software with scheduling or "to do List" features (without doing detailed design of the therapeutic prosthetic intervention). The three patients with the highest scores were offered participation in the study, and accepted informed consent.

The general problems for a patient was analyzed in depth. This involved a review of rehabilitation efforts, and a visit to the patient's home to collect additional data on methods which were being used to attempt to deal with the rehabilitation problem. A review was then conducted to try to understand the nature of the failure and to define the intervention goal. An initial intervention design was developed jointly with computer scientists and cognitive remediation therapists. The design was then presented as a series of components to the subject in design and testing sessions. An error-free design approach was taken, and redesign continued until the subject was able to understand how to use the prosthetic software. All of the subjects played a significant role in the redesign of their software. Two of the subjects became the primary designer of their initial system. After each of the modules had been tested, redesigned where necessary, and accepted, the system was integrated and patients trained in the rehabilitation suite.

At this point the system was delivered to the subject. Two of the subjects were given desktop computers which were installed along with dedicated phone lines in their home; the third subject was given a portable "notebook" computer. All computers were equipped with 386SX processors, 2 Mb RAM, a 40Mb harddisk, a VGA color monitor, and a 2400 baud modem. Printers were issued when appropriate; all three systems had printers by the end of the study. All computers used MS-DOS 5.01 and, when appropriate, the DESQview multi-tasking environment.

Extensive data was collected on interface and functional changes and the role of the individual who initiated the change. System logs provided extensive data on patient use. Clinical data included progress notes and the Saykin Neurobehavioral Inventory and ADL Scale.

Intervention Goals for Subjects

Prosthetic software was developed and customized to assist each subject in performing an everyday task which had been an unattained rehabilitation goal. Each subject had different deficits and different therapeutic goals that could be remediated with portions of the same underlying application computer code and different interface designs. Each subject started with an initial rehabilitation goal, and then additional goals. The goals for each subject were:

Subject 1
Initial goal:
getting him to his activities on time; improve ability to work with concept of time; reducing impulsivity in attempting to perform a 2nd activity while performing the 1st; improve attention to detail (was determined through combining his notes in various places in the house, ...)

Goal 2:
enable communication between patient and therapist via computer

Subject 2
Initial goal:
to initiate an unsupervised activity in the home with cuing at a pre-set time daily; if possible, to initiate an unsupervised activity spontaneously during the day

Goal 2:
to follow a brief daily schedule of activities

Goal 3:
to provide a medium of scheduled, structured writing; to enhance reading activity and comprehension

Goal 4
to increase Subject's ability to make decisions; to follow increasingly complex sequence pattern.

Subject 3
Initial goal:
To set priorities in her daily activities, particularly errands; to provide memory support for activities and errands; to have a socially appropriate compensatory strategy; to have a compensatory strategy which she could use anytime, anywhere.

Goal 2
To support her ability to track and manage her work through providing organization and structure.

Development Effort / Functionality and User Interface

The research objective was to deliver a system to each subject that will satisfy critical needs and would require only minutes of training. The iterative nature of our approach required the delivery of multiple systems to ensure the success of the prosthesis. Over the course of 4 months 23 versions of the different systems were delivered to patients: to gradually increase functional enhancements, to improve interface, and to remove errors. The final applications delivered were: Daily Schedule, Daily To Do List, Priority List, Rolodex, Word Processor, Case Tracking, and External Activity Calls.

Functionality

The functionality of the systems delivered were defined by a collaborative effort. Day-to-day problems of the subjects were analyzed and translated into system functionality. In the original systems a set of 35 functions were delivered. As subjects used the systems, it was necessary to add or revise 50 other features. These features were partially shared among the subjects, with unique features of all the systems totalling 51.

Subjects one and two, who had more cognitive deficits than subject three, were given minimum functionality for their initial systems. Later, subject two showed readiness for more functions; therefore a word processing application was provided with the capability to save and retrieve documents. Subject one, who has the same word processor was limited to using and saving one document at a time. Subject three, who was the highest functioning subject, initially required and was able to use the most number of features. In addition, a new application was added with a large pool of features.

One major change was made to subject one's system without first testing it with him. Although clinicians had requested a computerized weekly schedule for subject one, they decided against presenting it to him even though it matched his manual system. When clinicians saw the weekly schedule on the computer, they realized that the complexity of a weekly format, combined with manipulation on the computer, would be burdensome to the subject. Consequently, a daily schedule was designed.

The initial design of the subjects' systems as well as the overall design was based on clinicians' input. Because of their long-term relationships with the subjects, therapists are most familiar with their needs and appropriate uses of the systems. The subjects felt comfortable discussing their needs and requesting feature changes which better suited their needs.

To support all the delivered functions, an average of 7063 lines of code were written per subject's system. However, 51% of the average lines were shared among the three systems. An additional 5% was shared between S1 and S2's systems, and 3% shared between S1 and S3's systems. About 10,000 unique lines of code are needed to support the functionalities identified during this study.

In addition to the systems delivered to the subjects, we developed a system for clinicians. During the study, it became evident that there were some unique requirement of the therapists in providing treatment. In addition, there were some subtasks which were assigned to the therapists which could be better performed through a separate executable manipulating a common database.

Interface

Interface components were originally designed by ICP's interface designer with clinical input. Interface characteristics of all three systems changed before system delivery. During design session with clinicians and during testing with subjects, changes were identified and implemented in the delivered system. This was an iterative process, until clinicians considered the system appropriate for subjects' private use.

When this research was completed, a total of 304 interface components were specified for all three subjects. The first version delivered to subjects included a total of 254 interface specifications (84%). To design the initial systems, many decisions had to be made as to what components should be included and how they should be specified. A total of 91 unique interface components were identified as details of 24 unique objects. For example, for a menu object we specified details of menu colors, number of options in menus, and menu styles. Examples of other higher level objects were menus, sound, cursor, and commands. Each change to an interface component affected various lines of code in the underlying programs.

Throughout the study, 66% of these original components had to be changed one or more times during the study to better accommodate subjects. For example, the color of the appointment highlighter for subject one's To Do List changed from the original design and changed when editing was added. This was to draw his attention to the function at hand. The rest of the interface components (33%) were not changed during the study. For example, borders around boxes were determined at the onset to be single or double lines depending on their content. Neither the clinicians nor the subjects requested them to be changed.

Participatory Design

Almost two thirds of the interface object changes were requested by either the patients or clinician. Almost three-quarters of the functionality was requested by the patients or clinicians. It is clear that at least some of the interface and functional changes would not have been suggested by those with systems expertise because those changes were either counter-intuitive or violated accepted guidelines. Also, the impact on both patient and therapist of the opportunity to have their ideas implemented cannot be understated.

Conclusion

While the main focus of this study is prosthesis/software design, the most important result of this study is in patient improvement. This study contributes to a literature which shows the impact of prosthetic software which is highly customized to individuals with disabilities due to cognitive deficits. Patients who showed minimal or slow recovery demonstrated an almost immediate increase in rehabilitation progress. Each subject demonstrated a generalized improvement in neurocognitive functioning even in the relatively short time of this study. Extended increases in level of functioning for cognitive deficits are considered difficult to achieve in brain injury patients. This improvement is in addition to the rapid increase in level of function for a targeted activity. The study design anticipated working on only a single goal (activity) for each subject; however the pace of patient progress was sufficiently rapid -- in the case of task initiation, merely 1 week -- that we took the opportunity to add another therapeutically appropriate goal when the previous one was achieved.

Part of the success of this study needs to be attributed to the flexibility imposed on the software environment. As detailed intervention planning took place, it became evident that achieving the intervention goal involved adding application functionality which was not part of the initial software library when the study began. This means that prosthesis design was driven more by patient needs than by software module inventory. The increasing availability of rapid prototyping tools, function libraries, and add-on boards allows the software development process to be more responsive to relatively inflexible user requirements often found in rehabilitation patients.

Finally, part of the success of this study needs to be attributed to the treatment team, which included patient, cognitive remediation therapist, and computer scientist. The intervention design was conducted in a highly participatory manner. Patients exhibited considerable insight into the design of their prosthetic software. Rapid prototyping tools allowed alternative designs to be tested and changed during a therapy session. The clinicians and the patients both felt empowered and enabled by the combination of the software technology coupled with the design approach.

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INTERFACE ANALYSIS USING A STANDARDISED FEEDBACK LANGUAGE

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ABSTRACT

With new multi-media computer technology it is possible to produce feedback through the auditory, visual and tactile channels. However, application programmes continue to provide feedback that is almost entirely visual thereby restricting access to computer technology to people who have good visual and cognitive skills. By designing feedback that is independent of modality, people who require non-visual feedback can take advantage of the multi-media environments. A model of modality independent feedback has been proposed by Fels, Shein, Chignell &Milner (1992) in the form of a standardised feedback language. An experiment was conducted to determine whether users could identify the elements of this language in actual existing interfaces. Results indicate that target users are able to learn and consistently apply the language with a 1-hour training period (average error rate of approximately .10 errors per total possible elements).

BACKGROUND

Computers using graphical user interfaces (GUI's) are quickly becoming standard in computing environments. For people with disabilities, the GUI environment has both enhanced and curtailed access to computers .

Feedback is one of the areas in which the GUI has curtailed access to computers. In the GUI environment consists almost entirely of visually enhanced and graphical elements such as windows and menus. The emphasis in designing feedback for the GUI has been on finding visual metaphors such as icons that can convey as much information as intuitively as possible to the user. People who are visually impaired or who are unable to understand visual information may be at a disadvantage or completely excluded from using this technology.

A model of modality independent feedback based on the information that must be conveyed to the user was proposed by Fels et. al., 1992. This model suggests that computer feedback can be represented using a standard feedback language that represents the context and the content of feedback. This language would reside as a layer in the computer-human interface between the application programme and the output device. A translator mechanism would convert the standardised feedback from the application programme into feedback that is acceptable and understandable by the user (using the appropriate modality for the user). This language would then allow access to the computer using the visual, auditory or tactile modalities. Users are not limited to using the visual modality to receive computer feedback.

Fels & Chignell (1992) conducted an experiment to determine the terms and definitions of the feedback language among target users (software programmers, system designers and clinicians). The results of this experiment produced, by consensus, a complete set of the terms and definitions to be used for the language. **Table 1** illustrates those terms and definitions.

Vanderheiden, Andersen, Mendenhall & Ford (1992) proposed a second model that defines feedback from computers in terms of information. In this model, feedback can be classified into 2 classes: 1) feedback that can be described using words such as text and icons; and 2) feedback that is inherently graphical and cannot be easily expressed using word descriptions (e.g., drawings and charts). Although this model addresses the content issues of feedback, there is also contextual information that can enhance or subtract from the user's ability to understand that content. For example, a prompt cue (such as a flashing bar or an auditory equivalent) followed by a description of contents of the prompt can assist the user by informing the user that a response is required without actually describing that requirement specifically. In addition, visual attributes such as colour and size (which could be classified as inherently graphical) can have meaningful equivalents in the auditory modality without requiring any textual description.

	Term	Definition
Context	message	relay system information
	cursor/position	location/position information
	prompt	asks for user response/action
	menu	set of choices from which to choose
	block	one section of many
Content	text	letter and numbers
	symbol	represents a "real-world" concept
	echo	placeholder/immediate response
	graphic	lines, arcs, etc, drawings

Table 1: Summary of the Terms and Definitions to be Used for a Standard Feedback Language

This paper presents the results of an experiment that was conducted to determine whether target users could interpret existing graphical computer interfaces based on the feedback language proposed in Fels, et. al. (1992). The experiment discussed in this paper is one of a series of experiments being conducted to determine the applicability and usability of the standardised feedback language.

RESEARCH QUESTION

The research questions considered for this experiment are:

- Can target users learn and consistently apply the feedback language to common and conventional user interfaces?
- Is the feedback language interpreted and used differently between clinicians and non-clinician users?
- Are there any of the elements of the language more difficult to understand and apply than others?

METHOD

An experiment was developed to determine whether the feedback language could be used by target users to identify or decompose a variety of existing interfaces from representative application programmes. Existing interfaces contain multiple examples of all of the elements in the feedback language. If users could consistently decompose interfaces in terms of the feedback language then we could say that users could successfully learn and apply the concepts of the language.

Feedback of many common interfaces is composed of multiple and complex combinations of the feedback elements. It may then be hypothesised that this may cause confusion, high error rates and inconsistent application of the language among users. However, as a result of a previous experiment conducted for this research (Fels & Chignell, 1992), the terms in the feedback language are few in number and conceptually distinct to potentially reduce the confusion among users. It is, therefore, suggested that users will experience low error rates, accurate application of the language, and less confusion in using the language.

Ten randomly ordered examples of different displays from MS Windows 3.1, Macintosh System 7, MS DOS 5.0, MS Word 4.0 for System 7 and MS Word 2.0 for MS Windows 3.1, Word Perfect, and Harvard Graphics 2.3 were simulated in Hypercard 2.1 on a Macintosh Quadra 900 and Macintosh IIfx. All of the examples were represented solely in the visual modality to simulate the actual interface. There are few, if any, auditory feedback elements for these interfaces and therefore none were presented to participants. The feedback elements were available as selectable buttons.

Following a timed training exercise, participants were required to identify the feedback elements directly on the interfaces presented to them. They could "pick up" a stamp with the name of a feedback primitive on it and stamp the appropriate component on the interface. A delete stamp was also available for error correction. **Figure 1** is an example of an interface that has been "stamped" with feedback elements.

By identifying the feedback elements directly on the interface examples, participants had a direct link between the name of an object and its visual display as well as its relationship to other objects in that interface. In addition, having a direct visual connection between an interface object and its label promotes the distinction between the content and context elements. For example, it was visually obvious what objects were graphics but also that those graphics were contained within a context element. This hierarchical relationship was thus established through identification of objects directly on the interface example.

The data collected during the experiment consisted of feedback elements stamped directly on interface objects, the order of "stamping" and the time for each stamp to be entered. The stamped interfaces were compared with a set of pre-labelled interfaces established through pilot experiments where all of the interface objects were identified using the language. Discrepancies between the default interface and the experimental interface were denoted as errors. Errors consisted of labels that had been omitted, extra labels, or mislabelled objects. Each error was also identified as a context or content label. A total error score (sum of all errors) and an error rate (total error score per total possible interface elements) for each interface and for each participant was determined. Participants were also categorised into computer programmers and clinicians.

Participant Characteristics

Sixteen unpaid participants participated in the experiment. There were 11 computer programmers and 5 clinicians. Fourteen subjects had more than five years' experience using or programming computers. Two subjects had between 2 and 5 years' computer experience.

RESULTS

An analysis of variance (ANOVA) was performed with the data for the interfaces and for the individual participants to determine whether there was any significant differences in error rates. The analysis indicated that there was a significant difference in mean error rates between interfaces ($F=8.4$, $p<0.05$). The mean error rate between interfaces was .33 errors per total possible element. There was no significant difference for the mean error rates between individual subjects as well as between the programmer and clinician groups.

Errors were further analysed to determine the cause of the high error rate. Seventy-five percent of all errors made were errors of omission. It is difficult to determine the reason for making an error but in this experiment, it could be attributed to either a mis-interpretation or mis-application of the feedback language, or a mis-understanding of the interface. Errors of omission often indicated that participants mis-understood the interface rather than how to apply the feedback language to that interface. Since we wanted to determine participant's ability to apply the feedback language instead of their ability to understand the interface, errors of omission were eliminated from the data.

Re-analysing the data with the errors of omission eliminated, the analysis of variance indicated that there was a significant difference in the mean error scores between interfaces ($F=3.8$, $p<0.05$). The mean error rate between interfaces was reduced to .10 errors per possible element. The remainder of the analyses discussed in this section will relate to error rates that exclude the errors of omission.

There was a significance difference in mean error rates between the programmer and clinician groups ($t=-2.1$, $p<0.05$). The mean error rate for the clinician group was .07 and for the programmer group, it was .12.

Further analysis of the errors by feedback element indicated that there was a significant difference ($F=2.1$, $p<0.05$) in the mean element error rate (errors by element normalised by total possible elements for an interface). Twenty-eight percent of the errors were responses to the graphic and symbol elements. Most of the errors for these two elements were errors of confusion (mis-labelling) of a graphic for a symbol and vice versa.

To determine the cause of the significant difference in mean error rate between the interfaces, the interfaces were divided into 3 categories of complexity (indicated by the number of possible elements contained in the interface). An interface complexity of low contained less than 10 elements, of medium contained between 11 and 29 elements and of high contained more than 30 elements. Three interfaces were categorised high, 4 as medium and 3 as low. An ANOVA was performed on the error rates for the three categories and there was a significant difference between error rates for the number of elements in an interface ($F=6.1$, $p<0.05$).

DISCUSSION

There was no significant difference between error rates of individual participants, indicating that all participants performed similarly in applying the feedback language to existing interfaces. Based on these results, the intended users (clinicians, interface designers and programmers) of the feedback language developed for this research can thus consistently apply the language to existing interface styles. However, there was a significance difference in performance between the clinician and the programmer groups (mean error rate of .07 for the clinicians compared with a higher mean error rate of .12 for the programmers). As found in the previous experiment (Fels and Chignell, 1992), clinicians seem to have a better understanding of terms in the feedback language due to their experience and use of those terms in other areas. They are thus, better able to apply the terms to computer interfaces.

The overall mean error rate of .33 is high and may indicate that participants have difficulty using the feedback language. However, upon further analysis of the error types, it appears that errors of omission could be attributed to the ambiguities of the interface design rather than any mis-understanding with the application of the feedback language to the interface. As a result of this analysis, participant mean error rates were reduced to .10 (fluctuating between .26 and .03) for all interfaces. While this residual error

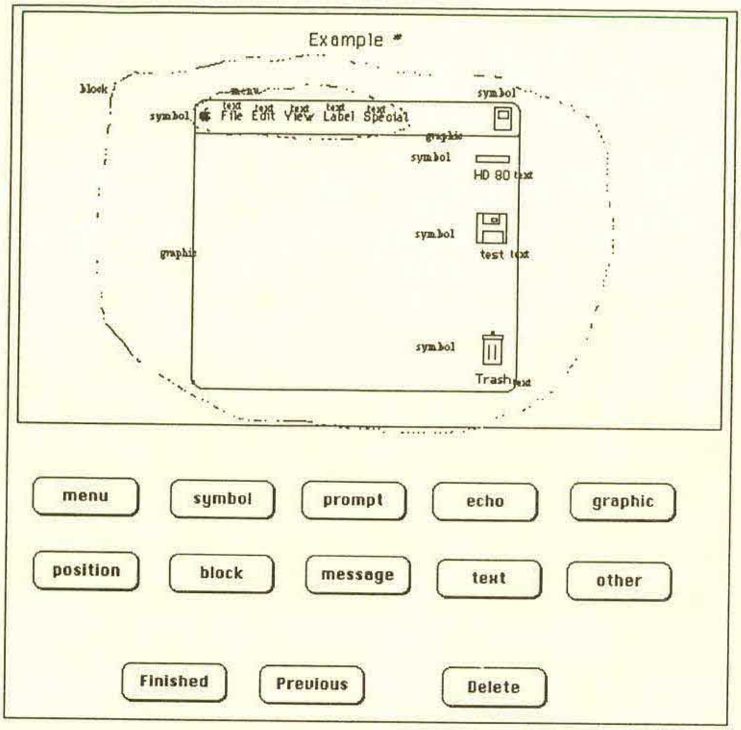

Figure 1: Example of a test interface that has been "stamped" with feedback elements.

rate may still seem high, one would expect it to be reduced significantly with further training and experience.

Among the feedback elements of the language, participants seemed to confuse graphics and symbol most often (of the total errors, graphic and symbol elements had the highest mean element error rate; .28). This indicates that the difference between graphic and symbol on interfaces or in the feedback language definitions is not distinct enough and must be clarified to be more understandable by users. The variance in error rates between interfaces was significant and upon further analysis, the difference could be attributed to number of elements contained within the interface. The results indicate that the lower the number of elements, the higher the error rate (the interfaces in the complexity category of low had the highest mean error rate; .17). However, the interfaces with the lowest number of elements also had a higher proportion of context to content elements. Context elements such as block and message are more abstract and difficult to identify than the content elements such as text and graphic.

The implications of designing a system that could provide feedback in multiple and different modalities using this information feedback language are wide ranging. Not only can designers enhance the flexibility of a system to produce multi-modal displays but in addition, much needed access can simultaneously be provided to these systems for people with disabilities.

The next phase in the process of determining the usability and applicability of the feedback language is to be able to produce a new interface using the feedback language. This new interface would be able to be expressed and understood in the tactile, auditory or visual modalities without any modifications to the structure of the interface or the feedback language. Work is in progress to accomplish this next phase.

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INFORMATION AND REFERRAL SYSTEM CONSIDERATIONS

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ABSTRACT

In the interest of efficiency and system accessibility in the office, computer based information and referral systems are becoming increasingly popular. There are a number of alternatives to system implementation that should be considered during the design stage that will greatly affect the final success of the system. The main decision to be made will be whether to develop the system in-house or use a referral system package already available. This paper will discuss several system considerations that should be discussed and examined by the design or implementation team contemplating the installation of a computer based information and referral system.

BACKGROUND

We will assume here that a study has been completed and the decision has been made to install a computer based information and referral system. The information center may have experienced growth that requires replacement of the existing manual system, or this could be an initial system effort. To implement the information system there are basically two ways to proceed with the design. One, purchase a package currently offered through sources such as TRACE Center and New England INDEX, or two, develop your own system using commercially available database development packages such as dBASE IV, FoxPro, and Advanced Revelation on the medium scale side, or Oracle and DB2 on the large scale side. There are a number of advantages that can be realized by following either path, however, each one requires a much different type of expertise on the design and / or implementation team.

Every group establishing an information and referral system will impose requirements that may not be met in a pre-written package. The development of the system in-house will usually allow more flexibility in determining the type of information the system can contain and the interface presented to the Information Specialist. Demands and system requirements will surely change over time and a high degree of flexibility may be necessary. The subsequent software development and maintenance, however, can be extremely expensive and time consuming.

OBJECTIVE

The objective here will be to examine some basic advantages and disadvantages of software available through the Trace Center and New England INDEX. These packages will be compared to what could be realized through an in-house development effort. In the interest of space we will examine only topics such as implementation costs, expansion capability, and system configuration options.

METHOD/APPROACH

The initial planning stage can be the most important part of system implementation. The more careful design and thought given here can greatly minimize development time.

-Plan your system needs carefully. Involve users that can focus on the problem to be solved, yet not be afraid to say "what if".

-Consider **all** possibilities.

-Examine packages from TRACE Center and New England INDEX. Do these packages satisfy the organizations need?

The following lists a number of key advantages and disadvantages of the software available from these two sources.

Advantages -> Trace CSD
-The Trace Center's Cooperative Service Directory (CSD) software uses a graphics interface for PC Windows and Macintosh users. This will tend to make the system more user friendly and shorten the learning curve.
-The Trace CSD allows for sharing of the information that has been compiled. This information can be sent to remote sites or other states on diskette, thereby sharing your directory.
- Runs on both Macintosh and PCs
-TRACE reputation
-Many users
-Cost : FREE

Disadvantages -> Trace CSD
-The Trace CSD software can tend to operate slowly unless the computer is not **at least** a 33 Mhz 386. (NOTE: This is actually not a limitation of the Trace development effort rather the nature of the PC Windows environment.)
-The software does not allow for compiling any information on the caller. This information may prove to be very necessary to your organization in terms of compiling statistics on number and types of calls received.
-The Trace software does not run on a network. If the site requires access to the system by multiple Information Specialists, there will be much effort spent copying diskettes and sending them to other workstations.
-If the center's requirements change there will be no way to modify the software to accommodate the new demands.

Advantages ->New England INDEX
-The software is written using a DOS based version of DataEase which is designed to run on a network. Since the interface is character based rather than graphic, the software will tend to run faster.
-The character based system is desirable if you intend to allow callers to dial directly into the information system.
-New England INDEX will modify the software to fit your immediate needs. In most cases the source code will also be furnished with the delivered system so that the customer may make future enhancements.

Disadvantages -> N.E. INDEX
- Character based system is not quite as intuitive to learn.
- Runs only on PCs.
- Software cost: > $10,000.00

It may be determined that neither of these packages meet the needs of the information center in question. The other option would be to generate the application using a database development software package. The following is a list of some advantages and disadvantages of this approach.

Advantage -> In-House Development
-System can be tailored to your immediate needs.
-System can be modified to allow for future enhancements
-Choose the development package currently offering greatest features for your particular situation. Some packages offer features that tend to optimize themselves in a network environment where there may be many workstations (example: dBASE IV, FoxPro/LAN). Other packages offer faster development time, yet less than desirable results in terms of overall power. PC Magazine, March, 1992 has an excellent performance and feature review of nine popular database application development packages.

Disadvantages ->In House Development
-Expertise required to **develop** application. It should be noted that most packages offer a development environment that will fall somewhere between little or no programming to considerable programming effort. More powerful and advanced features can sometimes only be realized with **some** programming.
-Expertise to **maintain** application. Don't be fooled, there **will** be an ongoing need for modifications and system maintenance.
-No software development effort is ever really finished.

SUMMARY

The Trace Center offers an excellent graphics oriented package for the user that wishes to put together a service directory that will run in both Macintosh and the PC Windows environment. Three limitations here, however, would be the lack of network support, no capability to log caller information, and slower system operation due to the graphics interface.

New England INDEX offers an excellent character based package for the PC that they will customize to your immediate needs. It is designed for network operation, and can be supplied with source code to allow future modifications. The only negative here could be the cost.

An in-house development effort offers the greatest flexibility to the information center desiring to implement an information and referral system. With careful planning, the system can be modified to follow the changing needs of the center. The development and ongoing maintenance costs may be more of a financial burden than some organizations can absorb.

ACKNOWLEDGMENT

I wish to acknowledge the Center For Rehabilitation Technology, Georgia Institute of Technology, for it's support in the development of our information and referral system. Our initial effort will involve a package from New England INDEX, followed by a larger Oracle based service and product directory that will be wide area networked throughout the state of Georgia.

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Extending the User Interface for X Windows to Include Persons with Disabilities

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ABSTRACT

Computer operating systems with graphical user interfaces (GUI) have proliferated (i.e., IBM OS/2™, Macintosh™, etc.) in parallel with the advent of new and more powerful computer hardware. While studies have shown that GUI systems can increase employee productivity, these same GUI have created new barriers for individuals with disabilities. Since GUI typically do not present information to the computer user in a character-by-character or "text" fashion, past access strategies used by people with physical and sensory disabilities may no longer provide access to such systems.

UNIX workstations running X, combined with a windows manager such as OSF/Motif, are used by companies in areas like banking, hospitals, corporate accounting offices, universities and government agencies. For employees in such fields, a job may depend upon the ability to access these workstations. Until recently, providing any kind of common access solutions for workstations was difficult due to the variation in the underlying platform-dependent UNIX operating system. However, X Windows, developed under the guidance of the vendor-neutral X Consortium headquartered at MIT, can provide the common access platform needed to achieve accessibility solutions for the various UNIX computer workstations.

BACKGROUND

Since the early 1980s, the Trace Center has worked closely with companies like Apple, IBM, and Microsoft to develop strategies which make computers and operating systems more accessible. These strategies have been used to provide access in a number of operating systems (i.e., AccessDOS for IBM computers running DOS, Easy Access for the Macintosh, Access Pack for Microsoft Windows™, and those being built into IBM OS/2).

Many of these strategies have been developed to assist people with physical disabilities in operating the standard input devices (i.e., keyboard and mouse) more readily. People with a moderate physical disability may require assistance in accessing a computer due to one or more of the following reasons:

- An individual may not be able to press more than a single key simultaneously , preventing them from using most programs which require multiple simultaneous key presses. Many times, this is the only major computer access barrier for people who type with a mouthstick or headpointer.
- An individual may have poor coordination with slow or irregular response time capability, which makes time dependent input unreliable. These individuals find themselves generating numerous unwanted key repetitions simply because they cannot release a key within the repeat tolerance of the keyboard.
- An individual may have limited eye/finger (eye/stick) coordination and often strike unwanted keys before targeting the desired key. Those individuals who have hand tremors, eye/hand coordination difficulty, or utilize a headpointer or mouthstick often may spend more time trying to delete unwanted keys than selecting the desired key.
- An individual without fine motor control, with paralysis, tremors, or using a mouthstick or headpointer for computer input, may not be able to control or manipulate a pointing device such as the mouse or joystick with fine enough movements nor activate the buttons on a pointing device such as the mouse while simultaneously maneuvering it.
- Individuals with more severe physical disabilities are often unable to access a computer, even when modifications to the standard input devices are available. These individuals require some mechanism to connect and use an alternate input device(s) to emulate the standard keyboard or mouse.

CURRENT APPROACH

Cooperative development directly between the Trace Center and single companies such as Apple, IBM, or Microsoft to provide access strategies for their personal computers and operating systems was possible and effective because there is only one Apple Macintosh operating system and, until recently, only one DOS. This is not the case, however, with UNIX workstations. Almost every major manufacturer of UNIX computer workstations has UNIX configured to match its particular workstation hardware. While X Windows can avoid many of these platform dependent UNIX differences, portions of X Windows such as the X Server have layers closely tied to the workstation hardware.

Since accessibility issues for all the various computer workstations are becoming a reality, an expanded style of cooperative development is needed. To address this issue, the Trace Center brought together a group of researchers and companies interested in developing access solutions for X Windows. The group is called Disabilities Action Committee for X (DACX). An initial meeting of DACX was held in Minneapolis in October, 1992, in conjunction with the Closing the Gap Conference. Discussion at the meeting centered around what is being done to provide accessibility features for computer workstations. Subcommittees were formed to further research three specific areas: the definition of hooks and library calls needed to provide screen reader access; implementation of screen magnification in X; and implementation of built-in physical access features for X.

Members of DACX at the present time include people from Digital Equipment Corporation, IBM, Bell Atlantic, Bellcore, MIT, Berkeley Systems Inc., Georgia Tech, SUN Microsystems, and Hewlett Packard. The Trace Center is acting as the coordinator and secretariat for DACX, as well as assisting in X access software development and testing. The Trace Center maintains a DACX electronic mail account at the University to allow subcommittee and DACX members to communicate issues quickly. In January, 1993, two papers, one addressing "blind" access issues and the other paper addressing "physical" access issues in X Windows, were presented by DACX members at the 7th Annual X Windows Technical Conference at MIT.

RELATED ACCESS WORK AT THE TRACE CENTER

To maximize compatibility with other access products, the disability access features under development for X Windows are extensions of work previously done for other operating systems/environments. These include, the Trace Transparent Access Module (T-TAM) which is distributed by several manufacturers (September 1990), the Access Pack for the Windows, distributed by Microsoft Corporation (October 1990), and the AccessDOS Software Package distributed by IBM (June 1991).

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Evaluation of the TongueTouch Keypad™

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ABSTRACT

Individuals with physical disabilities who are non-ambulatory and do not have use of their hands are frequently prescribed a variety of separate devices to manipulate their surroundings. Requests are often made for a single multifunctional input device or for a device which is invisible to the non-user. In October 1991, Zofcom Inc. introduced the TongueTouch Keypad™ (TTK), a battery-operated, wireless input device worn inside the mouth, which could control a variety of standard equipment available to this population of disabled individuals. This paper describes a survey conducted with four TTK users and investigates the potential of controlling a wheelchair-mounted robotic arm with the same input device.

BACKGROUND

The TTK, initially sold by Zofcom Inc. and now available from New Abilities Systems, Inc.*, is a 9-key switch device worn in the roof of the mouth like a retainer. When the user presses one of the 9 buttons on the keypad with his or her tongue, the wireless keypad sends a signal to a receiver attached to the wheelchair. The receiver can then control a number of different appliances or devices in the environment. There is a small display unit, usually attached to the wheelchair, which presents a visual display to assist with correct operation.

A previous study compared subjects' performance using the TTK, Headmaster, and a mouthstick[1]. This study found that 1) input speed was fastest for the mouthstick; 2) accuracy did not vary significantly between the three; 3) the rate of perceived exertion was lowest for the TTK; and 4) the TTK rated highest on personal acceptability.

An alternative palatal tongue controller has been designed by Invent Aid** of the United Kingdom. It is a dental plate fitted to the upper teeth with small plates touched by the tongue. A minute receiver and transmitter signals the tongue movements to a coil worn around the user's neck [2]. It has seven keys, no battery inside the mouthpiece, and is designed to control the Invent Aid robotic arm. With further developments, it could also be used to control a wheelchair, computers, and the environment. At the writing of this paper, the system is not commercially available.

OBJECTIVE

The survey was conducted for two reasons. The first aim was to evaluate the TTK's functionality as the only commercially available tongue controller on the market. The second was to look at the potential for modifying the tongue controller to operate the Manus, a wheelchair mounted robotic arm available from Exact Dynamics*** in The Netherlands.

METHOD

Four TTK users were identified with the assistance of Zofcom Inc. and New Abilities Systems, Inc. All four agreed to participate in the study. One survey was conducted in person, the other three were conducted over the telephone. Two of the telephone interviews were conducted with a familiar interpreter (parent or guardian of the user) since the user did not have speech, or had difficulty with telephone communication.

The survey asked questions in the following areas:
- User demographics
- Use and comfort of the TTK
- Reliability of the TTK
- Functionality of the TTK
- Potential use for activating a robot
- General comments & suggested changes.

RESULTS

Demographics: Of the four participants, three were male students between the ages of 18 and 21. The fourth was a female, over forty, who runs a home for developmentally delayed foster clients. Two were disabled with cerebral palsy (CP), two were spinal cord injured (SCI). Of the latter, one was a C-5 quadriplegic, and one C 4-5 complete quadriplegic, with both about 2 years post injury. All had use of the TongueTouch Keypad for at least six months prior to the survey.

Use and comfort: The use and comfort varied dramatically across the four surveyed. All four users said that it took about 10 minutes to learn the functional control of the unit. Two users said that it took about 2

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months to feel comfortable activating the device reliably, and one never achieved competence. Only two of the four users were still using the device when surveyed. One had discontinued use because the receiver malfunctioned and s/he had enough functionality within his/her environment without it, so did not get it repaired. Another discontinued use because s/he could not comfortably activate the device because the thickness of the keypad caused a gag reflex and the user could not accurately activate some of the buttons. In each case, the disuse may have been related to the individual's disability. In the first case, there was enough residual hand function to manipulate the environment using hand splints (C-5 SCI). In the second, cerebral palsy limited accurate tongue manipulations, making access to the back buttons impossible.

Length of use: Of the two who continued use, one uses it 4-5 hours/day, 7 days a week, the other 7-8 hours/day (4-5 hours during the day, then an additional 2-3 hours during the evening), 7 days/ week. Before discontinuation, one had used it for 4-5 hours/day, about 3 days/week, while the other had used the device for about an hour/day.

Three of the four needed assistance in putting in and taking out the device. The individual with a C-5 SCI was able to insert and remove the device on his/her own. Body position (lying down) did not affect control for two users; the other two never tried it. However, one user noted that the short functional range of only 1-2 feet from the receiver made the device non-functional from bed if the wheelchair-mounted transceiver was too far away.

Eating: None of the users ate with it in. One said that s/he could, but that it was not practical. The second said that s/he did not like to, and the third said that s/ he was afraid of damaging it and did not want to try it. The last had not attempted eating with it at all.

Drinking: Three of the users did drink with it in place, but one said that it felt weird having liquid flow above and around the TTK. Again, the fourth did not attempt drinking with it in place.

Battery replacement: Three users said that the battery replacement was not a problem. Of these, the first user said that 1 battery lasted 6 months, and a second battery for 3 months. The second had used the device for about 9 months and had not yet needed to replace the battery. The third did not have to replace the battery in a 6 month time period before the receiver malfunctioned. The fourth individual's battery died after its use was discontinued (within six months). All had a back-up controller except the fourth who had sent the mouthpiece back for modifications.

Distortion of speech: Three users said that it did distort speech but had varying degrees of difficulty. One of the SCI users said that the distortion wasn't significant, while the second said that it was difficult to be understood on the speaker phone. One user with cerebral palsy said that the speech distortion was significant. The second CP user does not have speech.

Shape, size & comfort: Three users said that they would like it better if it were thinner, one did not. One of the three had a family member file down the mouthpiece, which made the device more comfortable. The user who suffered from a gag reflex sent the unit back to have the buttons moved forward and have the mouthpiece shortened. This helped to diminish the gag reflex, but did not resolve the problem. The remake also caused discomfort in that it was tight around the teeth.

Reliability: For the SCI users, reliability was very high (90% or better). The front buttons and center buttons were the easiest to hit. One had difficulty with outside center row buttons, the other had difficulty with the back left button. For the CP users, one was 70-80% reliable, while the other never achieved reliability. The back row of buttons were the hardest to activate for both.

Functionality: One CP user chose only to operate a computer keyboard and mouse with the device and regarded interaction a great success. (The TTK is the only interface this person has for computer access.) One SCI user, who is frequently alone for up to 4 hours at a time, prefers a mouthstick for typing on the computer, but can use the mouthstick with the keypad in place. This allows the user to keep working should s/he drop the mouthstick and be unable to retrieve it. This person also uses it for lights, a heater, a fan, and a radio, but the TV caused too much interference and the telephone interface was too unreliable to meet the user's needs. The other SCI user had controlled the TV, VCR, lights, computer keyboard and mouse, before the receiver malfunctioned. An attempt was made to interface the device with the telephone and bed, but neither was successful. The fourth never achieved enough functionality to use the controller with any devices.

Three out of the four would like to control their electric wheelchair with the device, the fourth said that s/ he didn't need it because s/he had a joystick controller that worked satisfactorily. (At the time of the survey, wheelchair control is pending FDA approval). One also said that s/he would like to open and close doors using the TTK.

Each user had a different means of alternate interface:

- another person to do everything;

- a mouthstick for keyboard, but another person for environmental control;
- a KY Enterprises ECU and Headmaster system for the computer;
- residual hand function for the telephone, VCR, lights, and computer, but another person to turn the computer on and off and move the bed.

The first two listed are the two who are currently using the device.

Use with a wheelchair mounted robotic arm: Three out of the four users said that they would like to operate a wheelchair mounted robotic arm with the TTK, but one voiced a concern that the fragility of the robot might limit his/her lifestyle (which included working out in the barn with horses). Consequently, this person wanted a robotic arm which was easy to attach and detach. All three required an attendant or family member to accomplish tasks listed as those performed by the Manus robotic arm, and all three wanted the robotic arm no matter how long it took to accomplish a task. The fourth said that s/he did not feel that it would provide enough function to warrant the effort of acquisition (this person had residual hand function and accomplished some of the tasks listed as those performed by the robotic arm, with the use of his/her hand splints). All users said that they could not use the robotic arm if it caused their wheelchair to be 6 inches wider, but that the weight was not a problem.

General comments & user suggestions: All users agreed that the TTK was desirable because it was invisible, added independence, and provided the ability to control the environment. One user voiced a desire for a longer battery life and another for an improved telephone interface because the one available was too bulky and not reliable. Another said that the receiver was unreliable and its range was too short (1-2 feet). One very technically knowledgeable family said that there was too much equipment to hook up and there needed to be better technical support.

Number and placement of buttons: The SCI user who chose to discontinue use said that s/he would like to have 10 buttons so that s/he could dial a unique number on the telephone. The same person said that all 9 buttons were necessary to provide functionality. The other SCI user said that s/he did not want any more buttons added because they were already operating at a maximum number of buttons for the limited space. The CP user who had sent the unit back to have the buttons moved forward and the keypad shortened was assisted in comfort but still did not have accurate activation. This user suggested that if the device was concave in shape, then it would both allow the buttons to be spaced further apart, and might add enough room to add more buttons. The same user said that s/he was able to accurately touch 8 different places on the inside of his/her teeth and that if the buttons were located there, then s/he could have accurate control.

Finally, the user who previously had no other means of control "changed from an observer to a full participant overnight".

DISCUSSION

The TTK clearly addresses the consumers' request for an invisible, multiple-input device. The aesthetic qualities of the TTK are rated very highly. The users, however, indicated that reliability is equally important for functional use, and two of the users experienced difficulties with reliability (one with the TV interference and telephone, and the other with the TTK receiver). The user's physical abilities directly correlated to their successful use of the TTK. The user who was not able to use the tip of his/her tongue to touch the keys was not successful. The other user with CP also demonstrated less accuracy. However, the latter was a successful user probably due to the fact that this individual had no other means of controlling computer input. Hand function played an important part of the user's success with the TTK. The user who was able to manipulate the environment with some hand function preferred that mode of input over the TTK. Finally, the population of successful TTK users is consistent with the population of potential wheelchair mounted robotic arm users. The multi-functionality provided with the TTK indicates that this device could be an ideal interface for a robotic arm provided that reliability and accurate functionality are assured.

ACKNOWLEDGEMENTS

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HAWKEYE, A "PENLIGHT" HEAD POINTER

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ABSTRACT

The cordless optical head pointer, Hawkeye, replaces the mouse for Windows 3.1. It includes a remote unit and a base unit. The remote unit, which is battery operated, is placed on the user's head. The user sits anywhere, up to two meters, in front of the computer. The base unit is placed next to the monitor and connects to the computer's mouse port. Infrared light pulses are transmitted from the base towards the remote. The incident light is focused on a Position Sensing Detector (PSD). The electronic circuit measures the position of the incident light dot on the PSD and calculates the corresponding rotations of the remote unit. The measured head rotations are converted into cursor movement on the screen. Better than 10 bit resolution allows the user to move the cursor to each pixel with ease. All the mouse buttons functions are implemented by time and position selection. The user can change all parameters: Needed head rotation (vertical and horizontal), stability, responsiveness, slow mode, mouse functions, and time.

BACKGROUND

Different head pointers exist on the market today.
Penlight head pointer
Penlight head pointers is used by persons with disabilities for communication and selections. The penlight is worn by the user, who shines the light on a piece of paper with written symbols placed in a matrix. It is really low tech.

Optical head pointer for dedicated communication aids
A) LightTalker.
The light talker communication aid from Prentke Romich uses a matrix of infrared light diodes (LEDs) and optical sensor. The sensor is worn by the user and connected to the communication aid by a cord. The system lights the LED which the user is pointing to. A new head pointer for the Liberator is just announced.
B) RealVoice
The RealVoice communication aid from ACS Inc. uses an active light source and a matrix of light sensors and visible LEDs. The light source is worn by the user and connected to the communication aid by a cord. The system lights the LED which the user is pointing to.

Long Range Optical Pointer (LROP)
The long-range light pen is developed by the Trace Center. It was originally developed for use with two CRT monitors , and a cord is needed between the user and the electronics. The current new versions of this system can be used with only one CRT monitor, but the user must look away from the CRT in order to send typed text to the application software. It only works with CGA graphics monitors on IBM PC's. This system cannot be used with a laptop. New improvements to the LROP are being made by the team at Hugh MacMillan Rehabilitation Center.

HeadMaster
The HeadMaster head pointer from Prentke Romich is based on ultrasonic technology. It consists of on transmitter and three receivers. The user must wear a head set with three transducers and a switch, and this head set must be connected by a cord to an electronics box. The user is hooked up to the computer and must wear a bulky head set. The system works as a mouse replacement on a personal computer. This system cannot be used with a laptop.

FreeWheel
The FreeWheel head pointer is a cordless infrared head pointer system, which draws its power from the computer's serial or mouse port. The system is based on infrared technology. The user wears a small retroreflective target, which is lightweight and cosmetically pleasing. The system includes a time and position button function. The system works as a mouse replacement on a personal computer. This system can be used on a laptop computer.

STATEMENT OF THE PROBLEM

Different problems exist with the existing head pointers.
Cordless
Most of the existing head pointers are not cordless. It is essential for the person with disabilities that the head pointer is cordless for maximum independence.

Workarea
All the corded head pointers have a problem with the workarea; they can only operate as long as the cord reaches. Some head pointers have problems with the limited work area in which the user had to be positioned during operations, and problems with realignment and resolution. Some systems require extremely good head control.

Computer access
Only the FreeWheel and the headMaster head pointers work directly as mouse replacements on personal computers. Many disabled users can not operate any buttons or switches, so the software driver needs to include a time and position function switching.

Many physically disabled people lack the fine motor skills needed to use a standard mouse and/or trackball on a Personal Computer. There is a need for the development of special cursor controllers and associated software drivers, which allows the disabled user access to graphics software while utilizing the motor skills they have left. The Hawkeye headpointer system was developed in order to fulfill such a need.

RATIONALE

Hawkeye is based on infrared optical technology - a fusion of the penlight and the infrared remote controller which resulted in an ideal head pointer. The Hawkeye system utilizes the most intuitive access, natural pointing , what could be easier. The user simply points to where on the screen he or she wants the cursor with the "penlight" type remote unit. The user is free to move around anywhere in an area of up to two meters in front of the computer. The miniature size (about the size of a small dice or 15 mm cube) and low weight (less than 2 grams) of the optical part of the remote "penlight" unit allows for adaptation to any application. Significant breakthroughs in the optical design provides a resolution of better than 10 bits, better than any existing head pointers, and allows for ease of use even with high resolution monitors.

DESIGN

The Hawkeye is an improved long range optical pointer operating with infrared light. (Reference 1-3) The Hawkeye system consists of a remote unit (which includes a camera) and a base unit. The camera is placed on the user's head. The user sits in front of a computer. The base unit is placed in the vicinity of the computer's screen. The Base unit is connected to the mouse port on the computer. The Hawkeye moves the cursor on the computer screen. The Hawkeye works as a mouse replacement. By the use of keyboard emulators on the screen the user will have full access to the computer.

Short infrared light pulses are transmitted from the base unit towards the remote unit. The incident infrared light is focused on a position sensing detector (PSD). The electronic circuit measures the position changes of the incident light dot on the PSD and calculates the corresponding position changes for the remote unit. The incident light dot's position changes on the PSD is converted to cursor position changes on the screen. The cursor position changes are sent to the computer.

DEVELOPMENT

The Hawkeye system, Figure 1, consists of a stationary base unit and a remote unit, which the user moves in order to move the cursor on the screen.

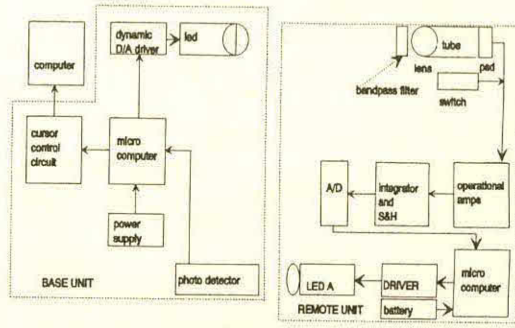

FIGURE 1 CORDLESS OPTICAL POINTER

The remote unit consists of a camera with selection switches and an on/off switch, operational preamplifiers, and Sample and hold circuitry, A/D converter, microcomputer, battery, and a data link LED with its driver. The camera consists of a focusing lens, an elongated tube and a Position Sensing Detector (PSD). The PSD can be either a dual-axis Charge Couple Device (CCD) or a dual-axis Lateral photo detector. The remote unit is powered from a battery. The base unit consists of infrared data link receiver, cursor control circuit, dynamic gain control driver, microcomputer and an infrared LED. The use of the dynamic gain control of the intensity of the pulses transmitted from the LED allows for a much wider range of operation, faster response time, and shorter pulses.

The camera measures the position change of the incident light caused by the movement of the remote unit. It transmits this data back to the base unit via an infrared data link. The base unit receives the transmitted infrared data signal via an integrated light detecting unit. The microcomputer translates the data into cursor movement on the screen. The position LED and the data link LED do not transmit at the same time.

<u>Remote detector movements</u>
The hawkeye system can detect rotations of the remote unit in the vertical plane and in the horizontal plane. It can also detect translations in the vertical and the horizontal plane. The PSD must be oriented so that its horizontal axis is close to parallel with the computer screen's horizontal axes. If these axis are not close to parallel the cursor movement will not be horizontal when

the user moves horizontally and the cursor movement will not be vertical when the user moves vertically.

Work area
The work area of the Hawkeye system is determined by the radiation pattern of the LED and the amount of power transmitted from the LED. The Hawkeye works anywhere up to two meters from the monitor. The maximum rotation angles for the remote unit depends upon the optics in the camera.

Position Sensing Detector (PSD)
The Position Sensing Detector (PSD) used currently in the Hawkeye system is a dual-axis lateral photo diode. It consists of two light-sensitive square plates. A current will be generated in the plates when hit by an incident light dot. The current will flow through the two horizontal electrodes and through the two vertical electrodes. The difference of the currents is dependent upon intensity and position. The sum of the two currents are dependent upon intensity only. Measurements of the four currents can therefore be used to find the vertical position x and the horizontal position y. The lateral photo diode measures the position of the center of the centroid of the incident light dot. This means that inexpensive lenses can be used, since no position measurement accuracy is lost due to blurred images.

Accuracy and resolution
The Hawkeye system is an absolute measurement system and the conversion factors between PSD position and screen position depend on the PSD's measurement resolution and the computer screen's pixel resolution. The position resolution on a lateral photo diode is the same for the horizontal and the vertical plane. The pixel resolution on a computer is generally higher in the horizontal direction than in the vertical direction so the conversion factors are generally different for the two directions. The current Hawkeye system has a ten bit resolution in both directions. This translates to 1024 by 1024 pixels.

Software driver
A software driver for cursor controllers for disabled persons is developed for use with Windows 3.1 on IBM and compatible personal computers. The software is fully Microsoft mouse driver compatible. The software has two parts: 1) Reading of the electronic signals on the mouse port and placement of the cursor on the screen, and 2) Time and position functions for mouse buttons. The cursor control parameters controls: 1) The movement available left-right, 2) The movement available up-down, 3) Stability: Low-pass filtering for tremors, 4) Responsitivity: Weighted running averages for "speed" control, 5) Slow motion: for fine cursor control with coarse motions. The time and position button parameters control: 1) Time before switch action, 2) Size of area used for time control, 3) Switch mode: left or right switch, one click, two clicks, and drag. The software allows the disabled user to select even the smallest icons with ease with whatever motor control he or she has left.

EVALUATION

The Hawkeye head pointer has been tested by our consumer advocate on staff. The Trace Center serves as beta tester and clinical evaluation Center for this project. Results from the clinical evaluations will be reported at a later conference. These results will include guidance for setting of all the parameters for various physical disabilities.

DISCUSSION

A beta test version has been developed of the Hawkeye head pointer. A software driver for Windows 3.1 has been developed. The software driver includes cursor control and time and position mouse button functions. The system has been tested extensively. It can be used by persons with disabilities who could not use a head pointer before.

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SOFTWARE DRIVERS FOR POINTERS USED BY PERSONS WITH DISABILITIES

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ABSTRACT

A software driver for cursor controllers for disabled persons is developed for use with Windows 3.1 on IBM and compatible personal computers. The software is fully Microsoft mouse driver compatible. The software has two parts: 1) Reading of the electronic signals on the mouse port and placement of the cursor on the screen, and 2) Time and position functions for mouse buttons. The software is developed to work with the Hawkeye optical head pointer (Reference 1-3), but will work with other pointers as well. The software includes many different parameter settings, which allows the disabled user to select even the smallest icons with ease with whatever motor control he or she has left.

BACKGROUND

The new software for the personal computer is graphics oriented. The mouse and trackball are the standard cursor controllers for the personal computer. A software driver reads the electronic signals from the device on the mouse port and/or serial port and converts these signals into cursor movements on the computer screen. For IBM and compatible computers such a software driver must be fully Microsoft mouse driver compatible (Reference 4), since Microsoft develops the very popular Windows 3.1 operation software. It is possible to operate the computer from the keyboard only, but doing this would not take full advantage of the powerful Graphics User Interface (GUI). The new software is written for the most part with a cursor controller in mind.

STATEMENT OF THE PROBLEM

Many physical disabled people lack the fine motor skills needed to use a standard mouse and/or trackball on a Personal Computer. There is a need for the development of special cursor controller and associated software drivers, which allows the disabled user access to graphics software while utilizing the motor skills they have left. The mouse and its software driver serve two functions: 1) Placement of the cursor on the screen and 2) Activation of the buttons, which includes: Left or right button, single click, double click and hold down. Many disabled users can not operate any buttons or switches, so the software driver needs to include a time and position function switching. The software drivers described in this paper are developed for the Hawkeye headpointer system in order to fulfill such a need.

RATIONALE

The special pointer and the software driver must be able to allow the person with disability to move the cursor into even the smallest icons on the screen and to make the desired mouse button actions. They have to facilitate all this taken into account the users lack of fine motor skills. The software needs to be flexible to adapt for different disabilities and computer usage. All different parameters must be easily adjustable and be able to be adapted for each individual user for their optimal operation. The cursor control parameters controls: 1) The movement available left-right, 2) The movement available up-down, 3) Stability: Low-pass filtering for tremors, 4) Responsitivity: Weighted running averages for "speed" control, 5) Slow motion: for fine cursor control with coarse motions. The time and position button parameters control: 1) Time before switch action, 2) Size of area used for time control, 3) Switch mode: left or right switch, one click, two clicks, and drag. The clinician must also be able to set the parameters while the client is operating the device in a clinical setting. The software is divided into two parts one for cursor control and one for mouse button function controls, since some users needs only cursor control. The software must be easy install, to use, menu driven, and help menus provided. The software must be fully Microsoft Windows compatible and follow all the standards for development under Windows (Reference 5).

DESIGN AND DEVELOPMENT

The software design is divided into two parts: 1) Reading of the electronic signals from the device on the mouse port and placement of the cursor on the screen, Cursor driver and 2) The time and position button function, dbutton. The two parts work well together, but can also work by themselves.

Cursor control

Figure 1. Shows the control panel for parameter adjustments for the cursor controller.

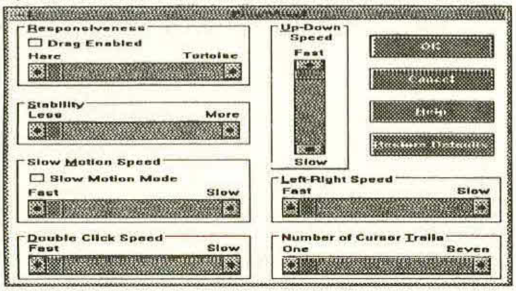

FIGURE 1. CURSOR CONTROL PANEL

A) Adjustment of rotation angle

The left-right speed adjustment cuts the receiving angle of the camera in the horizontal direction. Slow gives the full rotation angle and fast gives the smallest percentage of the rotation angle (typically 25%, but could be as low as 1%). The driver takes whatever percentage of rotation angle the setting is set at and forces these measurements to move the full range from left to right for the cursor on the screen. This means in the slow setting it takes typically a 40 degrees rotation angle to move the cursor from the left of the screen to the right of the screen. In the fast setting it takes a 10 degrees rotation angle to move the cursor from the left of the screen to the right of the screen. Settings between slow and fast will take a rotation angle between 40 degrees and 10 degrees. The up-down speed adjustment is the same , but just for vertical rotation motions. It results in lower resolutions, if the full rotation angle is not used, but it allows the user to reach the whole screen with less motion.

B) Stability

The stability is basically a low pass filter, which allows the user to be unstable, meaning moving the Hawkeye slightly (small tremors) without the cursor moving on the screen. It simply filters out any motion in a small box around the current cursor position. The system keeps averages of the last measurements and compare them to the next measurements.

If abs(x(t)-x average) < delta x min Then calculate new average, but do not move the cursor
Else calculate new average x new average and move to this position
Continue

C) Responsiveness

The responsiveness is made in order to "fool" the host system. It is only useful if the Hawkeye does not have as much resolution as the host system. The software driver keeps track of the measurements over time and makes weighted averages. The weights of the different measurements are dependent on the time they are received and the distances away from the past averages and past measurements. The cursor will get a dragging motion, seems to be a little slower in following motions, but will be able to follow access every pixel no matter what the resolution is for Hawkeye and the host system.

If abs(x(t)-x average(t)) < delta x (t) Then x(t) = w1 x(t) + w2 x average (t) Else x(t) = w3 x(t) + w4 x average (t)
Continue

The weights depends on the abs(x(t)-x average (t)) .

D) Slow motion mode

The slow motion mode allows the user to utilize higher resolution in a smaller area on the screen. This parameter takes the full rotation angle and uses it to move the cursor for only part of the screen. In the fast setting, the largest amount of screen will be utilized for the lowest resolution. In the slow setting, the minimum of the screen will be used for the highest resolution. The fast setting typically allows the user to use the full 40 degrees of rotation angle to move the cursor in 25% of the screen display. The slow setting typically allows the user to use the full 40 degrees rotation angle to move the cursor in 10% of the screen display. The percentages can however have any values down to 1 %. The user can shift between slow motion and regular motion speed by simply moving the hawkeye rapidly. Slow motions of the camera will revert the operation back into slow motion mode. It allows the user to access each pixel on the screen no matter how high the resolution is on the screen, even if the Hawkeye system does not have as high resolution in the rotation angle.

Time and position functions

A) Time and position "buttons"

FIGURE 2. MOUSE BUTTONS

Figure 2. Shows the mouse button function settings icons.The software driver also facilitates time and position activation of the mouse button functions. The user can adjust the time he/she has to keep the cursor in a selected area in order for the wanted mouse button function to be activated. The function can be: 1) one click, 2)double click, or 3) drag.

If abs(x(t)-x average(t)) < delta xt(t) And t >= t min Then perform button function, t=0
Continue

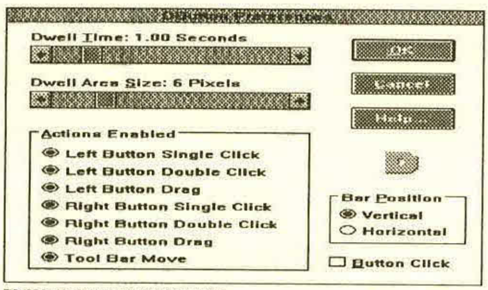

FIGURE 3. CONTROL PANEL MOUSE BUTTONS

Figure 3. Shows the control panel for the mouse button function time and position adjustments. The user can also adjust the size of the area in which the timing is accomplished and choose between right and left button.

Clinician control
The clinician or helper can adjust all the above parameters in for the cursor control and the time and position function from the keyboard. This makes it easier for the clinician in the evaluation process.

EVALUATION

The software has been tested by our consumer advocate on staff. The Trace Center serves as beta tester and clinical evaluation Center for this project. Results from the clinical evaluations will be reported at a later conference. These results will include guidance for setting of all the parameters for various physical disabilities.

DISCUSSION

The software has been developed and tested extensively. It is found to be fully compatible with Microsoft mouse driver and Microsoft Windows 3.1. It has been found to work very well with the Hawkeye head pointer, the FreeWheel head pointer, Trackballs, and mice. The mouse and trackball are now also easier to use for the person with disabilities, because of the compensations for lack of fine motor skills available in the software.

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ACKNOWLEDGMENTS

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Typing by Voice On The Macintosh

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Introduction

Voice input to a computer seems, at first glance, to be a "natural" input method. If the computer could only understand spoken input, using one would be no more difficult than asking another person for help. Nearly all science fiction, from Star Trek to Isaac Asimov's robot stories, assume voice input.

In practice, however, voice input is neither natural nor easy. In the few years that it has been available, it has made striking progress, but it remains quite limited. Systems like Dragon Dictate have very large vocabularies, and quite high accuracy rates from an engineering viewpoint, but are very expensive, and require very powerful computers to operate. To be accessible to the typical user, voice input systems must be less expensive, and operate on lower cost computers.

Low-cost voice input systems generally have a very limited vocabulary, and are not intended as general text entry systems. Rather, they are designed as interface control systems, which will issue a limited set of commands. It is possible to include the alphabet in the command set of such a system, to allow voice input, but letter-by-letter typing via voice is generally not considered a viable input technique.

If letter-by-letter voice input is combined with a word prediction system, significant improvements in efficiency might be realized. The combination of low cost voice input with word prediction might provide a functional method for voice text input for individuals with limited resources.

The current project is an exploration of voice input on the Macintosh family of computers using the combination of a low-cost voice control system and word prediction.

Approach

The voice input system selected for this project was the Voice Navigator SW, from Articulate Systems. This software-only voice control system will operate on any Macintosh computer which incorporates the built-in sound input circuitry, and sells for under $400. The software was run on a Macintosh IIsi computer, with five megabytes of memory and an 80 megabyte hard drive, running System 7.0. Voice Navigator is intended primarily as a menu control system, and not as a text input system, but includes text entry capabilities.

Voice Navigator allows the creation of application specific "languages," which may contain up to 200 commands at any "level." Through grouping, it is possible to create a sub-language which can be accessed from within voice Navigator, but which only occupies a single "command" at the top level of the language. This facility makes it possible to create a "text input" level within a complex application, and have a 200 command language available for text input. Each command can be a single keystroke, or a series of keystrokes for commonly used phrases.

After exploring a number of alternative approaches to a voice input language, we settled on a strategy of including the international radio alphabet for single characters, and the most common words of less than four letters as direct input entries. This strategy removes the need to remember if a word can be simply said, or must be spelled out. If the word is less than four letters, it can be said. (This strategy required some modification: see below.)

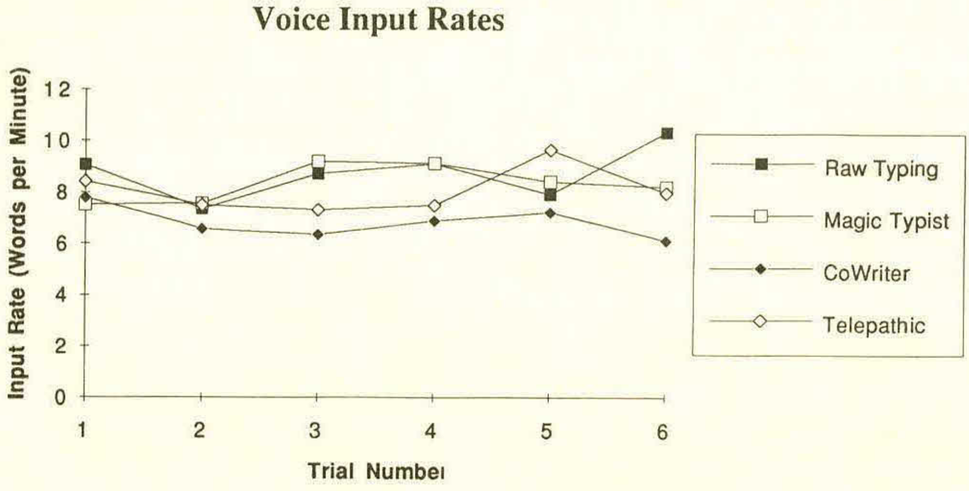
The study combined Voice Navigator with the currently available word prediction systems. The text passages were taken from standard reading comprehension tests, and required reading levels from 6th through 12th grades. All input was performed by the investigator over a period of approximately three months.

The Navigator was paired with the currently available word prediction systems for the Macintosh in this study. The systems compared were CoWriter, from Don Johnston Developmental Equipment; Magic Typist, from Tactic Software; and Telepathic, from Madenta Communications.

Co:Writer, from Don Johnston Developmental Equipment includes a forty thousand word, grammar sensitive prediction dictionary. Text input is performed in a "Writer" window, and the composed text is injected into an application at the end of each sentence. Co:Writer's prediction guesses can be from 1 to 9 words, including an "in line" prediction of the most likely word. Co:Writer does not normally "repredict" words. That is, if a word is displayed and not selected, it is not displayed when the next character is entered. Since the researcher finds the demand of scanning the prediction list after each character to be cumbersome when typing from copy, we included a "right arrow" in each character code to force reprediction. The speed of prediction did not seem to be greatly affected by this addition.

Magic Typist is a relatively simple word prediction program that was developed for computer programmers. This low cost program provides a simple alphabetical list of words from its dictionary as the user types in a pop-up window. Since the program works as a system extension, no specific action is necessary to start word prediction. Magic Typist can be configured to only learn words over a certain root length, and to only predict after the user has typed a certain number of characters. This can avoid distracting changes to the screen while typing short words. The current version of Magic Typist is delivered with a list of 7,000 common words, but inclusion of this list in the program makes the performance of the computer as a whole unacceptably slow.

Telepathic, from Madenta Communications, is a free standing application, like Co:Writer, but allows typing directly into the user's application. When a desired word is displayed in the Telepathic window, the user can select it by either clicking on it with a mouse or by typing the number preceding the word. Telepathic predicts words based on the statistical likelihood that it is desired. This decision is made based on the relative number of times the word has been selected in the past. Telepathic also offers "next word" prediction, but this feature was not used in the study as response times were unacceptably slow with version 1.1 of Telepathic.



Procedure

All input was performed using a Shure SM10A headset microphone, which was connected through the Mac IIsi microphone port.

In each session, the word processor and word prediction system were activated using the standard mouse and keyboard functions. (As a separate test, the setups were also completed using voice input only.) Text was entered from printed copy supported to the left of the monitor, in the plane of the monitor. Special "languages" were developed for the Telepathic and Co:Writer inputs. Magic Typist uses keyboard controls roughly equivalent to those of Telepathic, so the same control language was used. For Co:Writer, the language used for Telepathic was adapted to type a "\" character after each word, and a "right arrow" after each character. These commands "chop" a word at the letters typed, and force "best guess" prediction.

With all word prediction packages, the time spent scanning the prediction list was minimized by using a "type three then look" strategy. With this strategy, the user types three letters before looking at the word prediction list. After having typed three letters, the desired word is nearly always an available prediction. Use of this strategy required modification of the basic operation of CoWriter, which does not generally repredict words. If CoWriter had predicted the desired word on the first or second letter, it would not be available after the third letter. Adding a "right arrow" character after each letter of the alphabet forces CoWriter to repredict words, and allows use of the same strategy as was used with the other Word Prediction packages. Magic Typist can be configured to only start predicting after three letters have been typed, which naturally lends itself to this approach.

Timing for the session was from the first character typed until the last character typed. For each session, the date, total time, and number of words typed were recorded. From this information, an average "words per minute" statistic was computed.

Results

In general, the performance of all systems was fair. Voice Navigator is quite sensitive to background noise. It will work in a noisy environment, but must be trained at various noise levels. In some development sessions, the noise of a printer in the same room would degrade recognition until the system was retrained. Extensive training support would be necessary during the set-up phase of the device for a person with a disability.

The recognition speed of Voice Navigator is quite fast, as indicated by the "raw typing" input speeds. Voice Navigator, working within a word processor, will recognize an average of 1 character per second. The Voice Navigator will recognize at a faster rate, and will buffer recognitions, but for text input, the probability of incorrect recognition limits effective typing speeds to 1 character per second. Once the user learns the rhythm of the input, s/he can progress quite smoothly. Using Voice Navigator alone, it is possible to type text by spelling each word. This approach produces an average typing speed of 8.74 words per minute.

When combine with CoWriter, all text input takes place in a text box created by CoWriter. At the end of each sentence, CoWriter injects the new text into the base application. CoWriter's 40,000 word dictionary contained most of the words of the sample texts, so typing efficiency was very good. There seemed to be virtually no wait between predictions, so that it appeared that typing was significantly faster than typing without a word prediction package. However, typing speeds with CoWriter ranged from 7.7 to 6.1 words per minute, with an average speed of 6.82 words per minute.

Magic Typist did not begin predicting until three letters had been typed. When Magic Typist has a prediction, it flashes the menu bar of the computer and opens a window with a prediction list. Magic Typist automatically learns words that are longer than the set threshold as the user types. As noted above, the performance of the computer decreases as the vocabulary increases, so over time the results obtained with Magic Typist may decrease. During this study, Magic Typist produced typing speeds ranging from 7.5 to 9.2 words per minute, with an average speed of 8.34 words per minute.

Telepathic places a small word prediction window on the screen which displays the program's predictions. Though it is possible to use a "next word" prediction mode with this program, the delays that this introduces in prediction were considered to exceed the advantages obtained. (If efficiency were the primary concern, this would not be true.) Words are selected from the prediction list by typing numbers from either the numeric key pad, or the keyboard, depending on configuration. This splitting of the number keys allows both numbers and words to be selected by typing numbers, depending on the number key pressed. In this study, Telepathic produced typing speeds ranging from 7.3 to 9.7 words per minute, with an average speed of 8.06 words per minute.

Discussion

The unexpected result of this study was that the fastest average typing speed was obtained by using Voice Navigator without a word prediction package. However, this speed is obtained at the expense of increased fatigue, and poor acceptance. It appears that for all word prediction systems tested, the delays caused by the need to scan the prediction list, and for the program to find the desired words exceeds the speed gained by not having to speak all of the letters of a word.

A second unexpected result was the speed advantage of Telepathic over CoWriter. In its current version, Telepathic would often lag behind typing, forcing the user to wait while its predictions caught up. With CoWriter, the predictions were virtually always immediate. However, at the end of each sentence, CoWriter spends several seconds inserting the text into the word processing application. From the results, it appears that this delay is greater than that of waiting for Telepathic. In use, CoWriter feels faster because the user can watch the progress of the sentence appearing in the word processor rather than having to wait to make a new selection.

The input "language" for direct entry requires further refinement. Voice Navigator is not designed to provide high level discrimination. In fact, it uses just eight points to create the voice pattern for each command. Because of this, Voice Navigator is not able to discriminate homophones, or even very similar words. We consistently experienced confusions between "and" and "end" as single utterance entries. Even exaggerated pronunciations did not resolve this conflict, and we ultimately removed "end" from the vocabulary. We had to train the word "as" by exaggerating the "Z" sound to allow separation from the word "has." Use of Voice Navigator for direct entry requires careful evaluation of word frequency to allow unambiguous text entry.

Ultimately, no single word prediction package produced an overwhelming advantage over the others. All of the systems produced typing speeds in the range of 7 to 8 words per minute, with variation between sessions. Based on these results, it would appear that the selection of a word prediction package for use with voice input should be made based on personal style. Some people find CoWriter's input window to be intrusive and distracting. Others like the options of in-line prediction and large-print prediction lists. Some users prefer the "here when you need it" window of Telepathic, others may not find the cues strong enough to suggest that they use it. Although Magic Typist was the least expensive, and the quickest word prediction program used in this test, experiments with the provided word lists suggest that it may slow unacceptably with increased use.

Future developments may significantly change the results of this study. A future version of Telepathic promises faster word prediction, so that the problem of waiting for the predictions will be removed. Also, next word prediction will be faster, potentially increasing typing rates significantly. Likewise, it appears that most of the delay in using CoWriter stems from the text injection from the Writer window into the word processor. If this process can be made more efficient, typing speeds with CoWriter may increase significantly.

Conclusions

With current technology, voice input is possible on the Macintosh, but it is not fast. On-screen keyboards, Morse Code, and other "virtual keyboard" input methods are significantly faster. Voice input is not as "natural" as it might be, due to the need to spell words out a letter at a time. The typing speed of 8 words per minute obtained with Voice Navigator is at the very lowest levels of functional input.

Adding word prediction to voice input does not appear to increase typing speeds, though it does increase efficiency of typing. The delays introduced by the word prediction packages, combined with the need to scan the prediction list overwhelm any speed advantage obtained by having the word predictor complete words. However, the reduced vocalization makes text input easier, and allows the user to continue over longer periods of time.

Voice Navigator allows typing at from one half to one third of the rates obtainable from VoiceType on MS-DOS computers, which is a true voice input system. However, VoiceType requires significantly more computer power, and costs $3500. It appears that Voice Navigator, in conjunction with any of these word prediction packages can provide one third of the input rate at one tenth of the cost of a Voice Type system. Over extended use, this may not be a viable trade-off, but for training and evaluation purposes, it appears to be worth considering.

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SPECIALIZED APPROACH TO TEACHING VOICE RECOGNITION COMPUTER INTERFACES

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ABSTRACT

Voice recognition is often considered to be an "intuitive" interface between a human and a computer. The very intuitiveness of speech as a means of interaction requires that special care be taken in instructing people in the use of a voice recognition computer interface where rigid constraints apply. A specialized instructional method has been developed to reduce the frustration and tedium involved in learning to use a voice recognition computer interface.

BACKGROUND

Computer access and computer literacy are among the services provided by the rehabilitation engineering/assistive technology service delivery program at our center. Clients are evaluated for their computer access needs and instructed in the use of the computer hardware and software system that best enables them to perform desired computer tasks. The computer experience of clients ranges from the level of expert computer programmers to beginners who have never before had the opportunity to use a computer. Individualized instruction is provided for each client with the amount of detail and repetition being customized according to the client's experience and learning ability. As a result of this individualized approach, the staff is experienced in instructing clients from a variety of backgrounds in the use of many different adaptive user interfaces, including scanning, Morse code, and voice recognition, among others.

VOICE RECOGNITION INTERFACE

The voice recognition system that is used most frequently for demonstration and training in the computer access and computer literacy program is the IBM VoiceType[a] for IBM's and compatible systems. This voice recognition interface recognizes discrete words or phrases from an active vocabulary of 5,000 words with an additional 2,000 user definable words. The interface continually adapts to changes in the voice of the user, storing the adaptations in custom voice files. Mis-recognized words must therefore be corrected as they occur so that the interface adaptation is performed correctly. VoiceType is particularly useful for many people with disabilities because a computer can be operated entirely by voice control once it has been setup for a particular user.

STANDARD INSTRUCTIONAL METHOD

Until recently, similar instructional methods have been employed for teaching all types of adaptive user interfaces. The method involves three steps:

- Explanation of the Interface
- Setting Up the Interface
- Using the Interface
  - Posted Command Words

As applied to the VoiceType interface this method translated into the following: First, an explanation was provided with an overview of the manner in which the interface should be used, including the basic operation of the interface when it correctly recognizes words. Then the importance of correcting mis-recognized words as they occur was explained along with the methods to correct mis-recognized words.

The interface setup involved the training of VoiceType's 200 word command list. Since each of the words in the list was repeated 3 times, this training usually took around one and a half hours.

The client next practiced with the interface for a short time and then used the interface to control other programs on the computer. A list of the most commonly used VoiceType command words was posted as a reference. At this point in the instruction, the client had to integrate the explanations and the command words that had been trained in order to use the interface to operate the computer. The client may also be learning to operate the computer along with learning the voice recognition interface.

PROBLEMS TEACHING VOICETYPE

Using the standard instructional method to teach the VoiceType interface resulted in three distinct types of problems even though it worked well for teaching the scanning and Morse code interfaces. To begin with, the amount of time needed to train the interface before a potential user could try it out was daunting to many clients. Some clients declined to try the system because they did not wish to spend so much time doing a tedious activity in order to test a system that may not meet their needs. This was especially true among clients who were coping with newly acquired disabilities and needed to invest energies in other therapies.

The cognitive load of the interface posed another problem. In order to correct a word that has been mis-recognized, execution of one of six correction methods, several of which required special commands to operate, is required. Many of the correction methods involve spelling out part or all of the correct word using the International Communications Alphabet (alpha, bravo, charlie,...) instead of the well-known letter names.

With all these things to remember, many new users were quickly overwhelmed by the amount of thought required to operate the voice recognition interface. Clients who had not used a computer before also struggled with trying to understand what to do with the computer, in addition to how to use the interface.

Even in the early stages of training with the voice recognition interface it was not possible to reduce the cognitive load presented by the interface by ignoring mis-recognized words and correcting them later. The very first thing with which a new voice recognition user usually had to deal was correcting a mis-recognized word since the recognition rate is likely to be at its poorest when the interface is first used. Even among people who were computer literate, the desire to get correct results immediately, along with the multitude and complexity of the correction methods, resulted in the use of the simplest correction method in most cases. This method ("scratch that") removed the mis-recognized word but did not provide the voice recognition interface with any input on what the correct word might be. The voice recognition never improved when the "scratch that" response became a habit and the user was left trying to conform to the untrained voice model in the interface.

An additional problem was presented by the "intuitiveness" of speech as a means of interaction. In natural speech patterns, the listener is expected to identify continuous speech, recognize multiple words and phrases with analogous meanings, and perceive when the speaker is talking to another party. Since the voice recognition interface does none of these things, a user has to learn to speak in discrete utterances and not interject extraneous sounds. Words with similar meanings can not be interchanged (e.g. "equal sign" produces =, "equals" produces the word equals). Finally, the computer has to be specifically instructed to "go to sleep" when a user desires to talk to someone else.

The required departure from natural speech patterns and the cognitive load presented by the interface combined to bewilder many new users of voice recognition. When a word was mis-recognized, the natural response was to turn to the instructor and request assistance — verbally. This verbal response compounded the original problem by resulting in the generation of additional useless words. Although assistance could have been requested verbally if the voice recognition interface was first told to "go to sleep," this habit took time to develop.

SPECIALIZED INSTRUCTIONAL METHOD

These problems as well as additional ones noted by other investigators(1,2) represent a barrier to the use of voice recognition interfaces. It is unlikely that these interfaces will be used to full advantage unless instructional methods are formulated that provide the necessary knowledge and training with a minimum of frustration. A specialized instructional method has been developed in an attempt to meet this goal. The method consists of the following steps: explanation of the interface with limited correction methods; demonstration of the interface; setup of the interface using established voice files; Operation of the interface with a posted alphabet and correction methods; and introduction of expanded correction methods.

In order to decrease the time that must be invested in interface setup, the voice files of previous users are copied as a basis for the voice files of each new user. If the gender and dialect of the users are similar, the number of words that must be explicitly trained before the system can be tested may be reduced from 200 to as few as 16. Thus, vocabulary training can be accomplished in ten to fifteen minutes instead of one and a half hours.

The cognitive complexity of the interface has been decreased by only using three of the correction methods in the initial sessions. These methods deal with the correction of mis-recognized words or errant sounds immediately after the problem occurs. The simplest correction method ("scratch that") is not introduced because it is too easy to fall into the habit of using it for all cases. The client is told that it is possible to correct errors in other ways, but that to simplify the learning process, only these three methods will be used in the initial sessions.

A demonstration is provided in order to help the client become accustomed to choosing among the selection methods. The demonstration is set up so that a demonstrator operates the computer through the voice recognition system and a trainer narrates, explaining what is happening, pointing out the actions of the system, and answering questions. The trainer also presents guidelines for how to speak to the computer, especially firmness and normal voice volume. This allows the client to see the interface in operation without being pressured to perform. In addition, the client is able to ask questions and interact with the trainer in a way that would not be possible if the interface was being operated by the trainer or the client. After the basics of the interface have been explained, the demonstrator dictates a short paragraph. The client and the trainer decide which of the three correction methods should be used when a word is mis-recognized. The client directs the correction of mis-recognized words for the rest of the demonstration. This form of demonstration allows the client to go through the thought processes necessary to operate the interface without the pressure of speaking into the microphone. The opportunity for client interaction with the trainer is also preserved.

When the client has grasped the theory of correcting the voice recognition interface, an established voice file is loaded under the client's name. The client practices using the interface on a sample paragraph. No specific task is provided for the first session so that the pressure of producing a finished product is eliminated. The safe environment that this creates is especially important for new computer users because it eliminates the need to think about what task is being performed. A posted list of the three correction methods and the alphabet is used both as a resource and to allow the trainer to non-verbally prompt the client when the client seems uncertain as to the next action. The client can use the interface to enter any desired text into the word processor during subsequent sessions. After the client becomes proficient with the use of the initial three correction methods, additional methods can be introduced as appropriate situations occur. The statistics feature of the voice recognition interface is examined at the end of each session to track improvements in the client's performance with the interface. As instruction progresses, the client is encouraged to perform all control of the interface independently.

CASE STUDIES

TM, a client with C4-5 quadriplegia, was strongly motivated to return to his job, which involved data entry under the pressure of a quota system. A voice recognition interface was chosen as providing him with the best possibility of achieving a competitive text input rate.

TM was initially taught the VoiceType interface using the standard instructional method. TM developed the habit of using the simplest correction method whenever a word was mis-recognized. This was due to confusion about which correctional method to use and his inability to easily interact with the trainer to gain assistance. For every mis-recognized word, TM would say "scratch that," which would quickly and satisfyingly eliminate the wrong word. This correction method did not provide the computer with feedback to allow it to adapt to his voice. TM would therefore be unable to get the computer to recognize the word that he was saying and would try to spell it using the International Communications Alphabet.

When the specialized instructional method was developed, the explanation and demonstration sessions were tested with TM. TM was able to interact with the trainer during the demonstration to determine the best correction method for each mis-recognized word that occurred. By directing the demonstrator, he could work through his confusions about the interface without having to deal with the consequences of incorrect actions, since the demonstrator would only respond to correct instructions. After a short demonstration, TM again used the voice recognition interface with the computer where he was noticeably more comfortable with the correction methods and rarely reverted to the reflexive "scratch that" response.

Other clients have since learned the voice recognition interface entirely under the specialized instructional method. One client, who had previously refused to try the voice recognition due to the lengthy initial training time, decided to test it once the time investment had been decreased. Most clients are able to complete the explanation, demonstration, and training portions of the instructional method as well as begin practicing with the interface within approximately one hour.

CONCLUSION

Special care must be taken when people are instructed in the use of voice recognition interfaces in order to reduce frustration with the interface and make the complexity and training time manageable. With an adaptive interface like VoiceType, short cuts, such as using previously trained voice files, can be used to reduce the overhead training time. Small functional vocabularies can serve a similar purpose on other systems by enabling the new user to test the system and achieve positive results with a minimal initial investment of time.

The complexity of voice recognition systems must be presented in manageable chunks. Guidelines for how to address the computer for best recognition help the client to provide the computer with a voice model that will be optimal for a long period of time. Reducing the number of possible correction methods allows the client to gain confidence and experience success with the interface before tackling more advanced features.

Posting the correction methods with guidelines as to when each should be used allows the client to review the options without requesting aid and presents a natural, non-verbal means for the trainer to interact with the client. Since the trainer is not verbally interacting, the client does not feel pressured to verbally acknowledge the trainer's assistance, which might lead to more problems with the interface. Although posted methods may not be appropriate for all voice recognition interfaces, a non-verbal means of trainer interaction is advisable to reduce the number of instances of unintentional speech being interpreted by the interface.

Although voice recognition interfaces present a potentially useful method for people with disabilities to become independently functional with computer systems, special consideration is necessary in the delivery of this technology. Great care must be taken in the formulation of instructional methods for voice recognition interfaces since awkward teaching can make even a well-designed, highly usable system appear hopelessly frustrating and complex.

ACKNOWLEDGMENTS

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DEVELOPMENT OF A LOW COST SIP AND PUFF MOUSE

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ABSTRACT

A low cost (less than $75) sip and puff mouse has been developed for IBM PC type computers. The device consists of a controller board that is designed to interface to a commercially available computer mouse, the commercial mouse and a mechanical interface linking the joystick design mouse and the user. The electronic mouse controller board replaces the pick and place buttons on the mouse with sip and puff control. The amount of pressure required of the user for sip or puff is adjustable (for both sip and puff functions). The battery powered board activates only when the computer is powered. The controller board is housed in a specially milled and lined plastic case for trouble free use in a typical user environment. This paper describes the device, gives the controller board schematic, shows the printed circuit board layout, gives a parts list, describes the operation and setup of the circuit for potential users and describes the procedure to interface the device to the mouse. Since the controller board interfaces to a commercially available device, readers are encouraged to use the design and customize the device for the needs of each client.

BACKGROUND

Providing access to computers for the "differently abled" is a constant challenge to schools, institutions and employers. In addition, access to a computer in the home of the user is often a great advantage to the individual and, potentially, to their employer or school. Many devices are commercially available to help provide such access. While these devices do an excellent job at providing that access, they are usually very expensive. Many schools, institutions, employers do not have financial resources to provide several of these workstations. The price of a such a workstation is usually out of the question for an individual. Certainly, there must be an alternative to the high technology workstations on the market that will still provide a reasonable interface between the computer and user. The device described in this paper began as an immediate need in a university (with a modest budget for such access devices) by students enrolled in classes.

This paper describes the development, operation and design of a low cost (less than $75) sip and puff computer pointing device (frequently termed a mouse, joystick, trackball or puck) for IBM PC type computers. The device consists of a controller card that replaces the mechanical pick buttons on the mouse with sip and puff control, a commercially available mouse and a mechanical link between the user and the commercial device. The device design began mainly as an access mechanism for quadriplegic students that were (are) enrolled in our Computer Aided Design/Drafting (CAD) classes. Although one student could use a short joystick pointer in a limited way, no student could use a conventional mouse. No student could operate the buttons on the mouse. In addition, the computers that were capable of running the CAD program were only in the "CAD Lab." The students obviously needed a way to somehow operate the computer mice so they could stay in class with the other students. Additional software code was also necessary so the students could pick (by sipping or puffing) any keyed entry required by the program.

PROBLEM STATEMENT

A low cost device was needed that would either emulate a computer mouse or interface to a commercially available computer mouse. Regardless of the design, the device would be used by individuals with a wide variety of disabilities that limit hand mobility. The device would also be used in an environment where access for all students to all computers is a must because of limited computer resources. Therefore, the device could not interfere with the "conventional" setup of the computer.

Several designs and alternate solutions were investigated before the first conceptual design of the sip and puff mouse was selected. Low cost voice activated systems were tried in the past without success for the user. The laboratory environment is inherently noisy. The voice systems that were tried did not reject this noise well, seemed physically cumbersome and were difficult to train for some users. Better voice systems were too expensive for the budget that was available.

Because of the manufacturing facilities that were available in the department, it was reasonable to design a device ourselves. That way, the mechanical link between mouse or joystick and the user could be customized for the needs of the individual. The easiest way to provide equal access for all students was to make a device simulate or use the serial type computer mice that were already installed on the systems. Therefore, the design that was an interface to a commercially available serial mouse was investigated and developed. There are two parts to the device: a mechanical link to the mouse and an interface controller card for the mouse. This paper concentrates on the description of the electronic card since it can be used to provide sip and puff operation for computer pointing devices or any other device requiring a sequence of buttons to be pushed. The next phase of this project will be to interface this card to the low cost remote appliance control modules that are available commercially (from Radio Shack and Heath, for example).

DESIGN AND DEVELOPMENT

The design that was chosen for development consisted of two parts: a mechanical link between the commercial mouse, trackball or joystick and an electronic interface card that would replace the mechanical buttons with sip and puff control. The SunCom® ICONtroller serial mouse was chosen as the commercial device for the project. This mouse type pointing device was designed as a companion product for laptop computers and mechanically resembles a very small joystick. Since it emulates a Microsoft mouse, device drivers are available for it in all major software products. Although it is a mouse, the joystick type design makes it a very easy device to link to mechanically.

The computer to mouse interface card that was designed to replace the mechanical buttons with sip and puff control is a versatile device in itself. It can be interfaced to any device with similar electronic characteristics of the mouse circuit to replace mechanical buttons with sip and puff control. The changes required to interface the card to other circuits are minor. It is powered by a 9 volt battery and only turns on when the computer is powered (to ensure maximum battery life). In its present configuration, current draw is estimated to be 5.6 milliamps. The controller card is approximately 93% efficient.

Differential voltage is obtained from the single +9 volt battery through the use of a switched capacitor voltage inverter (LMC 7660). The 7660 provides a negative voltage which is equal in magnitude to the positive voltage introduced at the input. Low power consumption is obtained by using low power FET components.

The circuit detects whether or not a person is sipping or blowing into a tube that is attached to a pressure transducer on the controller card. The circuit function itself can be divided into two parts: the information circuit and the power supply circuit (see Figures 1 and 2). The parts list for the circuit is given in Table 1.

The main component of the information circuit is the SenSym® SX-15 pressure transducer. Any equivalent device could be substituted. The support circuit for the device was obtained directly from SenSym. The differential signal is fed to a differential amplifier (U2A and U2C). The differential gain is 600, but due to the configuration the usable gain is 300. The signal is then fed to the comparators U2B and U2D. The resistors R3 and R7 are

Table 1. Controller Card Parts List

DESIGNATOR	QUANTITY	DESCRIPTION
R1	1	RESISTOR, VARIABLE, CERMET, 10K, 3006P-103-ND
R3, R7	2	RESISTOR, VARIABLE, CERMET, 20K, 3006P-203-ND
R4, R6	2	RESISTOR, 300K, 1/8W, 5%
R5	1	RESISTOR, 1K, 1/8W, 5%
R8, R9	2	RESISTOR, 5K, 1/8W, 5%
R11 - R13	3	RESISTOR, 10K, 1/8W, 5%
R2	1	RESISTOR, 75K, 1/8W, 5%
C1, C4 - C6	4	CAP, 10uF, 16V, RADIAL LEADS, ELECTROLYTIC
C2, C3	2	CAP, .1uF, CERAMIC DISC
Q1 - Q4	4	TRANSISTOR, NPN, 2N5210, TO-92
Q5	1	TRANSISTOR, PNP, 2N5087, TO-92
U1	1	IC, PRESSURE TRANSDUCER, SX-15N
U2	1	IC, OP-AMP, LOW POWER, LF444
U3	1	IC, REGULATOR, +5V, LM78L05ACZ
U4	1	IC, NEG VOLTAGE CONVERTER, LMC7660IN
D1, D2	2	DIODE, 1N4148
J2(1)	1	POS BATTERY SOCKET
J2(1)	1	NEG BATTERY SOCKET
J1	1	MODULAR PHONE JACK
	1	BOX
	1	PRINTED CIRCUIT BOARD

used to adjust the sensitivity of both the sip and puff outputs. Q1 and Q2 provide open collector outputs to the SunCom ICONtroller.

The power supply circuit provides three functions. First, it provides regulated +5 volts to the pressure sensor and the +5 volt reference for the comparators. Second, the power supply circuit generates -8 volts needed by U4. The negative voltage is used by the operational amplifier (op amp) U2 to assure the outputs of the comparators go low enough to turn the transistors Q1 and Q2 off. The third function of the power supply circuit is to turn the circuit on and off. This is accomplished by monitoring the serial line from the computer. When the computer is on, there is always a + 10 volts or - 10 volts on this line. When the computer is off, the serial line is 0 volts. When the line is anything other than 0 volts, it will forward bias Q5 to turn on the rest of the circuit.

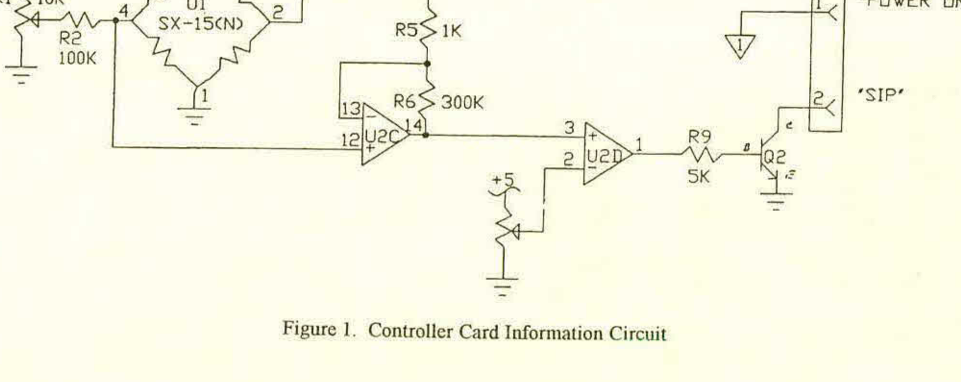

Figure 1. Controller Card Information Circuit

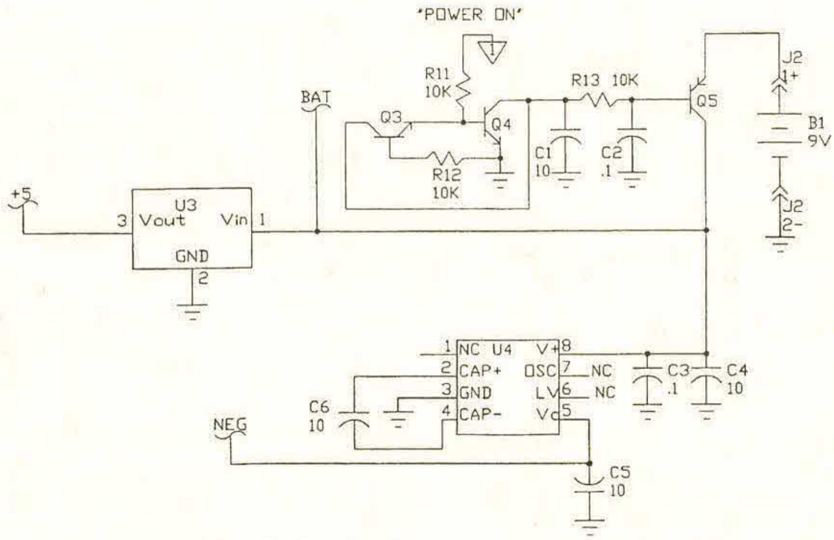

Figure 2. Controller Card Power Supply Circuit

Modular phone jacks and a phone cable link the controller card to the SunCom. The controller card is housed in a specially milled and lined plastic box designed to make the interface rugged enough for a typical laboratory environment. The four wires of the phone cable are connected to the inside of the SunCom. These four wires control two of the three buttons on the narrow end of the mouse. After the connections are made, the SunCom still functions normally. Thin wires are carefully soldered from the jack to the circuit board inside the SunCom. The controller card connections are power on input, sip output, ground and puff output. The connections inside the SunCom are power to serial cable wire W, sip to connection Y1 (near the crystal), ground to the serial cable labeled B and puff to connection Q1 (outer corner hole).

A few adjustments to the sip and puff controller card must be made before it is placed in service. R1 is adjusted until the voltage at pin 12 of U2 is slightly (0.01 volts) higher than pin 10 of U2. R1 is then adjusted clockwise until pin 8 of U3 equals pin 12. The voltage should be about 1.85 volts. Puff sensitivity adjustment is made through R3; sip sensitivity adjustment is made though R7. Do not adjust R1 is service.

The mechanical link to the SunCom is simply an extension of the existing joystick arm. The extension is attached to a chin cup. The SunCom and extension are mounted to an adjustable arm plate to the chest of the user. A tube connects the controller card and the user. A drain plug is attached to the tube for easy cleaning and tube exchange.

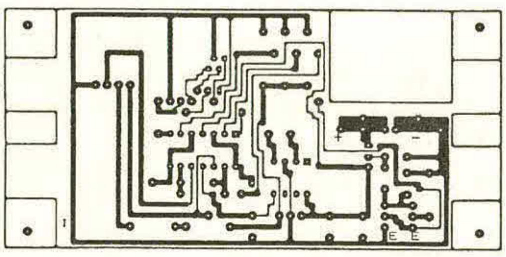

Figure 3. Controller Card PCB Layout

DISCUSSION

Approximately twenty of the sip and puff controller cards described in this paper have been manufactured. A robotic workcell has been designed to assemble to controller card package including milling the plastic box. The sip and puff circuit works well and has been tested with CAD software and Microsoft Windows® software. The testers have found it easy to double puff or double sip if the software requires. The device is versatile and easy to setup and use.

ACKNOWLEDGMENTS

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Two Simple Switch Options for High Quadriplegics

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ABSTRACT

For a high quadriplegic, the early stages of rehabilitation can be filled with feelings of fear and helplessness. Sometimes access to just one switch can give back a measure of control and independence, making it easier to gain the patient's interest and participation in other aspects of rehabilitation. These two switches were developed to clamp to "halo" cervical immobilization devices or to a tracheostomy respirator tube. They are designed to be simple, reliable, rugged, and inexpensive while providing access to a variety of switch-operated adaptive equipment.

BACKGROUND

An enormous variety of accessible switches are available commercially, including several very fine examples suitable for high quadriplegics. They use a wide range of mechanical, electronic, and optical methods to close a switch, from piezo film to electromyography, from copper leaves to microphones, from infrared light to ultrasound. Some are quite sophisticated, and some are refreshingly simple. We use and recommend them routinely at our facility, but there are many situations in which they are not quite suited to the needs of the patient.

A few require time-consuming setup or adjustments each time they are used. Too often they close inadvertently during normal eye or eyebrow movement, or in the course of activities such as speaking or eating. On the other hand, they may be so difficult to access or so sporadic in their function as to be unreliable in an anxious state or an emergency situation.

The headbands, tape, glue, eyeglass frames, etc., used to position some switches can be bothersome and uncomfortable, and may even cause skin problems.

Many are simply too fragile to withstand the everyday realities of the hospital or the home environment, for instance, accidentally being dropped into the sink or toilet, run over by wheelchairs, stepped on, crammed into backpacks or stuffed into drawers, yanked by their wires, or played with by children.

Many require a certain amount of training and practice on the part of the caregiver. Our patients come from all backgrounds and cultures, and it would be unrealistic to expect a high level of mechanical aptitude or technical knowledge from their attendants and family members. Likewise, many come from rural areas or foreign countries, where service or repairs may be difficult or impossible.

Some wear out too quickly, necessitating frequent replacement, and some are prohibitively expensive despite their thoughtful and innovative design.

Finally, aesthetics must be considered; any self-respecting patient will resist equipment that they believe makes them look like a mad scientist, an alien, a dork or a geek.

STATEMENT OF THE PROBLEM

A switch was needed that would be safe, reliable, and easy for the patient to use. It was felt that it should be so simple that its placement and operation would be almost intuitively apparent, even to people with limited exposure to technology. It had to move with the patient in a dynamic bed (such as Bio-Dyne, Therapulse, Kinnair, or Clinitron), rather than mounting on an arm or gooseneck from the wall or bedframe. Ideally, it should be easy to access when needed, yet not interfere with eating, talking, or other activities. It should be tough enough to stand up to the rigors of an active life or a careless environment, and the parts shouldn't be so exotic or specialized that a small-town electrical shop wouldn't be able to repair it. And naturally, it would have a 1/8" phono-plug to interface with existing adaptive equipment.

DESIGN AND DEVELOPMENT

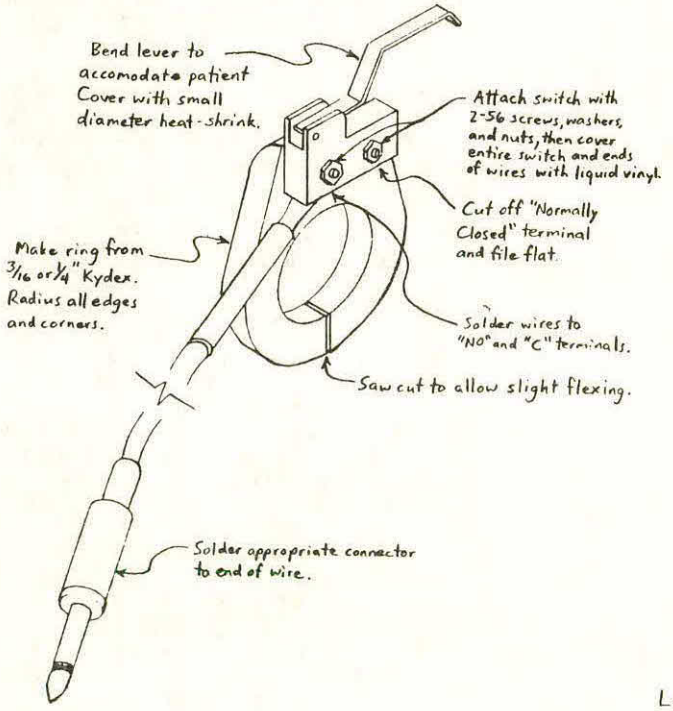
The Tracheostomy Switch

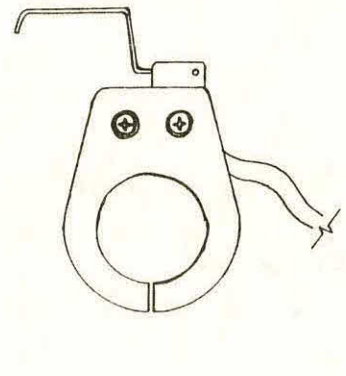
The respirator tube that connects to a patient's tracheostomy is a relatively convenient place to mount a switch. As the sketches show, the device is simply a common micro-switch mounted with small bolts and nuts to a mounting ring made from 1/4" thick Kydex plastic sheet. The ring fits snugly around the ventilator tube without distorting it or interfering in any way with respiratory function. The lever on the switch may be bent to accomodate the needs of the individual patient, or the mount itself can be made taller or shorter.

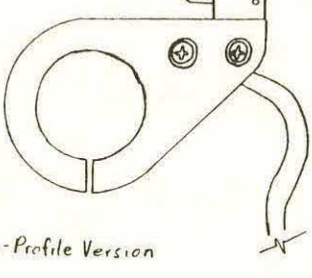
Most patients can consistently move their chins up and down, sometimes even when their injury doesn't permit them to close their lips or use sip and puff devices. If the patient has sufficient jaw range, the switch lever can usually be positioned far enough below the chin that it isn't touched while speaking or chewing, yet can be immediately activated with either a nod or a big yawn. Since the lever needn't be in constant contact with the skin, irritation and dermal problems are minimized.

The Halo Switch

The halo switch is similar in concept to the tracheostomy switch, but is instead clamped around one of the upright bars of the halo. Again, a piece of Kydex plastic is used to hold a small switch under the patient's chin, which is activated when the patient opens their jaw. (In this case, of course, a nod won't be possible.) In some patients, there is too much movement of the ventilator tube up and down during the respiration cycle to use a tracheostomy







Low-Profile Version

LIP MOUSE :
Cheaper way to get pointing device for the quadriplegia.

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ABSTRUCT

This paper describes some ideas for a mouse ; one of the input devices of the personal computers, and becomes key device for the Graphic User Interface (GUI). The authors developed a LIP MOUSE for the IBM PC/ AT , PS/2 or Apple Macintosh computers as a pointing device. The severely physically disabled will operate it with his/her lip and tongue when motor functions of these are remain.

BACKGROUND

In the field of the Computer Human Interaction (CHI) the GUI give users the benefit of intelligible and quick operation. The Macintosh and the MS-Windows are sharing the market. In the GUI nobody can operate without pointing devices like a mouse. However, the mouse has less advantage for the persons with severe inability in hand and/or finger functions, than keyboards (CUI). Many substitutes have been devised in these decade ; they emulate the mouse as the Joysticks, the Key array, the Track-ball, the Pen- Mouse, the Tablets, the Light-pen, the Scanning method, and so on. But these substitutes has some demerits in operation, quick access or cost. With advancement of Notebook PC, "Thumb Wheel Mouse" which is miniature track-ball operated by thumb comes on the market. On the other hand, human's mouth and lips are covered so widely with cranial nerve control, that the area has precision motor skills. Therefore the authors combined the "Thumb Wheel Mouse" and lip movement, then developed the LIP MOUSE.

STRATEGY OF LIP MOUSE

The mouse is connected to the special Bus I/F, the PS/2 mouse I/F or general purpose serial I/F (RS232-c) in PC, then installed to operating system via each driver software. In case of Macintosh, it is connected to serial I/F called ADB (Apple Desktop Bus : RS422). Basically, same mechanism are provided in any type of the mice ; two rotary encoders placed to contact to a ball, are located at right angle each other, generate rectangle waves according to the rotation of the ball, then the phases and frequencies index the direction and speed. Other mouse which is mount to the one of the most popular personal computers in Japan, has no control circuits in itself. The signal of the rotary encoders are connected directly to the special I/F. Then we have adopted the "Thumb Mouse" made by NEC corp. to our LIP MOUSE. It will be connected to each micro-tip as substitute of transducer unit (see figure 1). The NEC's "Thumb Mouse" are suitable object for us in its condensed shape ; 1 1/2" height, 3" length and 1" depth.

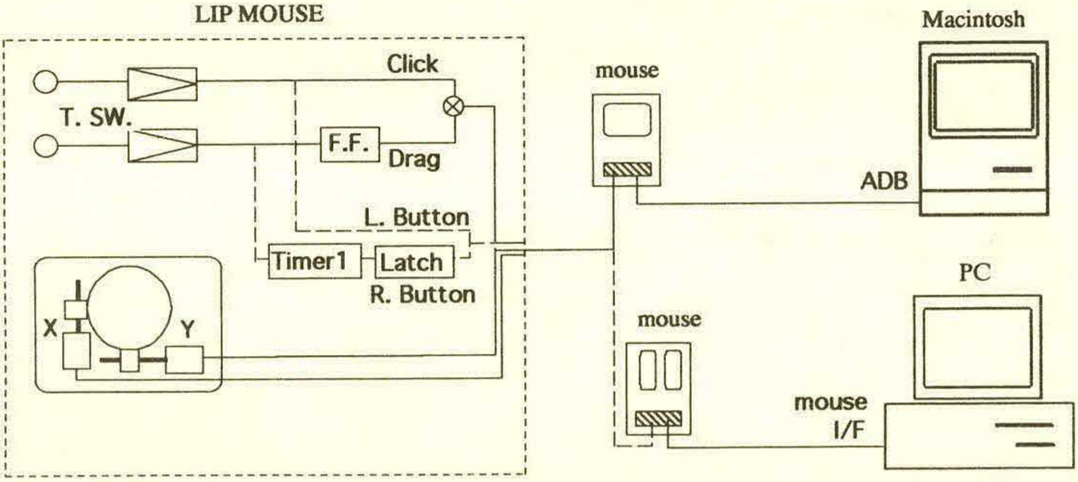

Figure 1. Block diagram of LIP MOUSE and connecting schema to IBM PC/AT, PS/2 or Macintosh.

switch, and there are a lot of patients that don't need respirators but are temporarily wearing a halo. The halo switch can provide an option for them until they are able to access other switches.

DISCUSSION

When one of these switches is fitted to a newly-arrived patient, it is initially used to access the nurse call system. The emotional state of a person who has experienced a devastating injury and is now on a respirator or in a halo is difficult to imagine. Unable to move, unable to look around the room, perhaps unable to speak, they may be feeling anxious, fearful, isolated, and helpless. This might be the first time since their injury that there are no family members at the bedside watching over them. To be able to trigger the nurse call may seem like a small thing, but it often makes a big difference in the patient's emotional state and confidence level.- Within a few days, the patient may be using the switch to play computer games or modified versions of Nintendo. As skill and confidence grow, the switch can be used to operate more complex computer programs, or in aphasic patients, to operate a speech synthesizer or other communication devices. As rehabilitation continues, it may be used to change modes and as a kill-switch on a power wheelchair.

ACKNOWLEDGMENTS

Thanks to Goff Harris for coming up with the idea of mounting a switch on a ventilator tube (some ten years ago), and to Dale Shisler, who made the first removable tracheostomy switch at Craig Hospital a couple of years later. And thanks to the patients and staff at Craig that have provided feedback for the continuing refinement of the ideas.

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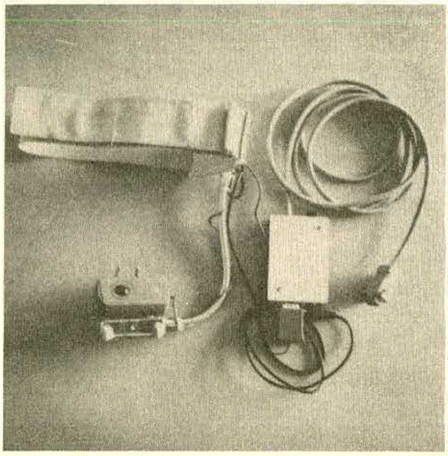

Figure 2. Assembled LIP MOUSE

Figure 3. Skech of in-use LIP MOUSE on PC.

The mouse must be equipped button(s) for click action , adding the position detector for the mouse cursor. While the mouse for the Macintosh has only one button, in case of PC, it has a couple of buttons. We replace the button operation to tongue-touch switches, however , the puff and sip control are also available. We considered the user wearing artificial breath controller could not operate breath switches. The Touch switch sense inducted electricity with C-MOS logical IC. Its sensitivity and ON-delay timing are adjustable.

"Thumb Mouse" is mounted on "Goose neck" to locate it at the nearest point of the lower lip. The opposite side of the "Goose neck" is braced to the user's head with head band or placed on the desk top with a cramp or heavy base. The later way may be preferable in the case of cervical cord injured. The figure 2 shows the assembled LIP MOUSE, and the figure 3 shows in-use.

RESULT

It is certified that the lip can work as a manipulator as good as thumb when the ball and the touch buttons are positioned well to the human body. Besides, the "Ballistic" movement effect quick access to the object than the Joystick or Key-Array. However, the drag operation is very hard in simultaneous tongue-touch and lip manipulation. The authors installed some additional logic circuits. To connect to the Macintosh touch operation of the right side button makes alternative change of hold down the button. In case of PC, durable touch input (adjustable) latches the signal to hold down, and next touch input release it. The total block diagram is also shown in figure 1.

CONCLUSION

The authors reported about the LIP MOUSE for the severe quadriplegia. The keyboard operation is still needed mainly in writing or calculating, however, the pointing devices allows to use a virtual keyboard software available in the market.

We will report the result of comparative test with other ordinary substitution devices.

ACKNOWLEDGMENT

The authors wish to give appreciation to Mr. Masafumi Ide in reference of touch switch circuit.

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Setup of an IBM based Computer for Access Evaluations

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Abstract

Switching between access techniques during a computer evaluation may involve loading and unloading software and changing input device hardware. This process can be time consuming and could lead to damaged equipment. The system described here was developed to simplify the setup, maintenance, and trouble shooting of a computer system used for access evaluations. The system is designed to make it easier to change between input methods and has made for more efficient alternate access evaluations.

Background

There are many computer alternate access strategies available for individuals with disabilities. Some require hardware, some require software, some require a combination of both. With all of the possible combinations of technologies, preparing and changing setups during an evaluation can be a difficult and time consuming process.

There is usually hardware required when using different input methods, and these adapters plug into the input/output ports on the computer. Plugging and unplugging these adapters can damage the adapters and computer ports. Additionally, these adapters usually operate on only one type of port (serial or parallel) and often on only one or two specific ports. For example, most computer mice can only be installed on serial port 1 or 2. Therefore, filling your computer with extra serial and parallel ports may not solve the problem.

Statement of the Problem

What was needed was a way of organizing the computer software, peripherals, and access software and hardware, that would require as little setup as possible and would simplify computer maintenance.

Design

The setup of the evaluation computer has two components, hardware and software. Each were important to the success of the system.

Hardware

We started with an 80486 DX, IBM compatible clone computer, with 8 MB RAM, 120 MB hard disk, 8 expansion slots, and 4 serial and 2 parallel ports. The serial ports were configured COM1 through COM4, and the parallel ports were configured as LPT1 and LPT2.

A four position data transfer switch box was used in order to connect multiple devices to parallel port 1 (LPT1). A data transfer switch is commonly referred to as an A/B printer switch box. This box allows several devices to share a single port. Device selection is made by turning a switch on the front of the box. Similar switching devices were obtained for serial ports 1 and 2 (COM1 and COM2). This setup allows four alternate access adapters to be connected to LPT1 and eight adapters to be connected to COM1 and COM2.

LPT2 was connected to an HP LaserJet III printer and all software which would use the laser printer (wordprocessing, spread sheet, database) was configured to direct printed output to LPT2. This ensures that user will be able to print from any application regardless of the access technique.

Software

Applications software, utilities and the operating system programs are organized in individual sub-directories. The computer access software is setup in individual sub-directories grouped by either manufacturer or type of solution. This makes update of software easier. Original program disks are filed with older copies of software for archive and backup purposes.

A menuing system was developed to allow clinicians to choose the desired access solution and step them through the setup of any required hardware. The system consists of a series of batch files which display information on how to set the data transfer switches to enable any necessary hardware. The menuing system resides in a separate sub-directory. Each file in the directory has the same format, for example: lines 1-5, title and remarks; line 6, data switch setting; lines 7-12, special user instructions; lines 13-15, command line with any special settings.

```
1    rem
2    rem   &&&& EZMORSE.BAT &&&&
3    rem
4    rem  EZMorse w/serial adapter
5    cls
6    type \bats\com-a.swi
7    echo
8    echo Make sure "Turbo" button
9    echo  on the computer is off
10   echo
11   echo Turbo light should be off
12   echo
13   pause
14   cd\ezmorse
15   ezmorse /1
```

Because the original program disks are filed, there is no need to back up program files for applications, utilities, or access software. The only files regularly backed up are data files and the sub-directory containing the menuing system. Using this setup, the structure could be reconstructed in the event of a disk failure.

Development/Evaluation

The system was implemented over a period of several months due to time constraints. While the new system was under development, the old system was still operational so that the computer could be used for evaluations. When the system was completed the old system was kept as a backup if problems arose during an evaluation. A single command would switch between the old and new systems. This was a extremely helpful during the development and testing of the menuing system.

Costs

The data transfer switches cost approximately $50 each. The main cost in the development of the menuing system was time. It took many hours over several months before it was operating satisfactorily, but it is believed that this time has been recovered in reduced maintenance time, reduced setup time, and easier trouble shooting. Because the system makes it easier to change between input methods, it has made for more efficient alternate access evaluations.

Discussion

When conducting a computer access evaluation, it is often necessary to evaluate an individual's performance using several different access strategies. Changing the setup during the evaluation may involve loading and unloading software and changing access hardware. This process can be time consuming and switching adapters could damage the access hardware or the computer ports. This system was developed out of a need to simplify the setup, maintenance, and trouble shooting of a computer access evaluation computer.

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THE DEVELOPMENT OF A WINDOWS-BASED INTERFACE FOR REMOTE CONTROL OF APPLIANCES

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ABSTRACT

Interface software to provide trainable wheelchair mounted infra-red control of consumer appliances is described. This software, running under Microsoft Windows 3.1® on a portable PC, provides ready access to household devices through a serially linked programmable infra-red controller.

The interface consists of a library addition to a commercially available Windows access software package, WiViK® (Shein, Hamann, Brownlow, Treviranus, Milner, Parnes, 1991), allowing users to operate the Serial Relax programmable infra-red controller.

BACKGROUND

Control of a variety of household entertainment devices and appliances is possible through either infra-red (IR) controllers that are matched to specific devices, or through X10 power control modules, which can be activated by IR when an IR-to-X10 converter is used. An obstacle in accessing these devices is that each device is usually provided with its own proprietary hand-held controller. These controllers are hand-held units with an array of small function buttons. The owner of a combination of devices is then faced with several individual controllers. This can present a barrier for a person with physical disabilities. Most of the problems in using such controllers relate to repetitively pressing buttons, aiming the controller at the appropriate device, and moving between different controllers.

Integrating the necessary control functions for multiple devices into one controller can reduce or eliminate many of the usability problems. Connecting this controller to a computer that is used for a variety of purposes, and is accessible by someone with a disability, further enhances usability.

RATIONALE

Integrated environmental control units (ECU) are already available commercially. There is, however, still a need for low cost integrated systems that can be modified to control the specific devices and appliances that a user has in their home environment. With minor additions, existing hardware and software can meet these needs.

DESIGN

An accessible software interface was already available in the form of WiViK, a Windows visual keyboard program designed for use with Microsoft Windows 3.1. This program displays a customizable keyboard that allows a Microsoft Windows user to transparently enter text into an application by use of either a single switch scanning device or a pointing device. Additions to the program were developed to support serial communication with a programmable IR controller, the Serial Relax controller. This controller can be programmed with, and generate, up to 96 IR command sets. Each command set consists of the control function provided by a button on an IR controller. These command sets are all accessible through a standard serial communications port.

DEVELOPMENT

The development of a Windows-based interface for control of consumer appliances consisted of three stages.

1. A module was added to the existing WiViK package to allow for serial communication with an external device.

2. A keyboard layout that provides for full access to all available functions without excessive detail was defined.

3. An installation package that allows the user to assign specific function names or graphics to device control buttons on the visual keyboard was written.

The Serial Relax controller accepts text strings to initiate training of IR command sets, transmission of IR command sets, and the running of various internal functions, such as battery level sensing. The communication is two-way, with the controller echoing commands that are accepted by the Serial Relax controller, and sending error messages if the controller did not accept the command.

A WiViK keyboard is defined by a text-based keyboard definition file. This file contains information detailing the layout of the keyboard, the graphics or text representation of the individual keys, the macro command to be run when the key is selected, and any parameter to be passed to the macro command when it is run. WiViK provides for the inclusion of new macro commands that are developed independently. These macro commands accept modifying parameters, as defined in the keyboard definition file, and are written in a high level programming language to be compiled as a Dynamic Link Library (DLL). The DLL and the commands it contains are then listed in a text file that is named in the keyboard definition file. WiViK takes care of linking the DLL and making the new macro commands available for use within the keyboard.

To enable WiViK to be used with the Serial Relax controller, a DLL had to be created with functions to support serial communication with this device. Included in these functions were start up routines to initialize serial communication and confirm battery levels in the controller, and routines to activate the training or transmission of one of the 96 programmable command sets.

The default keyboard layout groups devices according to their function; either as entertainment devices, security devices, or lighting devices. The keyboard layout consists of multiple pages, with additional groups of devices or functions being presented in response to user input, such as choosing a device type or specific device.

An example of a WiViK keyboard layout used to control the Serial Relax controller is shown in Figures 1 through 3. Figure 1 shows the initial screen that prompts the user to select a group of devices sorted by their function. Figure 2, displayed in response to the user selecting "Entertainment", prompts the user to select a specific device. Figure 3, presented in response to selecting "TV", prompts for selecting a function for controlling the television. Context sensitive help screens are available at all times to the user by selecting the "Help" button on the visual keyboard; movement to various places in the paged keyboard is also available by selecting either the "Main Menu" or "Previous Menu" commands. The WiViK keyboard is always visible, regardless of what other Windows applications are active.

A simple installation program needs to be run when the software is first installed. This allows for the selection of specific devices and functions, the assignment of these devices and functions to a keyboard button, and the assignment of either text or supplied images to the button. Training the controller to specific IR commands can occur at this step, or when the program is operating.

EVALUATION AND DISCUSSION

This project has progressed to a pre-release version of the Dynamic Link Library containing all serial communication routines and initialization routines. A library of bitmapped images for use as visual keyboard graphics has been collected and compiled. The installation program simplifying the selection of these graphics and their attachment to a keyboard is in the final development stage. The current stage of this project incorporates field evaluation of the software and hardware, operating on a portable notepad-size PC, in an independent living environment.

By combining home environment control with a multi-tasking environment such as Microsoft Windows 3.1 running on a portable PC, possibilities are offered to integrate this control system with additional assistive technology, such as e-mail, alternative communication, word processing, and wheelchair control, that runs on the same platform.

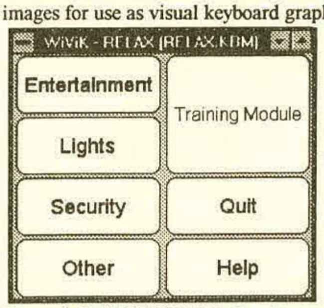

Figure 1: Initial WiViK-Relax Screen

Figure 2: Entertainment Level Screen

Figure 3: TV Function Level Screen

ACKNOWLEDGMENTS

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Shein, F., Hamann, G., Brownlow, N., Treviranus, J., Milner, M., Parnes, P. (1991) WiViK: A Visual Keyboard For Windows 3.0. *Proceedings of the 14th Annual Conference of RESNA*, Kansas City, Mo., 160-162.

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CURSOR SEQUENCING FOR SINGLE SWITCH ACCESS ON THE MACINTOSH

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Abstract

There are many systems to allow single switch scanning on text and graphical computers, and most of them rely on scanning either successively smaller sets of choices or by sequencing through a list of choices. These mechanisms are adequate for static interactions with a computer such as typing, but are not acceptable for position control interactions such as moving a mouse.

This paper describes a novel way to provide complete control of a mouse-based system using a scanning, single switch system which is unobtrusive yet provides control similar to, and operationally identical to a fully motion able graphical system user.

Background

There are many forms of single switch control available and several systems to allow signaling such as Morse Code. To make access to a mouse based system effective, there are two primary requirements: fast and flexible control, and the ability to allow the user to focus their attention where the work is being done.

Unlike text-based systems, there are several types of interactions which are common with graphical based computer systems. In addition to the expected text entry, there is the additional dimension of positional freedom. Unlike simpler text entry programs such as DOS based word processors or editors, graphical based systems often allow users to place text on a page with much more freedom. The key to this freedom in design is the mouse - a device which was designed almost completely with the able-bodied user in mind.

More than this, the typical graphics based application involved more than simple typing of text, but includes graphical components ranging from simple lines to more complex boxes and shapes to very complex illustrations which may consist of freely drawn lines and images scanned in from other sources.

The successful use of these packages relies again on the use of the mouse.

The Problem

Accessing and operating a graphical computer provides unique challenges to a motion-disabled user. The typical quadriplegic user cannot use a mouse, although many can use a Headpointer. Many cannot even utilize this solution as they either do not have an adequate range of head movement or cannot maintain stable positions for its use.

For this paper, the term "mouse" will refer to the traditional mouse as well as any pointing device which requires significant eye-limb coordination and includes such devices as Headpointer, trackballs, tablets and others. All require some degree of precise eye-limb coordination and a range of motion capability to be effective.

Discussion

Having looked over several existing products and ideas put forward in several concept papers, it became obvious that most of these ideas required changing the user's attention from the place on the screen where the work was being done, to a control area, and then back.

However, work on a graphical system requires that users focus their attention on the place where the **cursor** is located. Unlike text based systems, the cursor, also sometimes known as a **pointer**, can appear anywhere on the screen and can be moved anywhere on the screen directly.[1]

This immediately dictated two requirements: that the user be able to focus attention in one place - the cursor - and the cursor be steerable over the entire screen quickly and efficiently.

Unlike other systems, the design specified that the cursor itself become the selecting mechanism. This posed problems because the cursor already has several functions in most Macintosh applications: position selection (typically an arrow), function indication (any of a number of symbols) and busy indicator (usually a watch if the delay is short, a spinning beachball if a long wait). We would have to add a number of other indicators to this list on top of the application's uses yet allow the underlying application to communicate with the user without undue interference.

Some Common Cursors

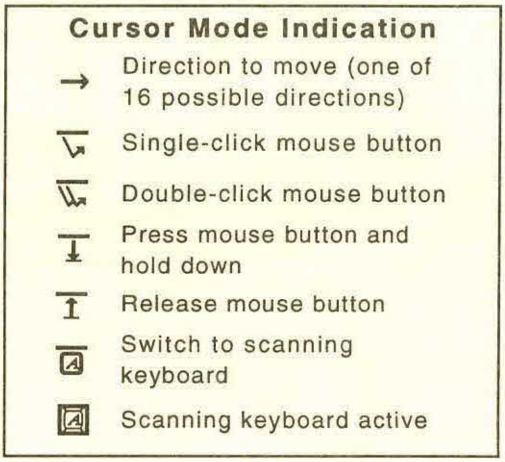
- Pointer (general selection and moving)
- Text editing
- Shape drawing
- Spreadsheet cell selecting
- Busy (short delay - animated)
- Busy (long delay - animated)

Approach

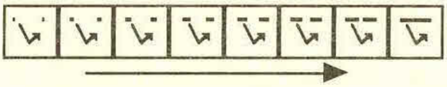
We have implemented a mechanism on the Macintosh computer which allows the severely motion limited user to access the Macintosh with the same level of skill and capability, and perhaps more importantly, with the same level of dexterity as a fully able user. Further, simple tests show that our system is easily used and can allow the user to achieve speeds of up to 25% of an able user.

After analyzing how a typical user interacts with a typical application, we realized that modal indicators - cursors who's shape indicate what mode of action is being done - only really needed to be viewed when the cursor is in motion. Usually, a palette of action options gives static confirmation of the current mode, which can provide mode status when the cursor is stationary.

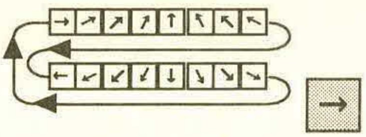
We also created a list of basic mouse action and assigned a symbol to them as summarized in the following table.



In early tests, it became clear that the totally static cursor gave the user no sense of how long they had before the cursor switched to its next state. This was remedied by the addition of a bar above the cursor which starts almost white and then fills in until completely black.



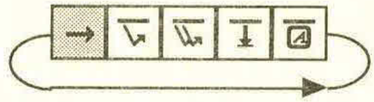
The sixteen arrows indicate the direction in which the cursor will begin drifting once the single switch is clicked. Our first experiments with this click-and-drift model showed that simply having the cursor drift at a constant speed was not acceptable. While it allowed for fast movement across the screen, necessary for larger screen sizes, it made small movement impossible and tended to make accurate stopping difficult.



This problem was solved by introducing an accelerating cursor similar to the one provided by Apple in its Easy Access product which starts out slowly then ramps up to a fairly quick speed. To retain the application's feedback to the user, whenever the cursor is moving, the application's selection for the cursor is returned to the screen.

Upon a second click, the directional arrow is backed up two positions and then the spinning cycle is repeated. We introduced this two position backup because we found that the most common action after stopping the cursor's drift was to restart it in nearly, if not exactly the same direction. This small backstep allows the user to recover from the stop and then reselect movement in the same direction.

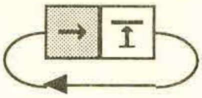
Normally, the sequence is as shown below:



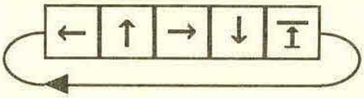
The grayed box indicates that all sixteen position cursors are shown in sequence, but for compactness, it is shown here as one arrow.

If we simply replicated the actions an able-bodied user is capable of using a mouse, this system would not really be much of an aid for the motion-limited user. The Macintosh system has areas which have specific function. Menus can only be clicked and held, if the mouse is already down, the only logical actions are to move or release the mouse and so on. To this end, several special actions have been built into our model.

If the mouse has been pressed down, the choices are shortened to:

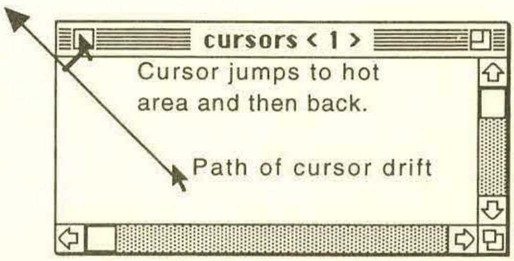


If the cursor is moved over the menu bar, the only logical action is to press the mouse down to pull down the menu. This is done for the user, and the range of choices is reduced to:

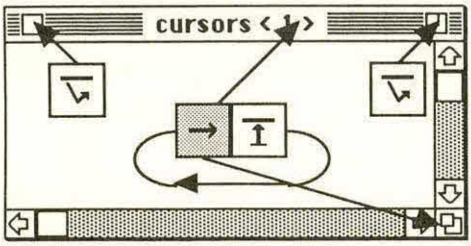


The Macintosh's primary on-screen entity is the **window** which has a number of rather small components. Even with our accelerating cursor, hitting these small regions can be difficult, so we are integrating awareness of all of these areas into the model.[2]

To make hitting these small areas simpler, as the cursor drifts across the screen, its position relative to the active window (if any) is monitored and if it should get close enough to an "action region" (the title bar, close and zoom box or resize icon), the cursor will snap to the closest action region, pause for a short period, then return to the exact position it was snapped from to resume drifting in the same direction and speed as it was prior to the snap.



If the cursor's drift is stopped over a window's close or zoom box, a single click is done and the user is returned to the normal sequence. If it is stopped over the grow area or on the title bar, the mouse button is pressed and held down and only the move and release button sequence is done as in both cases, the only logical action is either to drag the item or release the mouse.



Similar intelligence can and should be built in to the model for scroll bars, buttons and other user controls.

This model was implemented early in 1992 as a commercial program called "Revolving Doors" along with a scanning on-screen keyboard. Rather than ask the user to navigate over the keyboard and click, it was deemed reasonable to have the cursor switch to a keyboard mode and activate the on-screen keyboard.

This switch is done by activating the signaling switch when the cursor has cycled to the keyboard switch symbol.

The cursor will go static at this point and remain in its "waiting for keyboard" mode until the scanning keyboard returns control; a discussion of the scanning keyboard is outside the scope of this paper, but it is basically a standard scanning keyboard with an escape selection which transfers control back to the cursor.

Results[3]

The RevolvingDoor implementation of this concept runs as a background task on the Macintosh and modifies the appearance of the cursor in front of the current application.

Based on a trial which consisted of drawing a complex image using an unmodified version of Freehand 3.0 first using the single switch access method and then again using the mouse, we found that full mouse access took just over 30 minutes to complete the drawing and single switch access took just over 160 minutes - about 5 times longer with a relatively inexperienced user.

We believe that this system will allow many users who would not otherwise be able to create complex graphics or operate a Macintosh computer to become fully enabled.

Sample picture drawn with Freehand 3.0 using a single switch.[1]

1. This image has been converted into a PICT2 file for inclusion in this document. As part of the process, all shading information has been converted into dots. The actual lines which make up the image have not been modified in anyway.

[1] Apple Inc.:*Human Interface Guideline,* Addison-Wesley.

[2] Apple Inc.:*Inside Macintosh (Volumes 1-6), develop Monthly, Developer's CD-ROM Series,* Addison-Wesley, Apple Press and others.

[3] The Arrow cursor: A Pointing Device For People Who Use A Single Adaptive Switch, by James Blodgett, *Communication Outlook,* 1990

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INTEGRATING A STAND-ALONE AND PC-BASED ENVIRONMENTAL CONTROL SYSTEM

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Abstract
Both stand-alone and Personal Computer based (PC-based) environmental control systems (ECS's) have desirable qualities. One method of combining the advantages of each is to interface a stand-alone ECS with a PC-based ECS through a serial communications link. One such system, based on a Control 1 interfaced with an IBM-compatible computer, is described and analyzed in this paper.

Introduction
Assistive technology providers spend considerable effort attempting to assist people to achieve greater control over their environment. A typical means to this end is the Environmental Control System (ECS), which can come in many forms, from simple large-button thermostats to complex integrated units that control many devices from within one system. Tremendous diversity exists among available environmental control systems with many models to choose from.

One possible way of dividing the large integrated ECS market is between ECS's that are stand-alone, self-contained units (e.g. 1, 2) and ECS's that are in part or totally housed in a personal computer (PC-based ECS's) (e.g. 3, 4). Both stand-alone and PC-based ECS's have features desirable in an ECS and both suffer from shortcomings. The goal should be an ECS that comes as close as possible to providing the best of both possible worlds. An approach which meets this goal is to use the serial interfaces that many stand-alone ECS's come equipped with to interface the ECS with a computer.

An example of such a system is presented in this paper. This example is based on a system composed of a Prentke Romich Control 1 ("Ctrl 1") connected to an IBM-compatible computer. The goals of this paper are to present as background some of the advantages and disadvantages of current stand-alone and PC-based ECS's, describe two approaches to combining these two types of systems with the goal of creating an ECS that can take advantage of the best features of each, and analyze the resultant systems to draw conclusions as to what features should be provided with future ECS's.

Background
The most common variety of ECS is the stand-alone type. Stand-alone ECS's have several advantages. Much of the control functionality of a stand-alone system can be housed within one unit, with minimized reliance on peripheral accessories such as X-10 (5) modules or separate phones. This can often represent a cost-effective approach with the added advantage of compact size for the system. In addition, many stand-alone systems offer very flexible control options which allow them to operate a wide variety of different devices, from televisions and radios to thermostats, door openers, bed controls, and telephones.

PC-based ECS's, on the other hand, differ somewhat in their advantages and disadvantages. An ECS housed in a computer must depend on several peripherals to achieve the same level of functionality as a stand-alone system. Phone control requires a modem and a telephone. Access to switch closures (which are necessary for control of such items as electric beds and door openers) depends on an add-on board to the computer or the use of X-10 modules. Appliances are typically controlled through an X-10 computer interface. Infra-red controlled devices necessitate the use of a device like the TASH Serial Relax (6) to produce the proper infra-red signals. This dependance on accessory devices can increase the price and/or complexity of PC-based ECS's, but PC-based ECS's still have many merits.

First of all, a PC-based ECS is capable of providing many more input options than most stand-alone ECS's. Most stand-alone systems offer a choice of either single or dual switch scanning in some form, Morse Code, or perhaps voice input. A single PC-based ECS, on the other hand, is potentially capable of receiving input from a keyboard, voice recognition system, switch scanning system, mouse emulator, touch screen, or a combination of these, depending on the abilities of the user. This flexibility not only allows the PC-based ECS to be used by a wide variety of individuals, but also allows adaptation of the ECS to an individual's changing condition.

Another advantage of PC-based ECS's is the quality of the user-interface. Many stand-alone ECS's have a fixed display with only flashing LED's to indicate to the user the state of the system, although this is not true of all systems. For example, the Prentke Romich HECS (7) has a two-line LCD display which prints messages to the user. However, the system can not display graphics and requires the user to be able to read in order to use the system. Another group of stand-alone systems, the Quartet Series (2), have no visual feedback at all and rely solely on audio feedback to guide the completion of tasks. A PC-based ECS, on the other hand, is not so limited. A PC-based ECS's user-interface can have access to the full computer screen for display of messages, menus, pictures, and graphic icons. In addition, the interface can use color and a variety of sounds, from digitized recordings of speech and music to synthesized speech messages. This flexibility allows the same PC-based ECS to be appropriate for a large number of individuals or an individual with changing needs.

The dynamic user-interface of a PC-based system also offers other advantages. Because the display changes with the state of the system, more detailed information can be provided to the user. He or she can be made aware of the status of any equipment controlled by the ECS and can also be given warning messages in the event of an emergency. The memory and programmability of a PC-based system can also be utilized for developing macros to perform several tasks at once, store large lists of phone numbers, and keep track of the status of all of the devices attached to the system. A stand-alone system may also be capable of performing some of these tasks, but without a good user-interface it is difficult to take full advantage of these capabilities.

One possible solution to the input and interface difficulties experienced by users of stand-alone ECS's is to interface the ECS with an alternative and augmentative communication (AAC) device. Many stand-alone ECS's come with a serial communications interface that allows the ECS to be controlled via an AAC device. This allows the user some flexibility in controlling his or her ECS. However, an AAC device may still be limited in its display capability, and clearly, not every ECS user needs an AAC device, so that this is far from a complete solution.

Methods
Two approaches are described to operating the Ctrl1 through a DOS PC-based interface. First the requirements for the PC and the salient features of the Ctrl1 will be reviewed. Then two software interfaces will be described: first a control method based on a terminate-and-stay-resident (TSR) program and then a dedicated software application approach.

DOS-PC
In order to be interfaced with a Ctrl1, the IBM-compatible computer being used must have at least one serial port with which to transmit ASCII sequences to the Ctrl1. Any other system requirements are dependent on the nature of the interface being used. For example, if the interface is being operated via a voice recognition system then the computer might require as much as eight megabytes of RAM, space for an expansion board, a sizeable hard-disk, and a fast microprocessor, which might lead to the use of a 386- or 486-based desktop computer with enough space for an extra board and enough power to handle the computational demands of the system. On the other hand, if the interface chosen can be accessed by a standard keyboard and places very little demands on the underlying computer hardware, then a less expensive desktop or portable computer may be equally appropriate as a more powerful computer.

Control 1
The Ctrl1 is a stand-alone unit that offers flexible environmental control options through both the main unit and accessories. The Ctrl1's capabilities make it a desirable alternative for many patients. Unfortunately, some individuals experience difficulty learning and using the system, as is the case with many stand-alone units. This is due to the limitations of the interface such as the number of input options and the limitations of the visual display.

The Ctrl1 can receive input directly through the Ctrl1 Input Display (CID) or from a device which has a serial interface. Row-column scanning is the most common means used to access the Ctrl1 functions through the CID, although Morse code may also be used. The CID is a separate display which allows the user to select various functions available through the Ctrl1. The options available to the user are listed on the display in three columns, each headed by an LED and each containing sixteen items. The LEDs indicate which column is currently active. A fourth column composed entirely of LED's is used to indicate which item on the column lists is currently active. In scanning mode the user scans to the desired function and activates it. In Morse Code mode, the user does not rely on the visual display of the CID but instead uses two switches to enter multi-letter sequences in Morse Code corresponding to the desired operations to be performed by the Ctrl1.

Many individuals find that CID difficult to master. Common problems with row-column scanning include setting momentary switches to latched mode, changing the X-10 house code transmitted by the unit, and difficulties with the phone control functions. Using Morse Code is no less challenging. Each letter combination required for a function is at least four letters long and may be as long as 32. The user is given no feedback (other than the tones associated with each dot or dash) until the entire sequence has been entered as to whether or not a mistake was made, which makes entering long codes a daunting task.

On the other hand, if the user operates the Ctrl1 via a communication device, he or she must rely on the ECS's base unit for visual feedback and direct the Ctrl1 by transmitting to the ECS the same multi-letter sequences as when operating in Morse Code mode. However, in this mode the letters are transmitted via a serial connection as ASCII codes and not as Morse Code. This removes the burden of using Morse Code from the user. The codes required to operate the Ctrl1 can be sent one letter at a time or more effectively by configuring the communication device to send the entire code at once. This latter option obviates the need to learn the Ctrl1's codes but the user is still required to learn the selection sequences required by the communication device with little or no display feedback.

TSR-based Interface
The first method involves a terminate-and-stay-resident program called Altkey (8, 9). Altkey can be used in one switch scanning, two switch scanning, or Morse Code mode. In one and two switch scanning, Altkey displays a scan line on the screen and the user chooses from the selections offered on the scan line. Altkey maintains a hierarchy of scan lines known as a scan tree. By making choices in the scan line the user can move within the scan tree and also enter data to programs running at the same time Altkey is active. Altkey is typically used to provide switch access to programs like word processors and spread sheets, but Altkey can also be used to send ASCII codes through the serial ports of the computer to the Ctrl1. We have used this feature to construct an Altkey scan tree to provide scan-line control of the Ctrl1 that can be accessed from any program that is Altkey compatible.

At any time while using the computer the user can enter the Ctrl1 scan tree and perform a desired function on the Ctrl1. The scan tree is designed to present a series of scan lines that provide the user with all the available options. The user works through the scan lines one at a time to specify exactly which operation is desired. For instance, to answer the phone the user would first select the "Phone Control" option from the main scan line, and Altkey would then display the scan line containing all of the users phone control options. The user would then choose "Answer Phone" from this second scan line and the proper code would be sent to the Ctrl1 to instruct it to answer the phone.

An option (not implemented to date) provided by Altkey is its audio-scanning feature. If the computer is attached to a speech synthesizer then Altkey can work with the synthesizer to provide an audio-scanning interface either in addition to or instead of the visual scan line. This is potentially of value to people with impaired vision or individuals unable to read.

Dedicated Software Application
The other approach we have taken is a dedicated software application, written in the programming language C, which implements a menu-based interface. The program presents the user with a main menu listing all of the control option groups available. From this main menu the user can bring up separate screens to access X-10 appliances, switch closures, bed controls, and a telephone. When the user desires to perform some task, he or she chooses the appropriate functional group and the program displays a new menu providing the user with the appropriate options.

The user makes selections and enters data via the keyboard, a keyboard emulator such as Altkey, or a voice recognition program. These initial data entry options were chosen to allow the user a wide variety of input options in an attempt to make the program accessible to a large body of users. Additional interface designs could incorporate mouse emulators or other input methods to further widen the potential user pool.

The telephone control screen consists of two windows, the first of which lists the different actions the user can perform and the second of which contains a directory of phone numbers stored in memory. The Ctrl1 is only capable of storing ten numbers, but the computer is capable of storing many more. The user is able to answer and hang-up the phone, dial new and stored numbers and redial. In addition the user is also able to store and remove numbers from the computer's memory.

The X-10 appliances and switch closures control screens are very similar to the telephone control screen. The user is again presented with two windows, one displaying the users options and the second containing a directory of stored appliances or switches. The user is able to turn appliances on and off, brighten and dim lamps, and turn on all appliances at once. The switch controls provided enable the user to open and close switches, and toggle switches between momentary and latched modes. In each case the user can associate a name for a device to be displayed with the switch or appliance number.

The bed control operations provided by the program are the standard controls offered by many bed controls, namely raising and lowering the head, foot, and entire bed. The user selects the desired operation and then "presses" a key or switch (using whatever form of keyboard emulator desired) to put the bed in motion and then "presses" another key to stop the motion.

Discussion

It should be noted that the interfaces we have designed are just two of many possible interfaces and are not necessarily appropriate for every individual. For example, when a user is unable to read, a picture-based or audio-scanning interface may be a better solution. Also, there are many different input methods that could be used, including switch scanning, Morse code, voice, trackballs, mouse emulators, and various keyboards, to name a few.

There are limitations to the Altkey approach. Most important is that the scan tree can not change to reflect changes in the environment. For example, the scan tree allows the user to store numbers in the main unit, but the scan line used to dial stored numbers will not automatically change to display the contents of the phone directory stored in the Ctrl1. Another drawback is that Altkey limits the user to switch input.

This approach does, however, have its merits. Most importantly, it allows access to the Ctrl1 without dedicating the computer to running the interface. This allows the user to make use of his or her computer for other activities. In addition, this approach is relatively inexpensive. Altkey costs less than one hundred dollars and the only additional cost is the cost of the switch or switches. Finally, this approach does not require a great deal of computer power. A minimum amount of RAM is required, processing speed is not a factor, and no expansion boards are needed. Almost any IBM-compatible computer with one serial port that can be connected with the Ctrl1 and a second serial port for the Altkey switch input would suffice.

Unlike the TSR, the menu-based interface can not run in the background. However, it does allow the interface to change dynamically to display volatile information such as the phone numbers stored in the Ctrl1's memory and the last number dialed, or display a name associated with each X-10 appliance controlled by the Ctrl1. In addition, it can accept input from a larger number of input devices which makes it accessible to a wide variety of individuals. Lastly, storing information on a computer disk makes it less vulnerable to loss.

With any user-interface design a multitude of human-factors issues must be addressed. How much information the user is given, the number of choices the user must select from, and the methods of conveying information to the user are only a few of the many issues to be dealt with. While a detailed human-factors analysis of the interface design is beyond the scope of this paper, some discussion of the design choices we have made follows.

The menu-based interface offers the user access to every possible function of the Ctrl1 that the serial interface permits. No attempt was made to eliminate possibilities that might be too complex for a user, such as storing a telephone number in memory or associating a switch closure with a device name. In addition, all information is presented textually in the form of on-screen menus and message windows. No auditory or graphic feedback is given. Although this interface requires a higher level of cognitive ability than might be required by other interface designs, every attempt was made to provide the user with all the information required to perform any desired task. Message windows are used to prompt the user as to what input is expected next, and lists of all phone numbers, appliances and switch-controlled devices are presented by the system. The main drawback of this approach, of course, is that anyone who uses the interface must not only be able to read but also must be able to sift through all of this data while still accomplishing the desired operation in a reasonable amount of time.

One issue not addressed by either of our approaches is the integration of remote control capability, which is something that some stand-alone ECS's, including the Ctrl1, can provide. A computer-interface that conveys all of its information visually would be difficult to operate remotely, and might require that the user remain in visual contact with the screen. However, a PC-based ECS that provided audio feedback such as audio-scanning could be coupled with a transmitter-receiver system to allow the user to operate the ECS without being able to see the screen. Of course, this would also require that input to the interface be entered remotely, perhaps with switch closure signals sent by a radio transmitter or a voice recognition system operated by a remote microphone.

The subject of this paper also raises the larger question of what is needed in a PC-based or stand-alone ECS to remove the need for this particular approach. PC-based ECS's can already offer the wide variety of input methods and display options necessary to make an ECS effective. However, there is a need to provide users with a wider variety of controls than are typically offered. Users need to be provided with control over phones, infra-red devices, electrical appliances, hospital beds, and numerous other items but the authors are presently unaware of any PC-based ECS that can permit access to all of these things. There are many stand-alone ECS's that do provide access to all of these functions, but they do not offer the detailed dynamic display or the wide variety of input options available in PC-based ECS's.

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A COMPUTER-BASED MUSIC SYSTEM FOR BIOFEEDBACK AND RECREATIONAL THERAPY : TONGUE MUSIC FOR ORAL DYSPHAGIA

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ABSTRACT

Dysphagia refers to disorders of the swallowing mechanism. Poor oro-motor strength characterizes impairments in the oral phase of the mechanism. Current therapeutic techniques provide no quantitative feedback to the patient with respect to performance. We have developed a computer based Tongue Music System which provides quantitative feedback of the biomechanical parameters quantifying the oral phase of swallowing thereby allowing on-line real-time assessment of patient performance during therapy.

BACKGROUND

A constant challenge for therapists in the rehabilitation setting is that of patient motivation. Involving the patient in his own therapy has been known to accelerate the recuperative process. This is precisely the aim of biofeedback therapy. Biofeedback therapy is defined as the technique of using equipment (usually electronic) to provide auditory and visual feedback of a certain measured physiological variable, and inducing the patient to voluntarily or involuntarily control this measured physiological variable [1].

Recreational therapy harnesses the artistic and creative energies of a patient, and interlinks these to his overall recuperative process. Recreational therapy emphasizes the constructive use of leisure time. Like biofeedback therapy, recreational therapy also stresses patient involvement.

Both these therapies require creativity not only on part of the patients, but also on part of the therapists. The prescribed therapies should be able to captivate and challenge the patients over a long period of time.

Dysphagia refers to disorders of the swallowing mechanism, a condition frequently observed in head injury and stroke patients. Oral dysphagia is characterized by impaired oro-motor performance which can be improved by conducting resistance and range of motion oro-motor exercises.

Current techniques in oral dysphagia rehabilitation are qualitative in nature and provide no quantitative feedback about performance either to the patient or the clinician [2].

Reddy et al. have earlier developed methods to measure the biomechanical parameters that characterize oro-motor performance [3]. These include forward and lateral tongue thrust, lip pulling force, and lip closure pressure.

In this study, we have developed a patient controlled computer based system to be used for quantitative biofeedback and recreational therapy in the field of oral dysphagia rehabilitation. The system tries to stimulate the musical talents of patients, and encourages them to create their own music. The data-logging system stores patient performance data in an easily retrievable format in the computer. This patient data file can be analyzed later using the data-analysis software provided. Patient performance/ progress reports can also be obtained.

THE SYSTEM

Figure 1 is a block diagram of the various system components. The heart of the system is the 486-based IBM-PC compatible. The analog output of the transducer/signal processor system is digitized using a Keithley Metrabyte DAS-08 data acquisition board. The transducers used to measure oro-motor performance parameters were developed earlier by Reddy et al. during their study for quantifying the oral phase of swallowing using biomechanical parameters [3]. This digitized data is then processed by the software. Depending on the value of the measured parameter, the computer generates audio-visual feedback for the patient. Auditory feedback is in the form a musical note (higher the parameter value, higher the note). The primary display on the screen is that of a 51 key synthesizer keyboard. For visual feedback, the parameter value changes the relative position of the "Played Note" guide. This is a red bar that moves across the top of the keyboard. It indicates what key is being pressed (which note is being played). Depending on the value of the measured variable, the guide travels over the whole 51 key range. Target setting

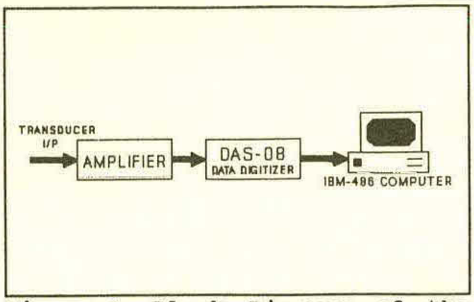

Figure 1 Block Diagram of the Tongue Music System

can be done on the system, so as to change the degree of difficulty depending on the abilities of the patient. Thus, the degree of difficulty can be increased as a patient progresses through therapy.

The patient performance data is stored on-line for future reference. Customized patient progress charts can be obtained from this data, thereby enabling better target setting during subsequent therapy sessions.

DISCUSSION

The Tongue Music System (TMS) presented here provides the clinicians with a tool that can prove useful in situations where patient involvement and motivation present a major problem. The system makes the patient an integral part of his own therapy, and provides for therapy which is more interesting than any existing therapeutic technique. The quantitative nature of the feedback provided by the system helps the patient as well as the clinician in assessing improvement.

The system interfaces to a wide variety of transducer and signal processor systems. This wide interfaceability and modular nature of the input was a major design consideration when designing this system. This system can alternatively be configured as a "Muscle Music System". This can be achieved by using muscle EMG activity as the input to the system instead of the tongue force measuring transducers. Thus, in this configuration, the system can be used to train or exercise atrophied muscle groups.

The advantage of this computer based system is the ease of customization. Patient progress charts can be customized as per the needs of the clinician. Various musical target routines can be programmed to provide for interesting target setting. We are currently in the process of studying the clinical efficacy of the Tongue Music System. Preliminary results indicate a high degree of interest in the system. This has been expressed by both clinicians as well as the test subjects.

ACKNOWLEDGEMENTS

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Computer Assisted Learning Modules on Environmental Control Units

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Abstract

This paper describes training materials developed at the Buffalo Rehabilitation Engineering and Research Center on Aging which use the computer as the medium of instruction. The materials teach occupational therapists how to match client needs with appropriate environmental control units. This paper summarizes the content of the instruction materials and describes the different ways in which the learner may use them. Finally, the procedures and difficulties in developing such materials are discussed.

Background and Purpose

New assistive technologies are constantly appearing and even occupational therapists trained relatively recently may have difficulty in keeping informed about developments in this field. One such area of assistive technology is that of environmental control units (E.C.U.s). In addition to keeping abreast of new devices, the occupational therapist must be thoroughly familiar with the characteristics of different classes of such devices and how these may influence their suitability for assisting with task performance by persons with different functional abilities. The interaction of the demands of the task, the abilities of the person and the characteristics of the device, makes E.C.U. selection a complex decision. Frequently, the occupational therapist is not sufficiently familiar with recent developments to enable them to consider the full range of possible E.C.U.s.

Objective

The purpose of this project was to make material available to universities and continuing education organizations for use in training students and professionals. The instructional system had to take into account the complexity of the subject matter, as well as the differences among users with respect to their knowledge, experience and objectives.

Content

A learning task analysis (Gagne, 1977) was performed to determine what the program should teach. Starting with the intended learning outcome (that is, to be able to select E.C.U.s which fit client needs), the members of the development team asked themselves what would a person need to be able to do in order to be able to make such a selection. After identifying the necessary skills (analyze environment, analyze person and identify characteristics of E.C.U.s), the question was repeated for each of these skills to identify another layer of pre-requisite abilities. By continuing to repeat the question, a chain or hierarchy of knowledge and skills was generated. The process was continued through successive levels, until the point was reached where team felt that most learners would already have acquired the sub-skill from some other course within their occupational therapy training. This analysis provided the team with the structure and sequence of the topics to be taught.

The program focuses on three main skills and content areas: 1) analyzing the client's environment and the tasks he wishes to perform, 2) assessing the client's functional abilities in light of the requirements for the operation of different E.C.U.s and 3) identifying characteristics of E.C.U.s (such as input type, selection method, output type and power source), which would make an E.C.U. suitable or not for a client with particular functional abilities who wished to perform a specific task in a certain environment.

Instructional Methods

The computer assisted instruction program was developed using the ToolBook authoring system. This is a system which provides the author with options for decisions about presenting different parts of the content. These include decisions about visuals, sound and feedback mechanisms.

In this program, the content is presented in four ways. The first is expository teaching, in which concepts and examples are presented in a logical sequence of topics. The learner may, however, opt to skip forward over topics with which he is already familiar, or move back to repeat information which he needs to recall as he progresses through the program.

The second modality is the problem solving approach. The learner is presented with a case study, a hypothetical client about whom information is provided. The learner must analyze this case and make several decisions about what type of E.C.U. seems to be most beneficial for this client. If the learner feels the need, he may consult the expository module, to obtain the concepts and information needed to solve this problem.

A third way of using the program is as a reference. The user can scan through a list of topics and choose those which he wishes to study. The information is that which is in the expository approach.

Finally, there is a data bank containing information about 100 E.C.U.s. The learner may browse through this information to obtain an idea of the types of devices available and their cost.

Project Status

A prototype of the program has been developed and is being field tested with occupational therapy students. This prototype is being demonstrated at the RESNA conference. It is anticipated that the final version will be ready for market by the end of 1993. In each year of the project cycle a new program will be developed. Future topics include pressure ulcers and wheelchair selection.

Issues in Developing Computer Aided Training Materials

Traditional teaching materials, such as books, may be prepared by a single author who is the content specialist. Videos require the participation of a media specialist. Computer assisted instruction seems to require a joint effort by a content specialist, a computer programmer and an education specialist. Besides the multidisciplinary composition of the development team, the time involved is much larger than for conventional materials. Chambers and Sprecher (1984) report that estimates for courseware development range from 50 to 500 hours of development time for one hour of student use, with 100 hours as the most widely accepted rule of thumb. When the team is developing programs for the first time, a learning process in required. Turnover within the development team can also slow the process. For example, a programmer may require several weeks to become familiar with the ToolBook system, and several months to become proficient in it. Due to continued advances in both assistive technology and instructional media, there is the additional need to commit time to the "maintenance," or periodic up-grading of educational software after it is developed.

Conclusion

In spite of the challenges, computer assisted instruction appears to be a promising way of providing training about many aspects of assistive technology. Given the fact that computer assisted instruction has been around for at least 20 years, it is surprising that there are not more materials on assistive technology which make use of the unique capabilities of this medium.

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SIG-12
Rural Rehabilitation

FARMERS AND RANCHERS WITH SPINAL CORD INJURIES — RURAL ACCESSIBILITY AND THE AMERICANS WITH DISABILITIES ACT

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ABSTRACT

A two-year study of the rehabilitation needs of farmers and ranchers with spinal cord injuries (SCI) was recently completed. As a result of this project the need to provide information about the ADA and rural accessibility was evident. ADA resources have been provided to rural professionals and over 25 ADA accessibility assessments of County Government Buildings, Extension Offices and 4-H Fairgrounds have been completed in the last year.

BACKGROUND

It is estimated that 8.5 million rural residents have disabilities. The RTC: Rural Institute at the University of Montana estimates that 13 million rural residents have at least one chronic or permanent impairment (RTC: Rural 1990). A recent report from the National Safety Council has classified agriculture as one of the most hazardous occupations in America (Accident Facts, 1991 Edition).

A survey sent out to over 300 farmers/ranchers with SCI's, and almost 70 on-site visits were completed between 1990-1992. From that survey it is estimated 300 SCI's occur in the agricultural population each year. The total number of persons in the agricultural population with SCI's is 4,500 to 6,000.

OBJECTIVE

In order to determine the worksite needs, vocational rehabilitation needs, employment experiences and community involvement and accessibility of public facilities for farmers/ranchers with SCI's a two-year study was completed. In completing the study 149 farmers/ranchers with SCI's completed the survey, 56 worksite needs assessments were completed and 10 follow-up visits were made 2 years after the initial survey to assess the progress and current problems of the original participants.

Over 25 ADA Assessments have been made of County Office Buildings and 4-H Fairgrounds.

APPROACH

In response to the needs of farmers/ranchers with SCI's (and other rural residents with disabilities) ADA accessibility assessments have been provided in over 25 County Office Buildings, Extension Offices and 4-H fairgrounds. An ADA resource packet was sent out to every Extension Office in the state. An ADA checklist was developed for rural professionals to assess rural offices and fairgrounds. Finally, an ADA video was developed and provided to every Extension Office in the state, to the fourteen AgrAbility states and other rural organizations.

Three different farmers with SCI's have assisted with many of the ADA assessments. This resulted in an increased awareness of farmers with disabilities by county officials, effective ADA assessments by consumers (farmers with SCI's), and greater understanding and willingness to remove physical and attitudinal barriers by local officials and agencies.

DISCUSSION

The survey of farmers/ranchers with SCI's found that almost 60% of the respondents were "very active" or "active" in church. Yet, over 40.9% of the churches were rated as "not accessible" or "partially accessible." Hunting and fishing were rated the second most popular activity with 48% being "active" or "very active." However, more than 52% of parks and recreational facilities were rated as "partially" or "not accessible." Farmers ranked farm organizations as their third most common form of community involvement, with 38% being "active" or "very active." Still, more than 48% of the county office buildings, 41% of the ASCS and Extension Offices, and 45% of the libraries were classified as "partially" or "not accessible" by the respondents.

By providing ADA accessibility assessments in rural communities, ADA Resource Packets, an ADA checklist, and an ADA video an increased awareness of the ADA, the removal of physical barriers, and low cost solutions have been provided throughout the entire state.

ACKNOWLEDGMENTS

Funding for the survey was provided by the Paralyzed Veterans of America's Spinal Cord Research Foundation (SCRF Grant #760-02). Funding for the ADA video: "The ADA and You: Compliance Guidelines for CES Offices and 4-H Fairgrounds" was supported by the Extension Service, U.S. Department of Agriculture (Project No. 91-EDFA-1-0001).

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IMPROVE FARMHOUSE ACCESSIBILITY: NO-COST AND LOW-COST SOLUTIONS

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ABSTRACT

Most farmhouses are not designed for wheelchair accessibility. The paper describes a systematic approach that can be used to help farm families analyze their housing situations and offers solutions for making their homes more accessible. No-cost and low-cost solutions are emphasized.

BACKGROUND

A farm family that needs to adapt its home to accommodate a wheelchair faces difficult challenges. Moving is not an option. Local resource people with expertise in planning and designing accessible housing modifications are not readily available. Financial resources to keep the farm operation going usually take precedence over housing expenditures.

After a farmer experiences a disabling accident or injury, the primary focus is usually placed on getting him or her "back in the field." The family may fail to recognize how much their outlook depends on how well their home fits their new needs. A home that is accessible and convenient can pay big dividends in terms of lifting spirits, increasing independence, and improving productivity.

OBJECTIVES

The purpose of the paper is to provide a resource that rehabilitation professionals can use with farm families to help them analyze their housing situation and identify no-cost or no-cost solutions to make their homes more accessible.

APPROACH AND DISCUSSION

Start with the Basics

It will be difficult or impossible for family members who use a wheelchair to live in the farmhouse unless they can answer *yes* to three basic questions:

1. Can they get in the house?
2. Can they get through the doorways?
3. Can they use the bathroom?

If the family has problems answering any of these questions, some additional issues need to be discussed before deciding whether to remodel the home or move to another location:

- Will they need more housing changes in the future if their abilities should decline?
- Do they need space to accommodate an outside caregiver?
- Do they need to postpone housing decisions until a caregiving routine has been established?
- Does the structural condition of their home warrant extensive remodeling?
- Can necessary modifications be made without destroying the architectural appearance or resale value of the home?
- Do they have enough money to pay for needed housing modifications and/or the services of a caregiver?

Once the family determines that they want to proceed with plans to improve accessibility, examples of possible solutions include the following:

Accessible entrance. At least one entrance with no steps, or a way to get around existing steps.

- use portable ramp as a temporary solution
- regrade site to make ground level entrance without steps
- build "bridge" to connect house and yard on sloping site
- build ramp with no more than 1-inch rise for every 12-inches length
- unload from wheelchair lift in van directly onto deck, porch, or landing pad

Wide doorways. At least a 32-inch clear opening is required to roll a wheelchair through a doorway without scraping knuckles.

- remove doors temporarily
- install swing-away hinges
- reverse swing of door to allow it to open wider
- remove some or all of woodwork around door
- replace existing door with wider one

Usable bathroom. At least a 60-inch diameter maneuvering space is needed to be able to reach fixtures.

- reverse swing of door to make it open out instead of into bathroom
- replace existing door with pocket door
- remove door (use curtain for privacy)
- relocate fixtures to create more floor space
- remove base cabinets to provide access space under lavatory
- replace tub with shower unit

- remove tub and/or shower unit and bathe while seated on toilet
- move lavatory to another space where privacy not needed
- relocate toilet or shower to corner of bedroom

Relocate, Restructure, and Rearrange
Before the family makes plans for additional remodeling, they should consider no-cost and low-cost ways to relocate activities, restructure tasks, and rearrange furnishings.

Relocate activities. If they live in a two-story home or split-level house, they need to consider ways to relocate activities for eating, sleeping, bathing, and living on one floor before installing an elevator or stair lift.

Restructure tasks. If some household tasks are no longer accessible for persons who use a wheelchair, eliminate these tasks or have another family member do them.

Rearrange furnishings. More space is needed for traffic lanes to maneuver a wheelchair. Large pieces of furniture may block access to rooms or make it difficult to get around. Rearrange furnishings in these rooms to create straight traffic lanes. Move large items to another location. Some furniture may need to be stored, given away, or sold.

Identify Problems and Solutions
The remainder of the presentation will provide a room-by-room analysis of potential problems in the farmhouse environment and possible solutions for eliminating them. A 10-page checklist will be distributed to members of the audience. Slides will be used to illustrate "before" and "after" examples of accessibility modifications. Possible funding sources and additional resources will also be identified.

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INVENTORY AND COMPUTERIZED MAPPING OF TRAILS: THE FIRST STEP TOWARDS ACCESS

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ABSTRACT

Building on the results of pilot work, this project will grade the accessibility of wilderness trails, using objective measurement criteria. Maps will be created using computerized mapping techniques to encode the measurements, giving prospective users objective and, insofar as possible, quantitative data on the difficulty of each trail. Trail caretakers will then have data with which to evaluate the trail for possible improvements without affecting the wilderness experience of hikers using the trail. Users with mobility considerations will have information enabling them to choose a trail appropriate to their abilities.

REASONS TO MAP AND INVENTORY

Maps provide information so a hiker can have a successful trip. Advance information about a trail allows the hiker to prepare with appropriate clothes, food, water and tools and to predetermine what assistance is necessary for the hike. Is a buddy (or two) necessary to assist with carrying extra gear, belay, push, or pull? The hiker can also decide whether reaching the destination is possible. This is an individual decision—one hiker is willing to clamber up a talus, another will find it too hard. Current grading systems, based on subjective information such as "easy hike" or "moderate slope," do not give enough specific or objective information to hikers.

Mapping also gives trail caretakers an opportunity to identify areas for maintenance and alteration. For instance, areas prone to saturation and frequent use may be selected for soil treatment to prevent erosion. If a trail is identified as relatively easy except for a short section obstructed by rock slide debris, caretakers may decide to modify that short section to open up the trail to people who would be discouraged by the climb.

As useful as inventory processes and maps are, their design could be improved to meet the needs of people with walking limitations, people with respiratory limitations, people with endurance limitations, people with impairments of lower extremity movement, inexperienced hikers, families with small children, and anyone else with special circumstances limiting their willingness or ability to navigate a difficult trail. Some may use the additional information to decide if a trail will require an all-terrain wheelchair or special tires; others may choose another trail. "The goal of land managers should be to provide a range of options that, to the extent possible, maximizes access without compromising wilderness." (Lais, 89).

SELECTION OF ATTRIBUTES TO CODE INTO MAPS

"Information required for definitive access knowledge varies with every kind of disability and every sort of wheelchair." (C.S.C.C., 1990) Objective information about trails must be quantified so that wheelchair users and others with mobility considerations can decide which trails they wish to hike based on their specific functional abilities and equipment. A pilot study identified four attributes as important for continual description: inclination , maximum side slope (left or right), minimum trail width, and surface characteristics of the trail (firmness). Graphic design students at Montana State University created prototype maps to develop coding techniques for mapping the trail attributes listed above.

Current work involves testing a system for categorizing these four trail attributes:

a. Inclination will be coded using the following categories:

5% or less

6%–9%

10%–13%

greater than 13%

(For reference, a 1:12 slope is equivalent to an 8.3% slope.)

b. Side slope/cross slope will be coded using the following categories:

2° or less

3°–6°

7°–11°,

greater than 11°

c. Width will be coded using the following categories:

60" or greater

28"–59"

13" - 27"

12" or less

d. Surface, will be coded using the following categories:

hard paved surface

hard packed surface

medium/average surface

soft/fine surface

very irregular and soft surface.

e. Obstacles

In addition to these four attributes, data on obstacles will be presented. Obstacles to be coded include:

tree roots (if larger than 2")

boulders or rocks larger than 2" in diameter

water crossings deeper than 2"

ruts deeper than 2"

vertical obstructions if less than 6 ft. 6 in.

steps (indicating number, depth, and height)

dangerous plants (e.g., poison oak)

drop off

METHODS OF INVENTORY

The survey techniques chosen to collect the proposed data on trails depend on the resources, needs and goals of the sponsoring organization. A municipality or local trail association with a small number of trails to survey, limited funds, and a desire to involve community members might sponsor a team-oriented assessment using traditional survey tools (compass, clinometer, rolo-tape, etc.). In addition to the trail inventory, the project might generate, through community involvement, an increased sensitivity to trail and access issues. At the opposite end of the spectrum, a federal agency needing to survey hundreds of miles of trails within a limited time may use a global positioning system (a satellite based navigation technology) and an in-house assessment team.

Beneficial Designs will train volunteers to conduct the measurement process. There are eight to ten people on an assessment team. A team ideally includes a representative of the trail managing organization, a wheelchair rider and person with partial vision, wheelchair assist people, someone with surveying or orienteering skills, someone with photography skills, a data recorder, and local volunteers. Training people to take the various measurements can be done in 15 to 20 minutes.

When a trail is being assessed, the beginning of the trail is marked, "A survey crew is measuring the trail for accessibility, please avoid scraping the dots from the dirt." The trail is measured and marked and measurements are recorded every 100 feet, more often if the trail has many curves. Readings on slope, side slope, width, trail surface and obstructions are made and recorded in any order. The data is checked at the end of the trail. If any measurements look strange or incorrect, they are checked on the return trip.

FUTURE WORK

Beneficial Designs, Inc. received approval for funding for Phase One of a Small Business Innovation Research project entitled *Computerized Mapping of Outdoor Trails for Accessibility* to develop and test a system for measuring and coding objective data on specific trail attributes into maps.

In May 1993, working with cartographer Joseph Wiedel and computer cartographer PohChin Lai, the investigators will perform trail assessments and map trails from the Santa Cruz County area. The results of collaboration with these experts will be presented. In July and August of 1993, twelve trails will be assessed: six trails in the Gallatin National Forest in Montana and six in Yellowstone National Park in Wyoming. The ten trails which best represent a range of terrain conditions will be coded, mapped and evaluated.

VOLUNTEERS TO BE USED

Each trail to be assessed requires an assessment coordinator and a team to take the measurements. If you are interested in participating in a trail assessment, or eventually being trained to perform trail assessments, please contact Beneficial Designs, Inc., in Santa Cruz, California. In Phase Two of the project, Beneficial Designs plans to develop a certification program for trail assessment coordinators to organize and initiate trail assessments in their own regions. The data collected would be sent to Beneficial Designs and coded into maps for printing and distribution.

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NOISE-INDUCED HEARING LOSS: A CONCERN FOR FARMERS

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Abstract

The picture many people have of farming is serene — a man and his dog on a sunny day, the only sound a gentle breeze blowing through a tall, golden crop of corn. In reality, farmers are frequently exposed to high levels of noise because of their jobs. Tractors, augers, combines, grain dryers, power tools, chain saws, lawn mowers and more, for example, each may produce noise exceeding recommended safe limits. These working conditions can make farmers and ranchers prime targets for a noise-induced hearing loss.

This publication will provide rural rehabilitation professionals with information concerning hearing loss that is relevant to serving the farming population. Types of hearing loss and ways to prevent noise-induced hearing loss are presented, as well as specific examples of on-farm work strategies and technologies for accommodating a hearing loss.

Background

An estimated 21 million Americans suffer from hearing loss or deafness [1]. Approximately 420,000 of those are farmers or ranchers and the number continues to grow. According to the American Safety Council, noise ranks as the number one cause of hearing loss, followed by injury and disease. One reason may be that many persons, do not associate overexposure to noise with a potential loss of hearing.

Objective

The objective of this publication is to identify for rural service providers the fact that farmers and ranchers are at risk of sustaining a noise-induced hearing loss. This report discusses the risks they face, outlines ways to reduce or prevent that risk, and identifies strategies and technologies for accommodating a hearing loss. By doing so, it is believed that rural rehabilitation professionals will be better able to serve the needs of a farm family member who has or may be at risk of incurring a noise-induced hearing loss.

Definitions

Degree of Hearing Loss
A person's degree of hearing loss is a quantitative measure of the volume of sound that can still be heard.

1. Slight — 25-40 dB: Difficulty hearing soft or distant speech in church or theater;
2. Mild — 40-55 dB;
3. Moderate — 55-70 dB: Difficulty hearing normal levels of speech (at 65 dB);
4. Severe — 70-90 dB: Can't hear loud speech or understand speech on the telephone, but can hear shouted speech;
5. Profound — greater than 90 dB: Difficulty hearing even shouted speech.

Types of Hearing Loss
The three major types of hearing loss are conductive, sensorineural, and mixed. ***Conductive hearing loss*** (or mechanical hearing loss) results from disease or obstructions in the outer or middle ear and usually effects all frequencies of hearing. Rarely does a person with a conductive hearing loss experience a Severe or Profound loss of hearing. Frequently an individual with this type of loss can be helped medically, surgically, or by the use of a hearing aid. ***Sensorineural hearing loss*** occurs when the delicate sensory hair cells of the inner ear or the auditory nerve has been damaged. Hearing loss ranges from Mild to Profound. Sounds become distorted only at certain frequencies, so a hearing aid proves to be of little help.

With a combination of conductive and sensorineural hearing losses in the same ear, a ***mixed hearing loss*** occurs. This loss includes problems in both the outer or middle ear and the inner ear.

Noise Sources

Prolonged exposure to sources of noise can gradually lead to hearing loss. Major sources of noise on the farm may include machinery, small engines, and power tools. Large machinery such as tractors and combines emit noise levels of 80 dB to 115 dB [2]. Two cycle engines such as lawn mowers and chain saws can damage hearing with repeated exposure. In addition, heaters, generators and radios inside the cab of tractors and combines can emit high noise levels that may damage hearing.

Damage may be incurred before it is diagnosed or before the individual notices any hearing loss. Be alert to a possible hearing loss if any of the following symptoms occur: difficulty hearing, ringing in the ears (hum, roar, or buzz), or dizziness. It is recommended that preventive steps be taken before any of these symptoms of hearing loss appear.

Prevention of Noise-Induced Hearing Loss

The first step in preventing a noise-induced hearing loss is to identify sources of noise in the shop and around the farm. They may have been taken for granted previously, so investigate thoroughly. Once sources are identified, reduce exposure to high levels of noise in one of the following ways [3,4]:

Reduce the level of noise at the source: The best method to prevent noise-induced hearing loss is to remove the source or reduce its volume to a safe level. Rarely will it be feasible to remove the source of noise, so it is important to identify steps that may be taken to reduce its volume.

- Replace worn, loose, or unbalanced machine parts to reduce vibration.
- Lubricate machine parts to reduce noise created by friction.
- Enclose the source in a sealed compartment to reduce noise levels.

Isolate the operator from the noise source: If the noise level cannot be reduced to a safe level at the source, attempt to isolate the operator from it. The obvious example is a tractor cab. In recent years, farm machinery manufacturers have designed cabs that reduce noise exposure to within safe limits by isolating the operator from the noise source.

Wear hearing protection: Hearing protection devices can dramatically reduce the level of noise reaching the ear drum and consequently reduce the risk of hearing loss. However, it is best to reduce noise at the source or to isolate the operator from it because hearing protection devices can be improperly fitted or used, resulting in damaging levels of noise reaching the ear. Hearing protection devices may also be lost, forgotten, or damaged, again resulting in no protection from harmful noise.

If a farmer must work in an environment with harmful levels of noise, there are many hearing protection devices sold commercially. They fall generally into the categories of ear plugs or ear muffs. ***Ear plugs*** are small, soft inserts that are placed into the outer ear canal. ***Ear muffs*** are worn outside the ear, actually covering the entire outer ear.

Properly fitted ear plugs or muffs reduce noise 15 to 30 dB. Simultaneous use of ear plugs and muffs usually adds 10 to 15 dB more protection than either used alone. Combined use should be considered when noise exceeds 105 dB [5].

Accommodating a Hearing Loss

Technology

There is an abundance of technology that attempts to aid communication by persons with hearing loss. Examples of technology falling into the general categories of personal, group, and telephone communication are presented below. Technology that assists daily activities is mentioned, as well.

Personal communication aids include hearing aids, portable/hand-held amplifiers, or even small, portable personal computers to allow typing of messages.

Communication aids used in group settings include infrared and ultrasound "public address" systems. Such systems can be found in churches, auditoriums, lecture halls, theaters and many other facilities.

Telephone communication aids are quite varied. Individuals who use hearing aids may use a portable amplifier that is placed over the phone's standard earpiece to increase the volume of the other person's voice. A person with a Profound hearing loss may use a text telephone (also called TDD) that allows communication between two text telephone users via typed messages. Commercial software allows a person with a hearing impairment to communicate with any party that has a touch-tone phone. The party being called simply types a response using the letters associated with each of the telephone buttons.

In addition to communication aids, technologies exist to enhance the ability of a person with a hearing loss to perform daily activities. A knock light flashes when someone knocks at the door. Alarm clocks can be purchased that flash a light or vibrate the bed to signal "Time to wake up!" Smoke detectors are available that use a strobe light warning instead of an audible warning. Devices that attach to a telephone will flicker a lamp to signal that the telephone is ringing. This short list of items represents the wide variety of aids available.

There are, of course, many strategies for coping with hearing loss that do not involve technology. These include speech reading, sign language, use of interpreters, hearing ear dogs, and even paper and pencil.

Work Strategies for the Farm

Farmers who have a hearing impairment will need more than technology to accommodate their loss of hearing. They will also need to develop accommodating work strategies for the farm.

When working with others while on or around farm equipment, a farmer with a hearing impairment is encouraged to use a clearly defined set of hand signals for safe, efficient, unambiguous communication. The American Society of Agricultural Engineers developed a set of agricultural hand signals (2) to be used around high-sound-level farm equipment that should be suitable for use by most farmers with hearing impairments.

Farmers who wear hearing aids may find communication difficult inside farm buildings constructed with sheet-metal roofs and siding. The metal surfaces tend to reflect background noises that are then amplified by the hearing aid, making the noise more likely to "cover up" any intended message. Adding sound-absorbing materials to the inside surfaces of metal buildings may reduce the amount of background noise amplified by the hearing aid and result in better, clearer communication while inside those buildings. Fibrous and porous materials such as mineral fibers, glass fibers, and open-cell foams have good sound-absorbing qualities [6].

Farms often have a great deal of "traffic" as automobiles, tractors and other equipment are moved from one point to the next. Just as often, the farmer is busy accomplishing one task and preoccupied with several other tasks awaiting completion. For safety, a farmer with a hearing loss must learn to always look before crossing any road or vehicle path on the farm.

Conclusion

Farmers and ranchers work in conditions that frequently expose them to high noise levels. Their risk of sustaining a noise-induced hearing loss can be reduced or prevented by first identifying sources of loud noise then by taking steps to reduce exposure to those sources. If a hearing loss occurs, appropriate technology and on-farm work strategies may be employed to accommodate the hearing loss while continuing to farm.

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FARMING WITH A COGNITIVE DISABILITY

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ABSTRACT

Farming is a dangerous occupation. Thousands of farmers are injured every year and hindered in their ability to continue farming. Although efforts have been taken to address rehabilitation and secondary injury prevention for farmers with physical disabilities, e.g. Breaking New Ground Resource Center, a paucity of information and/or intervention techniques have been developed for farmers with cognitive disabilities. A statement of the problem, proposed research agenda, and currently available resources is discussed in relation to assistive technology, secondary injury prevention, and rehabilitation intervention for farmers with disabilities.

BACKGROUND

An estimated 2.2 million farm family members produce the food and fiber for the Nation. In addition, another 1.7 million persons work on a partial or seasonal basis performing farm labor. An estimated 500,000 farmers, ranchers, and agricultural workers have a physical disability, hindering their ability to complete one or more agricultural tasks. A lack of empirically based information is available about farmers with cognitive disabilities. However, research and personal experience reveals farmers with disabilities do exist and they possess interest in remaining on the farm.

A difficulty lies in the lack of available and clear information regarding the number of farmers with cognitive disabilities and types of disabilities among this population. A research initiative will prompt a better understanding of the needs of this population, explore strategies to increase the use of appropriate technologies and, ultimately, develop much needed resources

A second problem pertains to rehabilitation professionals' inability to access social services, obtain information relating to assistive technologies, and locate peer support systems.

Availability, accessibility, and acceptability are important concepts to consider in delivering rural mental health delivery issues. Information about agricultural modifications and technologies are fairly new and forever changing, but are available. Available rural mental health services and technologies are discussed.

Another difficulty is lack of peer support for both the farmer with cognitive disabilities and other family members. Farmers and farm family members need someone to share common experiences, emotions, and turmoils. A nonprofessional with a similar background and experience of the persons with a disability may aid in the rehabilitation process and transition.

OBJECTIVE

To enhance the quality of life for farmers, ranchers, and other agricultural workers who have experienced a cognitive disability.

APPROACH

Initiatives such as research and agency linkages must ensure that knowledge of assistive technologies, secondary injury prevention, and rehabilitation intervention is extended into and throughout rural communities, and the result is greater continued agricultural employment for farmers with cognitive disabilities. Such linkages are discussed.

DISCUSSION

Farmers with cognitive disabilities are a significant, often overlooked, part of the rehabilitation profession. Research and professional experience dictate that farmers with cognitive disabilities exist, but have few rehabilitation service options. Efforts must prompt education and outreach to rehabilitation professionals, farmers, and farm family members to assure proper provision of services.

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RECENT PROGRESS OF REHABILITATION ENGINEERING IN CHINA

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ABSTRACT

Life has taught us to understand the profound significance of Rehabilitation Engineering Offering "Equality and Participation" for the disabled. This paper presents general view on the recent development of Rehabilitation Engineering in China. A new Institute of Rehabilitation Engineering, First in China, was set up in Shanghai Jiao Tong University to take charge of all research work, mainly including those aspects: *Myoelectrically Controlled Artificial Upper Limbs, Automatic Recognition and Classification of EMG, New Principle for Designing Assistant Device for Heart-Lung Machine, Computer-controlled and Vision-aided Speech Training System for the Deaf, Body Function Rehabili-Tester, Gait Analysis and Data-Processing of Medical Information* etc. All items will be presented with separate papers in case of necessity.

INTRODUCTION

According to sampling statistics by the Chinese Ministry of Civil Affairs in March 1988, there are over fifty millions of disabled persons in China. (Table 1.)

Table 1. Categories of the disabled

Kinds of Disease	Amount (in millions)
Auditory & Language disease	11.7
Intellectual disease	10.7
Limb disease	7.5
Visual disease	7.5
Mental disorder or Insanity	1.9
Synthetic disease	6.7

Facing such great amount of disabled persons, the severe attention must be paid by Government. A nation of over one billion people, China is in want of interdisciplinary experts in both engineering side and life science. A special program has been jointly organized by Shanghai Jiao Tong University and Shanghai Medical University to offer a new discipline in Biomedical and Rehabilitation Engineering. About six hundred undergraduates and over 100 graduates were well-trained from this area in both universities, excluding those in other provinces and cities.

PRESENT STATUS OF CHINESE REHABILITATION MEDICINE AND ENGINEERING

The State Council controls the Ministry of Public Health and the Ministry of Civil Affairs which in turn control the Bureau of Medical Administration and the Bureau of Welfare. Within those bureaus there are offices under the control of local, provincial, urban and autonomous region departments of medical and welfare administration. Welfare work is carried out in every province, city and autonomous region under the jurisdiction of the Government. Programs for the blind and deaf-mute have been set up by the Department of Special Education under the Bureau of Primary Education which is under the regulation of the Ministry of Education. Labor employment is administered by the Bureau of Training and Employment which falls under the Ministry of Personnel.

The National Organizations include:

1. Chinese Welfare Fund for the Disabled,
2. Chinese Association for the Blind and Deaf-mute,
3. Chinese Association of Rehabilitation Medicine

The latter organ consists of three special Committees:

1. Committee of Rehabilitation Medicine Education,
2. Committee of Traditional Chinese Medicine combined with Western Medicine and
3. Committee of Rehabilitation Engineering.

CHINA REHABILITATION RESEARCH CENTER (CRRC)

CRRC was started in April, 1986 and completed in October, 1988. It is affiliated with the China Disabled Person Federation, which is under the control of Ministry of Civil Affairs. CRRC is a comprehensive research institute in China which provides disabled persons with overall rehabilitation. It is also an educational institution for training rehabilitation professionals for the Country.

The center (CRRC) has been identified as the Key Project of China 7th Five-Year's plan and is established under the investment of the Chinese government and international gratis aid, including donations from Japan, USA, Germany, Canada and Others.

The Center comprehensively utilized the modern science, technology and Chinese traditional medicine for the rehabilitation of the handicapped following the "Equality and Participation", enables them to come back again to the society.

MYOELECTTRICALLY CONTROLLED ARTIFICIAL UPPER LIMBS

As mentioned above there are several millions of disabled people with limb disease in China, of whom about 95% are the losers of one or both forearms during industrial accidents. Medical rehabilitation, functional as well as cosmetic is of great demand. From the point of view of engineering side, the *Special Open Chain* composed of multiple links with 27 degrees of freedom was considered and EMG signals from a pair of loser's antagonistic muscles are used during the time of design.

Three important motions for daily life of the disabled are needed to perform: Opening and closing of the fingers, Rotation of the forearm, Extension and flexion of the wrist. The successful designed achievements with *R* (rotative joint)-*P* (pivot joint)-*R-P-R-P* system have obtained at the Institute.

AUTOMATIC RECOGNITION AND CLASSIFICATION OF EMG

The goal of this research is to develop a new type of Multi-functional Artificial Upper Limbs controlled by EMG signals. According to the mechanism and mathematical model of surface myoelectric signals (EMG), different limb function is resulted by contraction of different muscles, so that the patterns of the surface EMG of different limb functions at the position of electrodes will also be different. It is possible for us to search out the stable but different characteristics from the stochastic nature of EMG signals of every limb activation through Time-Series analysis technology.

The Primary and perspective results will be presented in great detail with separate paper by the authors.

NEW PRINCIPLE FOR DESIGNING ASSISTANT DEVICE FOR HEART-LUNG MACHINE

Any ideal design of artificial rehabilitation device or mechanism should be made to follow the *Theory of Similarity* in bionics. A stationary (non-pulsatile) circulation of blood flow produced by ordinary rotary tap heart-lung machine causes frequently the failure of normal micro-circulation and the death of patient by so-called *acidosis* even after fully successful heart surgical operation.

Along with the development of medical science, counter-pulsation as an aid-therapy method has been used in a wide range and developed in the practice.

A new device, jointly collaborated with Shanghai Ren-gi Hospital, holding *pulsatile bypass and counter-pulsation (PBCP)* with aortic balloon assistant circulation system can trace the dicrotic notch accurately with the real-time control.

The experimental device was showing itself with feasibility and superiority in dogs' experiments.

COMPUTER-CONTROLLED AND VISION-AIDED SPEECH TRAINING SYSTEM FOR THE DEAF

The speech rehabilitation for the deaf is one of the important theses in the area of rehabilitation engineering. The speech training system can be used to help the people who can't speak because of congenital loss of hearing to train pronunciation themselves.

The computer-controlled vision-aided speech training system proposed is a new type of visible speech training device, which is based on the technique of isolated word speech recognition. The system can compare the pronunciation produced by the deaf with the standard pronunciation to decide if the input pronunciation is correct and how its quality is. The system can convert these information into the visible signals to instruct the deaf to do training.

The speech training device has been accomplished on the IBM-PC/XT microcomputer. Some evaluating experiments are made to prove the adequateness of the system.

DATA-PROCESSING OF MEDICAL INFORMATION

From the point of view of System Engineering, the human body consisting of complex structures and providing various functions may be considered as a *Large Scale System (LSS)* with multiple input and output. Much work has been done by medical doctors on analyzing the human body signals in time domain. The parameters used are varied according to doctors' experiences. The spectral analysis with mini-FFT system are now used for detecting much more medical information hidden in time-domain waves.

The *Parametric Modeling Software System* for analyzing and calculating the stochastic sampling data with much higher efficiency has been developing recently at the Personal Computer (PC) in the Institute.

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PROVIDING REHABILITATION SERVICES TO MIGRANT AND SEASONAL FARMWORKERS

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ABSTRACT

Approximately 2.7 million migrant and seasonal farmworkers (MSFW) participate in the national labor force. There are approximately 280,000 handicapped MSFW in the labor force, and another 60,000 handicapped dependents of farmworkers. MSFW are eligible for programs such as job training, trainee financial aid, legal assistance, and health care services, but the resources are infrequently utilized due to delivery barriers such as language and transportation. Interest and proactive leadership on behalf of rehabilitation professionals must be initiated to ensure MSFW receive needed rehabilitation services.

BACKGROUND

Approximately 2.7 million migrant and seasonal farmworkers (MSFW) participate in the national labor force. The MSFW that plant, propagate, and harvest our food, are very poor, illiterate, and receive inadequate health care and rehabilitation services. On a national level, there are approximately 280,000 handicapped MSFW in the labor force, and another 60,000 handicapped dependents of farmworkers. Progressive actions must be taken to address the rehabilitation needs of MSFW, provide equitable accessibility to vocational rehabilitation services, and ensure coordination between service agencies.

How many MSFW are working in the fields? How many MSFW and dependants have a disability that impairs a life functions? Attempts to assess the MSFW population have raised more questions and posted fewer answers.

Data from the Department of Education / Rehabilitation Services Administration (RSA) reveals much about the migrant and seasonal agricultural labor force. The MSFW population as a whole is very poor. Housing, transportation, and health care are important issues for MSFW and service providers. MSFW are unemployed for over 26 weeks per year. In Louisiana, a MSFW can expect to earn between $3-9,000 per diem. Approximately, 75-90 percent of MSFW receive additional resources such as food stamps. Although MSFW are eligible for programs such as job training, trainee financial aid, training related services, legal assistance, and special health care services, the resources are infrequently utilized.

MSFW with disabilities often continue to work, despite their disability. However, the MSFW with a disability cannot compete successfully for agricultural employment and, thus, are even poorer than their nondisabled counterparts. Additional challenges for rehabilitation professionals and other service providers include language barriers and lack of education. Approximately 30 percent of Hispanic farmworkers regularly speak English. However, 75 percent of MSFW dependents speak English. A median educational level for MSFW is 6.6 years as compared to 11.3 years for RSA clients overall. Rehabilitation professionals must address the noted language and education barriers.

OBJECTIVE

MSFW must be ensured equitable accessibility to rehabilitation services. A survey by RSA revealed no farmworkers with disabilities were receiving vocational rehabilitation services. A computer data base search of clients served by Louisiana Rehabilitation Services from 1980-1992 reveals only two (2) agricultural workers were provided vocational services. Considering agriculture is ranked as one of the most dangerous occupations and agriculture is a top financial enterprise for Louisiana, a discrepancy exists between accountable statistics and provision of rehabilitation services, particularly in Louisiana. MSFW are not being reached by rehabilitation service providers.

Once MSFW access vocational services, a rehabilitation professional must ensure language and cultural barriers are addressed and/or removed. As stated previously, only 30 percent of MSFW speak English, but 75 percent of MSFW dependent children speak English. Dependents may be used to facilitate the rehabilitation process. Language skills must be enhanced to enable alternative employment options. Culturally sensitive counselors, preferably bilingual, must be used in the provision of services. Once language and cultural barriers are removed a proactive role may be taken by the counselor.

Resources are available for MSFW, including health care, nutritional consultation, and job training; however, these resources are not readily available due to lack of transportation and service hours, thus, resources must be coordinated. In addition, the rural nature of MSFW employment, coupled with an existing lack of services in rural communities, makes utilization of services difficult, if not impossible. Efforts must be taken to coordinate services as to ensure effectiveness and quality of services. Coordination of services begins with developing a strong knowledge base of available resources, prompting dissemination of information about individual agency services, and involving differing agencies on planning and administration boards. Though coordination, services may be maximized, and replication minimized.

DISCUSSION

MSFW require vocational rehabilitation services, but are unable to obtain services due to language barriers and transportation blocks. Various health and rehabilitation services are available for MSFW and greater coordination between agencies is needed. Although the challenge is great, interest and proactive leadership on behalf of vocational counselors and other service providers may ensure MSFW receive needed vocational rehabilitation services.

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SIG-13
Assistive Robotics and Mechatronics

An Introductory Laboratory Exercise in Rehabilitation Robotics

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ABSTRACT

The concept of using robots as manipulations devices for people with upper limb impairments was first proposed nearly 30 years ago. Since that time substantial progress has been made in developing robotic systems for rehabilitation applications. However, rehabilitation robotics has not been integrated into the mainstream education of many rehabilitation engineering students. This paper presents a cost effective, practical approach to teaching rehabilitation robotics.

Background

The use of robotic systems to serve people with upper extremity impairments has gained interest recently. Robotic systems may promote a greater feeling of independence on the part of the user, and less a sense of dependence on a personal assistant (3). Advances in robotic systems indicate that for some applications such systems may be cost effective (4).

The term "robot" has its roots from the Czech term, robota, meaning labor or work. The term, robot, began to acquire its modern meaning in 1921 when it was used in Karl Capek's play "Rossum's Universal Robot", which depicted the story of a society of artificial men and women. In 1942, Isaac Asimov introduced the Three Laws of Robotics in his book "The Caves of Steel": 1) a robot may not injure a human being, or through inaction allow a human being to come to harm; 2) a robot must obey the order given it by human beings except where such orders would conflict with the First Law; 3) a robot must protect its own existence as long as such protection does not conflict with the First or Second Laws (2). Although, these laws were developed for a fictional story they are of interest in rehabilitation robotics as well.

Presently, several robotics systems are being developed in private, government, and university research laboratories to assist people with upper limb impairments. Two basic approaches have received substantial attention: 1) robotic workstations, and 2) mobile robotic systems. Robotic workstations are systems optimized to operate within a semi-fixed environment. Such systems are being developed for kitchens and for a personal office environment. Workstation robotic systems may be mounted to a work surface or on an overhead mounting system. Mobile robotic systems present a greater number of technical challenges because the operating environment is expanded as well as the number of tasks performed by the system. Studies have been performed to explore the feasibility of low end mobile robotic systems. The HERO 2000 (Heathkit Inc.) has been used as an experimental base with moderate success.

Rehabilitation engineering has discovered the human-substitute concept and has employed robotics systems to serve as external assistants or artificial extensions of missing or impaired limbs. Some robotic systems have been accepted by people with upper extremity disabilities, primarily quadriplegia. Functions of rehabilitation robotics systems range from pick and place operations to performing activities of daily living (ADL). Activities such as preparing simple meals, feeding, washing, and brushing teeth have been performed successfully.

This paper will describe a laboratory exercise for teaching rehabilitation robotics using a PRO-ARM Robotic System (Marcraft, Model RS-2200). Each student was required to program the robotic system to assist with eating a bowl of cereal.

Statement of the Problem

Design and write a well documented Quick BASIC program to demonstrate assisting a person with quadriplegia to eat a bowl of cereal and to place a straw into a glass of liquid. The program must continuously repeat the task of presenting a spoon full of cereal "N" times, i.e., the program must automatically restart "N" times or repeat at a simple prompt by the user. The program must at least be able to control the PRO-ARM robot to scoop-out nearly all of the cereal in the bowl and place the straw into a cup. The attendant (student) can pour the cereal into the bowl and position the bowl and utensils. After the "feeding" program is aborted, the robot must return to the home position. Students are not permitted to use the teach mode.

Rationale

Rehabilitation robotic systems is an important area of research within rehabilitation engineering, and this area shows promise for substantially improving the quality of life for many people with mobility impairments. Rehabilitation engineering students must learn the theoretical and practical aspects of robotic systems applied to assist people with disabilities. The use of a simple and inexpensive workstation robotic system to perform an important independent living task forms a nice tie between the theory and practice of rehabilitation robotics.

Exercise Design

The exercise consists of familiarization with the robotic system (hardware and software), selection and modification of feeding accessories, and design, development and evaluation of feeding software.

The PRO-ARM Robotic System

The PRO-ARM Robotic System is a five-axis open-loop workstation type robot that is designed to simulate industrial robot operation for laboratory training and research.

The PRO-ARM is controlled by an external microcomputer (AT&T 386). The system is controlled using any programming language with the ability to send ASCII character codes to one of the computer's parallel printer ports. The system commands are sent to the robot controller to manipulate the various axes and the gripper. The robot controller also provides times delays, select speed, controller output ports, limit switch controls, and data storage. External devices can be software controlled by the PRO-ARM robotic system using 4 external input switches and a 4-bit output port.

The PRO-ARM is a joint-coordinate type robot. Each of its five axes and gripper imitate the action of a corresponding human joint. Joint coordinate robotic systems are commonly found in industrial and medical applications. The axes and gripper are actuated by six stepping motors, which can be instructed to move in increments as small as 0.04 degrees per step. The gripper is capable of lifting 500 grams. The critical specifications of the PRO-ARM robotic system for rehabilitation engineering applications are given in Table 1.

Table 1. PRO-ARM Specifications

Position Accuracy: ± 0.9 mm
Load Capacity: 500 g
Reach: 445 mm
Gripper Opening: 100 mm
Speed Range: 75 - 200 mm/sec
Operational Range:
- Base: 240 degrees
- Shoulder: 140
- Elbow: 100
- Wrist Roll: 360
- Wrist Pitch: 180

Memory Capacity (RAM): 100 positions (2K bytes)
Interface: 8-bit centronics parallel
External Device Ports:
- One 4-bit parallel output
- One 8-bit parallel output
- One interlock switch
- Four input switches

Power Supply:
- Input: 105-125 Vac, 60 Hz, 60 Wmax.
- Output: 5 Vdc @ 1.2 A, 12 Vdc @ 4 A

Selection and Design of Feeding Accessories

The task of assisting with feeding using a robotic workstation mandates the proper selection and design of the feeding utensils. The abilities of the potential user and the limitations of the robotic system must be clearly understood. The PRO-ARM robotic system has a quite limited usable workspace, and grip strength. To obtain optimal performance the spoon must be as light as possible with a large surface area in contact with the gripper surface. The handle length of the spoon should be kept to a minimum. The ladle of the spoon should be large enough to scoop a maximum of cereal without being uncomfortable for the user. The spoon loaded with cereal will induce a torque at the gripper center of pressure. If the torque is too large the spoon will rotate and the cereal will spill. More cereal can be carried by minimizing spoon weight. The handle of the spoon may require some curvature to optimize scooping.

Scooping cereal can also be a difficult task. To accommodate a range of cereal viscosities, the spoon must swirl within the bowl. The movement restrictions of the system suggests, and experience shows, that a shallow bowl with steep rims works best. The bowl should incorporate a nonslip material on its base to prevent slippage along the table top.

Straws which have been modified with a high density foam collar work most reliable with the robotic system. Any standard 8 oz glass work well.

Software Design

Many potential beneficiaries of rehabilitation robotic systems will have severely limited upper extremity voluntary control. Hence, the robotic system must be operated using an alternative to a standard computer keyboard interface. Some simple alternatives are use of limited function keys, joystick control, mouse control, head pointer control, or switch control. More advanced systems may use voice or EMG control. For the purpose of this exercise, control was limited to limited keyboard activity or a mouse or a joystick.

The robot's microprocessor recognizes a set of ASCII command codes that are transmitted by an external microcomputer. The command codes from the control computer are translated to action via the robot's microprocessor. A robot control (motion) program may be written with any editor. A simple text editor works well for most applications. A robot control program consists of a set of computer code which sends literal characters and numbers to a printer port. The robot will only recognize and accept command characters and strings, which are in a specific order. A robot command consists of an upper-case letter that is usually followed by a parameter list consisting of numbers. A robot commands must be preceded by a PRINT (or LPRINT) statement or equivalent if using a language other than BASIC. If the robot receives an improper or unknown command, an ERROR lamp on the robot will illuminate.

Development

Before beginning any program development and design of the feeding utensils, each student must read the PRO-ARM robotic system manual. As part of the preliminary work students complete the exercises outlined in the PRO-ARM manual and answer the questions under the "knowledge transferred" section at the end of each exercise. Each student performs both physical and software diagnostics on the robotic system at their workstation.

Each student designed/selected their eating utensils, and the cereal for their demonstration. Each student wrote software to control the robot to at minimum place a straw in a glass and then pick-up a spoon and assist with feeding a person until the bowl of cereal was (nearly) empty. Upon completing a working system, each student is required to demonstrate his/her system by eating a bowl of cereal with the system, Figure 1. A user/technical manual with fully documented software is the final product.

Programs range from being very simplistic assuming greater control by the user or human assistant to moderately complex (given the time and equipment resources available). A simple program to demonstrate the ability of the system to assist with eating is listed in Figure 2.

For the example program, an assistant must place the spoon, and bowl in the proper position. The assistant must also pour the cereal. The program can be compiled using QBASIC to create an executable file (.EXE), otherwise it must run from within a BASIC environment.

The example program requires that the robot be placed in the proper "home" position before execution. Another approach is to drive each of the joints to their limit by giving them a movement command beyond each joint's range of motion. This increases the likelihood for the joint being in a known position at the time of execution of the "feeding" program. The software allows the user to select the number of desired scoops, and provides some delay to eat each scoop of cereal. Other methods have the user press a switch or key when ready for another bite, this eliminates the need to guess the number of scoops desired, but requires greater user interaction.

```
 10 REM                                 'EATXXX Program
 20                                     'Student, Rehab
 30                                     'BME 262, Dr. Cooper
 40                                     'Date
 50 LPRINT"Z"                            'Set starting coordinate
 60 LPRINT"S5"                          'Set speed to maximum
 70 LPRINT"M500,-450,-150,-50,50,-2000" 'Move to spoon
 80 LPRINT"S5"                          'Set speed
 90 LPRINT"M0,-100,0,0,0,0"              'Moves down to spoon
100 LPRINT"C"                           'Closes gripper on spoon
110 LPRINT"H1"                          'Memory location 1 Here
120 INPUT"How many scoops do you want?";SPOONS%
130 FOR SCOOPS% = 1 to SPOONS% 'Selected # of scoops
140 LPRINT"G1"                  'Goes to stored memory location
150 LPRINT"M0,150,0,0,0,0"       'Lifts spoon to clear bowl
160 LPRINT"M200,150,-200,400,400,0"   'Spoon into bowl
170 LPRINT"M0,-250,0,0,0,0"           'Level spoon in bowl
180 LPRINT"M100,200,50,-400,-400,0".     .'Pick-up cereal
190 LPRINT"M-900,450,0,0,0,0"       'Move cereal to mouth
200 LPRINT"N"                 'Nest: returns to home z position
210 LPRINT"D10"                  'Delay to provide eating time
220 NEXT SCOOPS%                   'Increments to next scoop
230 LPRINT"G1"              'Returns to original spoon location
240 LPRINT"O"                      'Gripper releases spoon
250 LPRINT"M0,200,0,0,0,2000" 'Robot rises & closes grip
260 LPRINT"N"                      'Returns to home position
```

Figure 2. Example simple BASIC program for demonstrating feeding with a PRO-ARM robotic workstation.

Evaluation

Each student is required to eat a bowl of cereal using the utensils and software developed during this exercise. The systems are evaluated on their ability to assist with feeding. Students must demonstrate reliability, repeatability, and the motor skills required to operate the system. Systems vary substantially in complexity depending upon the abilities and interests of the students. All students have been able to meet the minimum requirements. The documentation of the entire system are also evaluated: both hardware and software.

Discussion

This exercise has been successful in teaching graduate students in rehabilitation engineering some basic practical aspects of using robotic systems to assist people with upper limb impairments. The exercise parallels lectures on robot kinematics, control and sensors. Typically, three three hour laboratory periods are allotted for this exercise over a three week period. Most students require time outside of normal laboratory hours to complete the work.

Students learn about the myriad of variables to be controlled or avoided when designing such a system. The limited ability of this particular robot makes selection of the proper bowl and spoon design critical to success. Another characteristic students often neglect is that cereals have various properties. Some cereals are quite dense compared to others, some are quite viscous compared to others. Various cereals require different scooping strategies. A "good" program can accommodate various types of cereals. Another area commonly neglected is developing a strategy for accommodating for the decreasing amount of cereal in the bowl as a person eats it.

Various systems have been successfully developed over the past three years. Systems which pour the cereal and milk, those which retrieve utensils from storage, learning systems, and some have attempted incorporating vision.

Figure 1. Photograph of robotic system during demonstration of assisting with feeding.

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MECHATRONIC SYSTEMS AS VOCATIONAL ENABLERS FOR PERSONS WITH SEVERE MULTIPLE HANDICAPS

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Abstract

This paper describes a collaborative effort between the College of Engineering, Wayne State University, and the Wayne County Regional Educational Service Agency. The objectives of this collaboration were to identify service areas where mechatronic systems could be applied and then to design and build systems to address these needs. Senior level engineering students designed and built four mechatronic systems. The specific applications were based on identified needs, available resources and time constraints.

Background

Wayne State University's Department of Electrical and Computer Engineering offers a senior level design course, The Design of Enabling Technologies. Of particular interest is the development of robotic systems that are part of and facilitate the rehabilitation, vocational rehabilitation, or educational processes. Hence many of the products designed and developed by students in this course deal with robotics, electronics, and electromechanical systems for material handling, all under computer control. Mechatronics is a term which denotes the integrated design approach of mechanical, electronic and computing elements [1,2]. Figure 1 illustrates the major components and their respective interactions. As noted, mechatronics design is at the intersection of these elements.

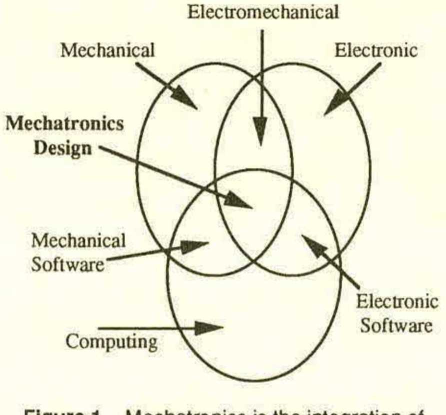

Figure 1. Mechatronics is the integration of mechanical, computing and electronic design and product development. Based on a figure in "Implementing Mechatronics" [2].

From the College of Engineering's perspective, the course is designed to provide a meaningful senior level design experience, while also introducing students to the principles of universal design and sensitizing them to the needs of disabled individuals. Most of these students will not go into bioengineering or rehabilitation engineering, but they all will have a deeper appreciation of the importance of using a universal design approach.

Wayne County Regional Educational Service Agency (WC RESA) is an intermediate school district providing direct and support services to 34 local school districts, including Detroit, in southeastern Michigan. WC RESA operates five center programs for students who are severely physically, mentally and/or emotionally challenged.

A partnership was formalized between Wayne State University (WSU) and the Wayne County RESA. The intended outcomes of the partnership were completion of design projects for Wayne State University students and provision of customized enabling technology to special education students.

It has been documented that the consistent repetition of the robotic manipulators is effective in a rehabilitative setting [3]. For example, a robotic arm smart exercise partner was developed to work with recovering stroke patients [4]. The robotic arm carried a special end-effector with prompting lights and switches. A patient follows the end-effector and touches a switch when prompted by a light. Occupational therapists can monitor several patients at a time and each patient has their own customized exercise regime. The University of Keele, Staffordshire, England, has shown the potential for a robotic feeding aid to improve oral/motor skills and foster independent eating in children with cerebral palsy [5]. In tasks that require many hundreds of repetitions before an individual masters a skill or concept, is seems reasonable that a mechatronic system can be used to facilitate such processes [3]. Based on these observations one application area considers training tasks that are highly repetitive and labor intensive, i.e., requires a teacher or therapist, but only to manipulate parts or the environment.

Another important area for the application of mechatronic systems is in the functional evaluation and assessment of individuals. The Rehabilitation Robotics Group at Wayne State University looked at some assessment possibilities, i.e., measuring range-of-motion, fatigue, etc. [6]. The Rehabilitation Robotics Group at Cambridge University is working with the Papworth Group Assessment Centre to identify and evaluate employment in the manufacturing industry which may be accessed by physically disabled individuals through the introduction of mechatronic systems [7, 8]. As part of that effort they have developed an interactive robot quantitative assessment test (IRQAT) to "provide quantitative measures of an individual's ability to control a robot performing a rigidly defined task using a range of controls" [8, p110]. Hence the use of mechatronic systems for functional evaluations and assessments is another key application area.

Lastly, of course, is the use of mechatronic systems as an enabling technology - to increase an individuals' independent participation in productive work activities. This defines a third area of mechatronic systems applications.

Objective

Participation in meaningful, productive work is a valued life outcome, resulting in either the potential to earn a paycheck or an increase in self-esteem based on the ability to have an effect on one's environment and provide a social contribution [9,10]. Students with severe cognitive and physical impairments face many challenges with regard to vocational training and job placement. Students may be dependent on staff or a partner worker for set-up of materials and frequent replenishment of supplies. Job opportunities for individuals who are single switch users may be limited. Students with severe cognitive impairments may require assistance or adaptations to make accurate decisions regarding counting of items (i.e., for packaging jobs) or measuring supplies i.e., laundry or dish soap). In addition, training often requires consistent repetition over an extended period of time.

Outcomes which may be enabled through mechatronic systems were identified as:

- increasing students' independent participation in productive work activities;
- increasing vocational opportunities for students who are switch users;
- providing varied levels of assistance during counting and measuring jobs;
- automation of simple motor actions such as moving items from one container to another, replenishing supplies, and removal of completed work;
- providing consistent, repetitive, multi-sensory feedback during training activities.

Approach

This course operated as a "consulting company" under contract with a client - The Wayne County Regional Educational Service Agency. Clients are viewed as partners in the design process. WSU students consulted with the client and instructor to define a specific project that could be completed in one semester. Students created a milestone chart, functional requirements and subsequent design requirements. These were translated into a concrete design. The products are prototypes, which are currently undergoing several months of field testing. If the field testing uncovers the need for modifications or redesign, either WC RESA will produce version two of the product, or WSU students in a subsequent class take on the redesign and production of version two.

Results

Twelve engineering students produced four prototypes: a switch activated packaging dispenser, an assembly trainer, a dispenser for soap powders, and a switch activated turntable. These are more fully described in a companion paper; "A Partnership: University Electrical and Computer Engineering and Special Education," in these proceedings.

The four systems are currently in various stages of the field testing process. WC RESA staff and students are using the systems. Staff are recording their observations and experiences. Several items have been identified for change in version two of the systems.

As WC RESA personnel gain experience with the systems they are identifying other potential application areas. This is an important result.

Discussion

The collaboration has meet its objectives in so far as we have identified specific areas for the application of mechatronic systems, and furthermore we have designed and built four systems targeted at these needs. This effort is only a beginning. WC RESA personnel are becoming familiar with available technology, and WSU engineers are becoming familiar with the WS RESA needs. Both groups are on a learning curve.

The systems developed so far, are not technologically very sophisticated. They represent a form of technology transfer - from manufacturing and assembly to areas of vocational rehabilitation and special education. This is an important point - we must first identify user needs (whom ever the user is), and then identify an appropriate technology to address those needs. From the special education system point of view, it is a valuable start in recognizing technology service delivery needs to maximize vocational opportunities. In the near term this may not be a significant research effort from the university perspective, but it lays the ground work for a long term relationship that eventually leads to cutting edge technologies being applied in ways that are significant from a university R&D perspective.

If collaborations such as this are to work it must be a win-win situation for all parties. So far we believe that we are on the right track.

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CONTROL PHILOSOPHY FOR A SIMULATED PROSTHETIC HAND

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ABSTRACT

Multifingered robot hands can approximate human hand functionality, and it is possible to consider their use in prosthetics. The Belgrade/USC robot hand is used as a prototype prosthetic hand in order to evaluate a system, PRESHAPE, that translates user commands into motor signals using the virtual finger concept. This paper describes the control philosophy of PRESHAPE and presents simulation results.

BACKGROUND

The human hand is a complex and versatile system, both structurally and functionally. It is capable of shaping into a variety of forms, each specialized for the task at hand. For prehensile tasks, the hand preshapes into a posture suitable to grasp the object for the given task, and then encloses the object [Jeannerod 1981]. Prosthetic hands, which ideally should serve the wearer naturally, are largely an elusive dream, and most amputees are fitted with a dual hook. Recently, where cost and complexity have not been as large a constraint as in prosthetics, multifingered sensor-based robot hands have been built, e.g., the Utah/MIT hand [Jacobsen et al 1985] and the Belgrade/USC hand [Bekey et al 1990]. For control, techniques in artificial intelligence allow the development of intelligent controllers [Bekey et al, in press]. With the emergence of new light weight alloys, miniaturized components, and reduced voltage requirements, electrically powered prosthetic hands are also available (e.g., Steeper Electric Hand, Otto Bock System Electric Hand). In addition, multifunction sensor-based prosthetic hands are being built in research labs. For example, the Southampton hand [Chappell and Kyberd 1991] uses 4 motors to control a 5 fingered hand in 7 basic postures. Intelligent controllers are needed that will allow amputees to take advantage of these emerging robotic and prosthetic hand developments.

RESEARCH QUESTION

In order to develop an intelligent controller for using a multifingered sensor-based robotic prototype prosthetic hand in a versatile way, a minimum set of control variables is needed. The challenge faced here is that both a human and a robot controller are in the control loop. The human controller, at the minimum, controls the arm, addressing the planning and control concerns associated with object identification, location and orientation, grasping location. In addition, the human can select operation modes, choose parameters, and control finger movement. The robot controller performs the selected operation mode and uses sensory events as triggers and/or as control loop feedback. Thus, the planning and control problem for computer-controlled movements is simplified, and the problem of developing an intelligent controller is how to effectively partition control across multiple controllers.

This paper concentrates on that partitioning, leading to the development of a prosthetics control architecture using an existing anthropomorphic robotic hand as a vehicle. Arm positioning is not addressed, because the assumption is that the user is a below-elbow amputee.

METHOD

Hands carry out tasks which are part of the activities of daily living. A task database has been developed containing over 300 hand-related tasks [Iberall et al 1991]. Included are tasks from the Jebsen Hand Function Test [Jebsen et al 1969] which is used to evaluate restored human hand function and which includes tasks such as write with a pen and stack checkers.

The multifingered sensor-based robotic prototype being used is the Belgrade/USC hand [Bekey et al 1990]. Somewhat similar to the Southampton hand, it has 4 fingers with 3 joints each, each finger pair being driven by one motor. The motion of the 3 joints is not independent, but embodies a built-in synergy modeled on observations of human hands. The articulated thumb moves in an arc into opposition to one or more fingers; another motor flexes and extends it at its 2nd joint. Finger, thumb, and palm surfaces are covered with 23 pressure sensors. The digits are equipped with potentiometers for sensing finger rotation with respect to the palm.

Hand posturing is based on the concept of a **virtual finger (VF)**, which is a grouping of 1 or more real fingers (or the palm) working together to apply a functionally effective force within a task [Arbib et al 1985]. Prehensile postures are constrained by the way the hand can apply opposing forces around an object for a given

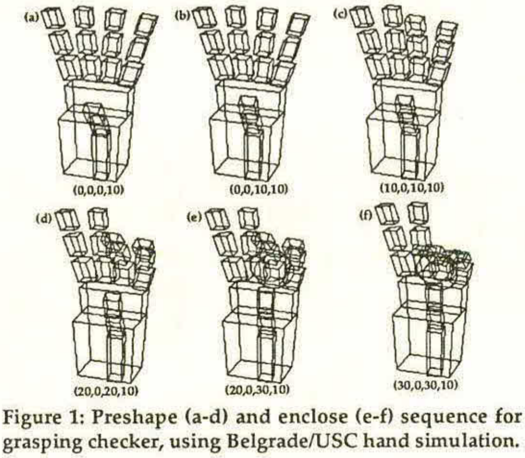

Figure 1: Preshape (a-d) and enclose (e-f) sequence for grasping checker, using Belgrade/USC hand simulation.

task [Iberall and MacKenzie 1990]. From our analysis of the prehensile classification literature [Iberall 1987], these can be classified into 3 basic methods. Pad opposition occurs between the finger and thumb pads along an axis roughly parallel to the palm. Palm opposition, along an axis roughly normal to the palm, occurs between the digits and the palm. Finally, side opposition has an opposition axis occurring primarily along a transverse axis. What gives this language of oppositions its expressive power is that the hand is not limited to one opposition at a time. At least 21 different combinations of oppositions have been observed [Iberall et al 1991], creating a large repertoire of hand shapes for driving prosthetic hands, in contrast to the Southampton hand which is fixed to use 1 of 7 postures.

The system under development is called PRESHAPE (Programmable Robotic Experimental System for Hands and Prosthetics Evaluation). The system takes user commands and generates motor commands for the Belgrade/USC hand motors. Commands can either be task level commands that are decoded using the task database, or else opposition level commands that describe which oppositions and VFs to use for the task. We have successfully simulated the preshaping and enclosing of the chosen posture. A hand simulator, developed by J. Henz at the Technical University of Berlin, allows us to simulate a sequence of movements on the Macintosh computer. Control is in terms of normalized finger angle settings from 0 to 100. The control simulation was done in SIMULINK and MATLAB.

RESULTS

An opposition level command is used to shape the hand, by selecting normalized angles and coordinating fingers and thumb movements. For example, the opposition level command and normalized preshape angles for two sample tasks are:

Task	Opposition	Preshape angles
pick up checker	9 medium	20, 0, 20, 10
grasp hammer	12 medium	40, 40, 40, 10

Figure 1 shows a sequence of postures for preshaping to grasp a stack of checkers. This task calls up posture #9 with a medium-sized hand opening, involving only one opposition, namely pad opposition between the thumb (VF1) and index and middle fingers (VF2). The thumb first rotates slightly outwards (Fig 1a). The index and middle fingers then curl (Fig 1b-c) through intermediate steps while the thumb curls into a posture of opposition to the two fingers until the desired preshape posture is reached (Fig 1d). The motor settings at the end of the preshape are (20,0,20,10).

In the control simulation, the preshape movement is triggered by an EMG signal from the wrist flexor muscles. Electrical signals from surface electrodes positioned over muscles are amplified, rectified, and filtered before being used as a control input. Once the processed EMG signal reaches a specified threshold, the coordinated preshape movement begins. For the task of picking up a checker, the processed EMG signal (Fig 2a)

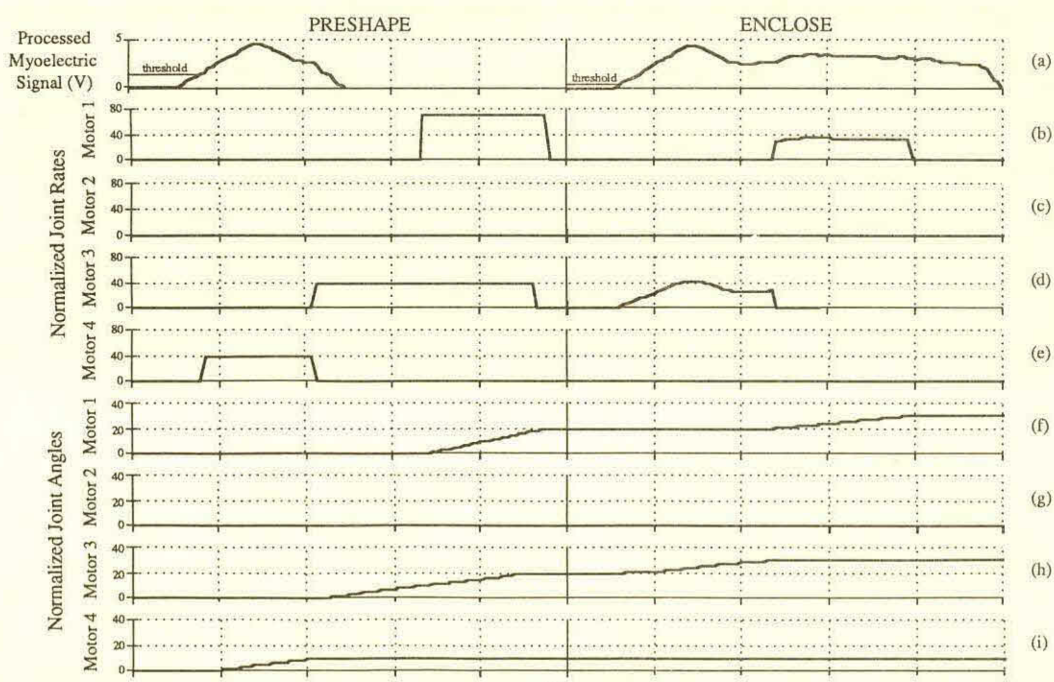

Figure 2: Simulated preshape and enclose sequence for grasping checker.

triggers the preshape movement when the signal reaches a threshold of 1.5V. The joint motors are driven at a constant rate with the VF movement coordinated to resemble natural hand motion. Figs. 2b-2i show the normalized joint rates and angles for the motors. The thumb first rotates slightly outward (motor 4). The thumb then curls (motor 3) into a posture in opposition to the index and middle fingers while the index and middle fingers (motor 1) curl into the desired preshape position.

For prehensile tasks only, the Enclose Module must be triggered after the hand has been preshaped and the user has positioned his or her arm. The hand encloses the object, ending when the specified sensory feedback has been reached. For this phase, proportional myoelectric control has been chosen as the method of control. In proportional myoelectric control, the joint motor voltage varies proportionally to the EMG signal giving the user control over the speed of the enclose motion.

The enclose movement begins when the simulated EMG signal from the wrist flexor muscles reaches a small threshold. The rate at which the VFs are driven is then proportional to the EMG signal. Referring to Fig 2, the enclose motion for picking up a checker begins when the processed EMG signal (Fig 2a) reaches 0.3V. The VFs are driven at a rate proportional to the EMG signal with the movement coordinated to resemble natural hand motion. Figs. 2b-2i show the normalized joint rates and angles for the motors. The thumb first flexes (motor 3) and then the index and middle fingers (motor 1) curl until contact is made by both the thumb pad sensor and the index radial sensor. When contact is made, a signal to the user indicates that the enclose is complete. Sensory feedback to the computer controller is used to maintain a steady grasp during the actual task.

DISCUSSION

Multifingered mechanical hands are attempts at approximating human hand functionality. Our goal is to use one as a prototype prosthetic hand in order to evaluate a system that translates task-level commands into motor commands. Using the virtual finger concept, PRESHAPE consists of a series of modules that selects sensors, preshapes the hand, encloses it around objects if necessary, and performs task movements. Using a simulator, hand sequences for various tasks have been generated. The advantage of this approach is that a large repertoire of functions can be generated with a simple control language. The user has control over selecting postures, triggering movements, and speed during hand enclosing. The computer provides the lower level coordination of motors. The disadvantage is that, while it allows the computer to generate the more automatic motions, preshaping motions occur at a constant rate. Following the experimental evidence of Jeannerod [1981], an alternative is to preshape the hand in a more realistic way by coordinating it with wrist acceleration. As noted by Jeannerod, the hand is preshaped by the time the wrist reaches peak deceleration, and then the enclosing movement is synchronized to the wrist's deceleration. Under development are algorithms and accelerometer hardware for driving joint motors by monitoring the user's movements. By using intelligent sensor-based robotics (within the constraint of what is possible to control), we believe that in the long term it will be possible to develop a new generation of sophisticated prosthetic hands.

ACKNOWLEDGMENTS

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REGENESIS ROBOTIC APPLIANCE EVALUATION PROGRESS REPORT

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Abstract

This paper is a progress report on current developments in the Neil Squire Foundation's robot program. The Regenesis Robotic Appliance, developed by the Foundation, is currently being evaluated in a study entitled "Impact of Robotic Assistive Appliances in Vocational Work-station Environments". The primary research question is as follows: "How much reduction in attendant time per unit work completed can be achieved through the employment of the RAA?" This paper presents the methodology and details of the execution of the study that may be of interest to anyone engaging in a similar evaluation.

Background

A major program of the Foundation's technical development group has been the development of a robotic manipulator which will help a person with a physical disability manipulate items of up to 2.3 Kg mass in a work-station.

One of the areas in which there is a need for performing manual tasks is in a vocational setting. Although the growth of the use of personal computers in the business world has made it much easier for someone with a disability to perform productive work, the ability to handle paper files, books, diskettes and mail is required in most business settings. It is possible to handle such tasks with a robot, as several such projects have demonstrated[1,2,3], but the widespread implementation of robots for such purposes has not yet taken place because the technology has not yet proven itself to be safe[4,5,6] or cost-effective. In addition, there are presently other barriers or problems unique to persons with disabilities that impede such persons in their pursuit of gainful employment. These include access to training, workplace accessibility, accessible transportation to and from work, hours of work, stamina, health, attendant care requirements at work and economic disincentives.

Currently, a person with a severe physical disability who wishes to work in a computer based occupation would typically require the assistance of an attendant to handle physical manipulations required in a "normal" office environment. Such assistance is costly, whether it is performed by a dedicated attendant, or by a disrupted co-worker. It is not clear whether or not the use of a robot can significantly affect the amount of such intervention and it is the intention of this study to begin to quantify this effect.

Description

The study is entitled "Impact of Robotic Assistive Appliances in Vocational Work-station Environments". For practical reasons, testing is carried out in two identical phases. Each phase is testing 3 subjects who are rotated between the two work-stations. The primary research question is as follows: "How much reduction in attendant time per unit work completed can be achieved through the employment of the RAA?"

The evaluation is comparing the amount of attendant intervention required at each of the two workstations. The workstations are essentially identical except that one is equipped with a robot system. It is assumed that an attendant will provide assistance when necessary at either work-station.

Set-up

Each station consists of an Anthro adjustable work surface, file, book and diskette storage racks, a book stand and an IBM 486 computer equipped with IBM Voicetype. An IBM laser printer is shared by the two stations.

The storage racks in the robot-equipped station are commercially available racks which have been altered slightly by the addition of access cutouts. The book stand is a custom-fabricated design. Modifications to the Anthro work-station consist of threading 8 existing holes to fit the robot mounting brackets. No other modifications are necessary. Components are attached to the desk surface with Velcro and locating marks are placed on the surface to position the components. Standard letter-size manila file folders are used in both stations. The folders used in the robotic station are modified slightly by trimming a corner and adding an adhesive tag to facilitate robotic handling.

The non-robotic station is set up without special modifications of any kind. The only obvious differences between it and a typical set-up for an able-bodied individual is the presence of a long gooseneck support for a microphone, the increased elevation of the desk surface and the absence of a chair.

The facilities available for the study consist of a 4.8m x 3.6m room in which the two work-stations are placed side-by-side. Video cameras are mounted on the opposite wall, behind and out of sight of the subjects. The physical arrangement makes it possible to observe two subjects at the same time.

The study facility is located at a Neil Squire Foundation employment training centre in Vancouver. The centre runs a program that provides work skills development for persons with physical disabilities. It is an accessible facility and a relatively friendly environment for persons using wheelchairs because most of the participants and several staff members use wheelchairs. A paid attendant provides lunchtime attendant services. Other attendant services are provided by instructors and administrative staff members.

Each individual performs a 2.5 hour work session at one station and then repeats the same work session at the other station. The order in which the stations are used is recorded and alternated to counterbalance learning effects from actual productivity effects. Each participant carries out 24 work sessions on each of the two workstations. A research assistant records the nature and duration of interruptions and interventions that occur during the work session. Each session is also recorded on videotape for permanent record.

Interventions are classified as assistance or social interaction and the apparent reason for the intervention, time at start and time at completion is also recorded.

In order to model a real environment more closely, the subjects are allowed to call any of the other office staff or participants for assistance. The Research Assistant however, is not permitted to perform attendant interventions.

Subjects typically complete one session on each of the two stations each day they attend. The typical attendance time is 6 to 7 hours, which allows for the two 2.5 hour sessions plus a lunch break. As noted above, lunchtime assistance is provided by an attendant or other office personnel. Periods such as lunchtime and the time prior to and preceding the observation periods and occurrences within those periods are not recorded.

All of the subjects have been exposed to word-processing at some point, so the tasks are designed around Wordperfect usage and exercises from a tutorial manual. The typical task involves retrieving the manual, turning to the correct page, typing the exercise, printing and proofing the output and storing the output in a file folder.

Difficulties

There are several difficulties which have occurred in carrying out this study.

It is difficult to find subjects who possess vocational training and are available for participation in a study of this nature. This limits the degree to which the study model reflects a real work situation because the productivity of the subjects is a factor. Several potential participants can not take part in the study because they are committed to part-time employment, schooling or other self-development programs which conflict with the study's schedule. In general, it seems that strongly-motivated individuals are already busy and do not necessarily have time to participate in studies which require a large time commitment.

Health problems have caused some disruption. One subject completed the training sessions and then had to withdraw from the study due to health reasons. The subject is a 22 year old male with Muscular Dystrophy. Apparently the he was becoming physically tired and experiencing difficulty breathing normally. The training sessions consisted of several 5 hour sessions with breaks that were carried out during a three week period. The total training time is 25 hours. Another subject developed a bladder infection during the first testing phase and had to postpone a session while receiving treatment.

There are other sources of disruption as well. One subject could not attend several days because of electrical problems with a wheelchair. Attendant care activities, such as suctioning, occurring at the lunch break sometimes delay the start of the second work session. This becomes a practical problem because the subject's transport is scheduled for pick-up at a certain time at the end of the day.

All of the subjects require assistance when getting up in the morning and preparing for work. The process is typically more time-consuming for such persons than it is for able-bodied workers. Hence, most subjects have difficulty arriving at the study at typical office hours. Also, all of the participants rely on the often difficult to schedule public transit Handidart vans for transportation to and from the test site.

Personal care and therapy schedules are an important factor in determining the day and time that individuals can attend the program. One potential participant requires most of one day a week for this and would be unable to attend the study that day.

The earliest time in the day that participants are able to attend the study varies from 9:00 A.M. to 11:00 A.M. One subject is able to get to the study by 9:00 A.M. Two other subjects find that 10:00 A.M. is the earliest they are willing to attend and two other subjects attend no earlier than 11:00 A.M. The differences in time are attributable to attendant care arrangements and daily personal care requirements. Typically, the subjects that are able to attend earlier are those that have private attendant care services.

The background and experience of the subjects varies greatly. Three of the subjects have experience from working prior to their spinal cord injury. One of these has some experience working part-time after the injury. The computer skills of the subjects varies somewhat, but all subjects have basic computer training. None have extensive computer training nor do any of the subjects have job-level training in any particular software package.

Developing the tasks for the participants has been more complicated than anticipated. The different levels of experience of the subjects and especially the lack of job-level training of most subjects makes it difficult to choose activities that completely model the real world.

The study is scheduled for completion by the end of April 1993 and the results will be published shortly thereafter.

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THE RAID WORKSTATION FOR OFFICE ENVIRONMENTS

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ABSTRACT

This paper describes the development of a robotic workstation for use by individuals with little or no upper limb function in office environments. The technical features of the workstation are presented and details of the evaluation process are noted. The demonstrator workstation is specifically configured for applications in Computer Aided Design (CAD).

BACKGROUND

The RAID (Robot for Assisting the Integration of the Disabled) project exists under the European Community TIDE (Technology for the socio-economic Integration of Disabled and Elderly people) initiative [1]. The RAID consortium consists of academic and industrial partners from France, Sweden and the UK. Development of the demonstrator workstation is now complete and initial user trials are scheduled to commence in March 1993. It is the experience of the RAID partners that projects which are led by the requirements of users have a substantially higher probability of success compared with those which seek to push technology into the marketplace. Considerable emphasis has therefore been placed on the creation and subsequent revision of a user requirements specification. This specification provided a focus within the project during the functional and technical specification phases.

SYSTEM DESCRIPTION

The RAID workstation is based around a custom designed mechanical structure providing storage for books, manuals, paper documents and other reference materials. An RT-series robot arm is mounted on a linear track in front of the storage zones. The robot arm features an extended vertical column which, together with the linear track, provides a considerably enhanced working envelope. A screen dump from a robot simulation system of the conceptual design for the workstation is shown in figure 1. The construction of the storage unit is designed to integrate with existing office furniture and therefore avoid the attraction of unnecessary attention. The appearance of assistive technology has been shown to significantly affect the acceptability of robotic devices [2].

The operator sits at an adjustable desk in front and to one side of the robot arm. The arm's working envelope includes a large proportion of the desk area but does not reach to the user for reasons of safety. The demonstrator system employs two interchangeable pneumatic end effectors. One end-effector is designed for the efficient transportation of books around the workstation. It incorporates a ledge on which objects rest to reduce the required clamping force. The other end-effector facilitates diskette manipulation and provides page-turning facilities. It uses a knife action to open books at an approximate indexing point. A suction pad provides for subsequent single page manipulation using a powered finger on the reader board to prevent book closure during page turning. An additional clamping device holds diskettes for transportation between diskette drives and a storage rack.

The control architecture of the workstation is illustrated in figure 2. The standard RT-series IP board is replaced by a transputer-based motor control board to improve the resolution and repeatability of arm motion. The arm gearing and encoders are also upgraded to take advantage of the superior control electronics.

Enhanced manipulator-level control facilitates a reduction in cycle time for many manipulative tasks through the use of via points. Arm trajectories are generated using a second transputer located on an ISA PC board. This processor communicates with the motor control board using an RS422-level serial link.

Supervisory control of the robot arm is provided using a Windows version of the MASTER robot control language

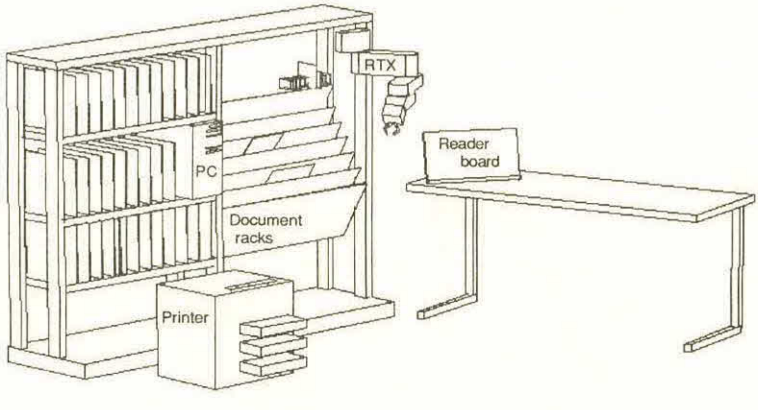

Figure 1. Screen dump of the conceptual workstation layout

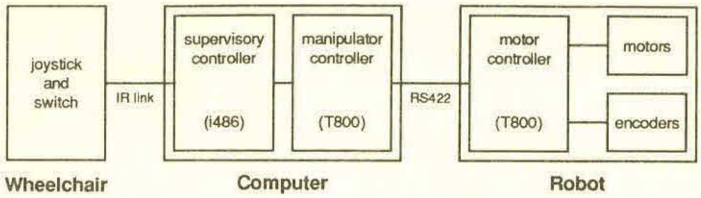

Figure 2. Control architecture of the RAID workstation

running on an i486-based PC. The MASTER language allows direct and pre-programmed control of the arm [3]. Repetitive tasks are defined using a programming utility prior to execution. The Microsoft Windows operating environment has been adopted to allow for the integration of the robot control software with vocationally related software such as the CAD application. Operators are therefore able to switch between co-existing computer processes which handle the various aspects of their work.

Communication between the operator and the PC is achieved using an Infra Red (IR) link between a wheelchair-mounted joystick and workstation-mounted mouse emulation hardware. A mode selection switch toggles joystick output between the wheelchair motors and the mouse emulator. Keyboard emulation is provided using the Windows Visual Keyboard (WiViK) [4]. This utility presents an image of a standard keyboard on the Windows desktop and inserts characters into a keyboard buffer when the mouse is clicked on the iconic representations of individual keys. The consistency with which Windows applications access the PC hardware enables a single access utility to support every application.

TASKS

The tasks specified for the RAID workstation were developed in collaboration with a reference group of seven potential users. These individuals are all wheelchair users who have insufficient functions to be able to operate a computer workstation unaided, but who have at least two degrees of movement available for the operation of a joystick, trackball or chin switch. The following techniques were utilised in developing the tasks:

- Individual discussions to establish specific requirements
- Feedback on presentations of possible tasks
- Existing expertise from project collaborators
- Indirect advice from qualified occupational therapists
- Hands-on exercises with prototype devices

The user requirements formed the primary input to a functional specification which represented tasks in terms of the information flow within the workstation [5]. Information may be stored within the workstation in physical form within the robot domain or in electronic form within the computer domain. Information transfer between these two domains is achieved using a scanner, a printer and a diskette drive as shown in figure 3. The RAID system employs a Document Image Processing (DIP) system to minimise paper handling. However, DIP can only be viewed as a partial solution to the document storage requirements of disabled workers since the temporary nature of many large documents renders scanning uneconomic.

The tasks specified for the RAID demonstrator are those which would be required by a CAD operator during a typical working day. While RAID is suitable for many computer related vocations, CAD presents the greatest challenge to the system due to the quantity and diversity of reference material which must be accessed during the design cycle.

EVALUATION

Initial trials of the RAID demonstrator have been designed to

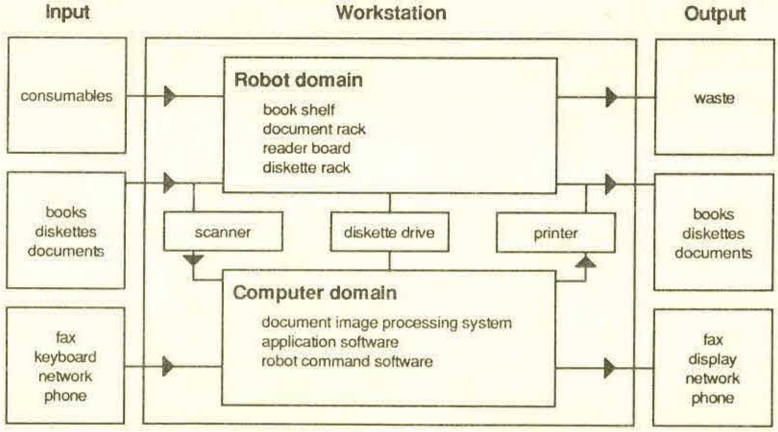

Figure 3. Information flow within the RAID workstation

provide an evaluation of the system at the following levels:

- User interface characteristics
- Task execution
- Use as a CAD workstation

In evaluating the user interface, the time taken to perform fixed sequences of commands within the Windows environment will be measured. These sequences will include the mouse actions of dragging and double clicking. The typing speed of individuals will be measured within a word processing context. These figures will be compared with those of non-disabled individuals to establish a performance ratio between joystick control and keyboard/mouse control for CAD applications.

Task execution will be evaluated using questionnaires which will be completed following the multiple execution of each task. The individual operators will also have the opportunity to discuss the tasks with each other and draw conclusions from video recordings of their actions.

Assessment of RAID as a CAD workstation will commence when the users have become familiar with the operation of the system. A benchmark sequence of CAD tasks will be used to simulate a typical CAD activity. This sequence will be developed by an experienced CAD worker in order to minimise the consequences of employing less experienced CAD operators in the trials.

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THE DESIGN AND DEVELOPMENT OF A REACHER/GRIPPER DEVICE FOR A CHILD WITH ARTHROGRYPOSIS

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ABSTRACT

An easy-to-use, unobtrusive device was designed to provide a young girl with arthrogryposis the ability to grip and transport objects from ground level to within reach while seated in her electric wheelchair. The device is highly adjustable and easy to manufacture. It has been very successful in gripping and transporting items such as pencils, paper, toothpaste, hairbrushes and clothes.

BACKGROUND

Many of the fine motor control functions that an able-bodied person takes for granted can be exceedingly difficult for a physically challenged individual who is confined to a wheelchair. For example, retrieving dropped objects requires fine motor control and targeting skills. This project involved designing a reacher/gripper device for a nine year old, female resident of a rehabilitation facility who is afflicted with arthrogryposis.

Arthrogryposis is characterized by deformities in the upper and lower extremities, and severe contracture and stiffness of the joints (1). The client has very gross movement capabilities but the fine motor control in her arms, hands, and legs is adversely affected. As a consequence of these symptoms, she is confined to a wheelchair and frequently drops objects. As would be expected, one of the most challenging and frustrating situations occurs when she drops an object from her grasp. She cannot reach it on the floor below because of her very elevated position in an electric wheelchair, and poor grasping capabilities resulting from her physical condition. Thus, she must depend on others to retrieve dropped objects.

Commercially available, manually operated reacher/gripper units have proven insufficient. These designs require not only a considerable amount of hand-eye coordination to position the "hand" around the object, but also that the user must maintain a constant application of force (to keep the object in its grasp) while pulling the object to within reach. Considering the physical limitations of our client, these are very difficult tasks to accomplish. Numerous meetings were held with the client and her occupational therapist to observe and discuss her physical capabilities. The following tests were administered and videotaped:

1. Asking her to pick up objects with the use of a commercial, manually operated reacher/gripper;

2. Employing a pinchmeter to determine the maximum force that she could apply with her fingers;

3. Placing objects at various locations on the floor around her wheelchair to determine her field of vision;

4. Attaching a wooden dowel to the frame of her leg rest to determine the accuracy with which she could position her wheelchair so that the protrusion was directly above objects placed on the ground;

5. Having her depress the buttons and switches of different devices to determine the optimum switch size and distribution for the control unit, should the device being designed need to be operated as such.

Results of tests 1 and 2 conclusively ruled out the use of a purely mechanical device. Tests 3 and 4 demonstrated that the client had excellent targeting capabilities while positioning her electric wheelchair. Thus, it was decided to design an electrically powered reacher/gripper that would be directly mounted on her wheelchair.

PROBLEM STATEMENT

The purpose of this project was to design and develop an easy-to-use unobtrusive device that would enable a young girl with arthrogryposis to grip and transport objects from ground level to within reach while seated in her electric wheelchair. In addition, the device must meet the following performance specifications:

1. The device can be operated without the assistance of a staff member of the rehabilitation facility.

2. The unit will attach to the frame of the client's electric wheelchair.

3. The design will be able to retrieve the following items efficiently and without damaging them:
   - school supplies (pencils, pens, paper)
   - items in the home (toothpaste, eyeglasses, hairbrush, clothes, cups, silverware)

4. The grip used will be of a locking type. That is, it will require no bodily force on the part of the user to maintain a hold on the object.

5. The device will be motorized and switch operated so as to provide ease of use.

6. The device will be aesthetically pleasing to the user.

7. The design must be durable enough to withstand constant, heavy, day-to-day operation.

8. The design must pose no safety threats to the operator or her environment.

9. When not in use, the device must not interfere with the normal functions of the wheelchair; it must be compact and not protrude excessively from the frame.

DESIGN

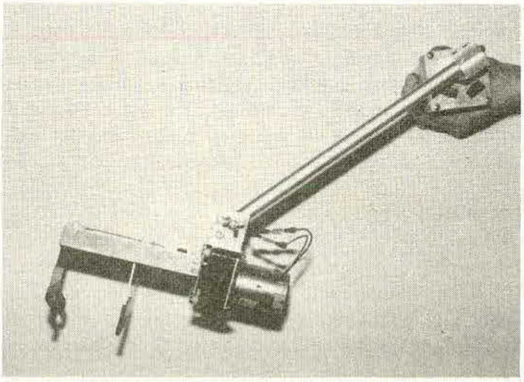

Figure 1. Reacher/gripper device

The final design (see Figure 1) consists of two basic parts: the arm and the gripper. Both portions of the design act independently of each other and are powered by reversible, 12-volt permanent magnet, direct current (PMDC) motors, which are controlled via momentary, center-off toggle switches. Momentary switches were chosen so that power to the motor ceases immediately upon release of the switch. Both motors have been fused to protect them from potentially damaging surges of current. The switch controlling the gripper's motor has been wired to two light emitting diodes (LED's) to indicate operation of the unit in the forward and reverse directions.

The arm of the gripper was manufactured from 5/8" outer diameter, 3/32" wall thickness aluminum tube stock. At the chair, the arm is attached to the shaft of a PMDC motor and gearbox transmitting 90 in-lb of torque and rotating at 5 rpm. The opposite end is mounted to the gripper with a custom-made clevis attachment that allows for adjustment of the angle the arm makes with the gripper and ground plane.

Microswitches are mounted on the faceplate of the motor to limit the travel of the arm between two extreme positions. Just as important, however, they protect the motor from burning out should the client fail to release the switch controlling the arm's motion.

The gripper (Figure 2) is likewise powered by a PMDC motor and gearbox that generates approximately 17 in-oz of torque at 600 rpm. The shaft of the motor is connected to a 1/4-20 threaded rod via a slip coupling. As the threaded rod rotates, it drives a set of "fingers", free to slide on roller type bearings made from delrin plastic in slots milled in the side pieces, towards a set of stationary fingers. Any object that is placed between the fingers will be held in place by the force resulting from the torque applied to the threaded rod. The fingers were manufactured from 1/16 inch thick aluminum sheet. The compliance inherent in such thin pieces of material has proved to be an added precaution against crushing gripped objects. To increase the friction between fingers and object and provide increased cushioning, the ends of the fingers have been coated with a flexible, rubber compound.

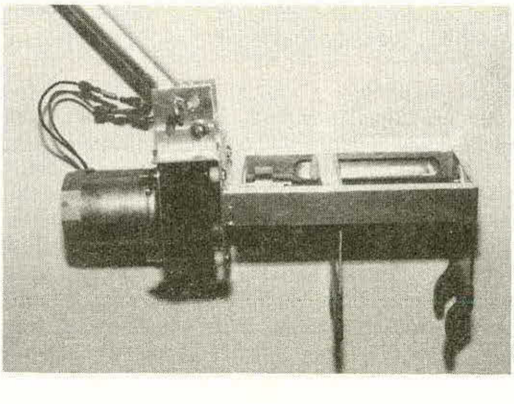

Figure 2. Gripper section with PMDC motor, cushioned fingers, and slip coupling.

Should the operator fail to release the switch when the fingers have closed fully around an object, the slip coupling will protect the gripper and object. This commercially available coupling consists of two friction plates that "slip" against each other when a certain torque is attained. In this application the coupling was adjusted to deliver a maximum resultant grip force of approximately 7 lbf which is comparable to that of a human grip (2). In this way, the threaded rod driving the fingers is halted while the motor shaft is allowed to continue rotating. Again, similar to the limit switches for the arm, the addition of this component serves to limit the gripping force generated by the gripper, and to protect the motor from burning out due to overload.

The sequence of operation for picking up an object is:

1. With the arm in the fully or partially upright position, and the gripper fingers completely open, the operator maneuvers her electric wheelchair to within reach of the dropped object.

2. The toggle switch controlling the raising and lowering of the arm is activated so that the gripper is directly over the object. At this point, wheelchair position may be readjusted accordingly.

3. The gripper is lowered the remainder of the distance to the ground so that the object is between the two sets of fingers.

4. The switch controlling the motion of the gripper fingers is activated until the object is securely grasped.

5. The arm is now raised to the completely upright position so that the gripper and object are well within the operator's reach.

EVALUATION

The reacher/gripper was tested and met all of the performance specifications. It was then delivered to the client and is currently in use. The device has proven to be very effective in gripping and transporting the objects for which it was designed. The device has markedly increased the client's level of independence, since she no longer has to rely upon others to retrieve dropped objects.

DISCUSSION

The design of the reacher/gripper incorporates a high degree of adjustability including: gripping force, angle with the ground, length of the arm, and limit switch positions. It is easily attached to a wide variety of wheelchairs. The design is easily manufactured and replicated. All of the machined pieces can be manufactured using only a basic knowledge of milling machines, lathes and drill presses (3). All parts obtained from vendors are readily accessible through precision components catalogs. The cost of the parts and materials was approximately $350.

The simple, two switch control box is very easy to understand and hence very user friendly. Adaptive devices, such as the reacher/gripper, provide individuals with the ability to more easily interact with their environment. They create an improved sense of independence and by doing so increase self-esteem and improve self-image.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the following people and organizations for making this project possible: Robin and the staff of the Massachusetts Hospital School in Canton, Massachusetts for agreeing to participate in this endeavor, Mr. John Grzyb and Mr. Richard Schachner for machining the parts; and the National Science Foundation for providing the funding for this project (grant #BCS-8907759).

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CURL - A ROBOT CONTROL ENVIRONMENT FOR MICROSOFT WINDOWS

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ABSTRACT

This paper describes recent developments of the Cambridge University Robot Language (CURL). In particular, CURL has been ported to the Microsoft Windows operating environment. The software is now structured to facilitate the control of novel devices through the creation of appropriate device drivers.

BACKGROUND

CURL is an interactive robot control environment which has been developed over a number of years at the Department of Engineering, University of Cambridge. The CURL environment facilitates both direct control and task-level control of a robot arm and has been specifically designed for applications in rehabilitation. It provides an intuitive method of performing pick and place operations through the definition of objects and goals within a world model. Objects are manipulated using commands which employ a natural language syntax. These commands may be combined to form CURL procedures. Previous versions of CURL have been evaluated in both educational and vocational contexts [1, 2].

CURL FOR WINDOWS

The original version of CURL was coded as an MS-DOS application to run on a PC compatible computer. However, the Microsoft Windows operating environment has now succeeded MS-DOS as the environment of choice for most PC users. CURL has recently been modified to run under Windows 3.1 in order to take advantage of the superior facilities offered by this environment.

The Windows Graphical User Interface (GUI) enforces a standard look and feel for all Windows applications. A combination of overlapping windows, drop-down menus and dialog boxes enables users to rapidly navigate an unfamiliar application and investigate its features. The nested menus of the original CURL application have been replaced by three MDI child windows and a menu bar (figure 1). One child window provides access to the direct control features of CURL. Another window allows direct entry of CURL commands and a third window lists pre-defined CURL procedures for immediate invocation. These child windows may be displayed concurrently to facilitate rapid switching between the various forms of control. Alternatively, those aspects of the human-computer interface which are not required for a specific installation may be reduced to iconic form. The novice user is therefore less likely to be distracted by irrelevant display elements. The menu bar provides access to lesser used configuration facilities.

The Windows operating environment also facilitates the integration of CURL with other application software. This is particularly important in computer related vocations where a robot arm is used as an assistive device. For example, CURL is able to co-exist with word processing software on the Windows desktop. A worker could therefore type documents and use the robot arm to manipulate reference materials in a particularly intuitive manner using a single computer.

The consistency with which Windows applications access the computer hardware has facilitated the development of software-based access products such as Switch Access to Windows (SAW) and the Windows Visual Keyboard (WiViK) [4]. These products enable non-keyboard users to gain full control of all applications on the Windows desktop using alternative input devices. It has not, therefore, been necessary to make provision for non-keyboard users within CURL itself.

CURL DEVICE DRIVERS

Previous versions of CURL have been primarily used to control the UMI RT series of robot arms. In certain installations, the software has been modified to accommodate auxiliary sensors and actuators. The syntax of the language, however, lends itself

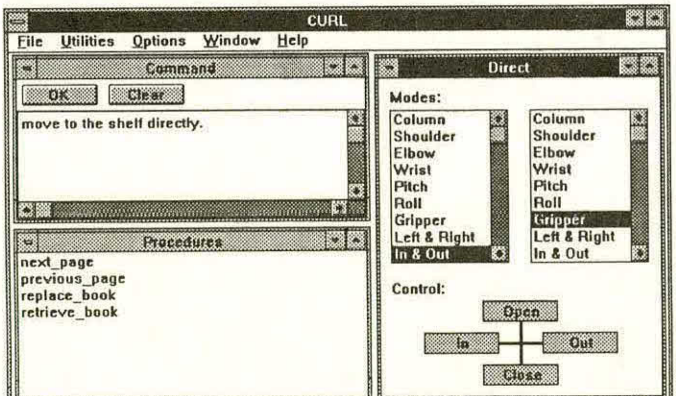

Figure 1. The CURL User Interface

to implementation with a number of other robotic devices. CURL has therefore been re-structured to separate the device specific code from the human-computer interface and interpreter [4]. It is now possible to write device independent CURL procedures for subsequent execution on a robot of unspecified geometry. Device independence is achieved by rigidly specifying the messages passed across a software interface between the CURL interpreter and the device-level control software.

Microsoft Windows provides an effective platform for the implementation of such an interface. It facilitates the development of robot drivers as separately compiled modules known as Windows Dynamic Link Libraries (DLLs). A DLL is a library of data and programming functions which is linked to an application at the time of execution. CURL may be configured to control a specific robot arm by coding a DLL to the CURL Device Driver (CDD) specification. A CDD for the UMI RT series of arms is currently available and a driver for the CRS Plus A251 is planned as part of a collaborative project with the Swedish AMU-HADAR organisation. The CDD specification allows third parties to develop their own drivers for custom hardware configurations.

ACKNOWLEDGEMENTS

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Job Accommodation and Employment Issues

TITLE I OF THE AMERICANS WITH DISABILITIES ACT: ERGONOMICS, RETURN-TO-WORK AND REASONABLE ACCOMMODATION

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ABSTRACT

Under Title I, employers must make reasonable accommodations for the known physical or mental limitations of an otherwise qualified disabled individual. Employers will need to analyze job descriptions to determine essential and nonessential job functions. Ergonomists routinely evaluate accommodations designed to reduce or eliminate ergonomic stresses in the work place. Ergonomists are also evaluating reasonable accommodations of the work place, its procedures, and access for disabled employees. The ADA will also affect the return-to-work of an injured employee. Many times an injured employee can be returned to work as a productive employee by making a reasonable accommodation. Currently, many companies are spending millions of dollars for injured employees who cannot return to their work place. By looking at the reasonable accommodation path, companies could save millions of dollars and keep the employees as productive as possible. During the process of complying with the ADA, ergonomists will play a vital role in job placement and the process of identifying and analyzing areas where reasonable accommodations need to be made.

BACKGROUND

The Americans with Disabilities Act (ADA) will impact nearly every employer, in both the public and private sector, in the United States by 1994. The deadline for most companies to implement Title I of the ADA was July 26, 1992. Title III (Public accommodations and services operated by private entities) went into effect as of January 26, 1992. Currently, employers are being encouraged to look at their businesses and to come up with a plan of action to address each Title that affects them. Also, employers are faced with increasing numbers of injured workers every year. Cumulative Trauma Disorders (CTDs) and low back injuries are the number one work place illnesses of the 1990's.

STATEMENT OF PROBLEM

Companies are spending millions of dollars on injured employees every year, and these employees are placed in medical pools or are at home for indefinite periods of time. There is also a large population of disabled people who want the opportunity to work that would benefit from employers looking at their work places and redesigning or restructuring jobs.

According to Title I of the ADA, employers must make reasonable accommodations to the known physical or mental limitations of an otherwise qualified disabled individual. This would also hold true for an employee who has been injured on the job. A reasonable accommodation is defined under the law as an adaptation of the work place, the equipment, or the job itself, which enables a disabled (or injured) employee to perform the essential functions of a particular job for which he or she is qualified by training and abilities.

APPROACH

Opening channels of communication with the employee will identify the need for accommodation, and is a key element of the evaluation/decision process. Once the need for accommodation is made known to an employer, sufficient information from the employee and from qualified experts must be gathered to determine what accommodations are necessary to enable the employee to do the the job successfully. The ergonomist and other members of a cross-functional task team (i.e., medical, safety, engineering, etc.) should begin to look at the job and what kinds of accommodation may be needed (see Figure 1).

IMPLICATIONS

With the help of reasonable accommodations, many more people can be put to work, and others can return to work after injury as productive employees. The two key factors for employers to remember when trying to place a disabled or injured employee in the work place is the need to identify the essential functions of the job through job analysis, and to make sure that no mismatches occur between job requirements and the person's abilities.

DISCUSSION

The process is the same whether the employee is disabled or injured. The first step the ergonomist would take would be to do a job analysis in order to find out what the essential functions of the job are. Job analysis is the process of breaking down a particular job into its component parts. A careful match of the individual's aptitudes and abilities with the job enhances the probability of success.

The next step in the process would be to match the individual to the job. If a mismatch is present, the ergonomist must look at possible job accommodations to bridge the gap. Accommodations include, but are not limited to, job restructuring; part-time or modified work schedules; reassignment to a vacant position; acquisition or modification of equipment or devices; provision of readers, interpreters, or other assistance; modification of training materials or practices; and making facilities readily accessible to and usable by people with disabilities.

Possible job accommodations must then be evaluated to determine if the recommended accommodation is, in fact, reasonable. Cost is typically considered when determining reasonableness of an accommodation. If no accommodation exists to place an employee in a job, then adequate documentation is essential. Proper documentation can include: video footage of an employee performing the essential functions, still photographs, interviews with the employee, shop supervision and co-workers, and direct observation of the job being performed.

Once it has been determined that an employee can be accommodated and the required equipment arrives, it is essential to properly inform the employee of the accommodation and how it will benefit them.

The final step in the accommodation process is follow-up. After a suitable length of time has passed, the ergonomist should return to the shop area and interview the accommodated worker to see if any further analysis or assistance is required. Shop supervision should also be contacted to see if the accommodation has had the desired effect of permitting the essential functions of the job to be performed.

Ergonomics provides the avenue to implement reasonable accommodations and promote implementation of the ADA. Companies will see increased worker's compensation savings and decreased medical costs, while attaining a more productive work force.

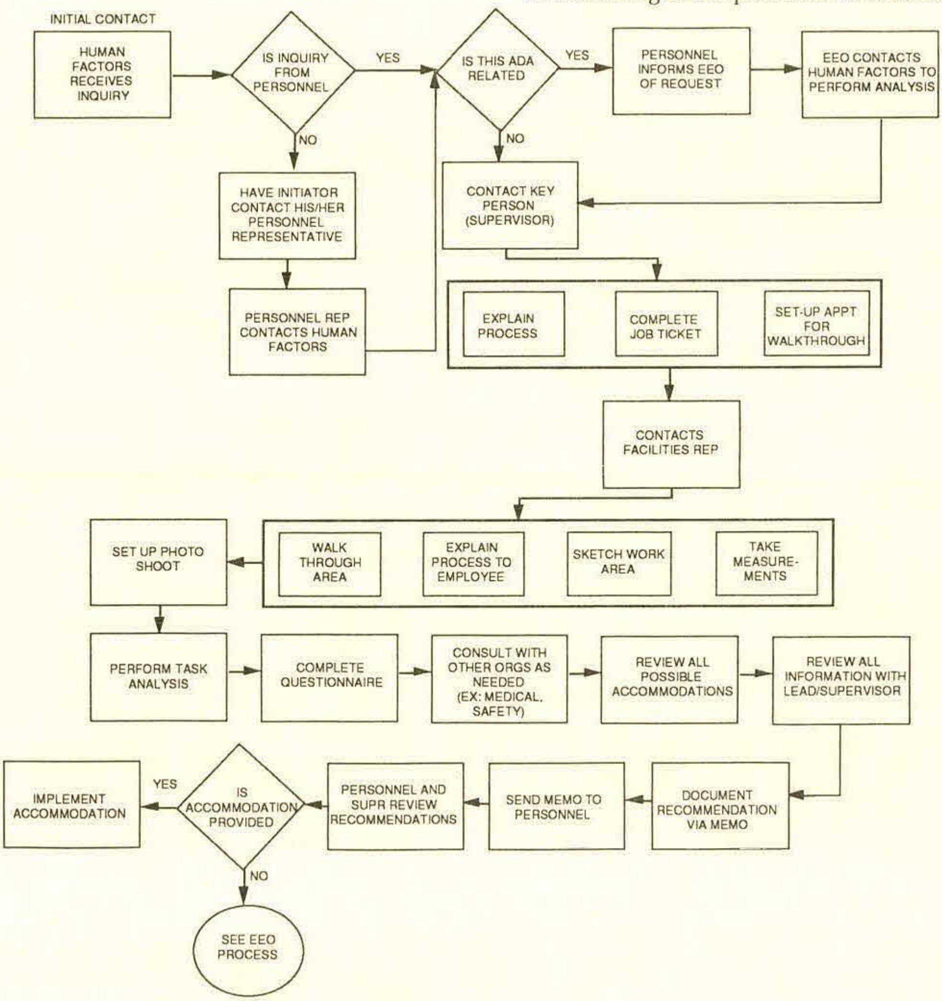

Figure 1. Human Factors Flow – Task Analysis for Job Accommodation

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REASONABLE ACCOMMODATION FOR CARPAL TUNNEL SYNDROME – AN ERGONOMIC CASE STUDY

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ABSTRACT

Cumulative Trauma Disorders (CTDs) have gained visibility in the workplace over the past few years. Title I of the Americans with Disabilities Act (ADA) provides for reasonable accommodation for the known physical or mental limitations of an otherwise qualified disabled individual. In some states, carpal tunnel syndrome is being classified as a full body disability. Recently published articles refer to CTDs, such as carpal tunnel syndrome, as the:

- "new computer-age health assault",
- "occupational hazard of the 90's", and
- "industrial disease of the decade".

Injured employees are returning to the workplace with specific medical limitations and are faced with still having to perform the essential functions of their jobs. This case study outlines the process one company is using to address issues faced by injured or disabled employees when they return to work.

BACKGROUND

The company's Human Factors and Ergonomics Development (HF) organization typically evaluates worksites to develop requirements and recommendations for reduction of ergonomic stressors. With the requirements under Title 1 of the ADA, the HF organization was further tasked to include recommendations and implementation of accommodations for injured or disabled employees.

The employee in this case study held a job which required extensive use of a computer keyboard. The employee developed bilateral carpal tunnel syndrome with shoulder involvement, and underwent surgery to correct the damage.

Upon coming back to work the employee's physician recommended several medical limitations. These included:

- Limited use of both arms; no more than 3-1/2 hours of keyboard work per eight hours
- Needs to use a trackball for computer work

After consulting with the company's Medical Department, it was determined that the employee might be returned to a full eight hour schedule provided her workstation was modified to accommodate her injury.

Originally the workstation contained the following components:

- Nonadjustable office desk
- Office chair with limited adjustability
- Computer system
- Document holder
- Telephone
- Overhead storage shelf

The HF organization was requested to perform a job and task analysis to determine if reasonable accommodations could be made.

OBJECTIVE

To accommodate the employee so she could return to being able to perform all of the essential functions of the job she held prior to being injured.

METHOD/APPROACH

1. Human Factors and Ergonomic Development organization received request to evaluate employee's job.

2. HF representative contacted Personnel representative to obtain company job code and description, medical limitations, and to ascertain who the employee's supervisor was.

3. HF representative then contacted supervision, met and discussed case, and set up meeting to perform job analysis.

4. HF representative performed a complete job analysis by talking with the employee and observing the tasks performed at the existing workstation. Eight essential functions were identified. Five of those eight functions

required keyboard use and totalled approximately ninety percent of her job.

5. After analyzing the components of the job, HF found several problems which could potentially violate the employee's medical limitations. Recommendations for accommodation were made based on the employee's medical limitations and the essential job functions.

RESULTS

The following suggestions were recommended and implemented:

1. Provision of an adjustable height computer table.

   It was determined that an adjustable table would allow the employee to work in a more neutral posture which would help alleviate some of the stress she was feeling in her shoulder region.

2. Provision of forearm supports.

   The forearm supports helped keep the employee's wrists in neutral posture as well as help alleviate stress in her shoulder region.

3. Provision of an ergonomically designed chair.

   Ergonomically designed chairs include features such as: adjustable arms, seat pan, back, and seat pan tilt, and good lumbar support. These features encouraged the employee to maintain proper postures and provided low back support.

4. Provision of a telephone headset.

   The employee was receiving or providing information over the telephone while working on the computer. This forced her to cradle the telephone receiver resulting in neck and shoulder strain. The telephone headset alleviated the need to cradle to the telephone receiver and reduced neck and shoulder strain.

5. Provision of a trackball for the computer.

   The movements required to use the trackball were less forceful and the wrist was kept in a neutral position.

6. Provision of training for accommodations provided.

   The employee needed to understand what accommodations were implemented and how they would help get her back to work. It was also important that the employee understand how to use and adjust the equipment so she could fully benefit from the workstation modification.

The accommodations provided will help pre_ vent reoccurrence of the same or similar type of injury.

DISCUSSION

Cumulative Trauma Disorders are becoming more prevalent for office workers. Repetitive tasks are a common component of office tasks. These, combined with improper wrist postures, are known factors for development of CTDs.

Cumulative Trauma Disorders carry a high dollar treatment. For example, an average bilateral carpal tunnel surgery costs thirty thousand dollars.

The increased occurrence and treatment costs of CTDs makes it imperative that preventative measures are developed. This case study showed some of the workstation modifications that can be implemented to prevent occurrence or reoccurrence of CTDs in the workplace.

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JOB ACCOMMODATION TECHNOLOGY FOR THE "WET LABORATORY"

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Abstract

The development of assistive technology for use in the "wet laboratory" by scientists or students with C6-C7 or lower quadriplegia is presented. This description traces the design process from the task analysis and the evaluation of the capabilities of a molecular biologist with C6-C7 quadriplegia through fabrication of working prototypes.

Background

We are trying to restore independence in the laboratory to a postdoctoral molecular biologist at this institution with C6-C7 quadriplegia. In order to have substantial effect in limited time, especially considering our financial constraints, a decision was made to focus on the equipment manipulation problems resulting from his decreased hand function rather than wheelchair accessibility problems. The existence of standards for wheelchair accessibility such as the Uniform Accessibility Standards and the American Chemical Society recommendations for laboratory design would have made the accessibility problem less demanding of innovation.

In addition to helping this individual, this work is important for several reasons. First, the Americans with Disabilities Act (ADA) recently became effective for employers of 25 or more, requiring nondiscrimination in employment and "reasonable accommodation" for people with disabilities--assuming the individual is "otherwise qualified" and the accommodation does not present "undue hardship" for the company. Given the ADA and the fact that there has been relatively little formal work done on developing assistive technology for the scientist with quadriplegia (as compared to the office environment, computer work, and activities of daily living), this project is timely. This lack of prior adaptive design efforts may be due in part to fewer students with disabilities working in laboratory science, the result, no doubt, of their being encouraged to steer away from these fields, because of the perception that they are too difficult or too dangerous.

Second, because of our limited budget, this project focuses on relatively low-cost solutions. This emphasis on economy should be of interest to employers as well as schools.

Third, while full-time assistance from another person is perhaps the most easily conceived option, this may be a situation that neither the employer, because of the additional salary to be paid, nor the scientist with a disability, because of the dependence on another person, wants. However, as with Activities of Daily Living (ADL), it may be more conventional and cost effective to have someone assist in the laboratory at the beginning and end of the day, much like a personal care attendant. This person could conceivably set-up the equipment to be used for that day and then clean-up at night. The designs that have been and are being developed were based on this view of independence.

Finally, the funding for this project is a unique situation in that two parties at this academic institution are benefitted at once. One party is able to have greater independence through modified equipment or newly designed devices while the other benefits from having gone through the rigor of this real world design problem en route to a Master's degree.

Objective

After further examination of the tasks in the molecular biology laboratory, six main protocols were identified. It was apparent that being able to perform some of the protocols "completely" would be more useful than being able to do bits and pieces of several protocols since assistance would frequently be needed in the latter case. This approach also fit our desire to have this scientist independent through the majority of the day. Consequently, it made sense to design for one protocol at a time. The decision as to which would be targeted first was made based on subjective importance to the user (very closely linked to how frequently the protocol is done); technical feasibility of accommodation as estimated by the designer; and generalizability, ie. the extent to which designing for one protocol would solve design problems inherent in other protocols. Table 1 shows the ratings of the six protocols on a one (less significant), to five (more significant) scale:

Protocol	Imp	Feas	Gen	Total
Bacteria Growth	4	3	1	8
DNA Isolation	4	3	3	10
DNA Analysis	5	2	4	11
PCR	3	4	3	10
Hybridization	3	3	2	8
Sequencing Gels	3	2	3	8

Table 1.

Based on these considerations, DNA Analysis was subsequently chosen as the protocol on which efforts would initially be focused.

Approach

In order to create an appropriate interface between any person and a set of tasks, information must be known about both. This is a standard principle of human factors engineering. The essential information that is desired is shown in Figure 1 where resources can be cognitive or physical (adapted from [1]). In the case that this project treated, the individual is limited by his physical resources and the physical requirements of the task, thus creating a disability.

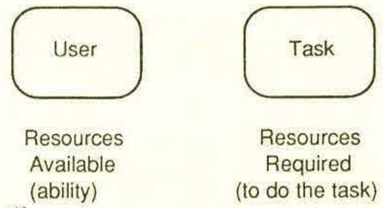

Figure 1.

Information on the scientist's physical abilities was initially obtained through observation in the laboratory as well as assessments made by an occupational therapist. However, more specific information on functional capability was desired as it became more and more apparent that hand function limitations were preventing him from carrying out the tasks in the laboratory (aside from wheelchair accessibility). This was true since much of the equipment required significant finger dexterity, and while the individual does have functional tenodesis grasp through wrist extension, he lacked control of the muscles that manipulate the fingers. Isometric testing of various tenodesis grasps was done with a load cell and cylinders ranging from 1/8" to 3" diameters to gain a more quantitative understanding of the individual's capabilities. This would especially be pertinent in the design phase.

The requirements of the protocols were determined from interviews, laboratory manuals and observation. The most useful information was obtained by observation of the scientist attempting all the functional steps in a protocol. As the these steps were further decomposed into their component acts, it became more evident what exactly the disabling problems were and what the requirements of the solutions would be.

Results

One of the designs in shown below in Figure 2. This is to be used in conjunction with a motorized pipetter, such as the Drummond Pipet-Aid, using glass pipettes from 1 mL to 25 mL with a ring of RTV rubber applied around the circumference of the pipetter. The device shown is to be mounted on the edge of the lab bench and is used to aid in removing and inserting pipettes into the pipetter. The scientist was unable to grip the pipettes tightly enough to perform this task. However, by having the device below act as a holder for the pipette, he can insert and remove pipettes by holding onto the pipetter with both hands.

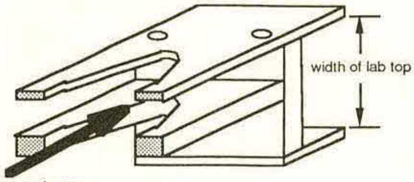

Figure 2.

For pipetting smaller volumes (anywhere from 1 µL to 1 mL), a "µpipetter" is used. To adapt this task, a motorized version was acquired (Rainin EDP2) and a phono jack was attached to allow connection to a plate switch. This was done as there was a trigger switch for aspirating and dispensing (same switch) which the individual was unable to actuate while holding the µpipetter. Additionally, using both hands to hold the µpipetter, press the trigger, and position the tip, was deemed too awkward and impractical for lab work. The paddle switch solution will be used in conjunction with a gooseneck to aid holding of the µpipetter and is subject to further evaluation.

Discussion

Under the assumption that an assistant would come in at the beginning and end of the day, the relatively low-cost approach used in this project provides the necessary independence in laboratory function. While the low-cost approach often leads to designs that are less universal, they achieve lower cost in part by taking advantage of as much of the user's capability as possible. It is this very function- and person- specific approach which makes it so important to have careful measures of what the person's abilities are and what the requirements of the task demand.

More designs to solve difficulties in the DNA Analysis protocol are being worked on at this time.

Acknowledgements

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Reasonable Accommodation and Assistive Technology: A Legal Analysis

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ABSTRACT

The Americans with Disabilities Act ("ADA") requires most employers to make reasonable accommodation to individuals with disabilities in all employment decisions, but only to the extent necessary for performance of the essential functions of the job. Reasonable accommodation does not need to be provided if it would impose an undue hardship on the operation of the business. Rehabilitation specialists need to be aware of job functions and the cost implications of assistive technology because the determination of essential functions and undue hardship are specific to the job circumstances. Without specific knowledge of the job structure, rehabilitation specialists are at a disadvantage in supporting the employment objectives of clients. Rehabilitation solutions that are costly or not related to essential job functions may jeopardize a client's employment opportunities.

BACKGROUND

Rehabilitation solutions are designed for individuals in a specific environment. Prior to the ADA, significant technological effort was applied to a clinical or institutional setting to affect social or personal needs. If ADA is to be effective in accelerating employment of disabled persons, designers and engineers must concentrate anew on employment settings and job related needs.

The law is written in such a way that it may be difficult for rehabilitation specialists to know how best to serve employment needs. A case by case determination has to be made, the employer controls much of the information used in this determination, employer judgment is very influential, and government regulations add little to promote quick and easy solutions.

DISCUSSION

An employer may be required to adjust or modify the work environment or manner in which a job is performed. This may include the acquisition or modification of equipment or devices, a category including assistive technology. Determining a reasonable accommodation is done on a case by case method, using a problem solving approach. In most cases, the employee will have to request an accommodation, and the employer will inquire of the employee what kind of accommodation is needed. Without professional guidance, neither the employer nor the employee may be in a good position to select an accommodation that is effective. A provider of assistive technology or services can provide an important support for employment success by recommending an appropriate accommodation.

There are several types of accommodations that could involve rehabilitation specialists. First, is the restructuring of a job including (a) redesigning procedures for accomplishing certain job tasks, and (b) changing when or how an essential function is performed. Second, is the acquisition or modification of equipment or devices including those designed for (a) the blind and visually impaired, (b) the hearing impaired, and (c) those with limited physical dexterity. In each case, the accommodation must be directed to performance of the essential job functions. Also consideration must be given to safety and emergency procedures in the workplace. Employers are not required to provide any devices that are primarily for personal benefit.

Two difficulties are presented. First, the rehabilitation specialist may not know the essential job functions without a dialogue with the employer. Second, the ability of the rehabilitation specialist to design a solution is limited by the undue hardship provision of the law.

Essential functions of a job are determined initially by the employer. Whether a particular job function is essential depends on evidence such as (a) employer's judgment, (b) written job description, (c) amount of time spent, (d) consequences of not performing, (e) work experience, and (f) terms of the collective bargaining agreement.

If the individual who holds the job is actually required to perform the function, three factors will be considered in determining whether the function is essential: (1) the position exists in order to perform that function; (2) a limited number of other employees are available to perform that function; (3) a high degree of expertise or skill is required to perform that function.

The information that is needed for this analysis may not be available to individuals seeking employment or to those who provide rehabilitation services or assistive technology. Unless an employer is forthcoming about the job analysis, an individual may be forced to resort to legal action in order to protect his/her rights to employment opportunities.

An employer is not required to make an accommodation if it would impose an undue hardship on the operation of the business. Undue hardship is defined as significant difficulty or expense. This is understood to mean something that is unduly costly, extensive, substantial, disruptive, or fundamentally altering the nature of the job. Factors involved in determining undue hardship are: (1) the nature and cost of the accommodation, (2) the characteristics of the facility involved, (3) the economic characteristics of the employer's company, and (4) the operational characteristics of the employer's company. The employer has the burden of proving hardship, but this proof would only be furnished in a legal proceeding. Therefore, a job applicant would be faced with the choice of accepting the employer's assertion that an accommodation can not be made because it is an undue hardship, or seeking legal assistance. The ADA, like other civil rights legislation, depends greatly upon voluntary compliance and attitude changes. It is possible then, that some very effective applications of assistive technology will not be adopted, persons will not be employed or promoted because of the erroneous assertion of undue hardship. In order to anticipate possible hardship assertions, a person would need detailed technical knowledge about the business which is generally unavailable to job applicants or providers of assistive technology and services.

CONCLUSION

The ADA shifts the responsibility for economic well-being of disabled persons from the public to the private sector. This is a major policy decision which can succeed only by attaining full employment. It will be difficult for rehabilitation specialists to effectively help every person with disabilities to obtain a job or promotion. Attention will have to be given to business economies and productivity, analysis of job functions and specific tasks, opening a constructive dialogue with employers, and a better understanding of the legal framework.

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CAN REHABILITATION ENGINEERING RESOURCES MOTIVATE CONSUMERS TO SEEK EMPLOYMENT?

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ABSTRACT

The objective of the project is to design and test consumer-oriented outreach approach to motivate SSDI (Social Security Disability Insurance) beneficiaries and to enroll them in job placement programs, via increased accessibility to rehabilitation engineering services. Over 900 beneficiaries were randomly selected from 5,000 who reside in the Baltimore area between the ages of 18 and 60, and who may benefit from Rehabilitation Engineering Services.

BACKGROUND

Preliminary findings of previous Social Security Administration (SSA) Research & Demonstration projects indicate that technological support, combined with the existing vocational rehabilitation systems is successful in providing beneficiaries with worksite and mobility accommodations necessary for securing employment.[1] As a result, the approach of this project is to organize and present various rehabilitation engineering information directly to S.S.D.I. recipients for the purpose of motivating these individuals, in conjunction with linking them with job placement personnel.

STATEMENT OF PROBLEM

As technology and the understanding of the human body has become increasingly sophisticated, assistive products and modifications have proliferated and made it possible for people with disabilities to accomplish tasks far beyond what they ever imagined. Unfortunately, the advances made in these areas have not been widely known, especially to those individuals who have been living with their disability for a few years and have not sought opportunities for employment, or those who are not generally exposed to the world of ergonomics, orthotics, physical and occupational therapy as well as other fields which may be acquainted with these assistive products and modifications.

APPROACH

The Research Question: "Does access to and information about Rehabilitation Engineering motivate physically disabled S.S.D.I. beneficiaries to enroll in a job placement program?" served as the guideline for developing and implementing a set of evaluation procedures involving both qualitative and quantitative analysis of project data.

The evaluation examines the process and effect of five rehabilitation engineering marketing approaches which have been developed and implemented to motivate beneficiaries. The following are marketing approaches:

1. Mailed Questionnaire
2. Telemarketed Questionnaire
3. "Normal Procedures" Mailing
4. Success Stories Mailing
5. Consumers' Expo.

In addition to these groups, a control group has been implemented to test the average. Results of the experimental group is available in Table 1.

FINDINGS

First, we contacted 752 S.S.D.I. beneficiaries, we were able to reach 97 (13%) of them, and had a response for job placement enrollment of 18. That is a 3% positive response of individuals that are contacted.

Additionally, we asked a sample of 36 individuals from the experimental group, what would interest them in returning to work:

- 69.5% were not interested in returning to work. Of that number, 5.6% indicated that

TABLE 1

MARKETING APPROACHES						
TASKS	#1	#2	#3	#4	#5	TOTAL
Mailed Information	151	151*	150	150	150	752
No. of Responses	25	55	5	4	8	97
Rate of Responses	17%	36%	3%	3%	5%	13%
Seek Employment	2	7	5	4	0	18

* Attempts have been made to contact these beneficiaries by phone, 55 successfully contacted and 96 unable to contact.

this was not applicable to them, 63.9% simply were not interested.

- 30.6% stated they would be interested in returning to work. The influencing factors were:
  - If they could make more money (25%)
  - If they would be able to support themselves (2.8%)
  - If work would provide them with the ability to get out of the house (2.8%)

Specific interview data were studied using qualitative and descriptive analysis procedures. The quantitative data from the interview and the Alliance Motivation Scale are reviewed using descriptive analysis and analysis of variance procedures. Examination of the six interview questions indicates that the majority of the sample did not know about rehabilitation engineering and did not have motivation for returning to work.

DISCUSSION

Rehabilitation Engineering is viewed as a source for opening up the possibility of improved functioning and interaction in every aspect of our society:

- This service needs to be offered to beneficiaries at a time when they have the greatest amount of hope. Demographics of the sample reveal an average mean age of 48 years, time on the roles for approximately 12 years receiving benefits.
- Telemarketing approach gave better responses (36%) over others, which signifies the impact of personal contact.
- A case management approach supported by a rehabilitation team, consisting of a rehabilitation engineer, is effective on job placement.
- The study also discovered that the beneficiaries have low expectations of the Federal system.
- Rehabilitation engineering (knowledge of and access to) could be implemented as a method to optimize the potential of goal achievement and job procurement. This intervention needs to occur at a time when beneficiaries have not passed the point of hope and expectancy.
- The outcome of experimental groups is so limited, as such, there is no significant difference with the results of the control group.

REFERENCE

[1]Research Demonstration Program: Increasing Employment Opportunities for the Disabled, SSA, 1990.

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SAFMEDS TEACHING TECHNOLOGY

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Abstract

The SAFMEDS ("Say All Fast A Minute Each Day, Shuffled") procedure was used as a component of a course in assistive technology for graduate students in rehabilitation counseling. The system provided a number of benefits, including frequent measurement of student academic behavior, non punitive treatment of errors, facilitation of fluent student performance, and easy accommodation of student differences.

Background

An explosive growth in rehabilitation and assistive technology (AT) services has occurred in the US. This growth been fueled by the increased recognition of the utility of technology in rehabilitation to help people with disabilities, and a concomitant increase in funding to support more technology professionals from a wider array of disciplines.

Rehabilitation counselors are among the clinicians who need to be technologically sophisticated, so their professional education should address AT. Also, just as AT is deployed to reach rehabilitation goals, technology may also assist in reaching educational goals. The present paper reports on a technological innovation called SAFMEDS used in teaching AT to student rehabilitation counselors. SAFMEDS is an acronym for "Say All Fast A Minute Each Day, Shuffled." The procedure was developed by O.R. Lindsley (1980) and has been discussed elsewhere (McDade and Olander, 1990). It is explained more fully below, after brief discussions of errors and measures of learning.

Emotional responses to errors

Gaps in knowledge are inevitable for any professional working in a dynamic area like AT. As a professional, it is expected that one readily recognize when a question or situation is beyond one's knowledge or skills, both from an ethical and a quality service delivery point of view, and study to rectify the gap or refer the client elsewhere. However, the author has observed that many students seem to conceal errors, express reluctance to admit ignorance, or express discomfort when it is exposed, sometimes to the point that they are unable to repeat previously correct performances. Such concealment, discomfort and even more extreme responses may be understandable if the student's educational system has previously punished errors/gaps, but these are unacceptable responses for professionals. Therefore, students must be trained readily to recognize, admit, and rectify gaps or errors without disruption of ongoing performance or uncomfortable emotional responses.

Objective measures of learning

Johnston and Pennypacker (1980), discuss frequency (count per minute) as a convenient dependent variable to study behavior change outcomes. Frequency has as several advantages over more subjective or ordinal systems (Merbitz, Morris, and Grip, 1989). If a student's frequencies of correct and incorrect performance on related academic material are measured at multiple points in time, acceleration (learning) defined as change in frequency over time (count / minute / week), can be visualized on a graph. If a calendar-synchronized semi-log graph, such as the Standard Celeration Chart (Pennypacker, Koenig and Lindsley, 1972) is used, both acceleration of corrects and deceleration of errors can easily be plotted and projected with straight lines. (If square graph paper is used, then learning curves and punishment curves must be plotted and prediction and comparison are more difficult.)

A goal for educational quality is student fluency with academic material. A fluent person performs at a high rate with few or no errors of commission. Over the semester, a student should accelerate corrects per minute and decelerate errors, until the performances are within specified ranges. The ability to measure and display acceleration allows focus on progress and future good performances, and the treatment of errors as learning opportunities. With multiple opportunities to measure, students can predict their academic performance and modify their individual learning activities before the end of the term. The students may also set and achieve goals for personal excellence that are objective, demonstrable, credible, and result in useful performance. Thus the system is also an environment in which students can learn to deal appropriately with gaps in their performance. Finally, fluent performances are retained and are available to be combined into larger, more complex responses (see Johnson and Layng, 1992, for a more complete discussion).

The present paper reports on a preservice graduate class for rehabilitation counselors that deployed the SAFMEDS procedure. This paper will discuss only the SAFMEDS evaluation component; the curriculum included readings, visits by skilled assistive technology service providers, field trips, and other elements. "Hands-on" laboratory exercises and case studies were also used.

OBJECTIVE

Students should respond fluently and correctly to technology questions. For the midterm and final, they should achieve over 35 questions per minute correct maintained over at least one minute on a random sample of questions from the course material, with fewer than 3 errors per minute. Errors should be recognized but not disrupt performance.

METHOD

Eight rehabilitation counseling graduate students were allowed to choose SAFMEDS performance or writing papers for a midterm exam grade and for a final exam grade in an introductory AT course.

Preparation

To prepare SAFMEDS, the universe of concepts to be taught and evaluated is defined. Courses are broken into multiple units of logically related material and a syllabus explicates the goals, study activities, lectures, demonstrations, or other educational activities for each unit. The important concepts in each unit are identified.

A question (or questions) for each concept is generated, typically resulting in about 60 to 120 questions per unit. Questions may have a diagram, picture, or similar graphic. Questions should be short; complex concepts are generally broken into several short questions. Each question will also have a short answer; one syllable is ideal but longer answers are common. Instructors may prepare questions and distribute them to the students at the beginning of the term, may distribute concept lists, or may require students to identify concepts and write questions. (Since the students in the present class were graduate students, they each wrote questions.) Then, each student prepares a personal SAFMEDS deck of index cards. Each question is written, typed, or printed on one side of a card with its answer on the other. Each student's deck is reviewed and approved by the instructor.

SAFMEDS (Lindsley, 1980)

The acronym stands for Say All Fast A Minute Each Day, Shuffled, and describes the procedure for daily measurement by the student. Each day the student shuffles the deck for the current unit, sets a 1 minute timer, and answers as many questions aloud as possible in the minute. Students read the question silently and say the answer (or say "go" if they are unsure), then check the back of the card to see if the answer is correct. Correctly answered cards are placed in one stack, and "go" cards in another. At the end of the minute the stacks are counted and the frequency of correct and incorrect responses is recorded on a data sheet. In other respects the material is studied following the student's normal procedures. When a student is fluent, or consistently above criterion for an A (in this case 35 questions correct per minute with fewer than 3 errors per minute) s/he makes an appointment with the instructor.

Testing

Testing is done individually during regular office hours. The instructor and student sit across a table. The student holds up each card as s/he says its answer so that the instructor is able to read the answer, monitor the response, and time the performance. Afterward, progress is plotted on a Standard Celeration Chart (Pennypacker, Lindsley, and Koenig, 1972), and the material is discussed as needed. Students are first tested as soon as decks are ready, regardless of how much study has occurred. This session allows the instructor to praise corrects and discuss the concepts of fluency and progress. Student are shown that errors are valuable indicators of gaps that can be filled as opposed to occasions for punishment. Saying "go" when a question is encountered to which one does not know the answer is discussed in the context of recognizing gaps and making an appropriate response while maintaining a fluent performance. Testing sessions take approximately 5 min. per student, most of which is spent discussing concepts.

Students are retested as they request until they demonstrate fluency in the material. Each test is a random sample of all concepts in the unit.

Pacing

Students were given dates by which all performances were to be completed. The dates were based on grade reporting requirements for the University, and were announced at the beginning of the term. General reminders to schedule testing were given approximately every other week thereafter.

RESULTS

Students were initially reluctant to try SAFMEDS and several expressed concern about reaching the 35 per minute criteria. In a class of 8 graduate students, one elected to do papers for both midterm and final. One did SAFMEDS for the midterm and a paper for the final, and the other six did SAFMEDS at both opportunities. Students were interviewed after the course and reported positive feelings about the SAFMEDS procedure. All students electing the SAFMEDS option demonstrated performances over the required 35 per minute correct, with some reaching frequencies over 40 per minute.

Students with disabilities

Several students with disabilities were in the course. One student with a learning disability initially expressed the absolute conviction that she would be unable to perform at 35 per minute. However, she agreed to try consistently for a week. Her data showed great progress and she was able to exceed the criterion, finally making over forty correct responses per minute. One student with cerebral palsy briefly tried SAFMEDS, but elected to write papers instead. One student who had only one functional hand developed a highly satisfactory technique for manipulating the cards and required no accommodation.

DISCUSSION

The SAFMEDS procedure provides a satisfactory organization for objective testing in the AT class. A large item pool with repeated testing and a random draw for each test allows controlled coverage of the material, testing on all important concepts, and insistence on perfect answers. Using frequency criteria is also reported to aid in retention and application, while the frequency data allow accurate prediction of student performance and remediation before the end of the term. Finally, students perceive the system as fair and as directed towards their education.

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SIG-15
Information Networking

EFFECTIVE, LOW-COST MARKETING STRATEGIES FOR ASSISTIVE TECHNOLOGY PROGRAMS AND I&R NETWORKS

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ABSTRACT

Marketing is essential for informing the public about assistive technology programs and information and referral networks. The marketing target audience should include not only individuals with disabilities, but also parents, service providers, special educators, parents, physicians, therapists, rehabilitation specialists, and the general public. Marketing budgets for assistive technology projects are typically small; therefore, in order to convey information to all target audiences statewide, effective but low-cost marketing strategies, using available community resources, must be utilized.

BACKGROUND

The Utah Assistive Technology Program (UATP) was one of the first nine states funded under the Technology Related Assistance Act for Individuals with Disabilities. Approximately, 42 states now have funding for assistive technology projects. One of the challenges of these projects is to inform people with disabilities, parents of children with disabilities, and providers about their services on a statewide basis without large marketing budgets. People must be aware that assistive technology projects exist in order to utilize the available information and services.

OBJECTIVE

The objective of marketing is to efficiently and cost-effectively reach all individuals who might need information about assistive technology devices or services. Target audiences for assistive technology information are heterogeneous, crossing socioeconomic status, age, and ethnicity. They should include individuals with disabilities, their families, co-workers and friends. Professionals should also be included in the target population, especially occupational and physical therapists, rehabilitation specialists, psychologists, and physicians. Marketing campaigns should not overlook people who are elderly, members of minority groups, and people who live in rural areas, a group that can be difficult to reach because of geographic isolation.

Campaigns should not only try to increase awareness of assistive technology programs and information and referral (I&R) networks, they also should strive to positively change public attitudes and empower individuals with disabilities.

APPROACH

Because marketing and public relations are interconnected, especially when dealing with attitudinal change, it is important to carefully consider the program's image when creating brochures or Public Service Announcements (PSA's). It is not only important to present the organization in a positive light, it also is important to change negative attitudes and stereotypes about people with disabilities. This is done by positively portraying individuals in videos and brochures and by showing them in integrated settings, including employment, community activities and family settings. The media often portrays people as objects of pity in isolated or segregated settings, which detracts from their abilities and dehumanizes their individuality. Using appropriate, nondiscriminatory language also is important. When referring to people with disabilities, its best to mention the person first and then, if necessary, their disability.

One key to effectively reaching a heterogeneous target population is to use a variety of marketing strategies. This ensures the most comprehensive message penetration. Marketing approaches include mass mailings; radio, television, and print PSA's; videotapes; live presentations; telephone directory listings; busboards; billboards; and posters.

Television and radio PSA's can be useful, but they also can be expensive to create. Some organizations have worked together to create PSAs in order to reduce costs. The UATP has customized their PSA's for other interested states. Universities often have low-cost production facilities, and sometimes television stations will produce PSA's for non-profit and not-for-profit organizations at a reduced rate and occasionally for free.

DISCUSSION

One effective marketing strategy for the UATP has been mass mailing campaigns. The UATP has sent brochures and other materials to all physicians, pharmacies, libraries, rehabilitation centers, senior citizen centers, independent living centers, and special educators throughout the state. For this method, a letter identifying the purpose, goals, and sponsors (both federal and state) of the project is sent to target audiences. Brochures are included with the letter, which asks the person to display the brochures in his or her pharmacy, clinic, classroom, senior citizen center, etc.

Physicians and pharmacies have been included in two mass mailing campaigns. The second mailing resulted in significantly more calls. It is unknown whether the increased call loads were caused by different components of the letter or because the second mailing was a repeat mailing, causing people to recognize the name easier. The letter used in the second mailing, which listed all the state agencies that support the program, may have increased the credibility of the informational materials. Mailing lists were obtained from state medical and pharmaceutical associations for a small fee, and addresses for rehabilitation centers were obtained from telephone directories.

Radio, television, and print PSA's have also been used. Radio PSA's can be written out in short and long versions and sent to each station within the state to be included in their community PSA's. Talking to stations individually helps increase the probability of getting air time.

Every television and cable station that has been contacted by UATP staff members has broadcast the recorded PSA's. The person in charge of PSA's, usually the public affairs director, is the best person to talk with when requesting air time for announcements. UATP project staff explain to directors that the PSA's are for a statewide, federally funded project that has a toll-free number to provide free information about devices and services for persons with disabilities.

It is important to ask what broadcast format the station uses (Betacam or 3/4 inch). The PSA's should be provided to station directors in the format they prefer. It also is useful to include brochures or other informational materials about the project with your PSA. Station-donated space can help alleviate marketing budget concerns but, unless the station agrees to donate preferred space, the announcements may be put in the time slots that no other commercial buyer has purchased. These time slots usually are not purchased because they don't reach many viewers. Sometimes, stations will donate more preferred time if the not-for-profit organization purchases some air time. Cable stations often broadcast the announcements at better time slots, although they sometimes do not have as large an audience.

Formats for PSA's should be carefully considered. All PSA's and videotapes should be closed or open captioned for people who have hearing impairments. Audio description is useful for describing on-screen action for people who have visual impairments. All print material should be available in alternative formats such as Braille, large print, taped texts, and computer diskettes. It also is desirable to provide PSA's and videotapes in other languages because this increases the number of people who can use the program and reaches populations that might not get reached otherwise. Also, some channels cater to individuals who speak a particular language (e.g., Spanish), and broadcasting on these channels can help the message reach a wider audience.

PSA's and videotapes are an effective method for conveying information, increasing public awareness, and changing attitudes. Videotapes have also been broadcast over state and national public and cable television stations. America's Disability Channel is the only television network specifically designed for people with disabilities. The channel is an excellent resource, with the capability to broadcast videotapes nationwide. (Their telephone number is 512-824-7446 voice or 512-824-1666 TDD.)

UATP staff members have worked with the Utah State University public relations department to mail newspaper articles to every newspaper within the state. Stories of people who use assistive technology or who have benefited from assistive technology services have been included because of their human interest qualities. Articles have been printed in state disability and special education newsletters as well. Advertisements have also been placed in senior citizen newspapers to directly target the elderly population.

News releases can be written and sent to all newspaper, radio, and television stations. US WEST prints a media guide, which lists all newspaper, radio, wire services, magazine, and television addresses for Utah. The editors of newspapers may be contacted to run small PSA's when there is space available.

The UATP I&R network currently lists approximately 200 used equipment items. This listing was printed with the name of the item, price, and brief item description, and was mailed to all independent living centers and vocational rehabilitation offices. This has resulted in many calls from people who were looking for specific equipment at a reduced price. Newspaper want ads related to used equipment also have drawn callers to use the service.

Presentations to health professionals, vocational rehabilitation counselors, educators, parents of children with disabilities, and students have been another excellent resource for increasing public awareness. Presentations are a unique marketing tool because they offer direct contact with program representatives, providing a more personal touch.

Busboards and billboards have also been utilized to increase public awareness. Billboards may also be donated by the sign company. The UATP currently is buying one sign and the sign company is donating the other; both signs change locations every month. Signs are also placed on the transit system that specifically serves individuals with disabilities. As with the sign company, the transit system is donating some space, and the UATP is purchasing some.

One way to access rural areas of the state is through listing network numbers in telephone directories. The telephone company may provide free listings for not-for-profit and nonprofit agencies in the community resource section of the telephone directory. The UATP is currently listed in the yellow pages (paid) and in the community resource sections of different telephone books, which costs nothing.

Informational posters and flyers can be placed throughout the community in state offices, independent living centers, malls, clinics, university campuses, or other locations. This marketing strategy provides information that consumers can take with them to use at their convenience. Lists of services offered by the UATP and the I&R Network and appropriate phone numbers are included for their convenience.

CONCLUSION

Marketing campaigns are important for increasing statewide public awareness, changing attitudes and practices, and supporting systems change related to people with disabilities. This paper has listed some of the methods used by the UATP to increase awareness. It is important to recognize the interconnected nature of public relations and marketing, especially when dealing with attitudinal change. Programs should strive to change stereotypes about people with disabilities, and they should strive to find new ways to change attitudes, empower people with disabilities, and market I&R networks.

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SIG-16
Gerontology

DISSATISFACTION WITH ASSISTIVE DEVICES AMONG ELDERLY PERSONS WITH DISABILITIES

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ABSTRACT

The RERC on Aging is conducting a longitudinal study of the needs of older persons for assistive devices and environmental interventions. This paper presents an analysis of the results of interviews with 180 home based seniors, focusing on the devices they own, but with which they are not satisfied. While previous reports from the RERC study indicate a relatively high rate of satisfaction with devices, this paper examines only those devices for which there is some problem. The numbers of problems with any category of device is directly related to the distribution of devices in the population.

BACKGROUND

The Consumer Assessments Study of the RERC on Aging is a 5 year, longitudinal investigation of the needs of older persons with disabilities for assistive devices and home modifications. In seeking to understand the needs of older persons, this study collects data along several dimensions:

- basic demographic information such as age, education, and housing;
- health status including number and types of diseases present, use of medications, and use of hospitals and physicians;
- functional status including ability to complete activities of daily living (such as bathing) and instrumental activities of daily living (such as shopping for groceries);
- psycho-social dimensions including mental status, depression, self-esteem, and sense of responsibility
- social resources, assistance available and caregiver needs;
- current use of assistive devices, including satisfaction and problems with devices, and ideas for new devices.

This last dimension is the focus of the analysis for this paper: satisfaction and problems with devices. Previous reports from the Consumer Assessments Study report overall a generally high rate of satisfaction with devices among older persons:[1] persons with visual impairments who use an average of 14.5 devices per person, are satisfied with 82% of the devices they own;[2] persons with arthritis are satisfied with 89% of the devices they own;[3] persons with hearing impairments are satisfied with 70% of the devices they own;[4] and persons with cognitive impairments are the satisfied with 67% of the devices they own.[5]

There has been little investigation of satisfaction with assistive devices, but a few studies have focused on rates of use or "disuse." These studies typically follow subjects immediately after a period of hospitalization and rehabilitation. Page found on follow-up after discharge, a disuse rate of almost 50% for devices given to patients while hospitalized.[6] Geiger found a 54% disuse rate for patients who were given assistive devices prescribed by occupational therapists while in a rehabilitation facility.[7] Bynum and Rogers, studying 30 recipients of home health care, determined an 82% use rate for devices.[8]

RESEARCH QUESTIONS

This paper examines the question: What problems do older persons have with assistive devices they own?

METHODS

The Consumer Assessments study interviews subjects in their homes, each interview averaging 2.2 hours. A major section of the interview focuses on use of assistive devices. Subjects are asked what devices they own, whether or not they use each device, and whether or not they are satisfied with each device. For each device that they do not use, or with which they are not satisfied, the interviewer asks "why?"

RESULTS

Data was collected over a one year period with 180 older persons participating. Tables were generated listing "Device Name" and "Reason Not Satisfied." Table 1 illustrates a small section of this 42 page table.

Table 2 provides the total number of "Not Satisfied" responses for each device for which there were at least 3 "Not Satisfied" responses.

DISCUSSION

Table 1 provides a glimpse of the reasons that older consumers are dissatisfied with some of their assistive devices. Three users of special playing cards find the cards difficult to play with: problems with glare, color, and distinguishing shapes result in a less-than-satisfactory solution for these consumers. Three users of reachers also have problems with the reachers they own: strength of the grasper, durability, "more trouble than its worth" - a nuisance." For devices such as canes and phones, where there were very large numbers of reasons for dissatisfaction, it is necessary to have a way to summarize these results. Basically, there are three major categories of responses for consumer dissatisfaction:

1) The device doesn't do what the consumer expected it would do.

Table 1 Reasons for Dissatisfaction with Assistive Devices

DEVICE	REASON NOT SATISFIED
Large playing cards	Does not use because the cards seem to glare; red is hard to see; black is much easier.
	Face cards confusing; difficult to play with.
	Has difficulty distinguishing colors; hard to get used to different figures i.e. spade and club look different
Reacher	Not strong enough to grasp items.
	Doesn't feel it is necessary; feels it is a nuisance.
	Broken; string/grasp is broken

Table 2: Number of Older Persons Not Satisfied with Assistive Devices

Device	Total/ Not Satis-fied	Don't Use/ Not Satisfied	Use/ Not Satisfied
Cane	78	61	17
Phones	69	14	55
Glasses	46	24	22
Magnifiers	44	28	16
Wheelchair	34	12	22
Walker	32	28	4
Grab Bars	24	21	3
Bath Chair	21	17	4
Remote Control for TV	21	6	15
Hearing Aid	18	14	4
Incontinence Briefs	16	2	14
Microwave Ovens	15	7	8
Brace	14	9	5
Emergency Alert System	10	3	7
Special Eating Utensils	10	8	2
Reachers	10	3	6

2) The device doesn't do what the consumer expected it would do as well as was expected.

3) The device doesn't do what it needs to do without calling unwanted attention to the user.

These categories are all consumer-centered, and underline the importance of consumer involvement in the selection of devices. The large number of "problems," also supports the need for, at a minimum, professional consultation prior to selecting devices. In many cases, especially with older persons who face multiple chronic conditions and impairments, there is a need for more than consultation: careful professional assessment, provision of the devices, and training and follow-up.

Table 2 lists all the devices for which there were at least 10 "Not Satisfied" responses from the 180 subjects. These 16 devices are good candidates for further study: there may simply be problems with getting the right device to the consumer (problem with service delivery). There might also be a need for development of "better" devices, which meet the needs of more users.

Analysis of these problems, along with other results from the Consumer Assessments Study provides direction for further research and device development. A full report of this study is available from the author.

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Interfaces for "High-tech" Medication Reminders: Some Guiding Principles

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ABSTRACT

Programmable products are now available to organize older adults' complex medication schedules and to remind them to take their medications. These products have the potential to assist people in managing their own medication regimens. However, to maximize this potential usefulness, these products must be user-friendly and intuitive to program and to use. Four programmable products were evaluated in the laboratory and in the home for a two week period. Each product was evaluated by four to eight older participants. This paper discusses potential modifications of key panel layout and software interface to make these products easier for older adults to use.

BACKGROUND

The complex medication regimens of some older adults can lead to difficulties taking medications consistently. Problems with medication-taking sometimes can be managed with greater ease and reliability by the use of programmable pill reminders. These "high tech" products sound an alarm to remind the user to take his or her pills. There are portable or counter-top versions which can give additional reminders ranging from pill refills to doctor's appointments. However, for these products to be used successfully, they must be easy to program and to use on a daily basis.

Perhaps, the most complicated task involved in using a high-tech product is programming it. While older adults often receive assistance in programming a product initially, changes in medication regimen frequently occur. If products have programming interfaces that are "friendly" and intuitive to older users, then these individuals could make the necessary changes with greater ease and confidence.

Frustration with using "high tech" products could be minimized if the user had an intuitive idea--an overall gestalt--of how the product should work. It has been shown that if an operator of an expert system has a good mental model of its operation, then he or she will perform better than someone with only a general idea of its operation [1]. For example, older adults may have experience setting a digital watch, clock, or microwave oven. Possibly, a pill reminder that operates in a manner similar to these common products would be easier to program.

In the present study, older adults evaluated several pill organizing products, including both programmable and nonprogrammable units. The purpose was to provide feedback to the manufacturers and to provide general information on the variety of pill organizing products to older consumers. While this study was not designed to investigate optimal programming interfaces, numerous observations were made of difficulties and successes encountered with each of the programming interfaces. This paper discusses some general interface principles relative to older adults.

METHOD

Twenty-two adults, ages 46 to 79 (avg. 69) participated in the study. Four to eight participants evaluated a programmable product in the laboratory and at home. During the laboratory evaluations, every function of a product was tested in a battery of tasks ranging from reading the instructions and installing batteries, to programming personal medication schedules and responding to programmed alarms. During the home evaluations, participants used the products to manage their daily medications for two weeks. Then, they rated the products along various usability criteria (e.g., reliability, ease of use) and were interviewed about their experiences.

Four programmable products were selected for evaluation. The products represented a wide range of key panel designs, programming requirements, and capabilities. The number of fixed-function (FF) keys used to input information in the 4 products ranged from 4 to 11. Each of these FF keys was dedicated to a single function. One product also combined FF keys with variable-function keys, whose functions could change during programming and were defined by prompts on an LCD display. Each product used an LCD display to provide programming prompts and/or daily messages.

FINDINGS AND IMPLICATIONS

The findings represent observations from laboratory and home evaluations, as well as from staff evaluations of each product. Presented are some principles guiding key panel interface and software interface to make the programming process more feasible for older adults.

KEY PANEL INTERFACE:

The key panels were generally used with few difficulties, but several problems were apparent in the following areas: 1) locating desired keys, 2) selecting appropriate keys and 3) activating keys.

Locating Desired Keys: Programming mode keys (e.g., 'Change,' 'Set') and frequently used response keys (e.g., 'Up,' 'Down,' 'Enter') should be clearly grouped together [2]. While all four products had common types of keys located physically adjacent to one another, all keys were similarly colored and uniformly spaced, thus lacking distinctive characteristics. This required the participants to search through all keys, rather than through a small subset of keys, to make their choice.

To minimize confusion, several methods could be employed to distinguish different key types. For example, physical space between different groups of keys, different colored keys, or black lines surrounding groups of keys may have made the keys easier to distinguish and locate quickly. Labeling groups of keys such as the "response" keys also may have facilitated this, and may have reduced confusion as to the purpose of various keys, especially for older adults who typically have had minimal experience with programmable products.

Selecting Appropriate Keys: Identification of programming mode keys can be aided by presenting them according to their sequence of use [2]. That is, the order of placement of the keys on the key panel should reflect the order in which the keys are activated during the programming process. When programming a medication reminder, a person might first *enter* medication schedule information, then *change* or edit the information and lastly, even *erase* it. Keys on one product reflected this principle of key sequencing particularly well. The mode keys, labeled 'Enter,' 'Change' and 'Erase,' were positioned across the top from left to right. Four of six participants selected these keys easily to begin programming each mode.

Once a user has entered a program mode, determining which key to press next in the programming process should be readily apparent. Users encountered problems to various degrees with all of the products evaluated. These problems in determining "what to do next" occurred mainly due to inconsistent use of LCD prompts and confusing LCD prompts. First, programming steps should be consistently prompted on the display screen to make programming easy. Screen prompts indicating the next step or next key to press greatly assisted in the use of one product. This product provided LCD prompts throughout the majority of the programming process. Older adults were able to follow these prompts with minimal difficulty. However, at one point in the programming process, there was no prompt which stymied four of six participants.

Other ways to minimize confusion in selecting keys include illuminating red LEDs next to each valid key and placing a permanent label on the product to remind the user of a common next response, such as, 'Press ENTER following each entry.' This might be especially true for products that use different sets of response keys for different LCD prompts. For example, the 'Up,' 'Down,' or 'Enter' keys on one product were active in response to a flashing number on the LCD, and the 'Yes' or 'No' keys were active in response to a '?' on the display. Since the user had to remember this convention, four of seven participants frequently hit a wrong response key.

Even if the user is guided to a key, the wording of key labels should describe clearly and intuitively the function of each key. Nonintuitive key labels created confusion with at least two of the products. For example, the user was required to press a key labeled 'Check' to enter an alarm time on one product, and to press a key labeled 'Set' to register information on another. Participants frequently forgot which key to push in both of these cases. In contrast, one product used a key labeled 'Enter' to register information. This label presented no confusion for 5 of 7 participants. Labels for uncommon product functions or nonintuitive key labels should be pilot-tested to ensure comprehensibility, especially by populations such as older adults who have less experience with "high tech" products and with typical programming conventions.

Activating Keys: Once the user determines the appropriate key and has located it on the key panel, the key must be easy to activate, especially for older users who may have conditions such as arthritis or tremors that can make key pushing difficult. One product used keys 0.6" square with 0.13 to 0.2" spacing and 0.05" travel with positive click. These keys were within the recommended 0.375 to 0.75" size, but less than the recommended 0.25" spacing and 0.25" travel [3]. While it is recognized that desired portability of this product constrained the key design, two of seven participants had difficulty with registering key depressions.

One product used a membrane keyboard. Even though the keys used the recommended raised edges that were visually demarcated, a center snap dome and auditory feedback [3,4], the keys could not be activated everywhere within the raised edges as recommended [3], especially causing difficulties for one participant with hand tremors.

Another product required the simultaneous activation of two very small keys positioned close together. While maintaining activation of two keys is an effective technique to prevent the inadvertent entering of programming modes, older individuals with manual dexterity problems caused by arthritis or stroke can have difficulty pressing multiple keys simultaneously. Thus, it is generally recommended that simultaneous key operations be avoided for older adults [3]. Two of eight participants, including one stroke survivor, had difficulty with simultaneous key activations.

Moreover, this product provided no tactile feedback to indicate when a key had been activated. It is generally recommended that positive clicks be felt to indicate actuation [3].

SOFTWARE INTERFACE:

While there were a variety of difficulties with programming each product, most of these problems could be classified into two categories, *selecting a mode* (e.g., "set alarm time," "review alarm time"), and *entering data* (e.g., alarm time, number of pills).

Selecting a Mode: The process of selecting a program mode should be as easy and familiar to the user as possible. Each of the 4 products required the user to enter a mode to input data. When the process for doing this was similar to that of a digital clock or microwave oven, then there seemed to be little confusion.

One product required the user to hit a FF key to enter a mode, such as, 'Change' to change an alarm time. This method created no difficulty for 5 of 7 participants. With this method the user may likely be able to enter modes without further reference to the instructions. On the other hand, another product required the user to enter each mode by pushing a nonintuitive, unique sequence of 2 keys to enter 1 of 3 different modes. This created difficulty for 4 of 8 participants (who were following written instructions), and would certainly render the product difficult to use without the instructions. Perhaps a single mode key could be used to step through each mode, keeping the existing requirement that the cap be removed before the device can be programmed.

Entering Data: When data were entered in a manner similar to a digital clock, for example, few difficulties were observed. With all products, the user pressed particular buttons to scroll or step forward or backwards through the choices. For example, to set the current time, one product used 'Up' and 'Down' keys shaped as up and down triangles to scroll rapidly if held or step through numbers if pushed. While it is generally recommended that autorepeat functions be avoided [3], this method is similar to many digital clocks and presented little difficulty for 6 of 8 participants.

However, another product used an unfamiliar method of entering data. This product required activation of '+' and '-' keys to step through the hours and minutes separately. Since these key labels have different connotations on other commonly used products such as calculators, "up" and "down" arrow keys may have been more intuitive to use.

CONCLUSION

Pill reminding products should be intuitive to program and to use. Ideally, the user should be guided along by message prompts and clear grouping and labeling of keys. When key panel design followed some recommended guidelines [3] and programming method was similar to more common "programmable" products, such as a digital clock or microwave oven, participants seemed to have fewer difficulties during programming.

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Accelerometric Motion Analysis of Standing Older Subjects During Floor Perturbation

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ABSTRACT
In previous reports [1,2] we described initial studies on upper body accelerometry to measure aging-related changes in balance, with the ultimate aim of preventing falls or minimizing resultant injury. Data were obtained using head- and waist-mounted accelerometers combined with a new wearable computer-based data acquisition system that permits unconstrained motion while subjects performed standard balance-assessment tasks. This paper reports on comparison of this balance assessment method with the EquiTest®, which measures ground reaction forces while standing on a moving floor.

BACKGROUND
Postural stability declines with age due to combined vestibular, proprioceptive and visual losses, causing impaired mobility and increased risk of injurious falls [2]. Precise diagnosis requires quantitative assessment of postural stability; qualitative observational measures cannot distinguish fine variations in stability or efficacy of various therapies [3].

Quantitative balance assessment presently can be done by video image analysis or force plates. However, these require that the patient come to the laboratory; they cannot duplicate all factors which may lead to a fall, and are expensive ($100,000 or more, or $360 per use). One force platform, the EquiTest® (Neurocom International, Inc., Clackamas, OR) permits controlled induction of falls and separation of vestibular from visual feedback by either fixing or moving a visual surround in proportion to sway [Figure 1] [4].

The EquiTest clinical protocol consists of the Sensory Organization Test (SOT) and Motor Control Test (MCT). In the SOT, center of pressure (assumed to be the projection of the center of mass, COM, of the body) on the force plate is measured eyes open and closed (visual input), with and without forward floor tilt (somatosensory cues), and with the visual surround either fixed or moving (visual processing). The MCT attempts to assess symmetry, latency and strength of responses to proprioceptive stimuli independent of visual and vestibular input, by measuring center of pressure of each leg independently during forward and backward translation and tilting of the platform [5].

Black, *et al.* [6], contend that upright posture during a perturbation is maintained either by "ankle" or "hip" strategies; by which is meant that rotation occurs about the respective joint with other joints relatively fixed. The ankle strategy is detected as minimal shear on the force plate (reflecting acceleration of the body's center of mass, COM) at frequencies below 0.5 Hz; "hip" movements involve larger shear (approaching the maximum of 25 lb) at frequencies above 1 Hz [7].

METHODS
The wearable balance assessment system employs twelve ±5 g range monolithic silicon accelerometers in surface mount packages, in four 3-axis assemblies, two mounted on each corner of an eyeglass frame to measure head motion and two on the left and right sides of a Velcro-covered waist belt to measure trunk accelerations. A thirteenth accelerometer was mounted on the moving platform. Also on the belt are the data recording computer, which digitized and stores sensor outputs at a 33 Hz rate, and a battery pack [2]. Segmental dimensions were measured for calculating angular accelerations and velocities [Figure 2].

Testing was performed using the EquiTest facility at the Audiology Laboratory of Stanford University Medical Center. The complete SOT and MCT battery was performed, plus repetitions of some tests with the subject's head turned to the left or tilted back, for altered vestibular input. This paper reports on tests involving forward and backward floor translation (at the fastest of 3 rates) and tilting (pitch), and coupling of floor and visual motion to the subject's center of pressure on the force plate.

RESULTS
To date, 7 older (4 male, 3 female, ages 64 to 82 years) and 5 younger (21 to 46) subjects have been examined (about half the total anticipated). All were mobile and independently living. Data in this report were obtained from a 64-year-old male subject.

Accelerometry
Smoothed (5-point rolling average) X-axis (sagittal plane) accelerometric data from the right head and waist sensors during forward translation are plotted in Figure 3. The first response at the waist to floor motion appears to be a slight backward tilt, followed by a forward acceleration peak of 0.06 g (3.4°). Head acceleration lags the waist by about 120 millisec [Figure 3, arrows] until floor motion stops, then the head and waist move in phase.

Two successive forward "toes down" perturbations are shown in Figure 4. The floor tilts 13° in 0.5 sec, remains at that angle for 1.5 sec, and returns linearly to horizontal in 2.5 sec, by accelerometric measurement. Both stimuli produce short impulses in the opposite direction at the head, but no prolonged change in angle relative to vertical. The first forward tilt simultaneously induces an 0.085 g (AZX = 4.9°) opposite angle at the waist, which returns to baseline gradually over 8.5 sec. The second trial produced a waist response of 0.06 g for only 5 sec.

The EquiTest can be operated such that the surround and floor provide positive visual and proprioceptive feedback (*e.g.*: the platform tilts in in the direction of foot pressure while the surround moves toward the subject if he/she leans toward it). These settings force the subject to rely entirely on vestibular input, and if the eyes are open, the conflict of vestibular and visual information is extremely destabilizing. Tests included positive feedback at gains of 1.33 and 1.66 [Figure 5]. The former was not sufficient to induce a fall; even though the floor tilted first forward 7°, then backward 17°; neither the head nor waist underwent extreme excursions, remaining within 7.2° and 4.3° of vertical. respectively.

At the higher gain, however, the floor tilted forward in several increments to 13°, then in the next 8 sec changed to 19° backward tilt. During the 2 sec before this angle reached its extreme, the waist began oscillating and the head pitched backward. These motions were followed by loss of balance [arrow in Figure 5] characterized by ±1 g spikes at the head and waist, forward pitching of the head in two episodes of about 2 sec each, and overall tracking of the waist and floor.

EquiTest results

The software supplied with the EquiTest is intended for generating clinical reports and does not yield quantitative ground reaction forces. The different trials of a single test are combined and plotted as bar charts, with a shaded area representing regions of unstable balance [Figure 6A]. Left and right foot forces are treated separately. The forward and backward floor translations are used to derive latencies (time lag of change in ground force behind floor motion). This subject was within normal limits for all forward translations, but borderline for backward translations. Force amplitudes during the same tests show adequate responses to forward translation, with only marginal response for the left foot during backward translation.

The floor-tilting tests were used to examine ability of the subject to anticipate the direction and magnitude of the stimulus after experiencing the first in a series; performance was adequate in all trials [Figure 6B]. The second forward-tilt trial had a lower value (in arbitrary units) than the first, in accord with the result from accelerometry at the waist [Figure 3].

DISCUSSION

One goal of this investigation was to see whether upper body accelerometry could identify body motions equivalent to those measured by the EquiTest. Response latencies between head and body, as well as between the body and floor, could be determined [Figure 3], with accuracies limited by data sampling rate. The head tended to be stabilized in space even when floor perturbations induced motion at the waist (approximately at the COM), as seen in Figure 4. Large head excursions are characteristic of loss of balance [8], accompanied by major motion of the COM if a fall actually occurs. Adaptation to successive floor perturbations could be distinguished in the acceleration profile as well as in the EquiTest output. The processing done by the EquiTest may ignore or obscure significant pre-fall responses to perturbation.

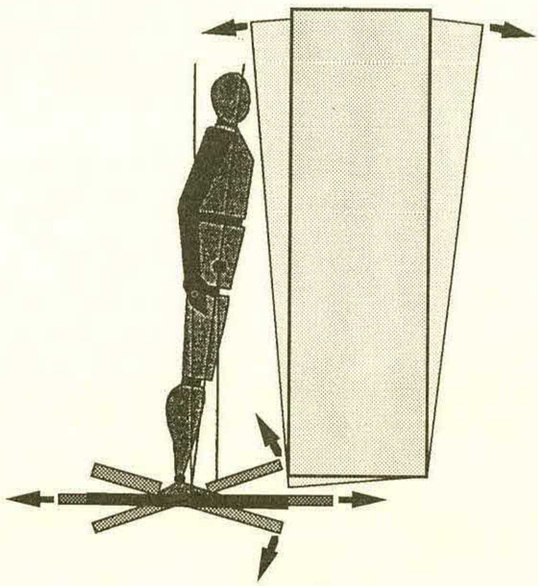

FIGURE 1: EquiTest® Platform & Visual Surround Motion Capabilities (after [5])

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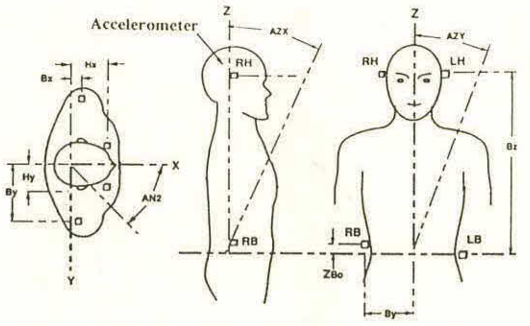

FIGURE 2: Accelerometer Locations, Subject Dimensions & Coordinates

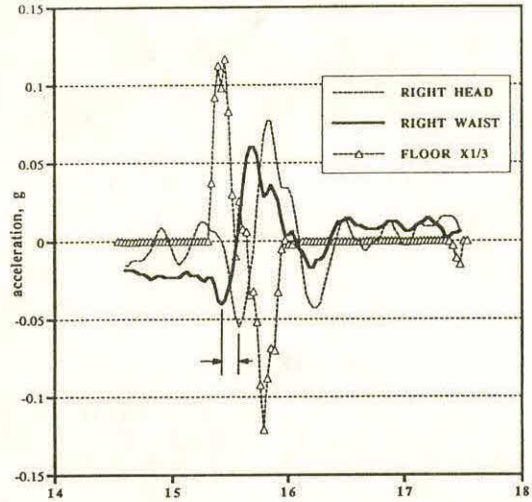

FIGURE 3: Forward Floor Translation (2nd of 3 trials, X-axis, smoothed, file DWA27)

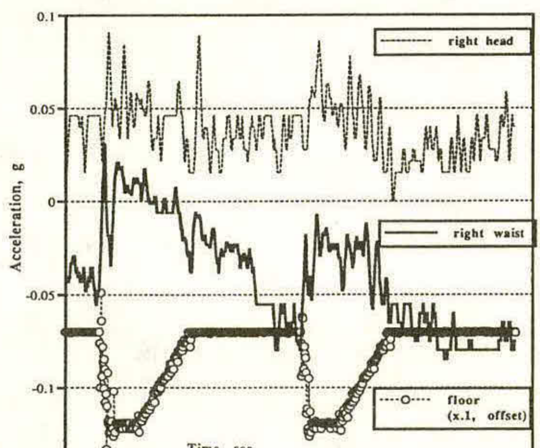

FIGURE 4: "Toes Down" Floor Tilt (1st 2 of 5 trials, X-axis smoothed, file DWA28)

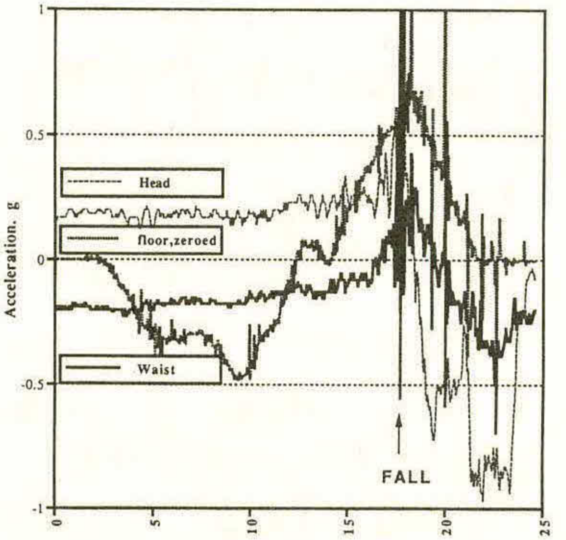

FIGURE 5: Positive Floor & Visual Feedback @ Gain = 1.66 (right side X-axis, file DWA72)

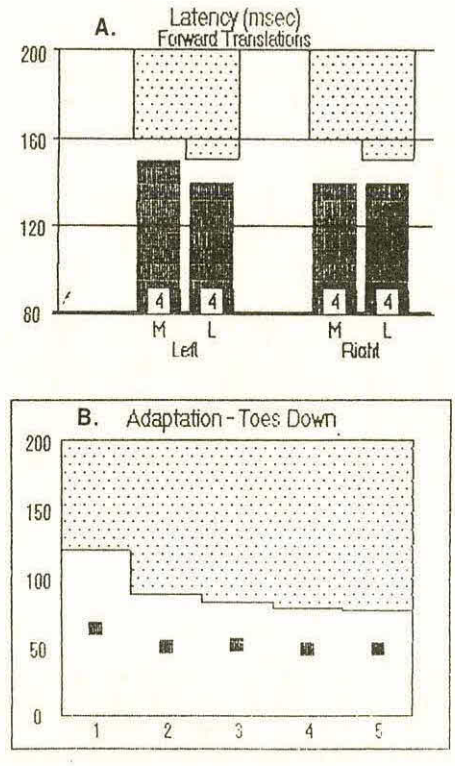

FIGURE 6: EquiTest® Output: A. Latency of Response to Forward Translation, B. Adaptation to Repeated Toes-Down Tilt

HYPERHOME RESOURCE: A TECHNICAL INFORMATION MANAGER FOR HOME MODIFICATION SERVICES TO OLDER PEOPLE

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Abstract

The provision of home modification services to older people requires access to technical information on a wide variety of topics. Microcomputer applications can be very useful in helping service providers obtain and use this information. However, existing applications have limitations in scope and flexibility. They are useful primarily to search an existing product database. HyperHome Resource takes a different approach, one that focuses on information management rather than providing a database of information that cannot be changed.

Background

For older people, home modifications must address a much wider array of concerns than the traditional focus for younger people. Not only is support for ADL important but, to insure independent living, a number of other environmental concerns must be addressed. Creating an enabling environment for the older person with a disability can include:

1. security improvements such as ugrading locks, adding outdoor lighting, or securing windows.
2. fire safety improvements such as eliminating overloaded electrical circuits and installing smoke detectors,
3. accident prevention and health measures, including repairing stairways, improved lighting, and repair of floor surfaces,
4. accessibility and usability interventions including construction of entry ramps, installation of grab bars, and garbage removal,
5. caregiver support modifications, particularly those that reduce the burden of caring for people with dementia,
6. construction related services such as emergency repairs, weatherization, maintenance and general rehabilitation.[1 2]

Due to the wide scope of services technical information is needed in the "front end" of service delivery - assessment of problems and recommendations for action. In these activities, constant reference is made to checklists and assessment forms, catalogs of products, guidebooks and con struction manuals. Computer applications can help to increase productivity when searching for information and help automate the matching of needs to recommendations. They can also help to convey expert knowledge to programs that do not have professional staff in either rehabilitation technology, environmental design or building construction.

Objective

A microcomputer application has been developed to help home modification service providers assist the older population. The program is an aid for managing the diverse technical information on products and environmental design ideas that is needed to deliver high quality services. This application allows users to customize databases to the specific needs of the services they provide.

Approach

There are two existing microcomputer tools that are currently available to access technical information for home modification. A review of their features demonstrates a need to take a different approach.

Hyper-Abledata[3] is a large database that is used to search for solutions to the varied needs of people with disabilities. It is inexpensive but requires a large capacity mass storage device. Although very useful for doing product searches, it focuses solely on assistive technology and does not include information on general construction products such as security devices, construction details such as handrail installation, design ideas like bathroom renovations or home maintenance actions like rodent elimination.

Ease[4] is designed specifically to help occupational therapists deliver home modification services. It guides a rehabilitation specialist through two assessments, an ADL assessment on the individual. and an environmental assessment on the home. The data is automatically compared to identify discrepancies in fit between person and environment. A database of products and design ideas is then searched to generate specific recommendations. The Ease product is a well integrated tool that could be of great value to a therapist. It focuses mostly on accessibility and safety issues but it can be customized for other issues if they can be tied to ADL concerns. New product data bases, data on design ideas and information on local vendors can be added. It's cost is much higher than HyperAbledata and it requires extensive training.

Both systems have two major limitations: the lack of product illustrations, and the lack of a user interface to add or remove information.

Written descriptions and technical data on products are not sufficient for making recommendations. Appearance plays a major role in consumer acceptance. Moreover, it is desirable to show clients photographs and sketches of recommendations to assist them in prioritizing needs. Although HyperAbledata has some graphics and is improving in this area all the time, there are still a lot of gaps. Ease is completely text based.

Individual home modification projects can vary from eliminating roof leaks, to renovating a bathroom, to reducing wandering out of the house. There is no comprehensive source of technical information on all the necessary subjects. Good service providers, through experience, continually identify new approaches, new products and new ideas all the time. Both applications are "closed systems" that can be modified only through the development of new versions. Ease can only be customized by the company. Incremental changes cannot be made as the information becomes available.

Ideally, a service provider should be able to modify their database at any time. This applies to assessments and expert knowledge as well as product information. For example, if a new, superior assessment methodology is available, the service provider should be able to make use of it immediately without abandoning the technical information in the database.

HyperHome Resource is designed to overcome the problems of closed systems. Rather than a database of information, it is actually a "technical information manager". Like "personal information managers" that keep track of appointments, contacts, notes and to-do lists, this program allows service providers to create their own custom database.

The program is written for Hypercard, the hypermedia database tool that comes with every Macintosh computer. The basic elements of a Hypercard database are "cards" and "stacks". Cards can contain a mixture of graphics, sound and text. Access to them is obtained through a menu card. Stacks are sets of similar cards.

HyperHome has two basic stacks - problems and recommendations. The stacks are organized into sections with 5 types of problems and recommendations. Scrolling windows allow the user to scan through items rapidly. Access to the database entries is obtained through "buttons" and other icons on the cards. By pointing and clicking with a mouse or other interface device, one can go forwards or backwards through a stack, jump to different locations or access different stacks. The most important button however, links each problem to related recommendations. Each recommendation may be linked to many different problems. This linkage builds intelligence into the database.

An edit menu card allows the user to add new cards and remove old cards easily as well as edit links between problems and recommendations. New stacks can also be added to reference additional types of information that one may wish to add, for example, lists of local suppliers and contractors. Problems and related recommendations can be printed out in a report for any client.

Graphic images are scanned into a separate data base. This gets around Hypercard's limited graphic resolution. From the recommendation card, users can activate a button that opens a window to the related image. These images can be photos, line drawings or even rough pencil sketches.

Supplementary information can be attached to a recommendations card. By pointing and clicking on a button, a comment window is opened. This window can be used to record any type of information desired, including product availability or feedback from previous use of the product or idea.

Discussion

There are several advantages of the information management approach. Only the information needed has to be included, reducing storage space to a minimum and increasing search speed. As a commercial product, the price does not have to reflect the cost of developing the database. Permission does not have to be obtained for use of information in the database that comes from a proprietary source, unless the database itself will be sold to others. The database can be expanded and edited in "real time".

There is also a major advantage to using Hypercard. As with Hyper-Abledata, only the script for the database will have to be distributed. Anyone who has a Macintosh computer will be able to use it without purchasing expensive software.

One major problem with the program is that all data entry has to be done by the user. As we develop our own comprehensive database further, we may be able to distribute it with the script. Another possibility is developing a means to port information from Hyper-Abledata and other computer databases into HyperHome Resource. A third option is sharing stacks among service providers.

We hope to add more features to make it more useful in everyday practice. Currently, an assessment is completed by hand and the results compiled as a list of problems. The problems are then used to search the database for solutions. We took this approach to keep the database independent from assessments. Individual users can thus utilize any assessment method and still make use of the program. In the future, we hope to add assessments with an editing feature that would allow the user to customize them to their own preferences. Items in the assessment tool could then be linked to problem cards in the existing database.

In summary, HyperHome Resource is a technical information manager that overcomes some of the limitations of existing microcomputer applications used for home modification. It is open ended and can support graphics with ease. The user interface is simple, requiring only a few minutes of training to master. The availability of the comment window allows users to supplement recommendations with any related information they desire. Although we have not yet made plans for distribution, we expect the cost (without databases) to be very low.

Acknowledgements

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Easter
Seal
Student
Design
Competition

1993 Easter Seal Student Design Competition

The landmark legislation known as ADA has literally opened countless new doors for Americans with disabilities, and figuratively done the same for creative inventors who are answering the challenge to even the odds against our disabled counterparts.

As you read the following seven exceptional student design papers, please bear in mind that there were 27 additional projects which may have held equal or even more favorable status with some of our nine judges. Unfortunately, those impressive works may never reach their intended audiences, the clinicians and practitioners whose rehab specialty may not have been as important to the majority of our review panel. My greatest regret is that we are not able to publish more of these entries. There were many gems which simply got inched out by our democratic judging process. I have no doubts that many of you could (and would) benefit from these terrific ideas. After all, that's what RESNA and the National Easter Seal Society (NESS) are all about; helping people overcome disabilities by sharing the creative experiences of others.

During the coming year, I will endeavor to establish the means to at least publish the list of our entry titles and authors, should a reader desire more information on that particular topic. That way, none of these great ideas will be lost, and perhaps I won't feel so sad for the rest of our contributors. My worst fear is that someone might develop the feeling that all of their hard work was for nothing. None of these projects are ever to be considered as losers! All of these young people offer proof that we are all in fact "Engineering the ADA." As you can see by our winning entries, we again present to you, projects that have solved a few more of the problems encountered by our friends having disabilities.

One of our judges asked the questions, "Where do all of these great ideas come from?" I replied, "Most likely, from young engineering scholars who have been lured into the reality of disability issues and concerns." That's the beauty of this competition. Many of our past winners are attending this very conference, because our student design competition simply provided them the impetus to look in this direction. One of our former winners is now a professor to one of our 1993 winners!

This was the closest competition that we have ever seen. Only a few percentage points separated the top entries. As you can see, we were locked into a tie for the runner-up position, which proves how good our entries really were this time around.

I am very proud to announce our winning entries for RESNA '93. In my opinion, they exemplify the missions of both RESNA and NESS to who we are very grateful for supporting this great challenge. Please join me in welcoming them to our Conference in Las Vegas. I'll place my bets on all of these students, that we have not seen the last of them!

David F. Law, Jr.
Chair
Easter Seal Student Design Competition

THE CARDIOGAUGE©: INTELLIGENT CARDIAC STATUS MONITOR

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ABSTRACT

Individuals under stress, patients in rehabilitation, and in particular those recovering from corrective cardiac surgery require extra-clinical monitoring of their cardiac performance at regular intervals in order to progressively build up their cardiovascular resistance. In this project, a novel, non-invasive cardiac status monitor is designed to provide reliable surveillance of the relative measures (indices) of all key parameters that illustrate the cardiovascular system's ability to perform optimally. The prototype hardware combines photoelectric detection of the pulse signal, sampling and data processing, computation of selected parameters, intelligent decision-making, and status display- all into a single, reliable, and compact CARDIOGAUGE for mainly non-clinical deployment.

OBJECTIVE

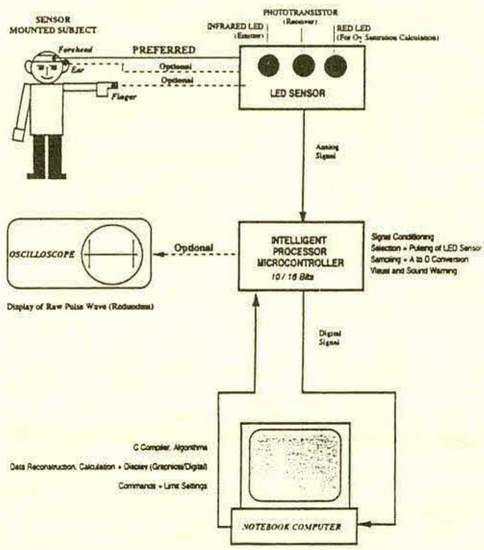
To design and construct a novel medical instrument, the CARDIOGAUGE, that provides reliable and accurate surveillance of all vital parameters that reflect the instantaneous status of human cardiovascular performance. It must be adaptable to all situations - in daily use (particularly for those with cardiovascular diseases or disabilities), in geriatrics, and in rehabilitation from corrective cardiac surgery - for non-clinical and potential clinical deployment.

OPERATING PRINCIPLE

The pulsatile flow of blood in an arterial bed situated close to the human skin is represented by pulsations in both axial and radial directions. An appropriately designed photoelectric sensor will reflect this fluctuation through variations in the reflected intensities of light and will represent plethysmographic arterial volume pulses of a given subject under a given physical condition (rest, mental or physical stress, deteriorated cardiovascular system, etc.). The pulse signals so obtained contain all the necessary information on the key cardiovascular status parameters (to be illustrated later) such as the pulse rate, respiration rate, circulation pressure, circulation time constant, and arterial oxygen saturation. The change in magnitude of these cardiac-based parameters are measured as status indices (factors) relative to a prescribed "resting" or normal state and are monitored using the proposed device. Any exceedence of a caution and/or danger state is indicated through visual and audible warnings for corrective action.

The principal stages of the CARDIOGAUGE operation are carried out by the following (Fig. 1): 1) A photoelectric sensor to monitor arterial volume pulses of different wavelengths associated with changes in blood volume; 2) A microcontroller to amplify, sample, and digitize the analog pulse signal and establish its characteristics; 3) A microcomputer to perform necessary calculations of the said cardiovascular indices through a set of algorithms, and also for commands and menu settings indicating caution / danger ranges.

Fig.1. THE CARDIOGAUGE / STATUS MONITOR



SCIENTIFIC CONCEPTS

The CARDIOGAUGE concept is extended and incorporated from earlier work done by the author over the past three years into a unique, multi-parameter measuring system. The monitored parameters are actually measured as cardiac status indices relative to a prescribed resting state. This is done by calculating the ratio of instantaneous - to - reference values for each index. Remarkably, all the stated physiological factors are derived exclusively from the blood volume pulse wave, through a miniscule photoelectric sensor.

Pulse Rate Factor (PF)

The arterial pulse is defined as the wave of arterial wall expansion and contraction spreading outwards and corresponding to the heart's cardiac cycle (systole and diastole). The pulse rate is a primary indicator of cardiac function and changes in proportion to physical/mental stress. It is given by the elapsed time from systole to systole (peak-to-peak), which is then averaged over the entire sampling period and multiplied by a numerical value to represent heart beat per minute.

Respiration Rate Factor (RF)

A second criterion for cardiovascular status is the rate of respiration, or ventilation capacity. RF is the ratio of the instantaneous respiration rate to a pre-set reference rate. The respiratory pulse is the overlapping low frequency envelope containing the arterial pulses. Generally, the respiratory pulse occurs for every 6-8 arterial pulses. Similar counting algorithms to PF gives the RF values in the apparatus.

Circulation Pressure Factor (CPF)

CPF is a newly proposed cardiovascular parameter which consistently examines the volume increment during a short but well-defined time interval with respect to the net volume change between systole and diastole. The set of values obtained represent a non-dimensional circulation index indicative of the mean arterial pressure fluctuations in the cardiovascular system and the capacity of the heart to drive blood through the system. CPF can replace conventional systolic, diastolic, and mean arterial pressure measurements. CPF is a ratio of instantaneous to reference values, calculated using appropriate algorithms.

Circulation Time Constant Factor (CTF)

This parameter is also proposed by the author as it signifies the compliance and elasticity of the arterial wall as well as the peripheral resistance to blood flow, and thus directly reflects the health of the arteries themselves. It involves calculation of the elapsed time between closure of the aortic valve (when the aorta is a closed reservoir of blood) and the point of diastole. During this interval, the complete ejection of blood from the aorta is a function of the aorta's maximum compliance as well as the peripheral resistance encountered at the entrance to the arterial system. CTF is the ratio of instantaneous to reference time constant values, which is calculated using the required algorithms. A new formula is proposed for CTF calculation using the pulse pressure, which can be given as supplementary information to CPF.

Arterial Oxygen Saturation Factor (OF)

OF is the relative measure of the percentage of oxygen saturation in arterial hemoglobin and reflects oxygen intake during certain physical conditions of the body. The optical density of hemoglobin becomes greater with higher oxygen content. The projection of two light sources on the arterial bed allows for the detection of variations in optical density solely due to O_2 saturation changes. Algorithms are made on the basis of new, more accurate, and less error-prone formulae, and OF is given by the ratio of instantaneous to reference values.

TECHNICAL OVERVIEW

Photoelectric Sensor

The photoelectric sensor consists of a light-emitting diode (LED) and a photo-sensitive detector. The 5V DC current is transmitted to the anode terminal of the LED. Since the cathode terminal is connected to the ground, the anode is set at a higher potential and the diode will emit a red or infrared light. A portion of the light emerges again through the skin and is detected by the phototransistor by way of reflection plethysmography. The amount of light detected will depend on the optical densities of structures in the light path. The variations in light intensities detected is attributed to the constantly changing volume of blood in the vascular bed. This continuous wave of varying light intensities (pulse) is captured by the collector terminal of the phototransistor. Since the phototransistor is a light-controlled current source, a current proportional to the collected light is driven through the emitter terminal.

Intelligent Microcontroller

The 10-bit microcontroller (MC) is programmed to respond to computer commands, carry out the necessary commands to the sensor, sample and process data, and send messages to the LCD. The MC has a built-in 2K memory for temporary data storage as well as a built-in serial port for information reception from the computer. However, voltage conversion through a driver/receiver must be made to facilitate character exchange between the two ports. The driver/receiver also serves as a power supply for the op amps.

The electrical signal representing the blood volume pulse is sent from the phototransistor (in the sensor) to a circuit block for AC coupling. The transients in the DC component are filtered out, and only the pulsatile AC component is transmitted. Next, the signal is amplified through an op amp and potentiometer, and this signal can be displayed on an oscilloscope for comparison.

After signal refinement, the MC samples the waveform every 5 milliseconds, and sends the information to the analog to digital converter. The A/D device transforms the sampled analog signal into equivalent 10-bit digital points (1024 possible values), and these are sent to the LCD. This flow of data is then manipulated with computer algorithms.

Computational Algorithms

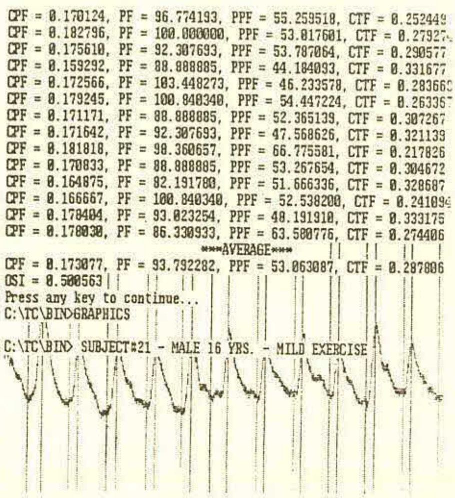
All the calculations are performed in a microcomputer (later to be integrated within MC board) using the transmitted digitized data. The algorithms (programs) are written in the C language for versatility in application and future miniaturization. The programs are straightforward steps to calculate the status parameters based upon the digitized pulse signal data, using formulations relating pulse characteristics to the cardiovascular parametric factors (non-dimensional). Three principal sets of Turbo C programs serve the following mathematical operations: 1) Sampling procedures, character setting, and graphical/digital data display; 2) Calculation procedures for the defined cardiovascular factors; 3) Limit settings and logic for activation of buzzer and warning lamps.

PROTOTYPE TESTING AND EVALUATION

Preliminary testing of the experimental prototype was undertaken. Cardiovascular status evaluations were obtained for 250 subjects, with several trials on each

(Fig. 2). The algorithm logic for limit setting is based on these normal values for the population, according to age and gender. The cardiovascular indices calculated by the CARDIOGAUGE responded accurately and effectively to pathological conditions known to be present in certain patients. Results also indicate that the CARDIOGAUGE exhibits consistent and superior precision in comparison to the standard deviations of several non-invasive medical devices in the market. However, more testing is required for full validation of the prototype.

Fig.2. Sample readout from CARDIOGAUGE



APPLICATIONS AND MENU SETTINGS

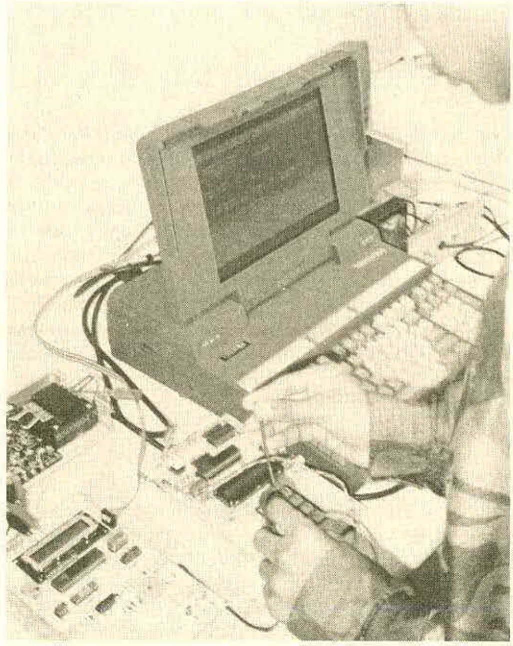
The CARDIOGAUGE developed possesses versatile applications in non-clinical environments and as a key instrument for cardiovascular performance assessment. It also has potential clinical usages once validation under rigorous medical supervision is completed. The target user applications include (i) persons under physical and mental stress, (ii) the elderly, (iii) rehabilitation after pathological corrections, (iv) recovery regimes for cardiac patients, (v) pharmaceutical and other medical research programs, (vi) ambulance and emergency care situations, etc.

Menu settings are prescribed on a customized individual basis. The limits on the exceedences of each cardiovascular factor are set in accordance with previous medical history, performance goals, progressive resistance step sizes, and physician/coach advice.

CONCLUSIONS

A totally new, versatile, life-saving cardiovascular performance monitor called the CARDIOGAUGE has been designed, developed, constructed, and demonstrated. It is versatile, compact, user-friendly, low-cost, tailored to individual needs, and requires no calibration or adjustment. It is based on a series of novel biomedical formulations using both qualitative and quantitative information from a scientifically sampled and analyzed sequence of vascular blood volume fluctu-

Fig.3. The CARDIOGAUGE system: photoelectric sensor (mounted on finger), intelligent micro-controller, and microcomputer



ation pulse signals gathered by a specially constructed photoelectric sensor. The factors calculated by the CARDIOGAUGE exhibit consistent precision in their readings as well as high sensitivity to changes in instantaneous cardiovascular performance. As an assistive technology, it has limitless potential.

The CARDIOGAUGE is **intelligent** since it expertly adjusts the sampling interval, searches and identifies representative pulse signals, computes six key cardiovascular factors simultaneously, averages over effective regimes for reliable results, calculates factor exceedences over prescribed limit settings for all single and combined occurences, and displays visual and audible warnings, **all automatically**. It is a knowledge-based expert system with the capability to continuously make decisions on the instantaneous status of an individual's cardiovascular performance and communicate it to the selected receiver.

ACKNOWLEDGEMENTS

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A WHEELCHAIR-ACCESSIBLE BABY CRIB

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ABSTRACT

This paper describes the design of a standard-size baby crib which provides for safe and effective use by wheelchair-rider parents and caretakers possessing a wide range of physical disabilities. It is an improvement on many earlier designs as it requires a minimum of space and is easy to access and use by both seated and standing caregivers. The crib's innovative gate design can be built into new cribs or added on as an adaptation. It can also be incorporated into accessible play pens and similar furniture. The gate is unique in that it was designed to pass a hazard analysis and approval process by the US Consumer Product Safety Commission.

BACKGROUND

Through the Looking Glass, an agency which specializes in research, training and resources serving parents with disabilities, has a grant from NIDRR (US Department of Education) entitled "Developing Adaptive Equipment and Techniques for Physically Disabled Parents and their Babies within the Context of Psychosocial Services." This project is demonstrating how to blend technology with infant mental health/family support services, and includes the adaptation and development of specialized baby care equipment.

The staff of TLG determined that a safe, easy-to-use adapted baby crib is greatly needed by a significant number of wheelchair-rider parents and caretakers. They requested that we design a crib which would be suitable for people possessing a wide range of physical abilities.

PROBLEM ANALYSIS

Our student design team researched existing cribs and crib designs developed for use by wheelchair-rider parents, conducted a literature review and patent search for relevant designs, and spoke with wheelchair-rider parents who had used adapted cribs. We also consulted with Occupational Therapists and other staff of Through the Looking Glass. We discovered that most adapted cribs address the issue of access by utilizing gates which either slide to one side, slide to both sides from the center, or swing open on hinges. These designs present numerous problems pertaining to safety and ease of use.

<u>Safety Issues</u>

•Cribs with gates which slide to one or both sides lack any safety barrier when the crib side is opened. The infant or child can easily fall out of the crib if left even momentarily unattended.

•Cribs with sliding gates also allow for the possibility of pinching of the infant's or child's fingers, hands, toes or feet as the vertical gate slats of the moving gates slide by.

•Swing-out crib gates lack any safety barrier when the crib gate is opened. These gates also require a wheelchair-rider to back up away from the crib in order to open the gate, creating added potential that the child may fall out of the crib at that time.

•Gate latches on many adapted cribs are potentially accessible to a child from within the crib. Additionally, some latches require only a single, weak motion to open. While this allows a person with limited hand strength to operate the latch, it often makes the latch easily-operable by the child as well.

•Some cribs utilize a top cross bar across the gate opening for structural stability, creating the danger of baby's head getting bumped as he or she is lifted from the crib by an ambulatory parent.

•Adapted cribs or gates are often "home-made," with the result that vertical crib wall slats are sometimes spaced too far apart, allowing for the possibility of the child becoming caught between them.

<u>Accessibility Issues</u>

•Cribs featuring gates which slide to one side require sufficient space to the side of the crib to accommodate the crib gate when opened, and often can't be used in small rooms.

•One design we encountered features a gate which slides to the side of the crib, with storage shelves added on to that side. When the gate is opened, access to childcare supplies stored on the shelves is blocked by the gate.

•Swing-out gates need a lot of space in front of the crib in order to swing open and often require a lot of maneuvering by a wheelchair rider.

•The top cross bars on some crib gate openings get in the way of a standing person leaning over and into the crib.

DESIGN CRITERIA

With the above issues in mind, we set forth to design a crib which would provide safety, accessibility, and ease of use by a wide range of wheelchair-rider parents and caretakers, and which would require minimal floorspace for efficient operation.

<u>Safety</u>

In order to ensure design safety, we endeavored to meet all applicable regulations pertaining to full-size baby cribs established by the US Consumer Product Safety Commission (CPSC). This agency has very specific standards for crib dimensions, mattress fit, vertical slat spacing, hardware, latching, overall construction and finish, and structural stress testing.

One key standard which all but one of the adapted cribs which we studied failed to address is the provision of a safety barrier when the gate is opened. CPSC crib regulations require that when the gate is dropped to its lowest position, the distance between its top rail and the mattress support should measure at least 9" (16 CFR SS1508.3(#1)).

This standard can pose a real problem for accessibility, as a wheelchair rider would have to lift a child over the barrier. This would be a very difficult if not impossible task for a person with limited range of motion or strength in his or her trunk or upper extremities. Inadvertent contact with the barrier might also cause abrasions to the child being transferred into or out of the crib. It is therefore no surprise that this feature has been ignored by almost all adaptive crib designers. However, leaving out this protection creates the very real risk of an infant falling out of the crib when the gate is opened.

Accessibility

We established the following design criteria to assure accessibility:

• Allow for the wheelchair-rider parent or caretaker to pull up under the crib, and to operate the crib gate without having to maneuver the wheelchair or to pull away from the crib.

• Crib gate operable by a parent or caretaker possessing limited strength and/or range of motion or with only one arm, either left or right.

• Latching mechanisms operable by a person with limit-ed strength and/or range of motion. Meet CPSC regulations by requiring two distinct actions to release.

• Crib gate opening allows the parent or caretaker easy access to the child within the crib.

• Crib to be height adjustable to accommodate both manual and power wheelchairs and joystick controls.

Additional Design Criteria

• Allow for visual access to the child, and do not cause the child to feel overly-isolated within the crib.

• Aesthetically pleasing to parents or caretakers.

• Design around a standard size crib, utilizing standard size mattress, waterproof pads, and sheets.

• Crib can be easily constructed of locally-available materials, thereby making it readily-reproducible.

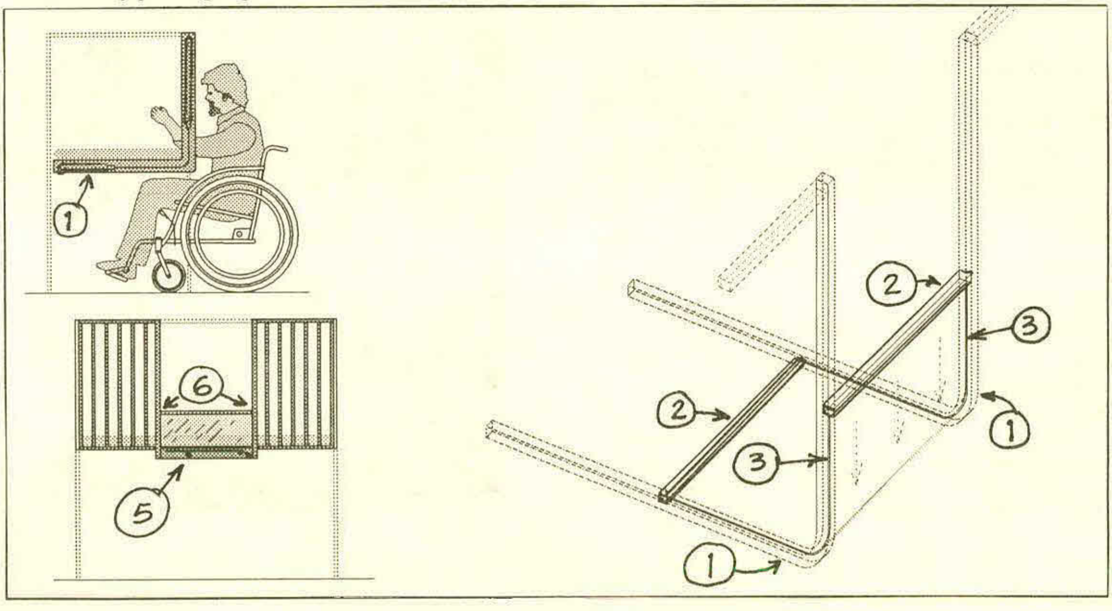
PROBLEM SOLUTION: DESCRIPTION OF THE CRIB DESIGN

Because the crib gate is the key to safe and easy accessibility, we focused on that aspect, designing a gate which could be installed either as a modification to a store-bought crib or as the centerpiece of a custom-built one.

The gate is built around a 30"–wide clear, flexible, non-toxic, vinyl door panel that slides down and turns under the mattress support frame in a track , much like an upside-down roll top desk. The plastic sheet is made of 3/32" Tufflex and allows visual contact and full view of the child at all times.

The track structure consists of a plywood platform mounted under the mattress frame to which two L-shaped upright support members are attached (see illustration, #1). Each support member has channels that enclose the plastic sheet at its sides. The plastic sheet has roller guides attached to its edges which allow it to slide smoothly up and down while keeping it from pulling out of the channels. Horizontal rails are attached to the top and bottom of the sheet (2).

This strong yet flexible door is supported and kept taut by a braided steel cable enclosed in each side member (3). This cable runs between the endpoints of the top and bottom horizontal rails and is guided over bearing pulleys. The sheet is kept from twisting and jamming in its channels as it moves up and down by a second cable system, designed like a draftsman's parallel rule, consisting of two cables that cross through the lower rail of the door, underneath the mattress support (4). (The bottom rail remains in the horizontal section of the frame underneath the crib at all times.)



The door is made to raise and lower by sliding a large knob along a horizontal channel mounted to the face of the crib at mattress height (5). The knob is attached to a cable loop which pulls the bottom rail of the door frontwards and rearwards under the crib, translating to an up or down motion of the door in its frame.

The top rail of the door engages latches at the maximum height of the door and again at a point 9" above the mattress support (6). The gate self-latches when it is raised or lowered to these points. To lower the door, one must activate a release mechanism.

In compliance with CPSC regulations, two distinct actions are required to release the door latches. The user rests one hand on a flat, pivoting pad mounted near the raise/lower knob (7). He or she must first push in a large button located just above the pad with the side of the hand and then rotate the pad 30° to release the door lock. The user can then slide that hand onto the knob and proceed to lower the gate. There is a release mechanism for both the top door height and the 9" barrier height.

As the door is unlocked and lowered below the 9" barrier height for access to the child, it compresses a set of springs which return the gate up to a locked barrier position once the caretaker takes the weight of his or her arms off of the top rail of the door.

THE CPSC APPROVAL PROCESS

We felt that we had a unique design providing both safety and access. Gaining CPSC acceptance on this crib feature would be important if it were to be manufactured and made available to a larger number of people. We therefore consulted with the CPSC and submitted our gate design for a hazard analysis. We subsequently learned that ours was the first submission ever of an adaptive design for a *pre-incident* safety analysis. (The CPSC normally only performs this assessment *after* a report of product incident/injury.)

After conducting a hazard analysis, CPSC staff, acknowledging the needs of individuals with disabilities for specialized products, concluded that our accessible crib design would be acceptable. However, they were prohibited from issuing a formal approval because our design did not meet the *specific* technical requirements of their *exisiting* regulations. We have therefore begun the process of petitioning for a change in CPSC regulations to allow for adapted cribs such as ours. This would set a precedent for the inclusion of standards for other adaptive equipment as well.

FURTHER DEVELOPMENT AND MARKETING

The specialized gate prototype is undergoing evaluation with selected parents before further modification. It is scheduled to be mounted on a both a crib and raised play pen presently being built by others working with Through the Looking Glass. Its ability to be mounted on both stock and custom-built cribs and other furniture promises a broad potential market among wheelchair-rider parents.

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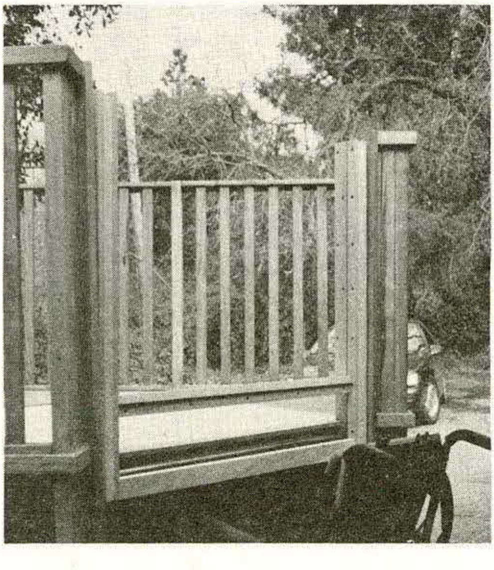

Sequential Task Trainer for Students with Cognitive Impairments

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ABSTRACT

Simple assembly and packaging of objects such as pens, nuts, bolts, etc. is a potential employment opportunity for students with cognitive impairments. However, the training for such tasks is typically labor intensive. A teacher must devote large amounts of time and effort to assist a student in the sequential assembly or packaging process. Each time new jobs are obtained, the students may need to be retrained. Therefore, it is highly desirable to automate the training process so that the teacher can assume a more supervisory role in the assembly process. In such a manner, the dignity of the individual is maintained while allowing the teacher to evenly distribute time fairly among the students.

The idea behind the Sequential Task Training System is simple. First the disassembled parts are placed in the bins. The staff member then easily programs the trainer to fit the students needs. The system then instructs the student only when necessary and praises them after each correct assembly. Hence, the students are allowed to progress to their highest potential without changing any of the parameters of the system.

INTRODUCTION

Special Education classes and vocational training schools work with students who are both physically and mentally impaired. Basic skills taught to students in vocational training curriculums include sequential assembly and packaging of tasks. These involve the mastery of concepts such as "one of", "two of", and "first this part, then that part", i.e. proper sequencing of tasks.

The current training process involves a teacher or staff member monitoring a student performing an assembly task. The teacher specifies training tasks, corrects mistakes, gives praise and encouragement, replaces parts as required, monitors improvement and gathers data on the student. It is a time and labor intensive process. For staff, it can quickly become boring and tedious, because students often need hundreds of repetitions to gain mastery of the concepts and skills.

Working with the staff at the Riley Center, a school program for students with severe cognitive impairments, we have designed and built a prototype Sequential Task Training System. This computer controlled system monitors the students performance and progress. The system also provides visual, vibratory, and auditory feedback to prompt the student to act or correct them if needed. The staff controls the parameters of assembly. These parameters include the number of parts for each bin, the amount of time the student is allowed to spend choosing a part before they are prompted (each bin is able to have its own setting), the number of bins with a maximum of 5, the order of assembly, and the messages which will prompt as well as praise the student. This way, each student will have his own customized trainer with the changeable messages giving the system a human characteristic.

METHODOLOGY

Criteria:

After discussing the staff's needs and desires, we were able to establish a list of criteria for the project which included:

1. Multisensory prompting mechanisms must be used to maintain attention and indicate proper action.
2. Staff must be able to configure system for individual student needs.
3. System must be able to fit on a table top.
4. System must be able to run with a standard PC.
5. Total cost should remain under $500 (not including cost of computer).
6. The system must be durable and extremely safe.

Initial Design:

The design of the system had to be foolproof. Any inconsistencies or mistakes made by the system would only confuse the students and hinder their learning process. It was decided that the trainer would react to the students just like a human instructor would react. With this in mind, we started our design plans.

The first task was to identify when the student picked up a part. After talking with the staff at the Riley Center, it was agreed that if a student was to reach into the bin, it is assumed that they would pick up the part. We used infrared photo-transistors to monitor the parts since they had both the sensitivity and the speed to monitor any motion within the bin. This however posed a problem. If a part was to block the sensor, the system would think that a student was picking up a part. To solve this, each bin would contain three sensors positioned so that a hand reaching in the bin would trip at least two of them. This way a false alarm would not be caused by a part blocking one sensor and spacing them far enough apart so a part would not block two.

Students need to be prompted as to which bin should be used to select a part. We provided two methods. The first method was to install a high intensity Light Emitting Diode (LED) in each bin. The LED will light the bin from which the part is to be picked. The second method was to provide a jack for vibratory actuators which can be placed in front of each bin. This way students with visual impairments can easily be guided to the correct bin.

We chose the Voicemaster Key Digital Voice Synthesizer, for voice production, to prompt the students in case a problem arose. This allows actual human voices to be recorded and easily changed. The teacher is able to record their own voice giving students a recognizable message. Three messages are included in the system. The first message tells the student to pick up the part. This was included since one of the biggest problems in the task is keeping students attentive on the assembly process. The second message informs the student that they incorrectly chose the wrong part. The third message praises the student after each completed assembly, thus giving the student gratification for a job well done.

In order to communicate with the PC, Motorola donated a M68HC11 EVBU Evaluation Board. This is our connection from the circuit of each bin to the PC.

Since each training process has to be individualized, the staff must be able to easily program the system on a per student basis. The software will allow this as well as tie all of the components together. The language of choice was C. The software was written so as to guide any staff member correctly through the program inputs. The software asks for the student's name, the number of bins needed, and verification of the data entered. It then asks for the number of parts in bin 1, the maximum time the student is allowed to spend on bin 1 before being prompted, and verification of data entered. This process is continued until each bin is correctly configured.

After the system is configured to meet the students needs, the training process begins. Once started, the system displays and records the number of correct choices as well as errors on a per bin basis. Other data collected includes average time spent on each part, the number of correctly completed assemblies, the number of possible incorrect assemblies, and the reason the training session was stopped. The system can be stopped manually by a staff member or automatically when a bin runs out of parts. This stops any confusion a student might encounter by looking for parts which do not exist. All of the information is then stored in the student's own file, thus allowing the staff to keep track of the student's progress over time.

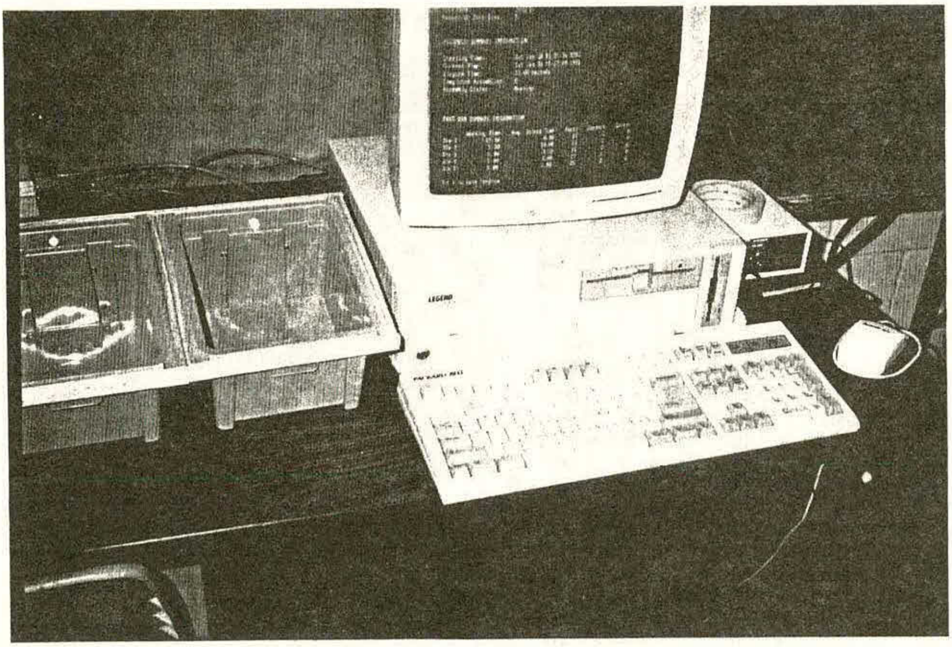

Figure 1. Sequential Task Training System.

Fabrication:

The system had to be compact, yet durable and safe. Each bin is plastic keeping them lightweight and flexible. The sensors are mounted on each bin in a strip of oak wood keeping them well protected in case a bin is dropped. Each bin contains a cable which runs to a main control box. The main control box, which contains the evaluation board, is constructed of 3/4" oak. This provides a heavy duty casing which can not be accidentally broken. Any edges of the system were routed leaving a rounded edge to increase the safety.

RESULTS

At this time the Sequential Task Training System is currently being tested at the Riley Center. The initial response from the students is an increase in attention to the training activity. Further testing will reveal if this increased attention remains after the novelty of the system diminished. This will be evident in the data collected by the system.

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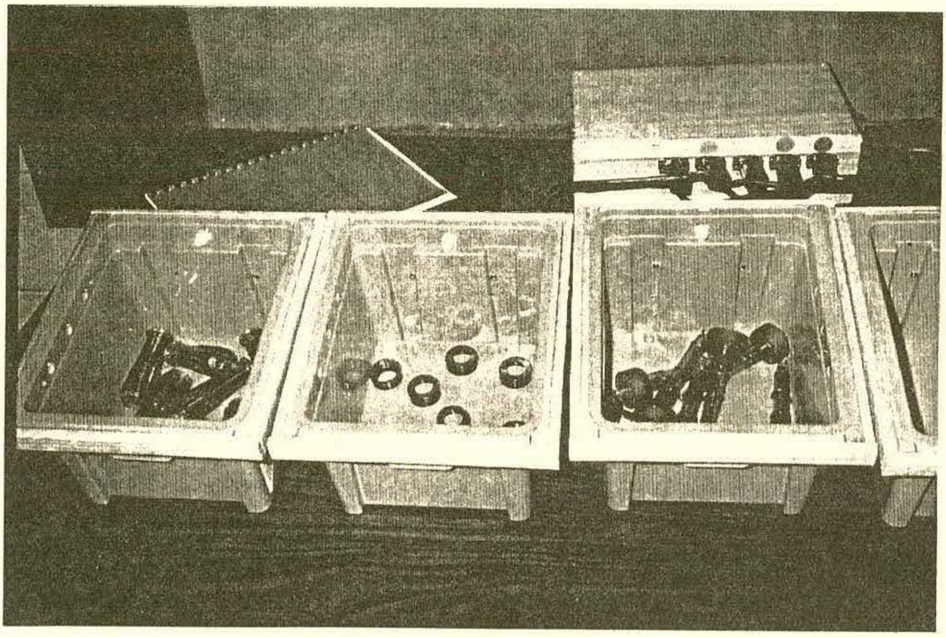

Figure 2. Hose nozzle parts shown in three bins. The bin controller is seen behind the bins.

Design and Implementation of a Computer-assisted Sign Language Tutorial

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ABSTRACT

Today, there are many books and video tapes available to aid people in their attempt to learn sign language. Only by direct interaction realized by using a teacher or tutor, can the user get the feedback that is so important in learning a language. The tutorial system which was created provides a computer based interactive learning experience for anyone wishing to learn American Sign Language (ASL).

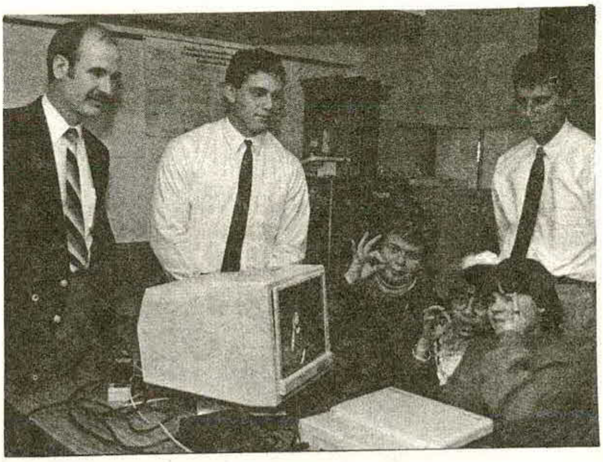
BACKGROUND

ASL is a communication tool used by thousands of people. Learning American Sign Language can be quite challenging for most individuals due to the fact that the quantity and quality of the available resources are limited. As classrooms grow in size, individual attention diminishes. In addition, books and video tapes are limited in their usefulness as an educational device due to the fact that they are not interactive. Interaction is an important part of the learning experience because it makes the process more enjoyable. When the students who are allowed to control the pace and direction of their learning experience, the entire process is usually more pleasant and productive.

The personal computer has great potential as a learning tool, especially in environments where interaction with the learning tool is essential. The American Sign Language Tutorial utilizes the potential of the personal computer while satisfying the need for an interactive learning aid.

OBJECTIVE

To create and implement a computer-assisted learning tool using dynamic human images demonstrating proper use of sign language.



APPROACH

The approach used for the design and development of the American Sign Language Tutorial was to get the end users involved in the project early on. Educators and American Sign Language Professionals were consulted to determine what their needs and the needs of individuals wanting to learn sign language were. Using this input, further discussion was held on how those needs could be most effectively met. In addition, as the project progressed, the end users were given opportunities to test the prototype at various stages of development. The input from the end users at different stages enabled "on the fly" enhancements to be made.

DISCUSSION

The result of this synthesis was a completely operational prototype that displays a menu from which the user can choose a sign to be viewed. Once the user has selected a sign to be viewed, a picture representing the given sign is displayed. Next, a fully animated, full color human image showing the complete motion required to produce a sign is displayed. The tutorial currently includes over 100 signs. The program was divided into two levels: Level 1 is designed for someone who is a beginner and Level 2 is targeted at the advanced user.

There are currently other computer programs available that teach sign language. However, these programs show only a sketch of the body movements necessary to perform the sign. The American Sign Language Tutorial uses digitized images taken from a video of a person performing a given sign. This animated, color display effectively depicts all of the subtleties required to perform a sign accurately. The digitized image of the person performing the sign provides the user with a great role model from which to emulate the motions. This allows the user to learn sign language faster and easier than with other sign language programs while enjoying the learning process.

The American Sign Language Tutorial was put into practical use in October 1992 and is currently being used on a daily basis by two school districts with very different needs. At one school, the students are physically and/or mentally disabled. These students primarily focus their attention on learning the entry level or beginning signs. Sign language is used as a means of communication for those who either have difficulty speaking or are slow to learn oral conversation skills. The program's ease of use is very evident in this situation. Students can use either a mouse or a touch screen to make selections. This luxury enables some of the severely physically disabled students to easily use the program. The other school enrolls students who are either hearing impaired or deaf. In most cases, these students already use sign language as a means of communication. The American Sign Language Tutorial has enhanced their sign language vocabulary through the use of the advanced or Level 2 signs. The signs help students grasp difficult concepts. For example, time, order, and sequence; synonyms and words involving quantities are the categories of signs that a user of Level 2 can choose.

The potential uses for this software are numerous. Individual students use the software to enhance their current sign language vocabulary and as a tool to help familiarize themselves with computers. Teachers can use the software as a regularly scheduled part of their lesson plan or to learn the basic signs that would allow them to communicate with a deaf student that has been "mainstreamed." Adults who are deaf can use the software to help their friends learn sign language. Businesses such as grocery stores, banks, and department stores can use the software to help train their employees so that some communication with the deaf is possible. this system offers a convenient way for emergency medical personnel and police to learn sign language so that they can communicate with the deaf in a crisis.

The feedback that we received from the users of the American Sign Language Tutorial has proved that the system provides a unique and effective learning experience. Users enjoy using the system and have expressed a desire to obtain more computers to be used as workstations for teaching sign language. In addition, the fully animated color images displayed on the computer screen help to maintain high levels of enthusiasm with the users of the system. The American Sign Language Tutorial continues to draw more interest every day as more people become aware of its existence. The creators of this program feel that it has a great deal of potential and we hope that its ability as an educational tool has been effectively portrayed.

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ENHANCING EARLY SPEECH THERAPY BY COMBINING A FLEXIBLE CIRCULAR SCANNING SYSTEM WITH SPEECH OUTPUT

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ABSTRACT

Assessment and rehabilitation of the speech-impaired often involves the use of specialized tools known as augmentative communication devices. These devices range from simple picture boards to elaborate electronic devices which produce human (or human sounding) speech. The simpler devices are generally used in initial assessment and early therapy, and as therapy progresses, the more complex devices are introduced corresponding to the client's needs and abilities. Each of these requires time to set up, has its own "learning curve" for therapist and client alike, and takes up precious storage space at the therapist's facility. The device described in this report can be configured to be used in both early and more advanced therapy, and its speech output and circular scanning display are useful in assessing a client's cognitive and language skills. The expandable design allows future modifications to be made with ease, and because of its flexibility, it can replace several other devices, allowing the therapist to concentrate on language and cognitive issues rather than the operation of several different systems.

BACKGROUND

In some cases, the goal of therapy is to provide effective spoken communications, particularly when therapy is used to restore speech lost as a result of injury or other trauma. The goal in many other cases, especially when a client presents severely limited motor function, is to bring him to the point to where he can independently use existing augmentative communication devices outside of the clinical setting (1). These devices typically consist of a rectangular array of lights and sensors such that the client can, by use of a light wand, switch, or other input, select a letter, word, or phrase to be outputted by the device in speech form.

In either case, therapy is likely to be enhanced by introducing speech at as early a point as possible; it can improve the social interaction between therapist and client, and it can help relieve fears the client may have about not being able to communicate effectively with others in a social setting (2). With this in mind, we reviewed existing augmentative communication devices being used at a nearby rehabilitation center. We were able to observe therapy sessions in which these devices were being used, and were fortunate to be able to attend a local conference and talk to speech-impaired people, their parents, and professionals in the field of alternate and augmentative communications. We found that one augmentative communication device, similar to a clock but with a single motorized pointer which could be made to move in either a clockwise or counterclockwise direction by means of switches, was very popular in early therapy. In response to the therapist's questions, the client activates a switch which causes the indicator to point to pictures or phrases on the display board. However, clients quickly get tired of using it, and the therapists feel that a similar device which produces speech output will hold the client's attention for a longer time and improve motivation. If such a device could also be made flexible enough to allow use in more advanced stages of therapy, it might ease the transition to the more complicated augmentative communication devices for those clients who would eventually require them. In fact, one very capable speech-impaired user of augmentative communication devices confirmed that he was most motivated in his therapy when he could finally use speech to communicate.

DESIGN SPECIFICATIONS

Therapists at the center requested a device which could produce speech corresponding to words, pictures, or phrases selected by the client. The device had to accommodate from two to 30 or so selections, and be configurable for quantities between these two extremes. It had to be light enough to be easily transported, and it would have to run on battery power for at least three hours to allow portable operation. The therapists also required that the device be able to operate on standard 120 volts AC, and they requested that the batteries not have to be removed in order to be recharged. Visual indication of the selection would have to be via a mechanical pointer or a circular array of lights, with provisions to control the speed at which the indicator moved. The device had to accept inputs (switches) commonly used with existing systems, and there would have to be a provision for controlling the direction in which the indicator moved (clockwise or counterclockwise). Switch inputs would require conditioning to reduce the possibility of false actuation. The quality of the speech output had to be good enough to be easily understood, and the speech memory contents had to be retained when the device was not in use. Since the device could also possibly be used outside of the rehabilitation setting, it had to be easy to use by people outside of the clinical setting. The therapists also suggested including different colored lights (if the visual indicator was to be a light array), as well as a brightness control for the display. Due to time constraints, these requests were relegated to future enhancements. There was even some debate among the therapists as to whether multicolored lights would really be desirable.

DESIGN AND DEVELOPMENT

At the earliest stages of design, it became apparent that a circular array of lights would be easier to implement than a mechanical pointer. A mechanical pointer would likely require either sensing the pointer's position (via a servo-resolver or an array of sensors) or guaranteeing the pointer's position under processor control (such as a stepper motor). Servo-resolvers would require a fairly bulky mechanical assembly, and a stepper motor would be likely to slip or at least require position calibration each time the device is used. A light array, which we chose to implement, would require fewer electronics than a sensor array and would eliminate moving parts. For future expandability, however, we included extra circuitry to accept a stepper motor or other device, and we made the display easily removable to accommodate rectangular light arrangements more suitable for portable use.

Also early in design we realized that a microprocessor would give us the greatest power and flexibility, since it would have to interface with a variety of switch, speech, and control inputs and several outputs (indicator lights, speech, etc.). We also opted to utilize existing telecommunications technology by using integrated circuits specifically designed to efficiently digitize and compress speech. The quality of the speech would be better than that of synthesized speech, and any language could be used with ease. Speech would be stored in battery backed-up Static Random Access Memory (SRAM); this is a trade-off between higher-capacity but volatile dynamic memories (the type of memory used in personal computers) and equal-capacity but much more costly nonvolatile memory components.

We then decided to use 40 lights in the circular array. The therapists requested that the circular array be large enough to accommodate the letters of the alphabet and be divisible into several "blocks" of lights. Since we also wanted future expandability for stepper motors, the lights had to be spaced an integer number of steps apart. Several small stepper motors are available with steps of 1.8 °, breaking up the circle into 200 steps. However, 200 lights are probably a little more than would be practical, so we chose 40. This number is easily divided into groups of 2,4,5,8,10,20 or 40 lights, giving a large number of possibilities for the therapist. In addition, other display boards can easily be substituted for the circular display if portable operation is desired, since the number 40 supports rectangular arrays of 4 x 5, 4 x 10 and 5 x 8 (to name a few possibilities).

The number 40 also works well for determining the size of the speech memory. The telecommunications circuits being used for digitizing and re-creating speech have a sampling rate of 8000 samples per second. Each sample uses 8 bits (1 byte) of memory, so each second of speech uses 8000 bytes. We chose to accommodate 120 seconds of recorded speech, divided equally among the number of blocks selected. Therefore, two blocks (20 lights per block) could each store up to 60 seconds of speech, and 40 blocks (one light per block) could each store up to three seconds, certainly enough time to say a letter, number, or short phrase. To make memory design easy (and expandable), we broke up the memory space into seven segments of 128 seconds each, stealing the first eight seconds worth of memory from the first segment for the microprocessor to use. The prototype would have only one segment filled with memory, but a fully expanded system could support 888 seconds, or nearly 15 minutes of speech.

During design, additional specifications were worked out, including speed control (8 settings), speech volume control, and a variable delay (4 settings) to allow the client to change selections before speech is produced (allows the client to change his mind in case he undershoots or overshoots his intended selection). During this phase, therapists also requested that switch inputs be configurable for continuous operation (switch must be constantly activated to advance through selections) or momentary operation (activate switch once to start advancing, activate again to stop). Also during the design phase, the therapists requested two modes of operation for the light array: *block*, in which lights move together as a block, the quantity of lights dependent on the number of blocks selected; and *single*, in which lights move one at a time, regardless of number of blocks selected.

To power the device with ordinary 120VAC, we chose to accept a wall transformer with a 12VDC, one ampere output. Battery power is provided by a 6VDC battery pack, which should provide four to five hours of operation before needing a recharge. An indicator alerts the user of the need to recharge the battery pack, which is handled by the wall transformer without having to remove the battery pack. Based on 260 days of operation per year (52 weeks @ five days per week), the pack should last at least a year (~ 400 charge/recharge cycles as specified by the manufacturer).

For retaining speech memory contents, a smaller battery is used; its life (over 10,000 hours) should easily exceed that of the battery pack, though it will be recommended that both be replaced at the same time to minimize the chance of leakage. Current cost to replace both batteries is under 20 dollars. This is more expensive than we would have liked, though all other battery options we researched would have been costlier.

EVALUATION

After initial debugging, the device was ready for evaluation. The prototype was delivered to the rehabilitation center, and the staff members were trained in its operation. Clinical assessment of the device's features and functions continues with clients deemed appropriate by the Augmentative Communications team. The system's performance is recorded in a device log, the contents of which are to be summarized following six months of use and assessment.

DISCUSSION

The device described in this report should provide considerable benefit for therapist and client alike; clinical evaluation will be the judge. Therapists who have seen the device in operation believe it is more powerful, more flexible, and easier to use than many other augmentative communication devices. They also feel that since it couples speech with an easy to interpret display, it will be valuable as a tool in client assessment, and will improve the transition to more complex devices.

In addition to fulfilling the technical requirements, our design work also focused on ease of manufacturing. All components used are readily available and relatively inexpensive. Even the tools used for developing the circuit, writing the software, and programming the operating system are widely used, so it will be a simple matter to move from prototype to product. In addition, a modular design approach was used to enable customizing without adversely affecting manufacturability; address and data buffering simplifies memory expansion, the removable display allows for customizing to a user's needs, and dual jacks accept a wide variety of standard and custom inputs. This flexibility, along with the device's ease of operation, should result in considerable market appeal. Since speech quality is excellent and there is no restriction on language (which cannot be said for many phoneme-based systems), this device should be successful even in the worldwide marketplace.

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EVALUATION OF A DEVICE TO EXERCISE THE HIP EXTENSOR MUSCLES IN CHILDREN WITH CEREBRAL PALSY: A CLINICAL AND FIELD STUDY

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ABSTRACT

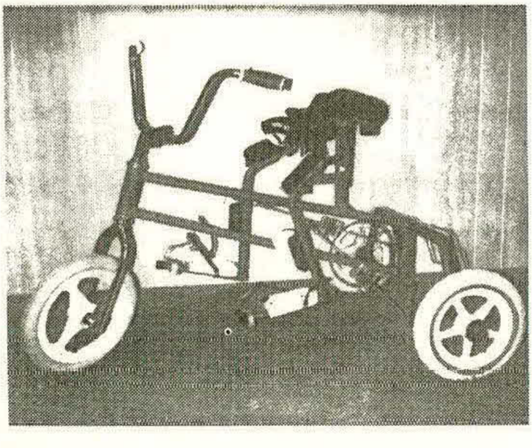
Many people diagnosed with cerebral palsy (CP) or similar disorders have difficulty walking. This research evaluated the effectiveness of a Hip Extensor Tricycle designed to isolate and exercise the hip extensor muscles in children with cerebral palsy. Four children diagnosed with cerebral palsy and one with Maple Syrup Urine Disease were given Hip Extensor Tricycles for home use during an eight-week test period. The subjects were tested every two weeks during the eight week study in which the effects of Hip Extensor Tricycle (HET) use were documented. It was found that the subjects experienced improved gait and increased self esteem.

BACKGROUND

Cerebral palsy (CP) is a chronic disability which can affect persons of all ages. CP can result from nerve damage before, during and after birth. There is no single effective preventive measure, and no cure[1].

A key factor in reducing the effects of CP is rehabilitative therapy. There is a general agreement that the effect of therapy is enhanced if initiated at an early age[2]. The lack of strength and motor control in the hip extensor muscle group is a primary reason people with CP experience difficultly walking. This group of muscles consist of the gluteus maximus, semitendinosus, semimembranosus, biceps femoris and adductor magnus.

Physical therapists experience difficulty getting children with CP to perform conventional calisthenic exercises because they tend to be unenjoyable[3]. Many children with CP lack the strength and coordination required to use traditional tricycles. A new therapeutic device called the Hip Extensor Tricycle (shown below) was developed to provide enjoyable therapeutic exercise.



The HET was designed to pattern the motion produced during walking. To accomplish this the seat of the tricycle was set up high so the user would approximate a standing position during use. A lower back brace and waist belt provided support and stability for the user. The legs were supported by braces with a bend at the knee. A four-bar linkage transferred power resulting from contraction of the hip extensor muscles and leg extension to rotary power in the rear wheels.

RESEARCH OBJECTIVE

It was determined from previous research that the HET isolated the desired muscle group during its use by normal children[4]. The objective of this research was to determine if extended use of the HET would help children with CP increase strength in the hip extensor muscle group, improve gait, and increase self esteem.

METHODS

Five subjects were chosen by a physical therapist for the study. All test subjects were male and ranged in age from five to seven years. Female children were unavailable during the test period. The subjects varied in strength and ability due to their age and type of CP. As noted earlier, one of the subjects was diagnosed with maple syrup urine disease which has many of the same symptoms and recommended therapies as CP[3]. The subjects were tested at the beginning of the test and after two, four, six and eight weeks of HET use.

The experimental methods are divided into three sections: strength tests, gait analysis, and parent evaluation.

Strength tests:
A prototype HET was modified into a stationary test device. The device was modified by: (1) adding a brace connected to the drive wheel which prevented crank rotation and (2) adding load cells in line with the connecting rods to measure the amount of force produced. The subject was placed on the test HET and encouraged to generate his maximum strength in leg extension at the hip. The physical therapist helped the subject understand which muscles to contract to produce the required backward pushing motion against the load cells. A second strength test consisted of a standing subject generating maximum hip extension against a strap around the ankle. Again the physical therapist helped the subject.

Gait Analysis:
The subject was video taped while walking approximately four meters in both directions several times during each of five tests over the eight-week test period.

A physical therapist who was familiar with each subject's personal therapy reviewed the videos of each subject for every test. The most representative gait pattern for each particular subject for each test was selected. This resulted in a single video tape of each subject in each direction for tests one through five (weeks 0,2,4,6, and 8) which was representative of the subject's gait pattern at that point in time. The videos of each subject's test series (one through five) were transferred to another single video in random order to conceal the actual order of the five tests. The random video was viewed by four rehabilitation physical therapists and one doctor of rehabilitative medicine who were asked to rank the five trials from worst (1) to best (5). The evaluators were not allowed to discuss their findings or opinions during the evaluation. In cases where a difference between two test series could not be determined, the evaluators were allowed to rank them as the same. The average ranking scores of tests one and two (week 0 and 2) were calculated and compared to the average ranking scores of test four and five (week 6 and 8) for each subject. Test three was excluded from the analysis to provide two equal groups for comparison of the beginning and ending of the test series. A paired samples t-test was performed between the average ranking scores of tests one and two and the average ranking scores of tests four and five for each subject. The same test was performed for all subjects combined.

Parent evaluation:
A parent evaluation form was used to document any noticeable physical or psychological changes in the subjects and suggestions concerning improvements in the HET.

RESULTS AND DISCUSSION

The results of the strength test were inconclusive. It was difficult for the children to consistently generate a maximum voluntary contraction.

The gait analysis indicated that four out of the five of the subjects experienced improved gait (the gate patterns became more normal) over the course of the study.

Figure 1 contains a plot of the sum average ranking scores of tests one and two compared to the sum average score of test four and five for each subject.

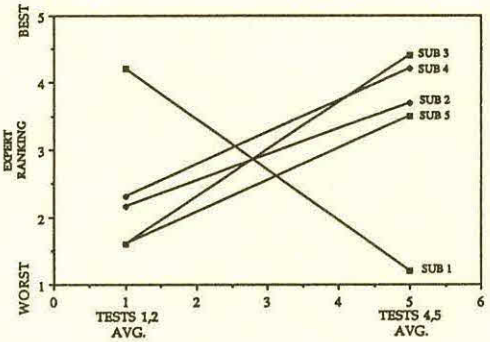


Figure 1 Gait analysis results.

This showed the differences between the expert evaluations of the beginning and end of the study. Upon further investigation it was found that subject 1 had a degenerative hip disorder which was preventing therapeutic progress. The paired samples t-test performed between the average score of test one and two and the average score of test four and five was significant to an alpha of less than or equal to 0.01 for the four subjects that exhibited improvement. The results of the parent evaluation showed that the subjects enjoyed the HET and used in on a daily basis. While there was some decrease in daily use, after the first week, the subjects used the HET for an average of approximately 30 minutes each use day and an average of about 2.5 hours per week. While this might seem modest, it must be emphasized that his "play" was, in fact, beneficial hip extension therapy. In the past it has been difficult to get the children to perform hip extension exercises for even a few minutes during their weekly one hour therapy sessions[3]. In addition, it was found that even the most nonfunctional subjects experienced an increased sense of accomplishment and self esteem. For some it was the first time they were able to ride a tricycle of any kind. For others it helped them fit into the normal sidewalk activities which take place in every neighborhood. *In at least one case the HET was viewed, not as a therapeutic device, but as a desirable tricycle by other kids in the neighborhood.*

CONCLUSIONS

The HET provides an enjoyable means for children with cerebral palsy and other similar disorders to exercise and enhance gait. The HET also seems to allow the user to be a part of normal neighborhood activities and enhances self esteem.

FUTURE RESEARCH

Additional research is being performed to determine the changes in gait and hip extensor strength over a longer test period. A period of six months is being considered. A modified strength test is being developed in which the subject will receive visual or auditory feedback relating his/her strength generation. This may increase the reliability of the strength data. Consideration is also being given to the inclusion of a metabolic energy index in the test battery. This will be used as a measure of changes in overall physical condition as a result of HET use.

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ELECTRONIC AUDIO COMMUNICATION AND CONTROL SYSTEM FOR INDIVIDUALS WITH SEVERE LIMITATIONS

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Abstract

This paper details the design and prototype of an electronic device that allows people with severe physical and mental disabilities the freedom to communicate ideas and partially control their environment without the aide of a therapist. It accomplishes this by playing 10 different sounds for the user to choose from. Once the user hears a noise or sound that corresponds to a need, he/she simply presses a button. The device then either sounds a buzzer and activates a display which notifies an attendant which request has been made or it will activate an electronic device located in the room.

Background

This project was started in an effort to build a communication system for a young man that was afflicted with severe brain damage and physical impairments including blindness. The goal was to allow him to communicate with his physical therapists and be able to control various electronic devices around his room. This was a challenge because he only had limited control of his right arm, was legally blind, had an IQ of under 20, and could not make any distinguishable sounds. Though he is severely handicapped, he can still responded to stimuli such as music, rattles, blowing air, and the sound of the television. The system needed to allow communication of personal needs such as "feed me" or "turn me over", and control of certain electronic devices that he enjoyed such as the radio or fan. Currently, no system is available at a reasonable cost that can accomplish these tasks or that is flexible enough to be adapted to almost any user.

Statement of Problem

The device must allow a person with severely limited physical capabilities and mental limitations to communicate ideas to a care provider or turn on/off selected electronic devices throughout the house. The system must be easy to learn, adaptable to individual needs, and compact so it does not interfere with the user's movement or equipment operating in the room. The system should also be portable and easily installed in any home.

Rationale

The design of this device was controlled by the needs of the intended user. Originally, a picture board that would cycle through various pictures until the user chose a picture corresponding to their request was proposed. This approach was eliminated since a large majority of the population who would use this device are partially or totally blind and would have problems with picture recognition or association. The only practical solution was to use different sounds to represent different requests. Even people with severe mental handicaps can distinguish between different sounds. The proposed device uses a system of 10 different sounds to symbolize 10 different requests. When a sound is chosen the machine will interpret the request and determine what action must be taken to meet the request.

Design

This communication device generates sounds using the ISD 1016 nonvolatile analog electronic recording chip that can record and play back up to sixteen seconds of sound. This sound or message can then be started or stopped using relatively a simple digital control system. An electronic controller was built using standard TTL and CMOS chips that linked ten of the electronic recording chips together in a logical manner. Each recording chip is activated by the controller, one at a time, until the user presses the button. When the user presses the button the sound chip being played along with all other sound chips are put on standby and the request is met. If fulfilling the request requires the aide of another person, the machine will sound a buzzer and display the request on a display screen. Once the request is met the machine can either be left in the idle mode (i.e. no sound) or reactivated by hitting the user button. Once the machine is reactivated it will continue to cycle through all ten recordings. If the user presses the button during a sound that corresponds to an electronic device request, the machine will go into the idle mode and then turn on that particular device. The selected device will remain on until the user presses the button to restart the messages.

The electronic devices that the user can turn on and off are controlled by sending a digital pulse through the house wiring. Each device is plugged into a small device controller that is then plugged into any desired outlet throughout the house. By sending the signal through the wiring in the wall it eliminates control wires running all over the room and allows the selected electronic devices to be plugged into any outlet within about 100 feet using a small outlet controller. Up to eight electronic devices can be controlled by the user though this system.

This communication system is all contained in a small box that plugs directly into any three prong wall outlet. The padded 4" X 8" user button is attached to main box with a set of long insulated wires. This allows the main communication system box to be place in a location that does not interfere with the user's movement or any traffic in the room. The button has a self-contained speaker that plays all the messages or sounds with and adjustable volume control to suit the user's needs.

The electronic recording chips are re-recordable by simply flipping a switch located on each chip. This allows all ten messages to be customized to each particular user. Once the chip is activated for recording, it will record the next 16 seconds of sound that occurs within 10 feet of the microphone located on the box. Recordings can includes things such as voice messages, music, tones, rhythmic beats, almost anything that the user will respond to. If the user does not respond to a particular sound after a period of time, it can simply be changed to a new sound or message.

Evaluation

This communication system has been built, tested, and is currently being used by a handicapped person in Colorado Springs, Colorado. He uses the machine to communicate ideas such as "feed me, turn me over, turn me around, rub my back, rub my stomach", and also has the ability to turn on and off a radio, fan, television, and chime machine. Despite his severe mental limitations he was able to learn how to use this device after a few weeks of training.

Discussion

There are thousands and thousands of disabled people that do not have the ability to communicate needs or control what goes on around them. This device is one solution to this problem. The devices has a recording capability that will allow it to be adapted to almost any user. The number of messages played can be adjusted so an intended user can be trained using only two messages and then the number can be slowly increased as the user's sound association improves. The length of the messages can also be varied from 2 to 16 seconds which will allow for the different reaction times of different users. All these aspects make this system very easy for therapist or parents to customize for the specific needs of the user.

This device offers a huge opportunity to people with severe handicaps to communicate and partially control their surroundings. It is a very flexible system that can be adapted to almost any user in any situation. The system is very reliable and should be able to be produced at a very low cost. The hardware in the prototype system cost about $650 due to each message chip costing $52. If an electronic company modified the device so only one message chip was used with enough memory for 160 seconds of sound, the cost would be reduced dramatically. A new system using this improved chip along with a microprocessor to control it, could accomplish the same task at a cost below $90. This is very reasonable when compared to the current costs of therapy and care. This device has the potential to help a large number of handicapped people and has already demonstrated its effectiveness and overall safety with a handicapped individual.

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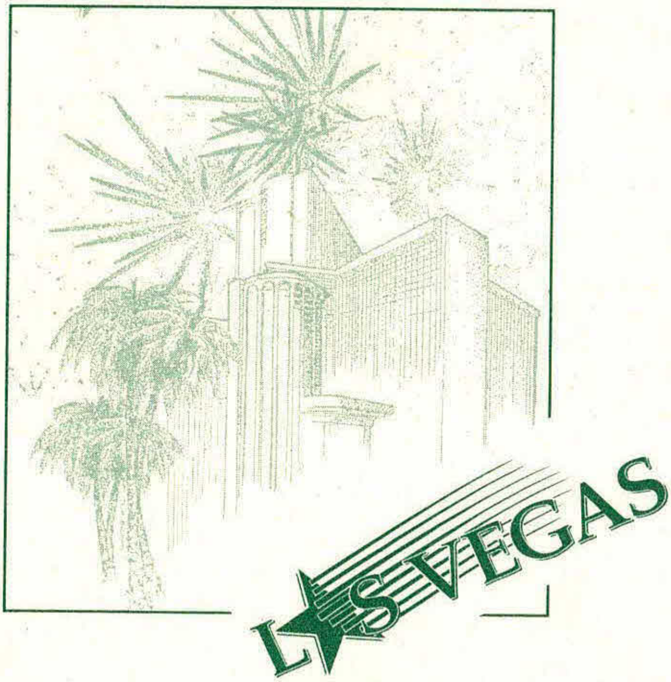

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