Proceedings of the Fourth Annual Conference on Rehabilitation Engineering

Washington, D.C., USA
August 30—September 3, 1981

International Year of Disabled Persons

TECHNOLOGY THAT ENABLES

PROCEEDINGS 1981

4TH ANNUAL CONFERENCE ON REHABILITATION ENGINEERING

August 30—September 3, 1981
Washington, D.C.

Published by the Rehabilitation Engineering
Society of North America

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Rehabilitation Engineering Program
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FOREWORD

These proceedings record engineering development efforts in the field of rehabilitation. They are a vital part of the Annual Conference on Rehabilitation Engineering because they constitute a road map of where we have been and indicate where we may be going. They permit current work to be shared with fellow workers while it is still in formative stages and this can play a significant role in the work's maturation.

These proceedings are a continuation of the publications begun in 1974 by the Conference on Systems and Devices for the Disabled. Documents from those conferences, along with proceedings of the 2nd Interagency Conference on Rehabilitation Engineering (Atlanta, 1979) and of the International Conference on Rehabilitation Engineering (Toronto, 1980) form an almost unbroken record of activities in rehabilitation engineering from the time this field began its rapid growth.

Rehabilitation Engineering is a multi-disciplinary field and investigators report their work in a wide number of journals as well as in proceedings from many other conferences. Consequently, it is difficult to maintain a comprehensive view of the literature of this field. This publication, because it concentrates on rehabilitation engineering activities, can be an important reference for finding where earlier or more comprehensive work of the field has been published.

This is the first year the Conference and the *Proceedings* have been sponsored by the Rehabilitation Engineering Society of North America (RESNA). This publication is, therefore, a milestone in the growth of the society. It seems appropriate for RESNA to begin this new activity during 1981, The International Year of Disabled Persons.

The conference planning committee has tried to expand the role of disabled persons in the meeting and this publication reflects this attempt through the three introductory papers. Three diabled persons, designated CMBES Conference Fellows through financial assistance of the Canadian Medical and Biological Engineering Society (CMBES), have prepared special position papers for the Conference. These papers, although not presented in the sessions, are intended to set a tone for the meeting and to give views from the consumer side to workers in the field of Rehabilitation Engineering.

This year papers of winners of the Student Design Competition are integrated with the other papers. This was done to permit the students to have the experience of participation in regular scientific sessions.

The number of papers related to orthotics and limb prosthetics is small this year. This is unfortunate because these fields are progenitors of much of rehabilitation engineering and extensive collaborative efforts between prosthetists, orthotists, and engineers seem important for the advancement of assistive systems for persons with physical disability.

A word of thanks must be given to the Conference Planning committee whose members donated generously of their time and resources to plan the Conference. Thanks also go to CMC, the Conference secretariat. Special thanks are appropriate to Ms. Jan Little for her invaluable help to the Program Chairman and for her many other contributions. Thanks are in order for the help of the staff of the Rehabilitation Engineering Program at Northwestern University, particularly the help of Ms. Bonnie Collard and Ms. Doreene Farrar.

D.S. Childress
General Program Chairman

Conference Support is gratefully acknowledged from:

National Institute of Handicapped Research
Veterans Administration
Canadian Medical and Biological Engineering Society
Paralyzed Veterans of America
Everest & Jennings, Inc.
Invacare Corporation
Baylor University

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THE CONSUMER'S ROLE IN REHABILITATION ENGINEERING

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A rationale is presented for viewing technology for the disabled not as providing bonuses but as providing tools to overcome the handicaps resulting from social and technological change. User involvement in rehabilitation engineering research and development at four critical levels is delineated. The four levels discussed are those of naive subject, experienced user, teacher or user/teacher, and pioneering subject or "test pilot." Recommendations are given for informing consumers of research results and available technology. Finally, a rationale is presented for the involvement of consumer groups.

This is not an article for consumers. It is written from the viewpoint of a lifelong consumer and addressed to fellow professionals in rehabilitation engineering. I am a user, teacher, and evaluator of communication aids for the blind in the Veterans Administration. The version of this article for consumers is much longer and will be published in installments in a consumer publication.

TOY OR TOOLS?

Should technology provide bonuses to make living more convenient, or do we need tools to reduce the handicaps resulting from the use of new technology? Our first message is this: toys are not the problem. We need tools to cope in a world of rapid change.

The erroneous view that all technology is progress can cloud our historical perspective. We can forget that the handicaps of people with a given disability change with social and technological change. For instance, the advent of silent movies decreased the relative handicaps of deaf people but increased the handicaps of blind people. The advent of radio did the reverse. Radio and television reduced the relative handicaps of many physically disabled people. However, motor vehicles had the general effect of increasing the handicaps of people using wheelchairs. Since industry concentrates on mass markets, conscious effort should be made in our behalf to keep our relative handicaps from increasing with the effects of industrialization. The invention of the printing press and linotype facilitated public education. When literacy became common, braille became a necessary tool. In this century, typewriters and computers have caused the need for reading machines and special computer terminals which most of the blind people who need them still do not have.

Social changes also effect handicaps. It seems probable that in the extended families and small villages of yesteryear, the tasks of living could be more efficiently divided according to the abilities of people than we are able or willing to do today. Perhaps our emphasis on independence and isolation has caused us to think more in terms of disability over ability. A current trend toward appreciating the values of interdependence and cooperation should result in a more rational and symbiotic division of labor. We should discover beyond lip service that abilities are more important than disabilities.

If applications of technology to our needs were only bonuses of an affluent society, then why go to the trouble of working with consumers? We can then consider research projects to be windfalls from a rich uncle rather than commissions to service.

Alternatively, the "bonus" is treated as a consolation prize--something to help poor, unfortunate people feel less miserable. In that case, we should be grateful for devices we can use regardless how useful, efficient or costly they are. Such attitudes have resulted in disaster. All too often, consumers have asked for and been promised new devices which work like box cameras and require no training. Then, inadequately funded projects to develop half-baked concepts have resulted in instruments which only the most capable, determined and desperate people among us could use. Often such utopian forays result in broken promises and a backlash of bitter disappointment. As projects fly apart, valuable personnel and useful concepts are lost to the field.

Surely such disasters will be less frequent if we approach technology as a means to reduce the handicaps it has helped to cause. Of course, the affluent society has its toys which we can use both as toys and as tools. Tape recorders and phonographs are notable examples of toys which

blind people need as tools. Appliance control devices and digital tuning are a convenience for many but a valuable aid for some of us who are physically disabled. Only if we view our aids as necessary tools can we attract competent personnel and expect teamwork with consumers.

ROLES OF THE USER IN THE EVOLUTION OF SPECIAL TECHNOLOGY

Is there something wrong with the way in which we apply research technology to the needs of the disabled? We think so, and here it is. In a given project, users are seldom involved at all the levels necessary for best results. Authorities on techniques for conducting rehabilitation engineering research and development recommend user testing of prototypes, production models and new ideas at all stages of development and deployment. Usually, however, only one or two levels of involvement by consumers or users is recommended. A protocol may call for training of naive subjects and later testing of experienced subjects.

Our experience has convinced us that there needs to be a continuum of user involvement which can best be described by identifying four levels or degrees. In conventional terminology, these levels can be labeled as testing, demonstrating, teaching and evaluation. Another way to put it is to say that we need naive subjects, experienced subjects, instructing subjects, and pioneering subjects. Still another useful delineation is to state that we need students, users, midwives, and test pilots. However, since everyone has a veritable zoo inside him, it should be more fun and more helpful to employ zoological terminology. Without carrying these analogies too far, let us consider for this purpose to be guinea pigs, trained seals, work horses, and eagles.

The intelligent guinea pig is the so-called naive subject who volunteers to try new instruments or techniques. He or she does so in order to benefit personally and also be of service. He often takes tests designed by researchers to study concepts. He faithfully answers questions put to him by market researchers and evaluation researchers. His reading is usually limited to consumer information about technology. There is nothing degrading about his roles in the evaluation process. If an instrument involving substantial training or practice proves useful to him, it should always be given or loaned to him. Besides being fair to him, that practice aids greatly in research and development. Some guinea pigs will then develop into trained seals.

The honorable trained seal or experienced user is not much like his counterpart in the zoo. He or she knows lots more tricks and invents some of his own. This is the experienced or resourceful subject--a user of prosthetic appliances or sensory aids. He can compare models and may have technical expertise in one area. He may serve on consumer panels and is usually not employed as a rehab professional. He seeks out knowledge and reads up on his area of involvement. The trained seal does not stop being a guinea pig but should not be asked to supply data available only from guinea pigs. He may be a star pupil and serve as a demonstrator or exhibitor. All too often he or she is exploited and projects suffer when unsubstantiated claims are made that what he does is so easy that anyone can do it or so hard that only a genius can do it. He also should have the use of aids which prove helpful to him. A few trained seals graduate to become midwives or work horses.

The noble work horse is a dedicated and patient teacher (by inclination and practice if not also by profession). Where feasible, he teaches others to use the skills and instruments being evaluated. Where that is not feasible, he works closely with those who do such teaching. He thus helps them develop a perspective or depth not otherwise possible. For example, every good braille teacher has successful students who had failed under less competent instruction. The same can be said for reading machines and mobility aids. Non-disabled teachers need not feel inferior to the work horse if they are willing to gain his or her perspective by close associations with him. He should be consulted in the development of protocols for new projects. Even when he is not a professional engineer, his suggestions for design changes should be taken seriously. Even when he is not a professional teacher, his ideas for teaching should be seriously tried. He may be a work horse with respect to one type of aid, but he keeps up with developments in research to benefit his disability group. He keeps up with the market place and may write for consumers. A non-disabled person can perform many of the functions of a midwife after many years of dedicated service if he has keen abilities to learn from experience, to empathize and a firm sense of his mission. The work horse has expertise in one field related to the research being done and sometimes two. Unless he loses patience or becomes discouraged, he will be a valuable asset. An occasional work horse, while retaining some of the roles of a guinea pig, trained seal and midwife, will become metamorphosed into a test pilot or soaring eagle.

After the manner of the mythical phoenix, the test pilot or eagle arises from the ashes of dead projects, but he neither rests on his laurels nor beats dead horses. He is needed because most people survive only one or two projects in these fields of endeavor. The populations being served are small and sometimes not very articulate. Rehabilitation engineering is not like designing an automobile in which there is plenty of living memory of old models. In this field, critical human engineering discoveries are often lost through discouragement, job mobility, lost trust and eratic funding. The eagle knows where to find what has been written and remembers what has not been written down.

The eagle is loved and respected or hated and feared depending on the motivations and the ability to venerate or respect of his associates. He can accomplish great good unless he loses his objectivity which is honesty or leses his own ability to venerate.

If he becomes selfish or embittered, he can do great harm. Astrology provides a useful point here by depicting the Scorpio options symbolically as eagle, lizzard and scorpion. A non-disabled person can perform many of the functions of a test pilot if he has extraordinary dedication, empathy and skill.

Though the eagle has a broad base of knowledge and involvement, his claim to fame as a test pilot will be focused. For example, the author considers himself an eagle for reading machines with audible outputs, a midwife for others like the Optacon with its tactile output, a trained seal for many aids including the Sonicguide mobility aid and a guinea pig for others. Remember not to judge by the pilot's failures but by the lessons learned from them. One would not be wise to select the novice pilot over the old bush pilot only on the basis of the number of planes crashed. Yet some developers and investigators insist on starting from scratch. Their faith in their objectivity and creativity is so weak that they fear they will duplicate mistakes. Their projects often abort and crash because midwives and test pilots have no places in them.

Much remains to be written about this new "ladder" of user involvement, but space permits only a few more examples. One serious pitfall is to try to evaluate an instrument requiring lengthy training by gathering data only from naive and partly-trained subjects--guinea pigs. In the 1960's, it was common to pass instruments from hand to hand, so no one became skillful while data was being intensively gathered. Another problem is that after an instrument is in regular use, no follow up is done (1). Yet, only at that time can experienced users--trained seals--show how the instrument fits into their lives. In the absence of systematic market research follow up, we must rely on grape-vine follow up and grape-vine sharing of the results. That process can be fast and efficient or slow and distorted. A classic example of slowness is provided by the field of education. It took a generation of experimenting to rediscover the value of phonics in the teaching of reading. Currently needed is a study of how the Optacon and Kurzweil reading machines are used now that several years of experience is available. Accurate follow up results are necessary in refining candidate selection procedures and in counseling prospective candidates.

Another mistake is to ask only guinea pigs what they would like in a new instrument. On the other hand, developers can take fatal short cuts by exclusive reliance on highly-skilled users. Valuable features may be dispensed with. For example, our reading aids have inadequate tracking aids probably because too much weight was given the advice of high-performance users who had never had a good tracking aid and who could most easily do without one.

Sometimes teachers are poorly trained when the experience of midwives is neglected. If we expect users to invest large amounts of effort in training, then teachers should be given training in appropriate amounts and of appropriate quality.

Another mistake is to rely only on written accounts of past projects. No historian worth his salt would rely as fully on research reports as some researchers do. People often avoid reporting their mistakes which can be as important in the evolution of technology as their successes. Some investigators stress statistics to the point of neglecting vital anecdotal results. Others use anecdotal reporting to hide a failure to collect relevant statistics. Even when the writers try to be thorough and truthful, they cannot know which factors will be important twenty years later. Only the living memories of pioneering test pilots-eagles--can bridge the ensuing gap.

KEEP INFORMED AND INFORM CONSUMERS

Don't just wait for the ads, and don't expect consumers to rely on advertising alone. A state rehab agency or a school system, for example, needs a technical resource person on its staff at the professional level to help keep staff members informed and plan in-service training activities. This is one of the author's responsibilities at the Hines VA Blind Center. Consumer groups should have research and technology committees to help them keep informed of developments for their particular disability groups. Knowledgeable committees, consumers, and professionals should screen material for publication in newsletters and organization periodicals. Heavy sensorship is not indicated, but without some effort at being selective, consumers end up reading highly technical reports, biased advertising, and skimpy news items. Comprehensive articles on a vital category of aid such as powered wheelchairs or speech compressors should be commissioned when necessary.

Some of the best and worst reports on technology are written by media people. We have found that when researchers and exhibitors behave responsibly before interviewers and cameras, accurate reporting nearly always results. Remember, though, that news coverage cannot provide the depth and detail needed to inform consumers.

Researchers, especially those doing evaluation research, should be excellent sources of information on new technology (1). When they write for research journals or make government agency reports their material may be too technical or too detailed for inclusion in consumer literature until it is edited. When, however, they write for rehabilitation journals, little or no editing may be required to meet the needs of consumers. Some researchers are prolific writers for their specialty publications but fail to communicate with other rehab professionals and consumers. The fault also lies with sponsoring academic and government agencies who ought to encourage more relevant communication.

Informing consumers does not end with publishing information. We need places to go to compare and try before we buy or are issued aids such as wheelchairs, hearing aids, low vision aids or guide dogs. As it is, the consumer must either let a vendor prescribe for him or go through extensive medical and social work ups in order to try a course of training or various prosthetic or sensory aids. The former course of action is seldom best, and the latter course is not always warranted.

THE ROLE OF CONSUMER GROUPS

Here come the watchdogs! The idea of accountability to groups of consumers is as welcomed by some bureaucrats and professionals as it is chilling to others. The reasons for these reactions are equally varied. Some of us welcome the collective efforts of representative consumer groups in securing funding in these times of tightening

budgets, in establishing priorities, and in enlisting user involvement. Others, even people who favor unions and professional organizations, resent collective action of the disabled. They site examples of uninformed and hostile groups acting against their own best interests. Consumer groups reacting to such negative receptions, accuse agency people of being paternalistic, lazy and exploitative.

Speaking as one who is involved in both consumerism and professionalism, the author has found the consumer groups to have been right most often. Consumer groups have worked very effectively for the reform of corrupt agency practices, the elimination of discrimination, and the promotion of worthwhile legislation.

Kenneth Jernigan, president of the National Federation of the Blind, states that as long as society insists on grouping us, self respecting people with disabilities should and will organize and work together (2). In recent years, consumer groups have had far too little involvement in innovative technology for the disabled. What is needed is better dissemination of information, a more optimistic approach to technology on the part of rehabilitation professionals and consumers, and the involvement of more consumer groups such as the fledgeling Foundation for Science and the Handicapped (3).

Some would argue that we don't need consumer participation because applying innovative technology is as automatic as vending machines. The antidote for this misconception is a study of history. For example, a blind person, Louis Braille, invented the application of braille to meet the needs of blind people; and blind people finally forced an end to the century-long conflict over standardization of the braille code. We also need friends among the able bodied. Warren Bledsoe, retired educator and administrator in the Rehabilitation Services Administration, begins his find article: "Braille: A Success Story" with this statement. "My function is to tell you about how six little dots won their way in the welter of good intentions, ambition, good will and vanity which washed around efforts to help blind people years ago, even as it does now"(4).

Furthermore, the effect of disabled consumers upon the market place is attenuated or less direct than is the case for the average consumer. This is because public or donated money is often used to buy the research, equipment and services we use. That fact alone should stimulate professional concern and consumer alertness.

One word summarizes this article and defines the role of the consumer in rehabilitation engineering. That word or concept was the key recommendation of a recent AAAS workshop on science and technology for the handicapped in Boston. The word is co/invention(5).

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THE PROMISE OF REHABILITATION ENGINEERING

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The Rehabilitation Act of 1973 was the result of the struggle of disabled consumers for what they believed to be their proportionate space in society. The Act created a climate of awareness in which great needs became identifiable. It also offered opportunities for the rehabilitation engineers to establish themselves as vitally important to the fulfillment of the promise of the Rehabilitation Act.

Rehabilitation Engineering is dedicated to improving the quality of life for persons with disabilities through the utilization of technology. And it shares a common assumption with other rehabilitation professions that independence and employability are not only important human aims, but sound economic goals as well. Costs must be considered with respect to the money saved when the use of technical aids permits persons with disabilities to earn their own living and/or reduces their need for attendant assistance.

The Kurzweil reading machine is one example of the technical aids which are changing the lives and opportunities for disabled persons. It converts printed words to spoken words with the help of a computer. Another example is the Optacon which utilizes dynamic embossing to present letters so that they can be felt by the fingers. Aids for the deaf are teletype communication networks, telephone coding units, and devices for making captional television more practical.

There is the Auto-Con and the Tufts Interactive Communicator for nonverbal persons; there are powered wheelchairs, lifts, and vans for the physically disabled -- equipment which has given new mobility particularly to persons with severe disabilities. Environmental systems have provided the disabled with greater control over their immediate environment in home or work sites. We haven't begun to experience the full impact of computers.

The promise of Rehabilitation Engineering is indeed great but, there are serious obstacles to its fulfillment.

It is regretable that at the present time, too often persons with disabilities are included in the rehabilitation process in only two ways: (1) as patient-clients, they are permitted to sit in on their own conferences; (2) as evaluators of new devices, often after a considerable investment of resources has been made, they are asked to put their stamp of approval on a technical aid without knowing its possible application to others. Frequently such a person is newly disabled or lacks knowledge of other individuals who are functioning in a community in a variety of situations. An experienced disabled person can help not only the client but other members of the rehabilitation team in evaluating the available options for a particular situation.

What is now being proposed is a comprehensive involvement of qualified consumers in every phase of the process from planning to testing.

Qualified consumers would include those persons with disabilities who use technical aids on a regular basis and/or those who have been trained as scientists. According to the RESEARCH AGENDA ON SCIENCE AND TECHNOLOGY FOR THE HANDICAPPED (AAAS Report, January, 1979). "When disabled people are regularly involved at all stages of research, the probability of useful outcomes is increased."

A second obstacle is that too often manufacturers and distributors of technical aids for the disabled do not realize what the potential market is. They need to be made more aware of the value of technical aids for directly meeting imperative needs of individuals with disabilities. Some commendable efforts along this line have been made on the part of Rehabilitation Engineering by opening and cultivating relationships with manufacturers and distributers. When a manufacturer is favorably impressed with the caliber of the engineer and the validity of the designs, the manufacturer may be less hesitant to undertake production. He can be assured of technical support if problems develop.

Once a manufacturer has been convinced of a genuine need for a particular device and of the reliability of the engineer's proposed design, the manufacturer/distributor should assume a responsibility for *a reliable product which can be adequately maintained.* If the product is good and meets a need, it is inevitable that the user becomes dependent upon it. Since even the most reliable equipment breaks down, a valuable service could be provided by *loaning or renting of a spare.* This could prevent a complete change of life style and *avoid a shift in dependency* back again to human beings. Because of the present practice of requiring full payment before a device is ordered, another value in the provision

of a "loaner" is that potential owners could get a *chance to try a product before an investment is made.*

A third obstacle is experienced by persons who because of their economic situation do not qualify as clients of agencies that might pay for technical aids. Such persons may not be on Public Aid or Social Security. They may be employed so are not in the Vocational Rehabilitation System. Some mechanism is needed to permit them to make term payments for expensive devices so that the total cost does not have to be payed on order. Long-term, low-cost loans for technical equipment should appear to be equal in merit to the readily available long-term, low-cost loans for college education. People in the financial world have yet to be approached in an organized way on this matter.

A fourth obstacle is the lack of knowledge on the part of prescribers and third-party payers about technical aids and their proper applications. These professionals need to take more responsibility for tapping all resources in order to provide maximum service for patient-clients consistent throughout the country. They need to be made more aware of the value of technical aids and to incorporate new ideas into their practices.

There are four specific resources that could improve services, not all of which may exist at the present time. These include the rehabilitation or clinical engineer, Rehabilitation Equipment Demonstration Units, Technical Assistance for the Disabled Projects, and a Consumers Report on Technical Aids.

Although some professionals have recognized the usefulness of engineering in the rehabilitation of persons with disabilities, the discipline seemingly has not been accepted as an integral part of the rehabilitation process. Not many facilities have a clinical engineer as part of their staff, and only a minute number of vocational counselors avail themselves of the services of Rehabilitation Engineering Clinics for their more severely disabled clients.

Greater utilization of the engineer and/or his clinic would insure better selection by the person of the most appropriate device for his particular disability. The clinical engineer works with disabled people to become aware of their needs and then guides them through the maze of available aids by means of his experience and knowledge. He then applies the technical aid to meet those needs. He can also provide assistance in suggesting and making modifications (e.g., methods of control) which could determine the difference in whether the disabled person uses or does not use the device to its fullest potential.

Aside from a few specially talented individuals within the rehabilitation process, there is presently no profession that can provide these services other than the clinical engineer.

Rehabilitation Equipment Demonstration Units *should be of particular interest to prescribers and third-party payers*. These units could provide additional assurance that the most appropriate technical aid is selected and best possible use made of available funds. What should be of equal importance to professionals is that a wise choice of technical aids and a careful expenditure of money have as an ultimate result a better quality of life for the disabled client.

Because of the large investment in set-up and maintenance, a Demonstration Unit should be located in a densely populared area and serve as many people as possible: (1) by offering technical assistance in the form of knowledgeable persons who can direct potential users to appropriate technical aids and guide them through a process of hands-on use; (2) by providing oral and written information on technical aids their similarities and differences, to assist in a final selection; (3) by displaying a wide variety of technical aids available for hands-on use set up in similated typical environments;(4) by joint planning in cooperation with all rehabilitation facilities in a particular area so that all would fee comfortable in utilizing this service.

In addition to demonstration units, an equally beneficial service would be the *establishment of Technical Assistance for Disabled Projects (TAD)*. The purpose of such projects would be to enable disabled persons to obtain maximum benefit from their technical aids. One aspect of such a project would be to organize volunteers (paid or unpaid) for the modification of home areas and/or job sites. Such modification could include building or altering work tables, installing simple electronic equipment such as environmental systems, changing doorknobs, providing interior or exterior ramps. The proposed service component could also *collect information on technical aids and on materials for use in modification*. In some cases, ideas and designs might be provided for the user. Further help might be provided by estimating costs, by suggesting sources for funding, and by supplying standard specifications such as size of doorways, ramp grades, etc. Further value to all concerned would probably lie in information obtained from follow-up procedures; (1) to see if a particular modification works well and could be applied to another's need; (2) to gain new ideas; (3) to supply information to manufacturers of technical aids which might be helpful for their design modifications.

The TAD Projects, as well as the Demonstration Units could, and should, be directed and operated by those persons who will most directly benefit -- the consumers.

Of great value to third-party payers and prescribers as well as to users, would be a Consumers' Report on Technical Aids, evaluations independent of the manufacturers. The evaluation of equipment takes on three aspects: (1) testing of engineering performance (the technical specifications); (2) studying a device's applicability, reliability, serviceability, maintenance system, (3) examining the subjective responses of the user and of professionals involved with its application.

Four serious obstacles to the fullfillment of the promise of rehabilitation engineering have been discussed and some suggestions given for their resolution. However, even if all these obstacles could be overcome, the products of rehabilitation engineering are not being used to their fullest potential because of an inaccessible environment, including physical, economic, and attitudinal barriers.

For instance no matter how well a wheelchair is designed, it cannot go up and down stairs or through a revolving door. No matter how educationally qualified or technically equipped, many disabled persons cannot work because of the disincentives in the Social Security and Tax System.

When considering attitudinal or philosophical barriers, one has to question the rationale underlying many of today's health insurance programs. Payment is readily made for medical care designed to bring a disabled person to full functioning. Many of the technical aids and systems proposed by rehabilitation engineering have exactly the same goal. Yet these aids, often prescribed outside of a hospital setting are not subject to equal reimbursement. The impact of just this one practice is tremendous, not only upon research and development, but upon the entire process of rehabilitating people.

The technology and other resources presently exist which promise solution to most of the major problems of persons with disabilities. The concern of many persons in the disabled community is that society as a whole does not really want to solve these problems. It is our hope that the Rehabilitation Engineering Society of North America (RESNA) may be sufficiently challenged to bring about significant change.

PARTIALLY UNKNOWN SYSTEMS

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Foundation for Science and the Handicapped

A deaf consumer/research scientist comments on the application of science and technology to the problems of the hearing impaired.

Hearing impairment as a descriptive term covers a broad range of deficiencies including speech problems directly related to the inability to hear. It refers to a loss of the essentials of communication - to one degree or another - at three distinct levels, the symbolic (sounds of speech and language); the signal (identification of events in the environment); and the primitive (recognition of "being" in the sense that one is part of an environment and "attached" to something real) (1). For these reasons, it has been noted that hearing loss is the most profound psychological insult that can be inflicted upon humans (2).

The normal level of frustration experienced by the deaf in a communications oriented society can be aggravated by the realization that few of the many advances in communications technology have been of practical benefit. A limited number of individuals have been helped and most of them are hearing impaired rather than deaf. Schein and Hamilton (3) have observed, "Too often the brilliant engineering remains in the laboratory. Companion ingenuity in applying technology has not been realized."

In general, progress has been in the area of signaling devices. A number of manufactured items and some custom-fabricated devices which provide visual alternatives to audio signal systems is available. It is at the symbolic level - sounds of speech and language - that technology has failed the deaf.

Hearing aids come in a number of shapes and forms. Sometimes it seems most of the progress has been in the cosmetic area because of miniaturization of components. This has led to smaller and less noticeable aids which many consumers prefer. But large and significant problems remain to be resolved before these communication devices fulfill their promise.

Hearing aids function as amplifiers and increase the level of sound. They are not selective in the sounds they amplify. Many users have problems with speech intellegibility as the ability to understand the amplified sound is dependent upon several factors which affect the signal (speech) to noise ratio. Unless the user is close to the speaker and the background noise is minimal, the hearing aid is not very effective. For the profoundly deaf aids may be of value only to monitor personal speech quality. They are most effective when used in connection with an induction loop. These loops permit users with instruments having telephone adapters to hear speakers quite well. The signal is clear and there is no disturbing noise.

Despite an initial lack of interest on the part of the telecommunication industry and some telephone company opposition the deaf have overcome their basic problems with telephone communication. An electro-acoustic coupler invented by a deaf physicist, links two teletypewriters (TTY) through a standard telephone wire. What is typed on one machine appears on the other - really old technology adapted to function as an assistive device. Product improvement does require input from technologists. Most of the TTY's are of the 5-bit Baudot codes and not of the 8-bit ASCII type. Modern technology is committed to the 8 level type so the deaf cannot interface with computers. The development of an inexpensive 5-bit to 8-bit converter would be welcomed. This is a must in view of the growth in the use of programmable computer terminals in which the telephone handset is just another peripheral!

The logical extension of the electro-acoustic coupler from wired to wireless communication took 12 years (3). The TTY system has been adapted for radio transmission. Information is converted, using a teletypewriter, to audio tones which correspond to digital information. The signal is broadcast and picked up by a special receiver and processed by an electro-acoustic coupler to print out the message. Use is limited now. Access to radio programming for most of us remains in the future.

Other devices have also been tried and found wanting. The Picturephone invented by the Bell System is technically excellent but uneconomical

as one Picturephone's video signal occupies more line capacity than 300 regular telephone calls (3). If present bandwidth requirements (10^6Hz) could be significantly reduced, perhaps through fiber optic links, the ability to see as well as hear telephone transmissions may become a reality.

We also have captioning of television programs. A good deal of controversy, not necessarily connected with the merits of the technology, precludes rapid development of this visual aid. There are, of course, some major technical problems to be resolved, but the broadcasters seem to be lagging behind this dynamic technology because of perceived conflicts between technical possibilities and social reality. Both the hearing society and the deaf community have asked pertinent questions. However, the adaption of videotapes and videodiscs for deaf consumers by supplementation with captions or signs will probably continue. Production of special programming will be advantageous to the deaf community for both entertainment and educational purposes.

We need a major effort to develop educational toys which would promote the cognitive and verbal skills of young children. My wish list runs from simple displays of words and images to more complex graphics connecting words, images and pronunciation. Such pre-school toys can partially substitute for the lack of auditory input hearing-impaired children need to develop language skills.

My dream is a portable speech to text computer like is the Texas Instrument learning aid called Speak and Spell. My version is Speak and Read. Speech is converted in real time to a light-emitting diode or a hard copy display - speech recognition by machine. Some investigators do not think it is possible to produce a system that could understand unconstrained natural speech with high accuracy. Others believe the necessary fundamental work will be available in short order. If the microelectronics industry is successful in it's push to create very large scale integrated circuits (VLSI) in which hundreds of thousands to millions of electronic components will be fabricated on a single chip, then the probability my dream will be realized approaches one. Bell Laboratories engineers have fabricated a signal processor (more than 45000 transistors on a single chip) that works fast enough to synthesize and recognize human speech in real time (4). This is encouraging.

Science in the garb of medicine and biology has not contributed much to improving our lot. The detailed structure and innervation of the inner ear has been demonstrated and the afferent and efferent pathways identified; bioelectric phenomena have been interpreted and the biochemical composition of inner ear fluids determined; some understanding of neural encoding in the inner ear and neural pathways to the brain have been obtained. Yet the only definite applications are effective middle ear surgery for conductive deafness; clinical measurement of acoustic impedance of the ear as a diagnostic aid for otologic surgery; and some technical and engineering developments which have led to improved hearing aids.

Cochlear implants do not do much more than provide access to environmental sounds and improve the quality of speech. While the present implant does generate sounds, speech recognition is still beyond the forseeable future. It would seem the major research effort must be concerned with the development of electronics for the implanted device. Perhaps a microprocessor could be designed to break down the speech signal, and resynthesize it in terms of coded electrical activity for stimulation of the auditory nerve. Obviously this includes the development of suitable electrodes which would be capable of delivering a complex, spatially distributed spectrum of electrical stimuli. Success is probably not around the corner.

Perhaps I expect too much. My expectations may go beyond what many perceive to be reasonable or even desirable. Perhaps other things are more important to the average deaf consumer than science and technology - daily living for example. But then I am not typical for not only am I a deaf consumer but a research scientist as well.

Due to my industrial orientation and the fact my livelihood is dependent upon my ability to translate scientific advances into products which society deems beneficial and my employer thinks profitable, my input may be considerably different and more controversial than that of my peers. It is not an altogether unfamiliar situation for it essentially duplicates my continual interaction with marketing personnel in determining consumer interest. In this regard consumers should understand important devices in science have had unexpected origins and are not necessarily related to intensified investigations or current technology. For example, the electronic revolution did not arise from increased research activity in the field of vacuum tube technology.

I, and all profoundly deaf persons, have a simple single desire. We wish to communicate in real time. We know that won't happen soon so things to ease the burden will be welcomed. But non-critical acceptance of the inability of science and technology to provide a solution to our major problem will result in the continual expenditure of resources on problems that are spurious or if real are actually trivial. We don't necessarily want to hear, we want to interact effectively with other human beings in the transfer of factual and abstract information which we must have to function and perhaps to survive.

As a consumer I do give priority to short term projects which help. But as a research scientist I prefer high quality multidisciplinary projects directed toward and understanding of the basic mechanisms of communication.

By definition rehabilitation is an increased ability to control the negative factors of our environment. In terms of deafness, this means

communication with the environment, an information processing system of signals through several channels, one of which is non-functional. To understand requires an in-depth look at language and cognitive processes by new and innovative experimental methods. What happens when a signal designed for two channel processing, visual and auditory, must be interpreted through a single channel? The degree of signal distortion and extraneous noise generated by crowding the single channel will have an effect on reception. Two options are open for improved reception. We can try to adapt the original signal for one channel reception by either modifying it or improving it's quality, and we can try to develop alternative channels for reception. But we must know something about the processes through which the acoustic signal is generated and retrieved. As the acoustic signal is a mixture of phonetic, syntactic, semantic, and contextual information, the problems are formidable. The development of models of auditory, perceptual and language processing is essential for their resolution. Good models can advance our fundamental understanding of how environmental information is processed and lead to improvement in the ability of the deaf to communicate. We will not accomplish this until the "unknown" in the title of this presentation can be changed to known.

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REHABILITATION TECHNOLOGY AT THE GRASSROOTS

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The concept of grassroots rehabilitation technology is discussed, with a focus on its special characteristics, advantages and disadvantages, and solutions to some of the problems it faces.

WHAT IS GRASSROOTS REHABILITATION TECHNOLOGY?

The main characteristic that differentiates grassroots rehabilitation technology from the field normally known as rehabilitation engineering is its orientation towards the provision of direct services rather than research. As a corollary of this, the client is at the center of the process, since a particular person to be served is in the mind of the designer.

WHERE IS IT DONE?

Grassroots rehabilitation technology (GRT) goes on wherever there are clients: schools, independent living projects, hospitals, neighborhoods. Often the sites are not directly connected with either rehabilitation or engineering, and may be as "humble" as someone's garage.

WHY IS IT DONE?

Out of necessity. There are huge gaps in the delivery of technical services to disabled people. These gaps arose for many reasons, not the least of which is the hit-or-miss way the field has grown. Lack of funds is also a critical cause of the shortage of services.

It might be worthwhile to examine the two principal roads open to someone looking for an adaptive device, in order to bring into focus what these gaps are like. Basically, there are commercially available devices sold through catalogue companies and medical supply houses, and there are the services of Rehabilitation Engineering Centers and similar institutions.

In the case of the former, the commercially available aids, we run up against a number of problems. For one thing, it is difficult to inform oneself as to the aids available; there are dozens of companies making conflicting claims and no clear consumer information. Expertise in the field of catalogue aids is itself a full-time occupation, something the average client or caseworker has neither the time nor the inclination to do.

In addition to this, aids that are manufactured are created for a mass market that often does not exist. There is no "average" paraplegic to design for, so many standardized devices are not suitable for many disabled people. Thus, often the very purpose of having items manufactured is self-defeating.

The Rehabilitation Engineering Center option also has some problems. For one thing, there are not enough of them. Just a handful scattered across the country is not enough to provide the desired devices for millions of people. And they really aren't there to provide services. We established the Centers to do research; the services they do provide are an adjunct to the research, and there is a definite funding limit for services.

HOW IS IT DONE?

So clients wind up with the option of GRT, the rubber band and paper clip option. And this is an apt description in many ways. The practitioners of GRT are most often not technically trained, and tend to use materials that are at hand in a makeshift way. Sometimes this works fine and sometimes it doesn't. And there are other factors.

ADVANTAGES AND DISADVANTAGES OF GRT

Among the advantages are two already mentioned: the focus on the client and the real need as stated by that client. In addition, the cost is generally low, as materials and labor are both inexpensive. The system is most often low in bureaucracy and high in client-involvement, which often leads to self-help.

Unfortunately, there are just as many disadvantages. The lack of technical sophistication on the part of most GRT practitioners means that some of the solutions may be unsafe or unreliable, and that there is a built-in bias against high technology. Case management is generally non-existent, so there is little planning or follow-up. also, there is no coordination of solutions, so that efforts to design a device in one setting are not disseminated to others with the same problem to solve. There is a great shortage of money for this type of technical services, and a difficult maze of regulations to thread through on the way to getting authorized payments from public or private institutions.

SOME SOLUTIONS

Clearinghouse

Many people have pointed to the success of an organization in Australia and New Zealand called Technical Aids to the Disabled (TAD). This organization uses volunteer engineers and technicians to design and build devices. The organization itself serves to disseminate successful solutions on a do-it-yourself basis. Perhaps we should have something similar to TAD, an organization that might also determine which solutions have manufacturing potential and seek capital for them.

Funding

State departments of rehabilitation should be encouraged to pay for on-site technical services by showing administrators the cost-effectiveness of those services compared with commercial devices where appropriate.

Training

Do we need rehabilitation engineers? Perhaps we should be offering machine shop courses to occupational therapists instead, and stealing the best bike mechanics we can and training them in the medical aspects of disability. Most of the problems encountered in the repair of a wheelchair do not require a thorough knowledge of the laws of thermodynamics.

Information

Any information system that is trying to serve people should include large doses of do-it-yourself designs as well as useful consumer evaluation reports.

CONCLUSION

There are presently many gaps in the delivery of technical services to disabled people. Grassroots rehabilitation technology can help fill those gaps if there is more encouragement on both the organizational and financial levels. It will require a great deal of cooperation and turf-negotiation on the part of presently existing institutions to guarantee that services are being provided in a context that puts the client's needs first.

DEVELOPMENT OF AN IN-HOSPITAL ENGINEERING SERVICE DELIVERY MODEL

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ABSTRACT

Outpatient rehabilitation engineering delivery programs have developed successful mechanisms for service provision and reimbursement. However, in-patient engineering procedures are still in the early stages of development.

The Rehabilitation Engineering Service in Philadelphia is one of the research projects of the REC #2. A primary objective is to investigate and develop appropriate delivery models for inpatient rehabilitation populations. This paper describes the initial phase of developing an inpatient engineering service, reports the results of the past year, and projects future directions.

INTRODUCTION

While the rehabilitation health care team provides effective and comprehensive treatment in their respective fields, engineering services are emerging with a distinct and valuable role within the rehabilitation setting. The Rehabilitation Engineering Service (RES) is developing importance within Moss Rehabilitation Hospital to facilitate the application of current science and technology to the needs of the physically disabled. Additionally, this RES exists to assist the rehabilitation team in the design of functional environments and the fitting of effective devices for their patients.

This paper briefly describes the history of the inpatient model and the roles of the RES team. The overall objectives are reviewed and the plan for the first year is described. Results of a twelve month period of inpatient RES activity is presented and discussed. In conclusion, future directions are projected.

BACKGROUND

The RES inpatient model originated from a special inpatient unit known as the Research Utilization Service (RUS) under the supervision of a physiatrist. While the primary purpose of this 12-bed unit was to utilize these patients as voluntary research subjects, it was found that there was a need for engineering expertise, in conjunction with therapists, in areas of activities of daily living, communication, mobility, and home evaluation.

In July, 1977 an engineer was assigned to provide direct patient services to this small inpatient unit. This in-hospital program continued on a limited basis until 1980 when a full-time occupational therapist was appointed to work in direct liaison with the rehabilitation engineer. Since that time a clinical consultation approach has been used with the basic team consisting of an engineer and an occupational therapist. This arrangement enables us to conduct research and development into engineering service delivery models while serving as a direct link to the engineering personnel and the hospital staff. Additional team members include a physiatrist, physical therapist, orthotist/prosthetist, and additional engineering support as needed.

The research aspect of this project was formally organized in 1980 and the anticipated date of completion of the research aspect is 1985. The specific objectives include developing both in-hospital and outpatient engineering programs including prototype procedures for operation of these programs, developing reimbursement procedures, developing generic and custom-made equipment, as well as establishing dissemination and training programs for rehabilitation engineering professionals

With regard to the inpatient engineering model, baseline data was required for the initial phase of this project. Specific information was required describing the technical needs of the Moss patients. It was decided that for a period of one year all referrals to the RES would be accepted while keeping careful documentation of services provided. At the completion of one year all hospital cases would be reviewed. Table 1 presents the one year results of inpatient RES activity.

RESULTS

A total of 47 cases were referred from hospital physicians representing 58 individual problems for engineering service solutions. Nine diagnostic groups are represented with the largest number of cases being cerebral trauma, spinal cord injury, and cerebral palsy. The highest percentage of service requests were in the areas of activities of daily living, seating and positioning, and home evaluations.

The area of activities of daily living had the greatest number of requests. One device for upper extremity dressing was custom-made. The majority of recommendations were unusual items that are commercially available with which the occupational therapy department was unfamiliar.

The second largest category was seating and positioning and represents 24% of the 58 requests.

TABLE 1

IN-HOSPITAL ENGINEERING SERVICE FEBRUARY 1980-FEBRUARY 1981

Diagnosis	# Pts.	# Problems	Activities of Daily Living	Seat./ Pos.	Home Eval.	Environ. Controls	Communication	Vocational Evaluation	Recreation
Cerebral trauma	16	20	4	2	4	4	6*	0	0
Spinal cord injury	13	16	5	5	4	1	0	1	0
Cerebral palsy	8	8	3	4	0	0	0	0	1
Multiple sclerosis	4	4	2	0	1	1	0	0	0
Cerebral vascular accident (CVA)	2	2	0	0	1	0	0	1	0
Amputation (BK)	1	1	0	1*	0	0	0	0	0
Amyotrophic lateral sclerosis	1	1	1*	0	0	0	0	0	0
Werdig-Hoffman	1	3	1	1*	0	1	0	0	0
Childhood infection with osteo-myelitis	1	3	0	1	1	1	0	0	0
Total	47	58	16	14	11	8	6	2	1
%			28%	24%	19%	14%	10%	3%	2%
* Custom-made device		-	1	2	-	-	1	-	-

Two of the fourteen cases required specially designed seating systems. The remaining twelve cases required newly developed commercial items with which the physical therapy staff was not yet familiar.

Of the 58 requests, 19% required home evaluations. One-half of the home evaluations recommended structural modifications. Structurally involved cases required more engineering expertise than the clinical therapy staff could typically provide.

Developing appropriate interfaces was the primary focus in providing environmental controls and represented 10% of the total requests. Once the interface was selected and the unit installed, then the clinical therapist was involved in training the patient in its use.

All six communication requests were for the cerebral trauma diagnostic group. This result is predictable because only those patients in this group were non-vocal. While Moss Hospital's Center for Communication Disorders is technically sophisticated, the requests for adapting communication device interfaces required more technical expertise than the speech therapy staff could provide.

Only 3% of the requests were vocationally related. This result was expected because the primary emphasis for most inpatient treatment at Moss is for functional independence at home. Once discharged, vocational plans are strongly pursued for the working-age population in conjunction with the Bureau of Vocational Rehabilitation (BVR). It should be noted that the RES handles a large percentage of Moss outpatients through BVR via a fee-for-service arrangement with that agency.

Of the total number of requests, only one was in the area of recreation. This represents 2% of

the total. The service provided was for an interface for a child's electric toy.

DISCUSSION

While some of the referrals could have been handled by appropriately trained therapists, there appears to be a need for in-hospital engineering expertise above and beyond the traditional disciplines. Examples of this are structural modifications to homes, specially-made seating inserts, technical interfaces for communication devices, environmental controls, and custom-made adaptive equipment.

The experience of the past year represents a sample of engineering cases that regularly arise in a rehabilitation hospital. The referrals received were generated from a small number of Moss physiatrists who are familiar with the potential of the RES.

Future plans include educating all hospital physicians about the engineering service and developing efficient channels for problem identification and service provision. Attendance is necessary at various medical rounds and clinics to facilitate identification of patient needs that can be technically satisfied. An effective screening process is required for referrals to avoid duplication of services. Appropriate channels will need to be established with the therapy staff to transfer knowledge of newly developed equipment to the clinical setting.

Future plans include obtaining followup information on case referrals in the form of written questionnaires, site visits, and phone calls. Development of fee schedules within the hospital for engineering services and equipment will be initiated. Contact will be made with third party payers to present the need for rehabilitation engineering services within the hospital.

SUMMARY

In summary, the activity of this inpatient rehabilitation service for the past year has been presented. This experience suggests a role for engineering services in the rehabilitation hospital setting. Future directions will focus on reimbursement for these services while integrating them more fully into the hospital environment.

ACKNOWLEDGMENTS

Acknowledgments to the following individuals for their assistance: C. Leiper, G. Moskowitz, N. Mayer, D. Biser. This work was supported in part by grant #G008003003 from the National Institue of Handicapped Research.

An Incomplete Guide to Establishing a Rehabilitation Engineering Program

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ABSTRACT

This paper provides some guidelines and references for establishing a rehabilitation engineering program for provision of services and conduct of research.

The Rehabilitation Engineering Center at Children's Hospital at Stanford provides services to over 1,000 clients a year, has three federally funded research projects, and serves as a regional resource for Northern California. The Center's program was initiated by borrowing slides from Ontario Crippled Children's Centre (1) to help promote the idea to the Hospital and community. After four years of developing client services and three years of developing a research effort, others now are borrowing slides from us to start programs elsewhere, therefore qualifying this Center as an expert.

Since experts are expected to impart great wisdom, herein are some observations for establishing a rehabilitation engineering center. Situations may be different from place to place, and names may be changed to protect the innocent, but certain truths prevail.

References (2-4) explain the background and clinical needs for centers. Reference (5) does an excellent job of presenting important considerations for setting up programs. References (6-10) relate to the subject. Below is "everything we should have known" in starting a center.

- Resist the temptation to construct a new building while building a new program. The tendency is to divert most of the effort into the structure, which demands attention and decisions, and less effort into the people and organization, which really are what make the program go (11).

- Determine the lay of the land in the community while planning. Sometimes a program can be put together using existing resources so little ground work needs to be done, no toes are stepped on, and the program can be integrated quickly. It is more difficult to bring new components and then make them fit.

- Establish client services first and research second. So doing provides a hard financial base upon which soft research support can fluctuate and provides real, live clinical needs on which to undertake research projects and evaluate results.

- Evaluate whether the emphasis of the center is to be small and special or large and less unique. The former connotes a small, highly competent staff addressing special and difficult client problems and "cutting-edge" research and commonly struggling for financial solvency. The latter connotes a large, less academic staff addressing more standard client needs and research but with more financial security. The differences between the two are significant.

- Develop and promote a good working relationship between the key physician and key engineer. Much has been said and unsaid on this subject, but achievement of it is rare. In most cases one leaves the other alone, or they are frequently at odds. When it works, collaborative synergism benefits individual learning and project results.

- Make allowances for future problems and make provisions to resolve them. It is very easy for staff members to go into a new program looking at all the positive and idealistic goals. When the honeymoon is over and problems begin to surface, as they surely will, the program needs an agreed-upon method to resolve the difficulties other than looking for a big fan.

- Withstand the inclination to take on too much to soon. A new program, with attendant publicity and desires of the community, can have unrealistic expectations heaped upon it. Better to start with a few winners than spread the staff too thinly and have many losers.

- Conduct client services on a strict, fee-for-service basis from the beginning with a logical and fair fee schedule rather than attempting to conduct services as one-of-a-kind demonstration or proof-of-concept research endeavors. The latter is limiting, is a grey area legally, and lets proper funding agencies off the hook.

- Do the work first and then talk about it. The temptation is to verbally advertise a new program before there is really much to show for it. This Center has found that once

good services are being provided, the word-of mouth information system by clients and professionals is amazingly fast and efficient, leading one to the conclusion that the center should put its effort into the product first.

- Go beyond the perfunctory in getting consumer/client input for services and research. For services, his/her input is essential to provide the right device (12). For research, it is more likely that the end products will be useful if consumers are involved from iniital need, inception of the research to be conducted, and all the way through rather than simply being asked to evaluate it or "what do you think" after the research project is completed.

- Do not start a program in isolation. Go borrow slides from an established center, and while there, ask about pros and cons, methods and procedures, problems and solutions, etc. There is a lot to be learned from other folks who have been there.

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THE REHABILITATION ENGINEERING SERVICE AT U.C. DAVIS

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The Rehabilitation Engineering Service was established in the School of Medicine, U.C. Davis, to apply engineering technology to problems of individuals with neuromuscular and musculoskeletal disabilities. The hope was to develop it to financial independence on a fee-for-service basis. Most of the projects involved problems in independent living at work, home, or school, in vocational needs, or in transportation. It was found that there is a market for this kind of service, that a larger scale of operation would be necessary for financial stability, but it is not known whether or not the community resources would be adequate for success on a fee-for-service basis.

INTRODUCTION

In August, 1979, the Rehabilitation Engineering Service was established in the Department of Physical Medicine and Rehabilitation in the School of Medicine of the University of California at Davis. It was funded primarily by a "seed money" grant from the California State Department of Rehabilitation. The hope was to develop it, in three years, to financial stability on a fee-for-service basis, and to have its services available to clients from a wide variety of referral sources in inland northern California. Clients with neuromuscular or musculoskeletal disabilities would be accepted. As a project on the University campus it would also serve as a center for research, and as a training facility for rehabilitation engineers.

But about a year later a drastic cut in Federal funds to the State forced a reduction in financing for this project. Other sources of temporary support during the growth period were sought, but unsuccessfully, and the lack of support money necessitated the termination of this Service at the end of March, 1981.

During this approximate year and a half we developed a number of resources and procedures for achieving our technical goals. Some of these and some of our experiences and tentative conclusions are presented here, as information for other individuals and groups interested in rehabilitation engineering.

PERSONNEL

The key person in the Service is the full-time Rehabilitation Engineer. He has a B.S. degree in mechanical engineering, with interest and experience in design engineering, including projects in private industry. He has secretarial help, as well as guidance and assistance from the project Director and the Chairman of the Department of Physical Medicine and Rehabilitation. General guidance for the Service is obtained from an Advisory Board, meeting quarterly and consisting of members from the Department of PM&R, the California State Department of Rehabilitation, and the consumer group, Services to Handicapped Students, on the Davis campus. Advice is obtained also in discussions at some of the monthly meetings of the Consortium of Rehabilitation Engineering Service Providers, which meets monthly in Sacramento and consists of representatives from the California State Department of Rehabilitation (rehabilitation engineers, vocational rehabilitation counselors, and others), the Rehabilitation Engineering Service at U.C. Davis, the Assistive Device Center at California State University, Sacramento, some consumer groups such as Resources for Independent Living (Sacramento) and United Cerebral Palsy of Sacramento-Yolo Counties, and a few others.

APPROACH AND FACILITIES

Our approach is that of problem solving, a standard engineering approach. The first step of course is problem definition. We emphasize that it is very important to listen, to ask questions, to get information. Several times we have come apparently to the end of a discussion, when it seems that the problem is clear, but then an off-hand remark by the client or by a family member has changed the whole perspective - indicated future plans, or changed the boundary conditions. The plan for solving the problem must incorporate

this information also. The temptation to start designing as the client starts talking must be vigorously resisted!

When the problem is clearly defined - what are the goals and what are the present limitations of the client - then a solution may be developed. It makes sense to us, so we assume everyone has the same common sense, to see first if some change in the activities of the client - the way he or she does things - can aid in the solution. Training by a therapist, teacher, or other person may be useful. Our resources include in our own Department at the UCD Medical Center in Sacramento, physical, occupational, and speech therapies, orthotics, and psychological, social, and vocational counseling. Sometimes a therapist or teacher is already associated with the client, and can be used in the plan.

If such a modification of behavior is insufficient (and often we see clients only after such modifications have been tried and found unsatisfactory), then is there a suitable device commercially available? To answer this it is important to have a well developed library or collection of catalogs and other manufacturers' and distributors' literature, with up-to-date price lists. We set up such a library in our Device Development Laboratory.

If there is no device commercially available, is there one which can be modified to do the job necessary? If not, then one must be custom designed and built. In these cases shop facilities are needed. For flexibility and quick turnaround time, we set up in the approximately 1200 square feet of our Device Development Laboratory on the Davis campus, facilities wherein we can do mechanical and electronic fabrication ourselves.

PROJECTS

Most of our 46 projects have been with problems in independent living at work, home, or school, in vocational needs, or in transportation by van, auto, or wheelchair. We go to the location of the problem, of course, in order to develop a realistic evaluation of the situation. This is quite important.

Work site problems have involved accessibility, modifications of the work situation, or equipment modifications. In one project, a clear Plexiglass top for a light table for drafting was developed at our Laboratory for a young man with one paralyzed arm. The top enabled him to do the precision work required, and avoided the need to buy an entire new and expensive drafting table. This saved money for the paying agency.

In another, a fork lift operator had injured his back, and the rough ride from the lift vibration caused almost unbearable pain. He could work only very short periods. The fork lift was modified to incorporate a commercially available shock reducing mounting for the seat. This modification enabled him to resume working a normal work period and so to keep his job.

A woman with a progressive muscle disease needed more independent living; less demands on an attendant, and safer procedures in her home. She is quadriplegic, with no use of her upper extremities. A hospital bed desk system was developed at our Laboratory. With a mouth stick, she can now do typing and page turning, and with a Sears Environmental Control Center her home safety is greatly increased, as well as her independence and comfort.

Another home problem involved primarily lifting. With the parents doing it, they were increasingly liable to back injuries. The girl, with cerebral palsy, needed to be lifted in and out of the bathtub, on and off the commode, and to be lifted and held for dressing. The bathroom was too narrow for a commercial bath lift to be operated safely. An overhead lift with a rail was developed at our Laboratory and installed. To hold her vertical for dressing, a special sling was designed and built by our orthotist.

Some solutions seem as simple as a ramp, but its shape and location has to be considered carefully. Or as simple as a lap tray for a wheelchair - but one young man had a problem from his distorted position, high knees, the need to see through the tray while driving his wheelchair, and his very limited motions used for control of the chair.

For a school child, a custom designed feeder was developed in our Laboratory, which gives him complete independence in feeding himself, unlike commercially available feeders. He can select each bite from the plate. In addition, the device can be taken apart and carried in a knapsack; it is quite portable.

SERVICE PROCEDURES

Table 1 outlines the sequence of our services. When a client is about to be referred to us, an initial quick case review (no charge), frequently by telephone, enables us to decide whether to accept the case or to refer it elsewhere. After written authorization from the paying party we make (for a stated charge) an initial evaluation and submit a report, summarizing the problem and the proposed solution or solutions, with estimated costs. When written authorization to proceed with the solution (or selected parts) is received, we then proceed with the work proposed.

This we find is a good scheme. There are two places where the procedure can be stopped by the purchaser of our services, so we do not cause embarrassment by going ahead and starting something, and then being told to stop. We attempted to use also a third step, authorization for follow-up of the service. But once a client has received something, the paying agency is reluctant to spend more money for follow-up. We

consider it important, and fit in visits as best we can among other activities in that geographic area, even without payment, and also we get feedback by telephone.

FINANCIAL PROCEDURES

Establishing a fee schedule turned out to be quite a headache. Discussions with others in rehabilitation engineering and especially with members of the Consortium meeting in Sacramento were very helpful, both in defining how to group activities into services offered, and in deciding what actual charges to set. An even greater and continuing headache was generated by the complexity of the University and the Medical Center billing and accounting procedures, the novelty of our needs for this project, the complexities of the Department of Rehabilitation accounting requirements and the variety of accounting and paying procedures among the variety of paying sources we worked with. But after a year or so most of these problems were worked out, and before the end of the project, payments were beginning to come to us through the financial pipeline.

CONCLUSIONS

At the time of writing this summary, only a preliminary survey of our experience has been made. We did show a need for this kind of technical services, and a gradual acceptance by consumers and third party payers. Our time of existence was too short to determine whether or not this kind of service can be financially self-supporting. We are agreed that it is not feasible to operate this kind of Service with only one person, the engineer, generating income for it. Some "critical mass" of personnel must be reached, and some volume of billable work must be regularly generated in order to cover the costs of his professional activities, and the technical (device fabrication), and secretarial services. Our next step would have been to add a technician to do the device fabrication, freeing the engineer to spend a higher proportion of his time in the professional evaluation and design activities (charged at higher rates). Other conclusions may be suggested by further evaluation of our experience.

TABLE 1

Sequence of Services Offered

Case Review

Initial Evaluation

Preliminary Design

Evaluation Report and Recommendations

Device Development

Fitting of Device (or other Solution of Problem)

Final Report

Follow-Up

REHABILITATION ENGINEERING TRAINING - A CLINICAL APPROACH

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ABSTRACT

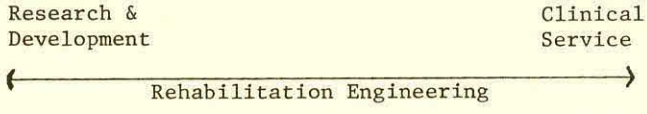
Clinical rehabilitation engineering service have been demonstrably successful. The need for trained engineers to supply these services is increasing. The program described here is one approach to providing engineers with practical, clinical experience. It also describes an alternative consortium approach that could be used for training as well as building or coordinating a services network.

INTRODUCTION

Rehabilitation Engineering is a relatively new field, with formal education and training programs still in the developmental stages. Current concensus and effort in this area focus on the belief that a rehabilitation engineer should first be a good engineer, and then should effect the transfer and application of academic education and professional experience to the clinical setting (1). The Rehabilitation Engineering Clinical Internship was established at the Rehabilitation Engineering Center at Children's hospital at Stanford in 1979 to facilitate the clinical education and experience of engineers wishing to enter the field of rehabilitation engineering.

CLINICAL REHABILITATION ENGINEERING

Rehabilitation Engineering can be seen as a continuum of effort:



The past ten to fifteen years has brought a rapid expansion in the quantity and quality of the technology available for application in rehabilitation. The development of more effective devices and the increased sophistication of both technology users and providers has encouraged the clinical provision of devices on a much larger scale. Rehabilitation engineering now has both the supply (of technology and the (consumer) demand for clinical services to be a feasible self-supporting endeavor (2).

As research is able to spinoff more of its effort into active clinical services, the need for clinically trained engineers increases. Current practioners have worked predominantly in research and demonstration efforts. They developed their clinical expertise over many years of necessarily limited involvement with active clinical populations. The new breed of clinical rehabilitation engineer is more likely to be a daily clinician, with less time or effort spent on the R&D side of the continuum. These rehabilitation Engineers will be consumers of R&D effort, and will give the more research oriented engineers a place to send their developments for use and evaluation. Clinical rehabilitation engineering is "coming of age" after more than a decade of planning and preparation (3).

REHABILITATION ENGINEERING CLINICAL INTERNSHIP

In an attempt to meet the rehabilitation engineers need for clinical expertise, a training program was established at the REC to provide clinical experience in various and diverse aspects of rehabilitation engineering. The internship program begins each October and runs for twelve months. It is focused on patient contact in a wide variety of settings and services. It includes:

- Six months of clinical experience at the Rehabilitation Engineering Center, composed of
  one month - Seating/Mobility Service
  one month - Communication/Control Service
  one month - Tissue Trauma Service
  one month - Orthotics/Prosthetics Service
  one month - Special Projects Service
  one month - Gait Lab and survey of local research Programs
- Two months of hospital experience on a rehabilitation unit, composed of
  one month - Santa Clara Valley Medical Center San Jose
  one month - Ralph K. Davies Medical Center San Francisco
- Two months of community experience, composed of
  one month - under the direction of a rehabilitation engineer in private practice
  one month - Independent Living Programs Berkeley and San Francisco
- Two months special project. The last portion of the internship focuses on designing, developing and implementing a project in an area of special interest to the intern. Emphasis is on synthesizing the year's experience, tying together any loose ends and generalizing the

problem solving process involved in the effective delivery of rehabilitation technology.
Other areas covered in the program include:

- Orientation to the field of Rehabilitation Engineering local, national international.
- Information gathering and resource utilization
- Effective written and oral communication skills
- Medical aspects of disabilities
- Appropriate use of medical terminology
- Participation in a multidisciplinary team approach to problem solving, evaluation and treatment implementation
- The economics of rehabilitation engineering service - fee for service mechanisms, third party payment, etc.

The REC offers no formal didactic program. Emphasis is wholly on "hands on" clinical experience and field work. The program is flexible in format and every effort is made to tailor the internship to the individual experience and needs of each participant. Interns take an active role in planning their programs. The engineers selected are self-initiating and highly flexible.

BENEFITS

The engineer is employed as a full time staff member of the REC, with a salary commensurate to a Stanford University research assistant. The status of "clinical intern", however, provides the engineer with the benefit of being identified as a learner. The person is not expected to be an instant expert; he/she can be an observer before being expected to perform autonomously. The intern is rewarded for asking questions, not thought less professional for doing so. The intern learns the role of a clinical rehabilitation engineer, learns to interface with service providers and with service recipients.

This experience has shown to be a two way street. Other rehabilitation professionals and consumers come to understand more clearly what rehabilitation engineers can do for them, and how and when to include the engineer as a team member or consultant. The community learns to use rehabilitation engineers effectively and jobs are generated. An example of this is a rehabilitation facility which, after participating in the rehabilitation engineering training program, has written a rehabilitation engineer into their next budget proposal. They have had in-house technical support for several years, but the presence of a rehabilitation engineer for a month field placement, helped them recognize the benefit and cost effectiveness of supporting their own in-house clinical rehabilitation engineer.

PROGRAM DEVELOPMENT AND ALTERNATIVES

Other REC's have shown interest in establishing training programs similar to this one. There also has been discussion about rotating interns among Rehabilitation Engineering Centers. Programs will hopefully develop which will remain responsive to the needs of their geographic area.

The San Francisco Bay Area is a resource rich area for rehabilitation engineering. Children's Hospital at Stanford, besides having these many resources available, has the added benefit of having a Rehabilitation Engineering Center that was founded as service center. With over six years of diversified service delivery history, the REC is able to offer clinical exposure in a broad range of experience under one roof.

In settings where this is not possible, a consortium program could be arranged with a two-fold purpose: (1) to provide clinical training for rehabilitation engineers and (2) to link together specialized community programs into a coordinated rehabilitation engineering network.

As proposed a Rehabilitation Engineering Center would take the lead, acting in a coordination /facilitation role. The focus on training engineers could create non-competitive momentum for cooperative comprehensive rehabilitation engineering services within a given geographic target area.

This type of program, to be effective, must emcompass the broadest possible continuum of clinical experience. It is important for the engineer to understand the environment and the people he/she is designing for: to understand the physical, environmental and psychological impact of the different disabilities; the implications of being disabled in an institution and in living independently; the effect a technological solution will have on varied lifestyles.

It is especially important in any program established along these lines to include experience in working with all ages. Disabled children grow up to be disabled adults; and disability is much more prevalent in the elderly than any other age group. The needs of children, especially the application of technology to the education of the handicapped child, have been repeatedly stressed (4-5). The experience of the Veteran's Administration, and demographic trends should alert us to learning to meet the needs of older people.

FUTURE DIRECTIONS

The program described here is an interim solution. Until formal programs are regularized and certified by an organization such as Rehabilitation Engineering Society of North America, it provides immediate training at a grass roots, practical level at a time when such training is clearly required. It is a developing program.

Two possible directions the program may take are a

(I) Master's Degree in Engineering from Stanford University. Combining one year of clinical experience with one year of academic work tailored to the needs of the clinical specialist, this program would be more similar to the University of Virginia's program (6).

After the long range programs are developed and refined, it could also evolve an

(II) Apprenticeship program. Providing a transition path into clinical rehabilitation engineering for professionals and technicians. This would be composed of two separate tracks. It would be an entry point for people changing careers.

Clinical training programs are needed in more places around the country. Their development will serve to build a network of clinical expertise that can be utilized and exchanged locally, regionally and nationally. It could also integrate local

geographic services and, most importantly, provide a promise of quality rehabilitation engineering services within a reasonable distance wherever a disabled person lives.

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ACKNOWLEDGEMENT

This program is supported by National Institute of Handicapped Research Grant # G008005817 under the Department of Education.

REHABILITATION ENGINEERING AT DUKE UNIVERSITY

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Dr. Timothy Hight
Assistant Professor

North Carolina Division of Vocational Rehabilitation
And Duke University

A mechanical engineering design course at Duke University, in which junior or senior students are exposed to real life handicapping conditions, is described and its effects evaluated from several viewpoints. A comparison is made between this course and similar ones in other educational settings. Projects are submitted to the class by the North Carolina Division of Vocational Rehabilitation through the Rehabilitation Engineer. Interaction occurs between the students and the engineer as well as with clients of the agency. Benefits of this course structure are perceived from the standpoint of Vocational Rehabilitation clients, the agency itself, and the students.

Finally, three examples of student projects are described in text and drawings: a jar opener, a door closer, and a camera mount for wheelchair users.

A UNIQUE DESIGN COURSE

The application of undergraduate design coursework to rehabilitation engineering projects has been in effect at Duke University for several years. Under the direction of Dr. Timothy Hight, Assistant Professor of Mechanical Engineering, the students in his design classes are encouraged to select from among problems presented by several rehabilitation and patient care agencies and institutions.

The design course (ME 141) is required for mechanical engineering students in their junior or senior year. The students study the design process, stimulation of creativity, and various mechanical components throughout the course and utilize this background during a semester long design project. Groups of three to six students choose between a variety of potential projects based on a brief description of the design problem. The course culminates in a formal written report and a public presentation of the design.

The course differs from similar projects in other universities in two important ways. First, few schools have an emphasis on rehabilitation engineering projects within a mechanical engineering design course. We have found the students very receptive to these projects and the scope and complexity of the problems are well suited to the background and time constraints of the course.

Second, and most significant, is the involvement of undergraduates in projects with direct client contact. This contact reinforces the need and reality aspects of the projects, provides direct feedback on design ideas, and greatly increases the feeling of accomplishment and relevance for the students.

Vocational Rehabilitation Connection

A significant number of projects are presented each semester by one of the North Carolina Vocational Rehabilitation Engineers. They are derived from problems reported by clients, counselors, or from the engineers' own experience. Whenever possible, students receive an opportunity to meet with clients, who serve both as consultants and a data resource in the design process. The engineer meets with the students, encouraging them to take advantage of their client interviews to obtain relevant data and to focus on problem definition.

Client Response. In every case, our clients have demonstrated deep interest in the students and appreciation for their involvement. The clients perceive the program as a positive contribution from Vocational Rehabilitation although they recognize that this involvement is "extra-curricular" on the part of the agency.

Student response. As discussed above, student response has been gratifying. We feel that their exposure to real life examples of severe physical limitations, and the participation in their reduction, developes insights of lasting value. Will the experience influence vocational decisions among these students? Perhaps a study will some day answer the question.

Agency response. Through the involvement of the agency Rehabilitation Engineer, we are able to provide the students with information and resources pertaining to current technology for their projects. This is an important avenue of information dissemination, not to mention the

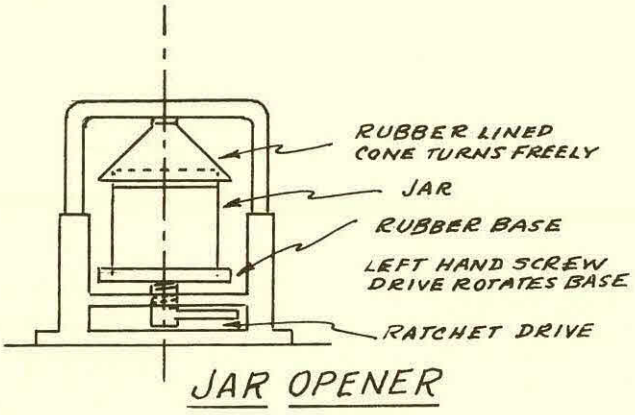
effect on project results.

The program provides the agency with an avenue for legitimately addressing some of the non-vocational needs of its clients without compromising the integrity of its vocational mandate. Further, it contributes to their feelings of self-approval by permitting them to interact as consultants and active participants in the rehabilitation process.

There is, of course, the possibility of more concrete results in the form of useful designs. Indeed, some projects have addressed important areas in need of development, such as wheelchair driver restraint systems.

THREE PROJECTS

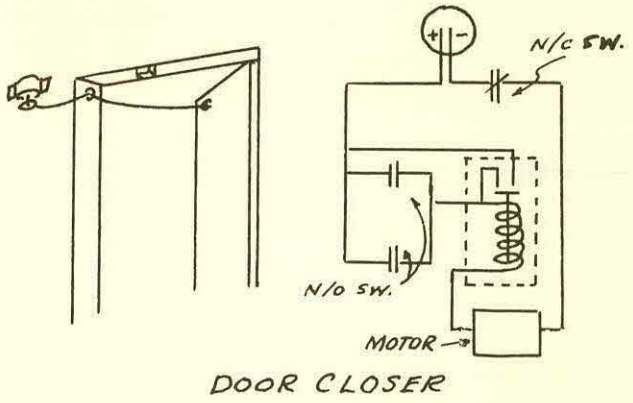
While the projects suggested by other agencies are generally quite specific, Vocational Rehabilitation encourages the students to design for the broadest possible population, even when the project originates from a specific case. Adaptability, adjustability, and broad anthropometric tolerances are suggested. Some projects are designed for the market place, and some for industrial application. Three representative projects are described below.



Jar Opener - For the Marketplace

A client reported that commercially available jar opening devices do not function well for him. Among the design objectives selected by the students were, 1) Easy to construct and inexpensive to manufacture. 2) Low strength and dexterity demand, 3) Adaptable to average kitchen environment.

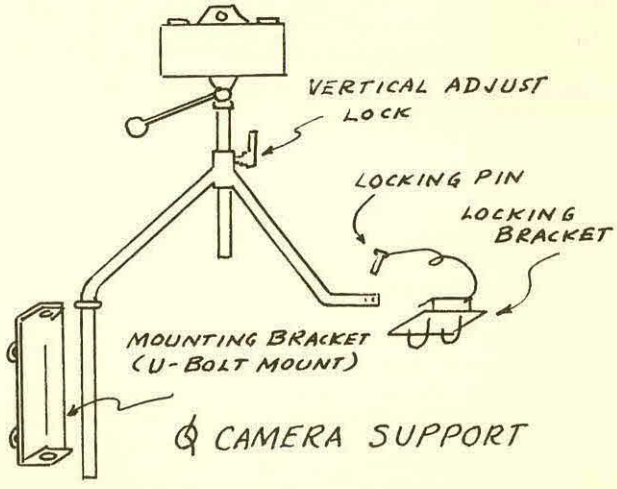
The resulting design consists of a rubber lined cone suspended over a circular rubber base which is rotated and compressed against the jar by means of a screw/rachet-lever system. The gross height of the system is adjustable by means of a telescoping tubular support. Variations in jar top diameter are accommodated by the conical shape of the upper component. The group fabricated a working model using wood and other common materials. It did not work perfectly, but demonstrated clearly that the design is valid and commercially feasible.



Door Closer - Another Marketplace Item

Automatic door opening systems are too expensive for most homeowners, and somewhat overdesigned for interior residential doors. A request was submitted for a design which would exert little resistance when pushing the door open yet exert sufficient positive force to close the door effectively.

In their "Introduction of Problem" the students established that the device should be "without....resistance when the door is opened ....installed easily on a conventional door.... esthetically pleasing....and as inexpensive as possible". The resulting device utilizes a small electric motor which functions as a take-up reel acting to draw the door closed by winding up a spool of string. Resistance to unwinding was very slight, and the necessary positive action is established by means of floor-pad microswitches and a relay. A small working model was fabricated and functioned perfectly.



Camera Mount for a Wheelchair - Recreational

This project was suggested by a quadriplegic client who wished to recapture the pleasure of photography, his hobby before the accident. The students presented an excellent summary of the client's physical capacities, including pinch strength of 2 lbs. The following design criteria were selected:

1. Structure must attach only to wheelchair.
2. Must be removable and leave no holes.
3. Light weight.
4. Provide 4 types of camera movement.
5. Non-interfering when left on chair.
6. Simple (easy to fabricate).
7. Maintenance free and reliable.
8. Minimum cost.
9. Rigid.

It is interesting to read the students' report of the design proposals considered and discarded, including a Luxo-Lamp arm, ball-bearing feeder, and table type support. The final design is a "bipod" ingeniously locked to the wheelchair arms. It can be released to pivot out of the way by pulling a pin. Vertical adjustment was achieved by means of a telescoping rod, while the other three movements were solved by incorporating a conventional pan-head tripod attachment.

The students fabricated this device from 3/4" electrical conduit and angle iron, and presented it to the client for his personal use.

Conclusion. The success of this type of program depends upon the motivation of the educator to include rehabilitation in his engineering curriculum and the availability of meaningful, client related projects in the surrounding community. At Duke University, the involvement of a service delivery rehabilitation engineer is making a significant contribution to its success.

A SHAPEABLE MATRIX FOR SEATING DISABLED CHILDREN

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Abstract

A mass producable custom fitted support surface for disabled children is presented. The system consists of a two dimensional matrix of modules strung on stainless steel wire. After shaping the matrix to the child the wires are tensioned to lock the matrix in its configuration. The seat is produced external to the clinical setting. One to two hours are required for fitting and final adjustments. The seat can easily be adjusted as the child grows and develops. All desired shapes have been obtained. It is expected that these seats can be fitted at isolated facilities by therapists and technicians who have recieved minor training.

Introduction

The results of improper positioning and supporting of disabled children are well known. They include nonoptimal development of neurological and psycological attributes as well as development of physical deformities. Improper seating is not due to lack of knowledge or technical expertise but due to the monetary and time cost of production. Efforts have been made in the development of systems that eliminate the time constraints, (1,2,3). These systems require specialized facilities for production which limits their clinical application. Modular seating bridges the production inadequacies but does not provide the intimate fit necessary for the serverely disabled. In light of this our emphasis has been in the development of a support surface which can be mass produced while providing a custom surface tailored to the needs of the individual. Our efforts with this conception were not initially in seating, they were originally oriented towards other aspects of orthotics and prosthetics. In 1978 the concept of applying an adjustable surface to seating was initiated clincally by Steve Cousins, (4). This system consisted of a matrix of balls and cylinders strung on stainless steel wire. The matrix could be formed to fit the needs of the child in question then locked by tensioning the wire. This matrix was upholstered by 1/4 inch thick shock absorbing foam and inserted in an adjustable frame. Improvements to the original design have now been completed.

The Design

The present matrix consists of a single module which plugs into neighbouring modules identical to itself.

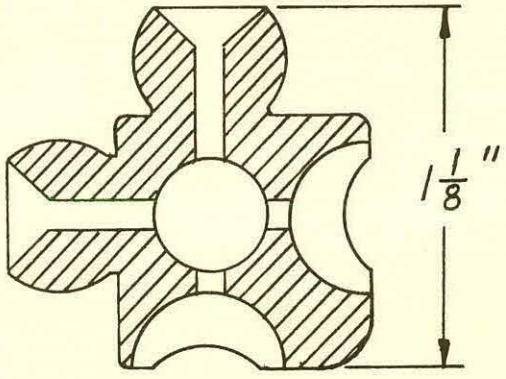

Figure 1: Cross section of module.

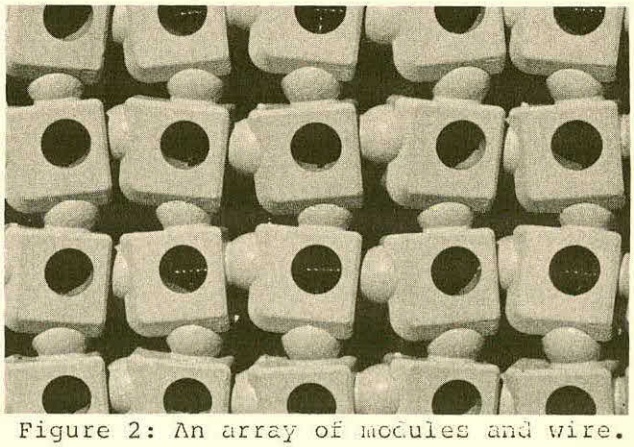

Figure 2: An array of modules and wire.

As in the original matrix stainless steel wire runs through the matrix in two directions. The wire is anchored at one end by a crimped sleeve. At the other end a reversible clamp is used.

Presently we are using an adjustable frame to hold the matricies. The frame

members telescope to accommodate different sizes. After fitting the seat the clamps and ends of the wire are covered by split polyvinal tubing. In this form the matrix provides a sufficient surface such that additional padding is not necessary. The headrest and abduction pommel may be included in the matrix or left separate.

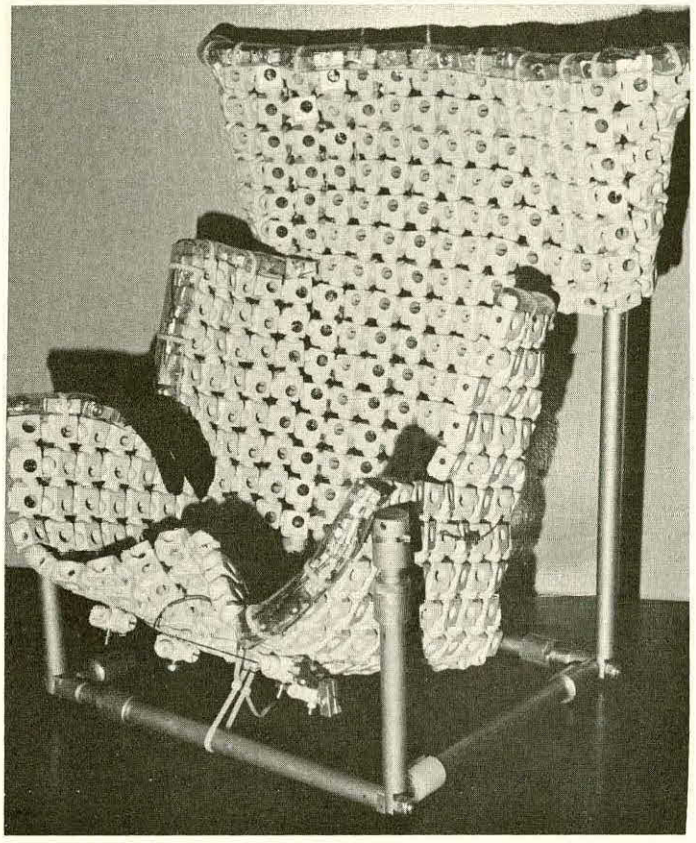

Figure 3: The finished seat.

Fitting the Seat

The matricies are manufactured in various sizes. The size for each child is dependent on his hip width, his upper leg length and the height of his axilla. Adjustments can be made to the dimensions of the matrix if necessary by adding or removing modules.

When the chosen matrix is mounted in the adjustable frame it is ready to be fitted to the child. The fitting procedure involves shaping the matrix to intimately fit the child, then altering the matrix to provide any desired position modifications. With a moderate amount of tension on the wires the matrix will hold the child for short periods of time without deforming while at the same time permitting the matrix to be shaped by hand. In this manner any inconsistancies can easily be determined with the child in the seat. The alterations are made when the child is taken out. To insure the fit is optimal pressure measurements are taken at the coccyx, the left and right ischia, and the sacrum. The optimal situation is taken as that with an even distribution of pressure over these four areas. Approximately 15 minutes is necessary to obtain an intimate fit. Once this is obtained any desired positional modifications may be made. This usually takes approximately 30 minutes. Decisions are made at this time in collaboration with the therapist. Modifications that have been made include:

- protraction of the shoulders
- extension of the lumbar region of the spine
- forward flection of the head
- alteration of seat-floor and seat-back angles.

Any modifications made at this time are not final. In fact, in most instances alterations are requested 2 or 3 weeks later. With this system these alterations are simple and quick to perform.

When the shape of the matrix is determined the wires are tightened to lock the matrix in its given configuration. This process involves stretching the wire then tightening the clamp to hold it. The average number of wires is 65, they take approximately 15 minutes to tension.

Next, split polyvinal tubing is inserted over the loose ends of the wires and the clamps to confine their sharp edges.

The last step is to apply strapping to meet the individuals needs. The strapping easily attaches to the matrix modules.

The entire procedure takes one person anywhere from one to two hours; this is dependent on the patient and his needs.

Results

The first question to be raised is: how long will the matrix hold its shape? The older version held its shape for 6 to 8 months which was sufficient. After this period changes were necessary to accommidate growth and developmental changes of the children. The expected stability span of the present model is double that of the earlier version. The life time of the seats is unknown. They can be altered and changed continually as the child grows and develops. When the child has ultimately outgrown the matrix, which is expected to be two years or longer, the seat may be handed down to a smaller child or it may be dismantaled for parts.

Of the 9 children fitted with the earlier model only one presented problems. The child had a gross hip obliquity, a large leg length discrepancy and she had frequent strong extensor spasms. Modifications were necessary to the ball and cylinder structure to accommidate her deformity. With the present system these modifications to accommidate lack of symmetry are made inherent within the system. The childs extensor spasms pushed the seat out of shape by collapsing the abductor pommel therefore increaseing the seat-back angle. Ultimately this was solved by supporting under the seat front. A new frame for the matrix supports this area thus eliminating the problem.

In the original model the upholstery presented a problem. It became dirty. The main soiling element was food that had been dropped then rubbed into the upholstery. With time the foam cover became ragged in appearance and began to smell terrible. This was the most negative aspect of the entire seat. In the present system we have eliminated the upholstery. The matrix is washable; its appearance can easily be kept up and hopefully the smell kept down. If not, a simple covering may be necessary to keep the matrix clean. The cover could either be washable or disposable.

Clinical results have been most favorable. There has not been any problem with tissue breakdown on any of the children seated to date. The children have all been positioned as desired. In all instances no compromises were necessary. Therapists, physicians, and parents have been enthusiastic about the results. This is to be expected since the children fitted have gone from poor or no seating to propor positioning and support. At present no monitoring of the development of scoliosis has been attempted.

Discussion

There has been no direct comparision studies between the shapeable matrix and other seating systems. The purpose behind the development of the shapeable matrix was primarily to reduce the time delay in receiving proper seating. This has the added attraction of increasing the supply of seating to the younger and less affected children who have not yet developed spinal and other deformities. With proper support their development may be optimized. To meet this goal we are presently seating 50 children in the Vancouver area. To do this manufacturing and distributing capabilities have been established. The components are mass produced and the matricies are assembled to fit the rough dimensions of the individual children. This is done by a private firm separate of the clinical operation.

Each seat requires approximately three hours of the clinical technician's time. The children are not seen prior to fitting the seats. The measurements necessary to order the seat are taken by the therapist. The technician may spend up to an hour to prepare the seat for the fitting then up to two hours to fit the seat. After 6 to 12 months another two hours for adjustment will increase the life span of the seat a further 6 to 12 months. The small amount of time the technician must spend with each seat greatly reduces its cost.

A great advantage of this system is that changes in the position or support of the child can easily be made after the initial fitting. Often the original position given the seated child is seen to be less than optimal after 2 or 3 weeks of observation. To make changes at this time is simple and quick.

Fitting and adjusting the matrix is not complicated. It is foreseen that therapists and other clinical or technical staff would be able to fit the seats after receiving adequate instruction. Seats could be ordered from a central manufacturing firm then fitted in the various clinical institutions regardless of their facilities.

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MODULAR PLASTIC INSERT FOR PHYSICALLY DISABLED CHILDREN

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ABSTRACT

The development of a modular plastic seating system to accommodate the needs of physically disabled children in the age range of 1-8 has enabled the Center for Adaptive Rehabilitation Engineering (C.A.R.E.) to provide a more efficient seating program to our clients.

INTRODUCTION

This paper is intended to outline the criteria necessary to the design and development of a postural seating system for physically disabled children in the general age range of 1-8 years. This age grouping could be considered the most dynamic and progressive age bracket in the human life cycle, thus, requiring the establishment of unique criteria. The following list of factors are considered to be important issues in the development of postural seating for this age group.

1. Growth - according to Diffrient et al (1974), at age 2, the child has reached about one-half the adult standing height. In designing seating for children, adjustability should be provided to accommodate the rapid growth of children as well as the variations above and below the average human factors data.

2. The seating system must be responsive to unique individual needs and abilities of the child and is intended to be an integral part of a total rehabilitation program.

3. Young children are traditionally involved in a variety of daily environments and educational placements. The typical classroom activities of infant programs, pre-kindergarten, and kindergarten, require the designed seating to be adaptable to a variety of play, feeding, and group interaction activities.

4. The seating system must also accommodate the needs of parents, teachers and therapists who assume the responsibility of secondary users; for example, these secondary users may be involved in transfer situations of both child and seat insert.

5. Many children engage in play and socialization at floor level. The seat insert must be capable of floor placement and tray attachment. Refer to Figure 3.

6. The seat insert must be designed in a straight forward manner, in order to reduce cost, allow for modifications of the original configuration, and make construction technologically incomplicated. Refer to Figures 3 & 5.

Our experiences in seating young children at the Center for Adaptive Rehabilitation Engineering (C.A.R.E.) has led to the development of a modular plastic seating system.

Insert Shell

The insert shell is constructed from 3/16" thick thermoformable kydex plastic. The seat and back are formed from a flat sheet by utilizing a simple wooden mold and a hot air gun or strip bender to obtain the four right angle bends to complete the back and seat shells. Once the seat and back are formed, they are joined together with two high density polyethelene blocks. The polyethelene blocks also serve as the tray supports. It should be pointed out that because the seat and back shell components have been designed as separate entities, they can be provided independently from each other. This separation of seat and back shells also allows for increases in seat depth, back height and angle relationship by changing the position and size of the polyethylene joining blocks. Refer to Figures 1, 4, 5.

Foam Components

Postural positioning is accomplished through the foam components which are built to measurements taken during the client's seating assessment. The seat foam component can be provided with a contoured wave formation seat or removable abduction pommell to facilitate a good base of support. The seat can also provide varying amounts of hip flexion. The back foam component(s) give excellent anterior protection capabilities in order to provide lateral trunk support. Several inserts have been produced with the ability to separate the insert at the top of the laterals to reduce the amount of support

being provided. Refer to Figure 3.

The Tray

The tray that is provided with the insert is surfaced with formica and can be washed to remove food, paint, glue and other substances that young children use. Attachment of the tray directly to the insert allows for its utilization outside of the mobility base. Postural positioning may be enhanced through the correct positioning of the tray. Many physically disabled children may be communicatively impaired and may use the tray as a communication aid to display pictures, symbols or alpha numeric information. Refer to Figure 1.

Covering Material

The material used to cover the foam components of the insert must be urine resistant, easily cleaned with common household products, and provide surface friction to enhance postural positioning. Most of the inserts that have been provided to date have utilized the traditional sewn vinyl approach. In order to reduce the construction time and increase the ability to cover complex curves, we have begun to use a sprayed vinyl coating, tumble forms™.

Other Options

Pelvic strapping, shoulder strapping, and a security strap attached to the back of the insert to enable placement of the insert into more typical chairs all have been provided to meet the needs of the client. In addition, adjustable headrests, adjustable footrests, and anti-tipping bases are available. Refer to Figures 1, 2, 3.

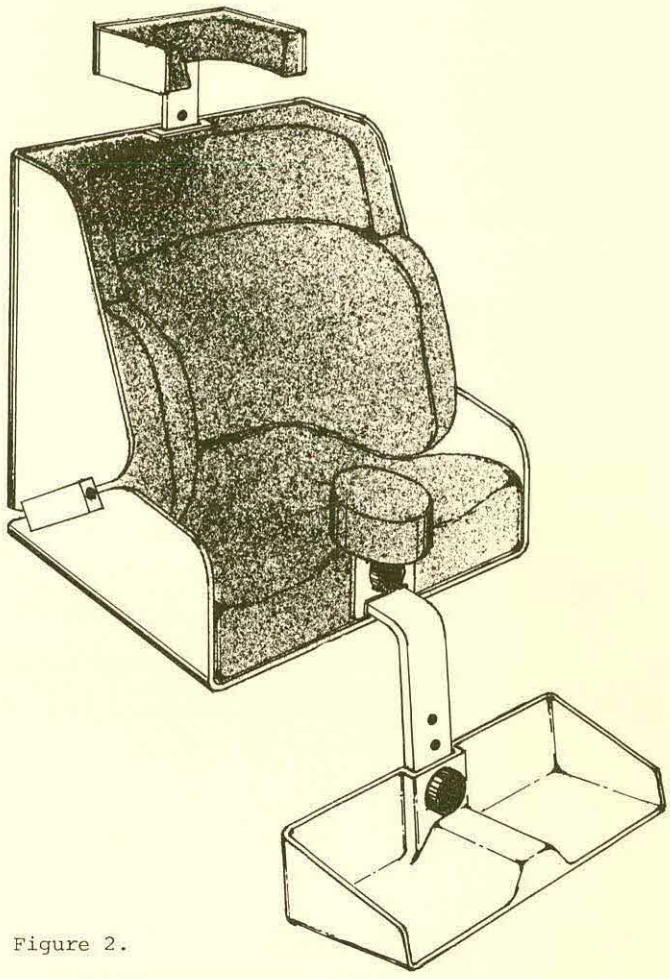
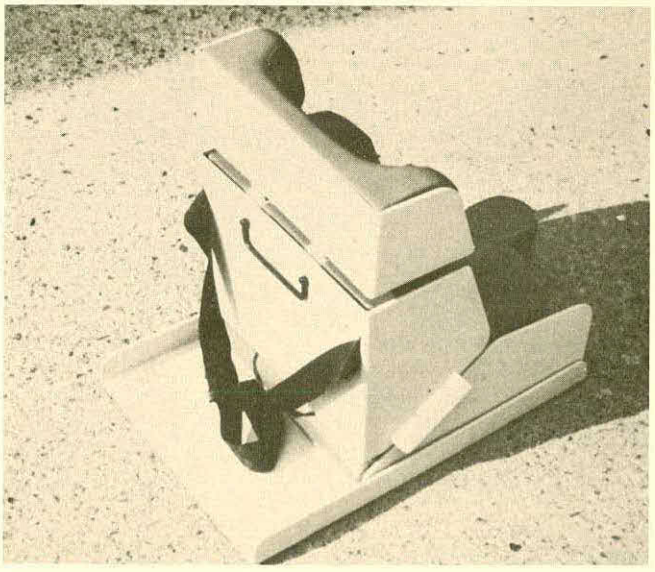


Figure 2.

Figure 1.

Figure 3.



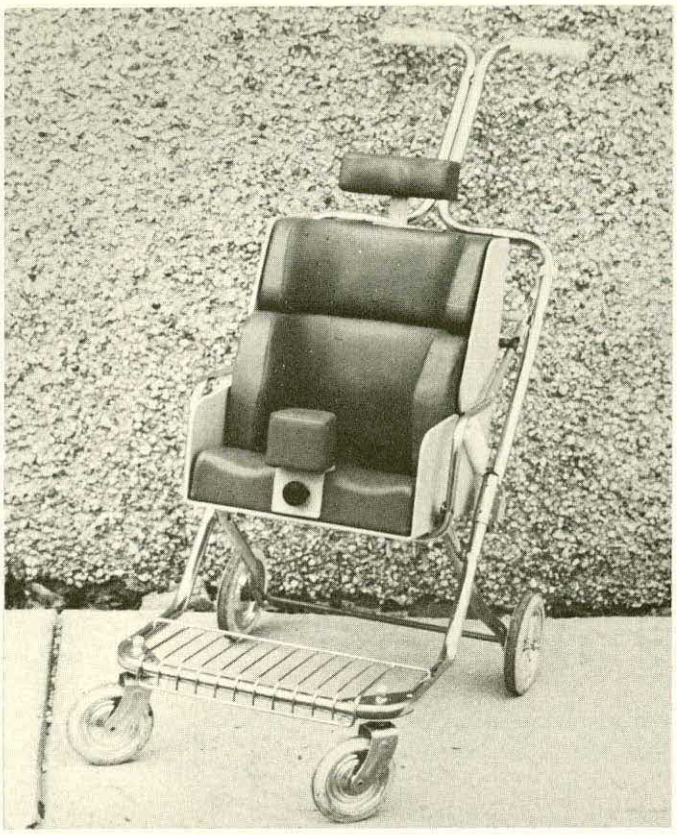
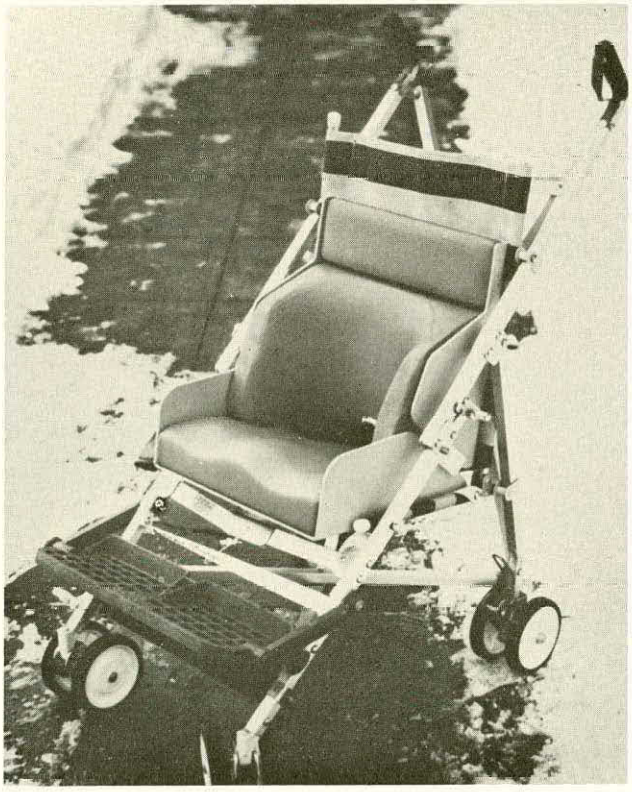


Figure 4.

Figure 5.



CONCLUSION

The Center for Adaptive Rehabilitation Engineering (C.A.R.E.) has provided 27 modular plastic inserts for physically disabled children. In evaluating the feedback from parents, therapists, educators and follow-up assessments, we feel that we have succeeded in meeting our design objectives. The C.A.R.E. Program is presently in the process of refining the modular plastic insert in its present state as well as researching new materials and processes to permit expansion of the user population.

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A PIVOTING HEADREST TO ENHANCE THE COMMUNICATION ABILITIES OF A SEVERELY DISABLED PERSON

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ABSTRACT

A cerebral palsy woman who is supported by a wheelchair in the reclined position requires a headrest for support while permitting rotation of her head through two degrees of freedom. As a result of her disability she has no functional speech. Her present headrest provides several important constraints which affect her comfort and communication. As a consequence of these problems a headrest has been designed which provides comfort and full support of the head and neck while still permitting the head to pivot with minimal resistance. The headrest incorporates a four bar linkage system with spherical bearings. The benefits gained by the individual include improved comfort, increased communication abilities and enhanced body image. The design has been developed for an individual application but it is hoped that this design can be applied to other situations.

INTRODUCTION

A cerebral palsy woman is confined to a wheelchair during the day. She has no functional control of her trunk and extremities and only limited control of her neck and facial muscles. She has good eye control but no functional speech. Her disability and functional deformity are such that she requires support in a reclined position using a total contact seat insert. The only support separate from the insert is an airbag headrest.

Presently she has two methods of communication. One is to indicate yes or no by movement of her eyes in response to questions. A more sophisticated communication system consists of directing a light beam at bliss symbols which are on a board mounted in front of her. A high intensity light is mounted on a cyclists helmet worn on the head. She directs the light at the bliss board by rotating her head within the headrest.

The above situation presents the following problems:

1. There is irritation of the skin on and around the ears due to rubbing between the head and headrest. The skin is red in colour, there is some swelling, and the area is sensitive to touch.

2. Head movement is difficult for the patient and movements are somewhat jerky in nature. Her neck muscles are too weak to maintain smooth and continuous rotation of the head. An additional contributing factor to resist head movement is friction caused by the headrest and head interface. These two factors, difficult and jerky movement, greatly reduce the ability of the patient to center the light beam on the desired bliss symbols.

3. Interference between the headrest and head interface separated by the helmet, decreases the stability of the light source. This causes some difficulty with accurately directing the light at a particular bliss symbol.

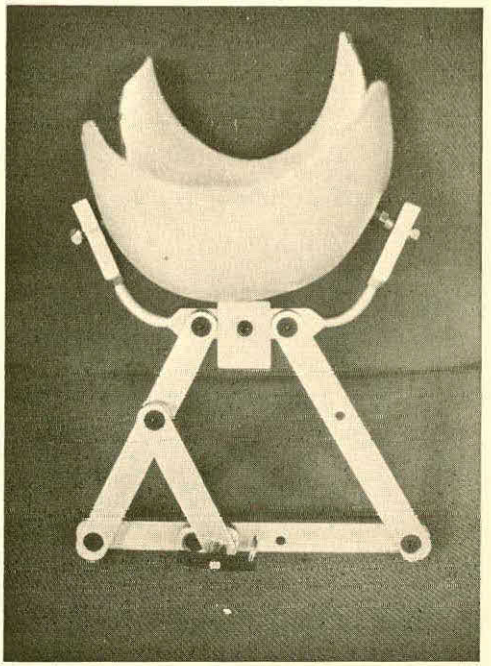

Figure 1: Top view of Headrest Assembly

OBJECTIVES

The objective of the project was to design a headrest that will provide full support of the head and neck while still allowing the head to pivot with minimal resistance to rotation, thereby eliminating the above problems.

For the health and comfort of the patient, irritation to the skin must be eliminated. Therefore movement between the headrest and head must be overcome.

In order to permit smooth and continuous rotation, resistance to rotation must be minimized.

To increase the stability of the light source the light must be mounted in such a way that it will not interfere with head movements while accurately following the movements of the head.

CRITERIA

The objectives outlined were determined as the principle criteria applied to the project. In addition, the following criteria were also included:

For safety of the patient during transport, a locking mechanism must be provided to maintain the headrest in a stable position.

To avoid over rotation of the head and possible injury to the patient, rotation stops must be incorporated at the functional limits for head movement. These stops will limit rotation in the transverse plane to 30 degrees on either side of the center position.

CONSTRAINTS

The following constraints have been imposed on the headrest design:

Attachment of the headrest to the wheelchair must not require modification to the wheelchair or seat insert.

The headrest must not restrict operation of the wheelchair.

The headrest locking mechanism must be simple to operate.

Materials used in construction of the headrest must not cause skin irritation.

The headrest must be easy to maintain and clean.

The headrest must not interfere with transfer of the patient into or out of the wheelchair.

The appearance of the headrest must be as attractive as possible without substituting for function.

The overall cost of development must be kept to a minimum.

The axis of rotation of the headrest must be located within the head.

The head must be secure in the headrest, eliminating the cyclists helmet.

The light source must accurately follow movements of the head.

PROCEDURE

Phase I

- Identify the Problem
- Define the Problem
- Search for Available Solution

PROJECT PROGRESSION

Phase II

- Generate Possible Solutions
- Evaluate Possible Solutions
- Choose Optimal Solution
- Model Optimal Solution
- Reevaluate Above Solution

Phase III

- Construct Prototype
- Clinical Trial Period
- Final Design Changes
- Construct Final Design
- Reporting

DISCUSSION

Several possible solutions to the problem were evaluated using a decision matrix according to the criteria and constraints previously outlined.

Results from the decision matrix were used to obtain the optimal solution for the problem from the possible methods evaluated. This solution incorporates a four bar linkage assembly as shown in figure 1. Component lengths for the side and base bars were determined from data which gave the least vertical displacement of the head during rotation in the transverse plane.

A plaster mold of the patients head was cast and from this mold a polypropelene interface was vacuum formed. This interface was used as the actual headrest. An insert was vacuum formed to fit the interface and provide padding for the head. The headrest interface was attached to the four bar linkage system utilizing spherical bearings mounted in ends of the yoke linkage on either side of the head. These bearings permit smooth and continuous rotation of the head in the sagittal plane. Rotation in the transverse plane is permited by the four bar linkage system. Bearings are located between each of the linkage bars to minimize resistance to rotation. According to the criteria, rotation in the transverse plane is limited to 30 degrees on either side of the center position by a polypropelene stop. For safety, a lock has been provided to maintain the headrest in a stable position during transport of the patient. This mechanism consists of a cross strut which locks the four linkage assembly in a neutral position. An adjustable ball and socket light mount is attached to the headrest interface to accommodate the light source.

The four bar linkage assembly is attached to the wheelchair by clamps between the base bar and the frame of the wheelchair. There are no modifications required to the wheelchair or seat insert and the four bar linkage assembly does not impair proper functioning and operation of the wheelchair.

CONCLUSION

The four bar linkage system has been evaluated through to the clinical trial period of Phase III. The system provides full support to the head while permitting rotation in the sagittal and transverse planes. Rotation is smooth and continuous in the sagittal plane with minimal resistance and

slight vertical displacement (¼-½ inch), in the transverse plane.

The single interface for the head has eliminated the need for the patient to wear the cyclists helmet while still providing an area for attachment of the light source. As a direct result, irritation to the skin around the ears has been overcome and stability of the light source has increased.

The four bar linkage system satisfies the criteria and constraints imposed on the project and meets the objectives of the design, providing comfort and increasing the communication abilities to the patient.

A RIGID URETHANE FOAM CONTOUR SEAT

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ABSTRACT

A technique for manufacturing customized seats, at a low cost and in a very short time is described. The system has evolved out of work on vacuum formed custom seating systems.

The seat described has a rigid urethane foam structure, with the working surface lined with a one inch polyethylene foam pad. It is formed with a cast of the user's contours. The seat weighs about two and one half pounds and requires no hardware to interface to a standard wheelchair.

Problems of durability, safety and appearance are addressed, as well as future plans for the system.

INTRODUCTION

The need for appropriate seating systems for severely disabled children and adults is widely recognized. The provision of an appropriate supporting system is felt to contribute to communication, use of extremities, self-image as well as aiding in the prevention of skin breakdown with its inherent complications, and the retardation of scoliosis and deformity. The level and diversity of activities in this area worldwide attest to the importance with which it is regarded.

Most customized seating systems which have been proposed and evaluated seem to share two major drawbacks, a high inherent cost, which does not show promise of being significantly reduced by a large volume of production, and a relatively long gestation period, from the time the decision to provide seating is made until the seat is provided. The latter seems to be most significant in the case of children whose growth rate limits the actual time that a given seat might be thought of as a correct fit. When the time between measurement (taken in a broad sense to include a casting or body impression process where this is the sizing technique) and delivery of the unit is a significant portion of the useful life of the seat, we have cause for serious concern.

This paper describes an approach we have developed to cope with these problems. Although still in the developmental stages in some respect, the process is currently in use with results we find most encouraging.

Our facility has been providing a molded contour seat for some time (1). This unit is manufactured using a combination of vacuum forming of foam, vinyl and ABS materials, and rigid urethane, expanded in place. The technique requires a considerable amount of hand finishing work, trimming, fitting of hardware for the interface, etc. There is a high cost associated with providing this device. One of our objectives is to reduce this cost as well as the inherent delays between the time of fitting and obtaining a body impression and the time the unit is finally delivered.

The unit described here addresses both these problems. It is provided at the time the client is fitted. The client leaves with this seat on his first visit. In addition, the labor and material costs are quite low compared to the provision of the seat we have been using.

The first seats of this type were made to cope with only one of these problems, the inordinate time delay. The objective was to make a seat which could be used as an interim unit until the finished product was ready. To do this we would need a very inexpensive unit. Such a system has been developed.

Although this design was not intended to reduce the total cost of providing a seat, but only the time lags involved, it has shown a durability far exceeding all expectations, and is now being studied as the preferred product, or the product of choice in some situations. This seems to be particularly worth considering for children who are in a period of fast growth, or other situations where the fitting of contoured seating can be expected to require repeating after a comparatively short interval.

SEATING SYSTEM

The seat provided under this system has a central structure made from rigid urethane foam, of two pound per cubic foot density, with the area in contact with the user lined with a one inch layer of polyethylene foam. The entire rigid

urethane structure is encased in a clear urethane film cover. The structure is molded to fit tightly into the user's wheelchair. (See Figures 1 and 2.)

The process of manufacture starts with the taking of a body impression. This process which has been described previously (1) is done using a vacuum bag or dilatancy technique. An effort is made to hold the user in a fixed position for as long as possible, as the position when the impression is made will be the position when the seat is finished. This must be a comfortable, stable position. Obviously, a successful seat can only be made from an impression of a good body position. It would be difficult to overestimate the importance of the care required at this phase.

A shell casting (positive) of the user is made from the vacuum bag. This is done using plaster bandage, and requires less than thirty minutes until a hard shell has been formed. This shell is the surface that the seat will conform to.

To add strength to this shell, the concave side is filled by placing it in a box and expanding rigid urethane foam into it. This results in a solid structure which only weighs a few pounds but is strong enough to vacuum form over.

The layer of soft foam is now vacuum formed over this cast. Forming is achieved after heating the foam for five to eight minutes in an oven at 300-320^{o} Farenheit.

The formed foam layer is temporarily attached to the cast with tape in preparation for using the foam covered cast as a mold against which the foam structure of the temporary (perhaps) seat can be expanded.

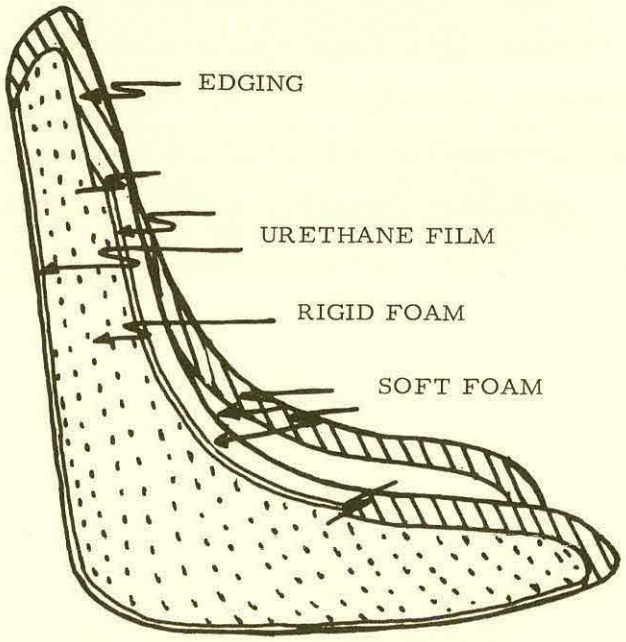

Figure 1 The Internal Structure of the Seat.

The rigid urethane is expanded in a clear urethane film bag, restrained between the form made up of the cast and pad, and the wheelchair the seat will be used in. The sling seat and back remain in the wheelchair, providing the primary support for the seat. The urethane film bag is slit to allow the expanding foam to contact the pad. The expanding foam adheres to both the form pad and the urethane film bag, making a single unit. The urethane film as part of the core, provides an easily cleaned, sealed surface. Duct tape is used to cover the edges of the foam pad, providing a relatively neat finish.

It is necessary to carefully position the cast relative to the chair, to make certain that the user is seated at the proper angle in the finished unit.

The entire unit can now be slipped in or out of the wheelchair with a minimum of effort. The use of the chair as part of the forming process leads to a firm interlock, while the urethane bag limits this to a manageable level.

The entire seat weighs approximately two and one half pounds, and is quite easily moved about.

MATERIALS

The materials used in making the seat are all readily available in quantities which are reasonable for the seating application. A little experimentation with them is in order before attempting a seat, but the reasonable costs allow this luxury.

The rigid urethane is manufactured by the Stephen Chemical Co. of Northfield, Illinois, and can be identified as "HC230". It is packaged by local distributors.

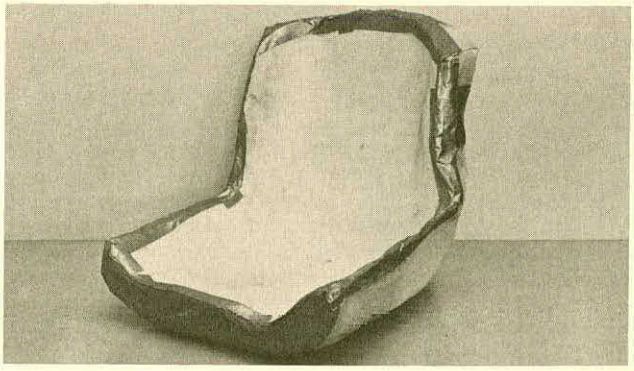

Figure 2 Photograph of the Completed Seat.

The polyethylene foam is one inch thick "Aliplast" distributed by Alimed, 138 Prince St., Boston, MA. 02113.

The urethane film bag is made for each seat by heat sealing commercial grade urethane of 0.005 inch thickness.

SAFETY

One of the chief concerns in seating is the safety of the product provided. If the seat is fitted properly, there remain three possible hazards which the seat may contribute. These are toxicity, flammability, and instability.

The urethane foam being used does present a hazard during the actual expansion process. This must be done in a well ventilated environment and the usual precautions taken for this kind of hazard. These materials have been in use for some time in a number of applications and it is felt they can be handled safely. We do not allow casual observers or users into the area when this work is being done. The material is quite stable once it is formed, and is used regularly in a number of consumer products. We see no real hazard from toxicity in the completed product.

The material is flammable, and this is of great concern. We are currently warning users of this hazard and looking into flame retardents which will not adversely affect the material performance.

The question of stability, that is the potential hazard of the user falling from the seat or the seat falling from the chair, is of great concern. A seat belt, properly fitted and used, prevents any problems here, but it is preferred that the seat be formed to minimize the hazard when the belt is not used, as so often this is allowed to happen.

OTHER CHARACTERISTICS

The durability of the finished product has been a most pleasant surprise to date. As was stated earlier, the expectation was for a few weeks of useful life, but the experience we're had has led us to consider the design as a permanent seat. With that change the durability requirement increases considerably, and we must gain some more long term experience before we are satisfied with that aspect of the system.

The seat does not have the cosmetic character one would like to see. Again, the duration of use expectation will determine the level of importance of this aspect. At present, we are most concerned about the appearance of the seat genuinely inhibiting its usefulness. We feel quite strongly that a good appearance is mandatory in any permanent seating system we are going to provide.

FUTURE WORK

Future evolution of the design will, of course, depend on evaluations of our user experience. If there appear to be no serious problems with long term usage, we plan work in several directions.

The cosmetic problem is one that we feel can be solved. Possible directions include the use of an opaque colored film to replace the current transparent material. This will allow options as well as giving a somewhat better appearance. We will also evaluate alternatives to the duct tape, seeking some more pleasant visual effect.

An alternative to those would be a cover over the entire seat. This possibility will also be considered.

As was stated earlier, there are additives which can be formulated into the rigid foam, to reduce flammability. These also will affect the strength, and durability of the structure. We hope to evaluate alternative foam systems to find the best compromise of durability and flammability for this application.

SUMMARY

At this time we feel that the seating system described here has considerable potential in meeting the seating needs of the population we serve. We expect to develop the system further and hope that it will gain wide acceptance.

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ACKNOWLEDGEMENT

Work supported by Grant #16-P-57856/1-05 from National Institute on Handicapped Research of United States Department of Education.

THERAPEUTIC POSITIONING AID FOR HANDICAPPED CHILDREN AGES ONE TO THREE

Anna E. Cronenwett, Kathleen Doyle

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INTRODUCTION

We are students of industrial design at the University of Michigan, Ann Arbor. This project is a six week independent study course. We are still in the process of fabricating a functional prototype, to be completed April 20, 1981. Through this project we had the opportunity to work with Eva Meyer, a neuro-developmental therapist at the Rackham School of Special Education in Ypsilanti, MI.

PROJECT BACKGROUND

Eva Meyer is one of the pioneers of neuro-developmental therapy in this country. She works with children between the ages of one and three, who have developmental delays and/or orthopedic abnormalities due to brain damage. Neuro-developmental therapy involves the concept of early intervention, in which a child begins therapy at an early age, in order to teach their bodies to assume correct physical positions. This encourages their individual abilities to develop physical control. Eva Meyer approached us with specific therapeutic needs which she felt were not being met by existing equipment design.

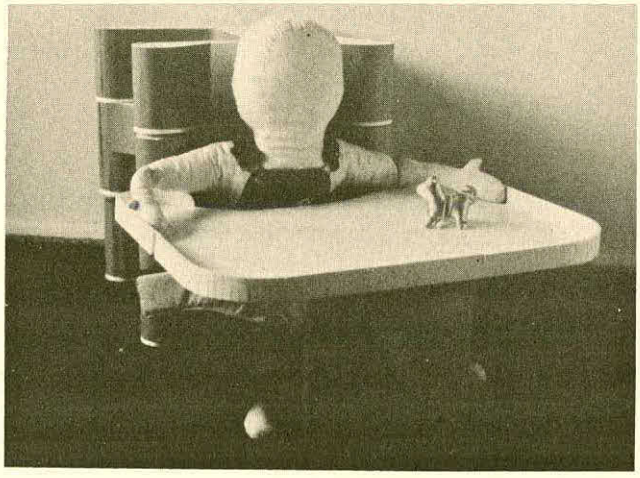


Figure: 1: Positioning Unit with Play Table

RESEARCH

The positions shown in figure A are a number of those which equipment design would need to accomodate. The dotted lines in figure A-1, indicate where proper support for the child is needed. We spent the first week and a half of this project observing Eva Meyer and her assistant in therapy with the children, meeting with Eva Meyer to discuss problems and ideas, and evaluating the existing equipment and procedures. We found much of the existing equipment to be of heavy plywood construction. This was bulky, hard to store and oppressive looking. Also, some of the needed body positions were not accommodated by the existing equipment. From observation and discussion the importance of therapy as a positive activity for the children became a major design criteria.

PROBLEM STATEMENT

Anna E. Cronenwett, and Kathleen Doyle will design and fabricate a therapeutic system which will assist the therapist in positioning handicapped children into the following postures (see figures A-1 to A-4).

DESIGN CRITERIA

1. Design must be flexible enough to accommodate all the different positions.
2. Design must encourage a positive involvement of the child (potential use as a toy).
3. Design must be adjustable to accommodate different sizes of children.
4. Design must allow for potential expansion. As unforeseen needs come up, the system must be readily adaptable.
5. Design must utilize safe, functional, comfortable and pleasing materials.
6. Design must be sensitive to economic constraints of the Rackham School of Special Education.
7. Design must provide the children with a play surface during therapy.
8. Design must be sensitive to storage space problems.

DESIGN PROCESS

The second and third weeks of the project were spent in rapid conceptualization, reviewing of ideas with both Eva Meyer and Professor Montalvo and building sketch models of the most promising ideas. Also during this time period we became heavily involved in researching potential materials and processes. We took advantage of numerous

resources within the University and the Detroit – Ann Arbor area. During the fourth week we received critical evaluation from Eva Meyer and Professor Montalvo and the most promising ideas were then combined into a final solution.

This final solution was further refined and modelled. At the present time, we are involved in the process of fabricating a functional prototype.

STATEMENT OF FINAL DESIGN

Our final solution for accommodating handicapped children in the therapeutic positions shown in figure A involves a stacking support unit, a mat and numerous foam shapes.

DESCRIPTION OF FINAL DESIGN

1. Velcro Mat (Figure B)

In the beginning conceptualization stages one of our initial and most promising ideas was the use of a large "pile" velcro surface (softside), upon which other positioning aids could be applied using hook velcro. One alternative was having the mat itself contain the necessary foam shapes, like a large puzzle. But we realized through discussion with our client, that there was a need for a smooth vinyl surface to the mat. Due to this factor, and the economic constraints of fabricating an entire mat, we decided to take the therapist's existing mat (standard high density 1" thick gym mat) and adhere the pile velcro material to one side; thus making the mat reversible. Adhesion will be accomplished with velcro brand adhesive, and all edges will be hand sewn for security. The pile velcro fabric as well as the existing mat are navy blue in color.

2. Foam Cushions (Figure C)

Realization of the velcro mat made possible creative use of velcro applied foam shapes, for use in holding children in the various positions. The use of velcro as a means of adhesion allows for the secure positioning of the children, while still using a soft giving material.

note: A 2" X 2" square area of velcro requires a 75 lb. direct force (not inclusive of "peeling" the velcro) to separate hook from pile.

Materials Used:

All of the foam cushions were formed from high density foam, and then covered with parapack fabric. This fabric (usually used in parachuting equipment) is light weight, soft, very strong, water resistant and easily cleaned. All fabric covers were sewn in such a way that they can be easily removed from the cushions for cleaning or replacement. We chose the primary colors, red, yellow and blue to cover the cushions. (Figure C illustrates all of the cushions).

Back cushion and leg supports secure the child in position A-4 with velcroing straps. The inner structure of the back cushion is a bent 3/16" thick piece of acrylic, which gives needed back support. The four leg cushions are increasingly larger in size to accommodate a variety of children. These cushions have hook velcro on two surfaces; making the cushions capable of being hooked down in either left or right side lying positions to the mat. The set of cushions shown in figure C-1 are color coded sky blue.

The system also involves a yellow head support cushion for use in the side lying positions or other needed positions. See figure C-2.

There are also four red triangular cushions, which are primarily used for supporting the play table, when the child is in the abduction position. (Figure A-3).

3. Stacking Unit (Figure D-1)

The stacking support unit breaks down into six pieces, which can be stacked in various combinations to accommodate different positions and different sized children. The organic shape is based on a square and can be rotated into a variety of configurations for the various positions. Stacking of the modules is secured by four male-female plugs 1" in diameter. Two of the faces of the unit are covered with red pile velcro, indicated in figure D-1 by the dotted line areas. This pile surface accomodates yellow hook body straps which support the child against the unit in the various positions. The support unit also involves a large play table (see figure D-2), which also plugs into any module. The entire support unit velcros down to the mat during therapy. (figure D-3) The unit supplies support to the knee, hip and chest when the child is in a standing position. A 4" X 24" yellow strap gives necessary security to the child's body. (figure D-4) In the kneeling position the unit offers hip and chest support.

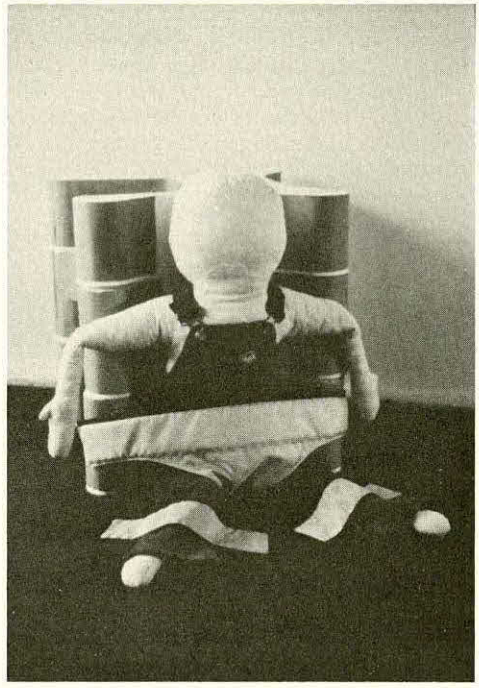


Figure 2: Abduction with Unit

(Figure D-5) The unit accommodates the child in the sitting positions, giving back support. A yellow strap (diaper strap) is used to keep the child's hips and lower torso flat against the support unit. The diaper strap velcros underneath the support unit, comes between the child's legs and hooks to the red pile areas on the support unit. The child's knees can be held out straight or in the abduction position by two velcro yellow straps 2" X 12", which cross the child's knees and fasten to the pile mat.

(Figure D-5) The red triangular cushions can then fit between the child's legs in the abduction position and support the table, which is also capable of velcroing to the support unit against the red pile area.

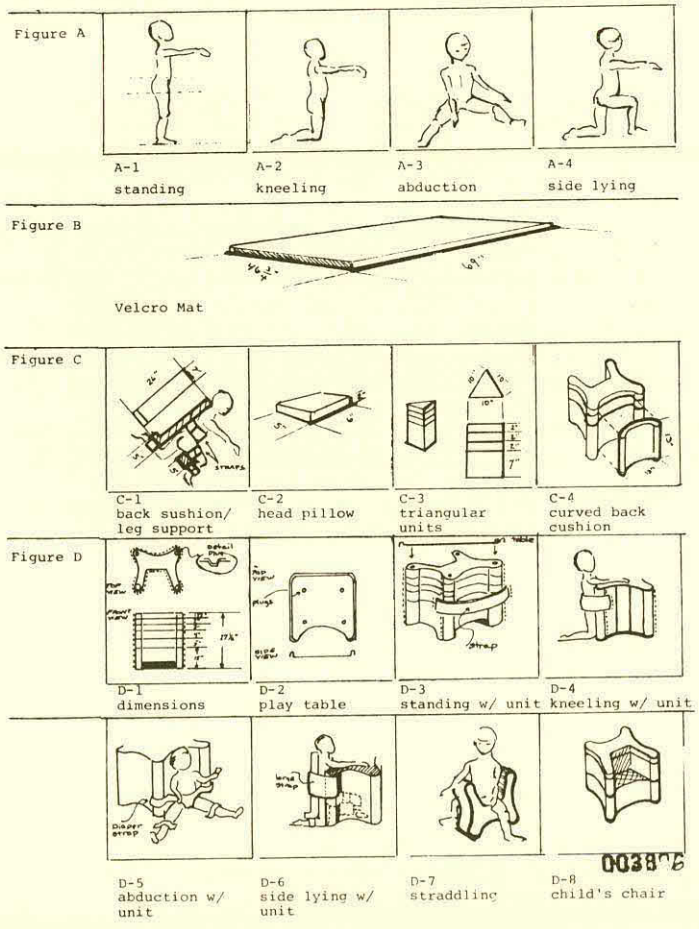
(Figure D-6) The supporting unit also allows for the child strapped into the side lying position to be turned vertically and strapped into the support unit.

The support unit could be manufactured in a variety of ways. The stacking pieces could be made from self-skinning polyurethane foam. It could also be injection molded plastic then covered with a thin skin of very dense foam (such as aliplast). Due to economic constraints and our fabrication limitations we chose to fabricate the prototype in the following way:

Each of the six stacking pieces will first be cut from dense styrofoam. Polystyrene support pieces will be heat bent and inlayed into the styrofoam. All corner areas will be covered with red pile velcro, over a layer of dense ¼" aliplast foam. Polystyrene end caps containing the plugging system will be adhered to top and bottom of each piece.

EXPANSION OF THE SYSTEM

One great merit of this system is its capabilities for expansion. Within the course of this project two such unforeseen "expansion" ideas have developed. If stacked in the proper configuration the support unit can become a chair (Figure D-8), or if placed on its side the unit could be straddled by the child. Eva Meyer found this possibility expecially useful.



THE EFFECT OF WHEELCHAIR CUSHIONS ON RIDE

by James J. Kauzlarich, Ph.D.

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Abstract

A powered wheelchair was instrumented with an accelerometer to study the effect of cushions on ride comfort. A "normal" human subject found that above 0.4-0.6 g's maximum acceleration the ride was uncomfortable. A flexible cushion was found to be necessary in order to reduce the maximum acceleration of the user to a comfortable level at wheelchair speeds above 4 km/hr (2.5 mi/hr) while rolling over a 1/4 inch bump.

Introduction

Since most wheelchairs do not have a spring suspension, the cushion plays an important role in limiting the effect on the user of wheelchair impact with bumps. Recent cushion studies have been concerned with the effect of the cushion on tissue breakdown which can cause decubitus ulcers [1], on indentation load deflection capability of polyurethane foam [2], and development of test methods [3]. This study concerns the measurement of maximum acceleration which a user will find uncomfortable while riding in a powered wheelchair and traversing sidewalk cracks or bumps.

Method

The laboratory measurements of powered wheelchair performance were conducted on a slider bed conveyor or wheelchair treadmill with a 36 inch wide nylon belt [4]. A 1/4 inch wood dowel was taped to the belt to simulate a sidewalk bump. Three or four 50 pound bags of gravel simulate the user and were placed, front to back, on a commercial powered wheelchair seat with various cushions. An accelerometer was clamped to a board which was sandwiched between the bags of gravel with the accelerometer placed to the side of the center of gravity of the bags. The maximum acceleration was observed when the rear wheels rolled over the bump, and this value was recorded along with the belt speed and natural frequency of the gravel bags. The natural frequency was measured by giving the bags a sudden deflection and calculating the natural frequency from the accelerometer voltage trace on a storage oscilloscope screen.

It is the sudden shocks produced by the impact with a bump which produce an uncomfortable sensation for the wheelchair user. Den Hartog [5, p. 147] discusses this phenomenon and shows that the important measurement when assessing comfort is the rate of change of user acceleration, called jerk. However, it can be shown that jerk is proportional to the maximum acceleration multiplied by the natural frequency. Linder [6] reviews a number of studies involving the effect of mechanical vibration on human beings and shows that the maximum acceleration with respect to frequency for the "severely disturbing" threshold level is $0.5 \pm .1$ g's over a range of freqency from 3 Hz to 10 Hz. The natural frequency of the patient riding in a wheelchair is in the range of 6 to 8 Hz. The natural frequency for human body organs is about 4.5 Hz [6], and this frequency should be avoided when designing wheelchairs.

A preliminary study comparing the ride performance of a human with the bags of gravel gave similar results; see Figure 1.

Results

The maximum acceleration experienced by the wheelchair load due to a 1/4 inch bump plotted against speed is shown on Figure 1 for a number of commercial wheelchair cushions. Most of the tests were conducted with gravel bags for the load. Tests with no cushion for a 150 pound human subject compare well with the results for 150 pounds of gravel, as shown on Figure 1.

To obtain reproducible results it was necessary to carefully position the accelerometer at the same position for each test and to be certain that the gravel bags did not shift during the test. Any loose wheelchair parts were tied down to eliminate spurious accelerometer signals. Also, the tires were inflated to the proper pressure for each test.

The measured acceleration exhibited stationary random variations on the order of 10%. A statistical study indicated that 10 measurements were needed for a true average as long as the baseline reading of the accelerometer voltage remained constant.

Discussion

All of the cushions significantly reduce the maximum acceleration measured except the T-Foam cushion. The T-Foam cushion distributed the load of the seated patient much slower than all of the other cushions, and for sudden impacts there was almost no cushion deflection. Thus, the T-Foam cushion acts like a board placed across the seat so that the force transmitted to the patient when going over a bump is about the same as when no cushion was used.

For riding comfort, a pillow of shredded polyurethane foam performed as well as most of the cushions tested in reducing the user acceleration due to the wheelchair riding over a bump.

Design recommendations for maximum acceleration in a wheelchair are based on human opinions. For this study a "normal" human subject was asked when the impact felt uncomfortable, and generally indicated discomfort from 0.4 to .7 g's depending on the cushion being tested. Jacobson [7] reviewed the literature on ride comfort and recommended that the maximum acceleration should not exceed 0.2 g's for vehicles. Linder [6] recommends 0.5 g's maximum.

In conclusion, the test results show that a flexible cushion is necessary for a comfortable ride by a "normal" subject in a E&J-3P powered wheelchair.

It is suggested that future studies of wheelchair ride should involve measurements of the discomfort level of a spinal cord injured user. Also, the determination of the effect of springs and dampers added to a wheelchair on ride quality would be useful for wheelchair design.

Acknowledgements

Graduate Research Assistant James Mercer-Moore and Undergraduate Assistant David Carmines carried out much of the testing.

This work was supported by Grant 23-P-55690, U. S. Nat. Inst. for Handicapped Research, Department of Education.

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Table 1

Cushion Name and Manufacturer

a. Stainless Foam Cushion
Stainless Medical Products
San Diego, California

b. Jobst Hydro-Float
Jobst Institute, Inc.
Toledo, Ohio

c. Bye-Bye Decubiti
Ken McRight Supplies, Inc.
Tulsa, Oklahoma

d. Bio Flote
Bio Clinic Co.
North Hollywood, California

e. Aqua-Seat
Aquatherm Products Corp.
Rahway, New Jersey

f. T-Foam
Alimed Inc.
Boston, Massachusetts

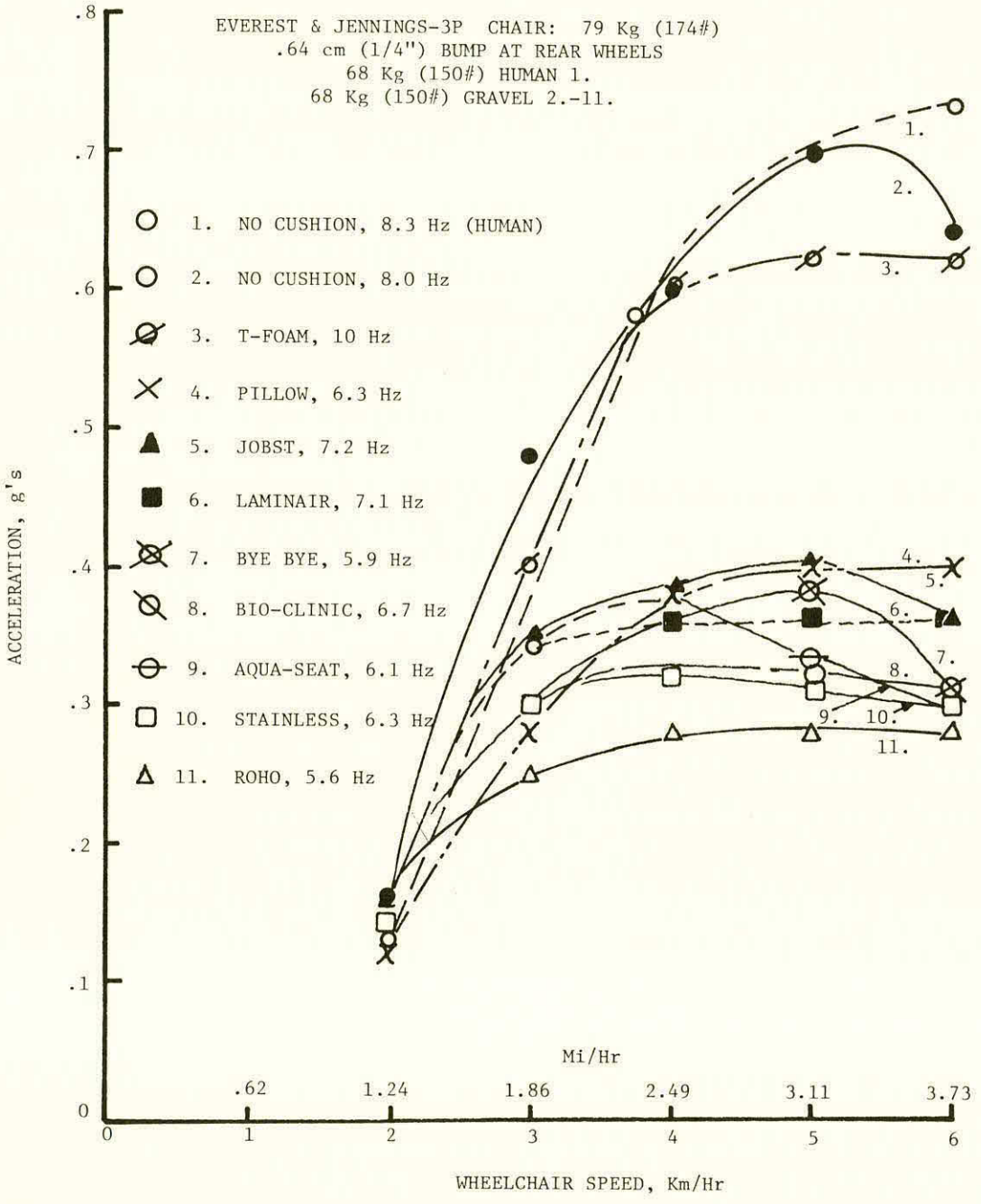
g. Laminair
Scimedics, Inc.
Anaheim, California

h. ROHO
ROHO R & D, Inc.
East St. Louis, Illinois

i. Shredded Urethane Foam Pillow
UVa Hospital
Charlottesville, Virginia

FIG. 1

EFFECT OF CUSHIONS ON RIDE



THE FOAM-IN-PLACE SEATING SYSTEM RESULTS OF TOXICITY STUDIES

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ABSTRACT

The University of Tennessee Rehabilitation Engineering Department has developed further the Foam-In-Place (FIP) technique first introduced at Shriner's Hospital in Winnipeg, Canada, as a possible solution to the problem of customized seating for individuals with severely handicapping conditions.

Essentially, this technique permits the direct foaming of contoured seating components using the individual himself as the mold. Through this technique the mold-making and fabrication steps associated with other techniques have been bypassed. Initial experience has also indicated that customized foam components can be produced and interfaced into a wheelchair in less than two hours.

Recent research efforts have focused on the issue of potential toxic hazards associated with the use of polyurethane materials in the FIP seating approach. Future efforts will emphasize the seat-user interface measurements.

INTRODUCTION

The importance of proper seating for those confined to the seated position throughout their daily activities has been stressed in recent years. Much more remains to be done in terms of designing proper seating systems and making them available to those within the handicapped population that so urgently need them.

The high cost of pressure sores, combined with the interruption of the living process associated with patients with sensation loss, (primarily paraplegics and quadriplegics) have inspired better solutions to the distribution of seating forces under areas of insensitive tissue and bony prominences. Both standardized and semi-custom wheelchair cushions have improved in recent years (9). These developments have paralleled basic studies that have provided an understanding of the basic causes of tissue breakdown that results from pressure sustained above tolerable levels for excessive time periods (2, 3, 4). The most common approach used to avoid tissue breakdown is to distribute forces over larger weight-bearing areas of the pelvis and thighs using force distributing cushions of various configurations. This approach results in a reduction of the pressure levels applied to the susceptible tissue areas, so that sitting may be safely maintained over longer time periods. A second approach, which has recieved much less emphasis, is to allow high pressures to exist but to permit them to be sustained only for short periods of time. This latter approach is a departure from the large contact area concept, and thereby potentially permits air circulation and related temperature/humidity control at the tissue/seat interface (5).

In addition to the above mentioned paraplegic and quadriplegic populations there is another larger group of developmentally disabled individuals requiring specialized seating. This group is comprised of severely handicapped children and young adults with disorders resulting from cerebral palsy, muscular dystrophy, multiple sclerosis, and other less common neuromuscular anomalies. These disorders often result in severe obliquities of the pelvis, contractures of hip and knee joints, and scoliosis of the spine. These individuals usually have complete sensation, and therefore comfort and maintenance of good body alignment in the seated position is the primary goal, rather than protection of insensitive tissue as in the former group. To provide the required comfort and body alignment, forces of considerable magnitude often must be applied to specific areas on the pelvis and trunk. To maximize comfort, these forces must be maintained at the lowest possible levels. Considering these factors and the additional complications resulting from a lack of neuromuscular control, total contact support appears to offer the greatest potential.

Seating for the severely handicapped cerebral palsied and muscular dystrophy population has traditionally involved the custom-making of inserts which fit into a standard wheelchair (10, 7, 1, 6, 8). The amount of customaization achieved is related to the capabilities of the seating technician, orthotist, or therapist responsible for specialized seating, because of the labor intensive nature of specialized seating, the cost is usually high. As a result, the services are generally available only through a few larger rehabilitation facilities which have sufficient volume and funding to justify the required specialized staff and facilities. Recent developments have indicated that approximately 50% of children and young adults that require

specialized seating can be accommodated by standardized components fabricated from vacuum-formable plastic materials in standard size increments. However, the remaining 40-50% require customized seating to compensate for their severe deformities or lack of neuromuscular control. It is for this population of severely handicapped individuals that the FIP approach has been persued at the University of Tennessee--Rehabilitation Engineering Center.

FOAM-IN-PLACE TECHNIQUE

The FIP technique uses a foaming frame into which a series of standardized seat and back molds can be inserted. The box shaped molds are fabricated from polyurethane plastic and are closed on all sides except one. A sheet of thin latex sheeting (5 ml) is lightly stretched over the open side of the mold. This stretchy surface is then in direct contact with the user during the foaming process. Once in position in the foaming chair and seated upon the latex skin, a two-part polyurethane foam (CPR 1947 N) is injected into the front of the mold. The injection hole is then closed off and the reaction between the two foam components causes the foam to rise up and force the latex skin around the shape of the user. Within five minutes the foam gels into a soft foam cushion and the user can then be removed from the foaming frame after ten minutes. In the same manner, back components can be made to contour perfectly to the shape of the individual. (Fig. 1) The time saving advantages are that the individual provides the mold shape for contouring the supporting foam surfaces, and the polyurethane mold provides the shape of all other surfaces of the foam. This latter point is important since the standardized outer shapes of the foamed components permit rapid interfacing into wheelchairs or other wheeled bases. That is, in addition to a series of standardized molds which cover the range of body sizes, there is a matching series of interfacing receptacles that receive the final foam components, so that they may be placed securely in a variety of wheeled bases.

The Toxicity Issue

Toxicity, although the word itself has "lethal" or "deadly" connotations, is, in face, a matter of degree and not an absolute. It is the characteristic of a substance to cause some degree of injury to a living organism. The degree of injury may range from minor (barely detectable) to lethal, covering all mild irritations inbetween. In most cases, toxicity is dose dependent.

As with most industrial chemicals, some degree of hazard exists in the use, or particularly in the misuse, of polyurethane chemicals and components. The degree of hazard is influenced by the physical and chemical properties of the material and the circumstances of use or misuse. In the use of polyurethane systems this hazard arises principally from the isocyanate component, and to a lesser degree from the catalysts and other additives present in the polymer component.

Safety Issues Related To The Foam-In-Place Seating Application

There are essentially two primary concerns pertaining to the potential health hazard of polyurethanes in the Foam-In-Place application.
(1) The inhalation hazard to technician and handicapped client from the vapors both before and during the foaming procedures.
(2) The possible hazard of toxic agents leaching out of the freshly polymerized foam and thereby coming in contact with vulnerable tissue surfaces of the seated client.

An indepth three-part study was initiated to address these concerns. The study was comprised of: (1) In-Vitro toxological evaluation
(2) Dermatological testing (Skin Patch)
(3) Vapor analysis
Toxological evaluations were conducted in cooperation with the Department of Pharmacology-Material Science Toxological Laboratorues at the University of Tennessee Center for the Health Sciences. Vapor analysis tests were undertaken in cooperation with the Department of Pathology at the University of Tennessee. Dermatological tests were conducted by the Department of Dermatology at the University of California at Los Angeles under the direction of Dr. Marvin Rapaport.

Note: It is not within the scope of this article to discuss in detail the testing methods and procedures used in the toxicity studies. A detailed preliminary report entitled "Foam-In-Place Seating for the Severely Disabled" is available on request from the University of Tennessee - Rehabilitation Engineering Center, 1248 LaPaloma Street, Memphis, Tennessee 38114. This paper therefore will be confined to a discussion of the conclusions of the three-part study.

Results - Toxological Evaluation

1. All samples tested (both CPR 1947 N and commercial samples) were cytotoxic as per the criteria for the Tissue Culture Agar Overlay Test. This is not surprising in that this test is designed to detect leachable toxic substances and is one of the most sensitive in-vitro acute toxicity tests available. (Note: A commonly used polyurethane wheelchair cushion was one of the commercial samples tested)

2. The acute cytotoxicity of the CPR 1947 N material as used in the Foam-In-Place procedure is not statistically different than for the other (commercial) foams tested.

3. The acute toxicity of the Foam-In-Place seat components (latex and foam components) declines in the first two weeks after fabrication.

4. Although the most probable components of the foam material which would be leachable and toxic

are the catalyst or the isocyanate monomer(s) (non-reactive residuals), the Agar Overlay Tissue Culture Tests does not distinguish the nature of the leachable toxic components.

Results - Dermatological Testing

As a result of the findings of the UCLA Patch Test combined with the clinical observations of the University of Tennessee - Rehabilitation Engineering Center over the past three years, it was concluded that:

> CPR 1947 N polyurethane foam material, although showing a positive response in the in-vitro Agar Overlay studies, does not present an undue risk to health as a sensitizer or an irritant when placed in contact with human skin within one hour after polymerization has taken place.

Results - Vapor Analysis

After testing methylene bio (4-phenylisocyanate) (MDI), tris (2-chloroethyl) phosphate, and trichlorofluoromethane, for inhalation toxicity it was concluded that:

> MDI will not cause major skin or eye irritation in the Foam-In-Place application provided proper ventilation of the work area is observed and safe laboratory practices are followed. It was also concluded that as long as good engineering practices are followed and the Foam-In-Place technique is carried out in a well ventilated area concentrations of trichlorofluoromethane will pose no health hazard to the technician or client.

Results - Foam-In-Place Clinical Trials

To date, forty subjects have received FIP Seating Components. The distribution is: 17 Cerebral Palsy, 10 Muscular Dystrophy, 4 Myelomeningocele, and 9 others. In the other category, three individuals were adults with insensitive tissue and a history of tissue breakdown problems. The approximate average foaming time for a combined seat and back support was 2½ hours. Many of the subjects have been using the FIP components for more than two years with the longest in use being 40 months. In most cases the components endured daily use for more than two years, before a replacement was required either due to growth or deterioration of the foam material itself.

All subjects when given a choice desired to have a replacement of the Foam-In-Place component, rather than resort to an alternate type system. No incidence of skin or respiratory problems was reported from the study group. The three subjects with insensitive tissue have had no recurrence of tissue breakdown related to the FIP support, and have expressed a desire to continue with the system when replacement was required.

Future research plans call for the development of principles for custom designing of FIP seating supports, through the use of laboratory instrumentation that will permit the more accurate interpretation of interface conditions (pressure, temperature, humidity); particularly with reference to supporting individuals with insensitive tissue. A second objective will be to further refine the existing system to facilitate the clinical application in facilities working with the seating needs of individuals with severe physical deformities, primarily due to cerebral palsy.

CONCLUSIONS

The successful clinical trials to date with the Foam-In-Place technique, the findings in the industrial regulatory literature, the detailed responses from the manufactures of the material, the safety record of polyurethane materials in the prosthetics field over the past fifteen years, in addition to the results of the extensive experimental studies summarized in this report, regarding vapor inhalation and toxological evaluation, all strongly support the position that flexible polyurethane foam CPR 1947 N presents hazards to health and safety that are within safe limits. And these hazards are outweighted by the potential benefits to be gained by severely handicapped individuals requiring customized seating devices. It can further be concluded that if routine safety precautions are observed as outlined above, no undue hazards to health can be expected to occur to either personnel or clients as a result of the application of the Foam-In-Place system as described.

ACKNOWLEDGEMENT

The Authors wish to acknowledge the contribution and support of Drs. E.L. Tood and D.T. Stafford of the University of Tennessee - Department of Pathology, Drs. J. Autian and E.O. Dillingham of the University of Tennessee Materials Science Toxicology Laboratories, and Plough Incorporated towards the toxicity studies of the Foam-In-Place Seating System.

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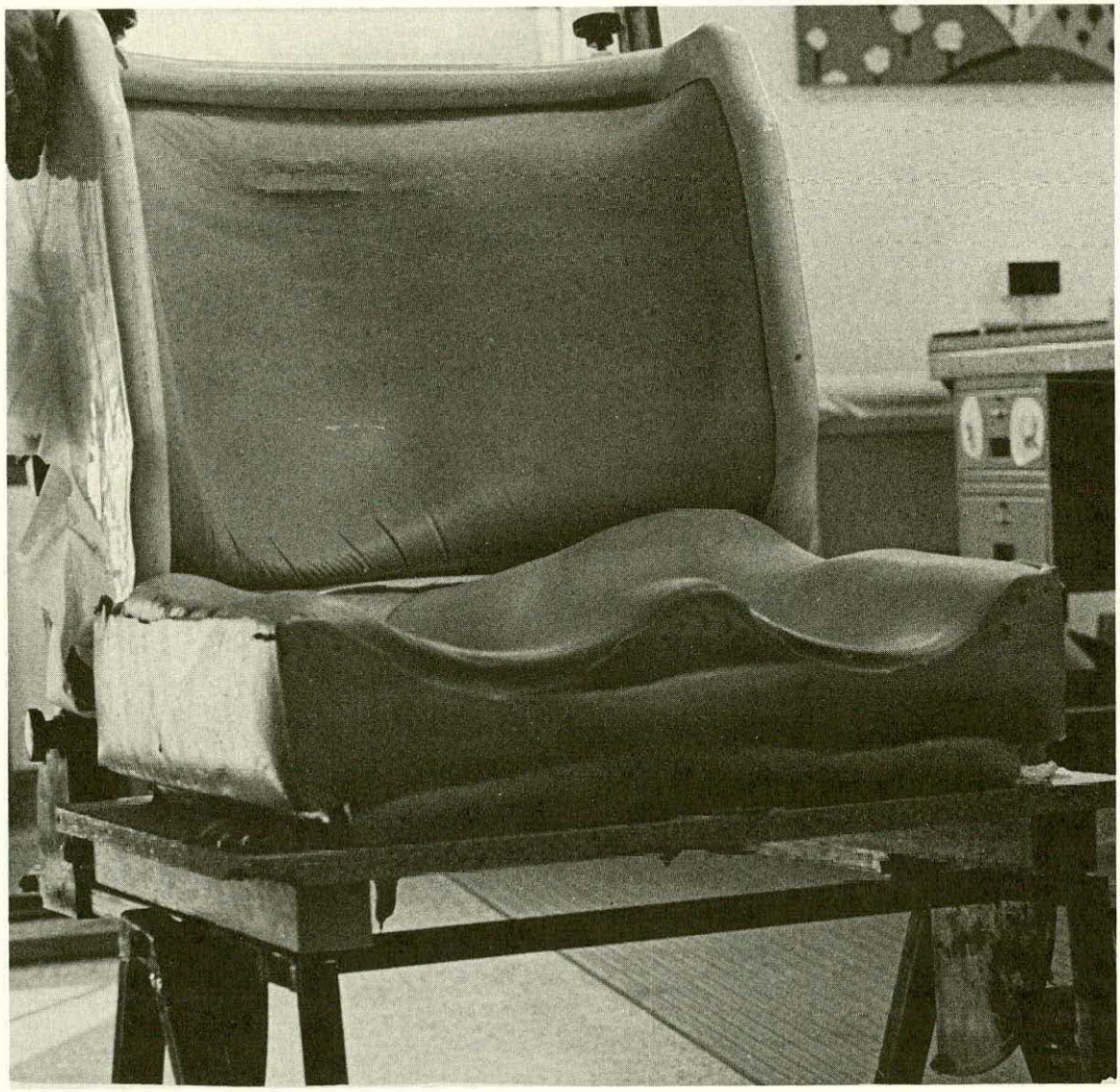

Fig. 1 - Polymerized polyurethane components in the foaming chair. Back component still in mold.

SEATING SYSTEMS FOR BODY SUPPORT AND PREVENTION OF TISSUE TRAUMA

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ABSTRACT

This paper describes the present status of "Seating Systems for Body Support and Prevention of Tissue Trauma" (1) designed specifically for the spinal cord injured community. Recognizing that a prophylactic and sound orthopedic seating system can be devised for spinal cord injured patients to allow greater independence and freedom, the investigators from the Veteran's Administration Medical Center, Palo Alto, and Children's Hospital at Stanford have examined, developed, and tested a number of prototype cushions. The Veteran's Administration Seating Interface Orthosis-Paraplegic (VASIO-P) has proven to be the most viable modular system so far. Twenty-three candidates have been tested on the latest prototype and are still using the cushion with favorable results.

INTRODUCTION

Within the Veteran's Administration medical system, and for that matter the entire national medical community, patients with quadriplegia or paraplegia secondary to a spinal cord injury form an important population whose long-term needs cannot be ignored. Expenses for conservative and surgical treatment for ischemic ulcers and biomechanical deformities secondary to the spinal cord injury are extremely high and exceed the annual rate of injury incidence. Current cost estimates for repair of decubiti in a single patient may range from $10,000 to $46,000 depending on the extent of involvement and related length of hospital stay (2). Furthermore, biomechanical deformities such as spinal curvature, pelvic obliquity, or hip dislocations contribute to ischemic ulcer formation as a result of poor sitting posture.

In this light, there is general agreement that prevention of these highly debilitating medical complications is better than cure. For example, the presence of decubiti retards the patient's recovery process, complicates post-injury management problems, delays discharge planning, and in some cases may even be a cause of death. Post discharge, the gradual increase in spinal and pelvic malalignment secondary to inadequate body support can predispose a person to ischemic ulcers, affect functional capacity and increase dependency during transfers and other activities of daily living. For patients who must remain recumbent for extended periods of time there are several products used both in the home and institutional environment that are effective in preventing ischemic ulcers. However, the cushions used by sitting-dependent persons are less reliable. There is no single commercially available product that can provide both spinal/pelvic stability and protection from ischemia, a fact particularly true of cushions which rely on air, fluid or gel as the supporting medium. Furthermore, all of these products can leak fluid and complicate patient problems.

This project proposes to develop a seating system for spinal cord injured patients which prevents both musculoskeletal deformities and decubitus ulcers. This system will incorporate interchangeable, modular components compatible with today's standard wheelchairs. Also proposed is an assessment worksheet for clinicians and a protocol for prescription writing principles.

SIGNIFICANCE AND IMPACT OF INVESTIGATION

The incidence and prevalence of ischemic ulcers among Veteran's Administration Medical Center inpatients is yet unknown but conservative national statistics estimate that three percent of all inpatients are hospitalized for decubitus ulcers (2). The 1979 Summary of Medical Programs from the Veteran's Administration showed a daily census of 46,563 patients (3). If the national prevalence rate can be applied to the VA population, then each day at least 1,397 beds are occupied by veterans with decubitus ulcers.

Prolonged inpatient care required for treatment of pressure ulceration could be eliminated by directing attention to weight distribution problems derived from scoliosis, pelvic obliquity and hip dislocations and to provision of appropriate trunk supports and seating systems.

Although it is difficult to quantify medical and functional aspects of wheelchair effectiveness, it is certain that without effective interfacing, the seating surface of the present day conventional wheelchair is inadequate for the sensory-impaired wheelchair-dependent person with spinal cord injury. The modular components will afford a range of seating environments integrated with economy and ease of assembly (Figure 1).

Swearingen (4) emphasized the significance of loading in normal subjects by observing that approximately 50% of the body weight is supported by only 8% of the sitting surface, and 58% of the sitting area received pressures lower than average capillary (6.5 to 26 mm Hg). This view points to the advantage of selective repartitioning of the weight to reduce pressure. This idea,

considered "state of the art" by pioneers, is a concept which has received considerable support (5,6,7). It is obvious that the greater the flesh thickness, the better its ability to sustain a load by dissipating the force over a larger area (8). Swearingen (4) showed that approximately one-third of the body weight on the sitting surface could be removed by the incorporation of foot and arm rests and a back support placed at 15° to the vertical. The proposed support system will incorporate these concepts through provision of a lap tray with an arm trough, leg and trunk supports and seating cushions which comprise a total support system for patients with high cervical lesions. These authors believe that the support and cushion system will repartition weight distribution and will prevent ischemic ulceration.

BIOMECHANICS

Many wheelchair patients using conventional seating surfaces continue to develop musculoskeletal deformities, such as scoliosis, because of an imbalance of muscle power and inadequate support of the trunk and pelvis. It is critically important to provide support immediately post-injury. Early in the history of developing deformities, the range of motion diminishes and fixation may occur. In this process, post-injury time becomes important, and this data will be incorporated into the biomechanical analysis worksheet. The combined effects of gravity, ligament flexibility, muscle weakness and imbalance of power in functional groups of muscles contribute to a loss of truncal stability in the spinal cord injured which results in malalignment.

Several studies (9,10) have pointed out that spinal rotation and curvature can be minimized by immobilizing the spine in an extended or hyperextended position which interlocks the spinous processes of the vertebra (primarily in the lumbar spine). In this position rotational movement is minimized, and locking of the facets in extension prevents lateral deviation of the spinal column.

Contrary to related research activities, no plywood was placed under the cushions as this would not be representative of how the cushions would be used. In fact, every attempt was made to allow the clinical and testing atmosphere to exhibit, as closely as practical, those variables which exist normally in any tissue trauma clinic and later in the home or other discharge environment.

RESULTS

During the two week trial those who were inpatients were monitored twice daily by the hospital nursing staff for the appearance of erythemas or other soft tissue insults, although the testing protocol was designed to eliminate such difficulties.

Each patient studied was a spinal cord injured adult male for whom commercially available wheelchair cushions did not provide adequate pressure relief under the ischial tuberosities. Unlike other studies, a rather large group of subjects who are at high risk for tissue trauma continue to be evaluated; most are asensory; and none have received special training to participate in the study. No attempt will be made to modify their daily routine of activities.

Thus far the latest VASIO-P has fared well in its clinical evaluations as indicated in the following responses from seventeen patients who have used the cushion from 4 months to a minimum of 2 weeks.

POSITIVE		NEGATIVE		NO CHANGE
82%	More comfortable	12%	Less comfortable	6%
6%	Colder	18%	Hotter	76%
41%	↑ sitting time	12%	↓ sitting time	47%
53%	Cleaner	6%	Less clean	41%
70%	More practical	18%	Less practical	12%
41%	Transfers easier	41%	Transfers harder	18%
82%	Improved posture	0%	Worsened posture	18%
70%	Improved balance	6%	Worsened balance	24%
18%	Easier to propel	12%	Harder to propel	70%
82%	Generally more favorable	12%	Generally less favorable	6%

To date the feature of the abduction pommel has elicited a consistently negative comment, primarily related to difficulties in transferring. However, this problem will be addressed in the final product. The difficulty may be rectified by making the abduction pommel removable. Enough data has been collected on patients with cervical level lesions that further evaluation by these subjects is no longer needed. The final step is to produce a new prototype that may include inflatable bladders instead of rigid inserts to avoid the development of reddened areas by those who might be malpositioned by a hurried attendant.

As anticipated, the improvements in posture, balance, comfort and practicality have proven to be the most desirable features of the VASIO-P. (Figure 2). These improvements result in greater ease for traveling over rough terrain, wheelchair manipulation, enhancement in two-handed and table top activities, and the long-term benefit of deterring pelvic/spinal malalignment and related biomechanical sequelae.

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ACKNOWLEDGEMENTS

This project is funded by a grant from the Veteran's Administration Central Office (Washington, D.C.) Rehabilitative Engineering Research and Development Service. The principal investigator is Inder Perkash, M.D., Chief, Spinal Cord Injury Service, Veteran's Administration Medical Center, Palo Alto.

Copies of Reference (1) are available through the Children's Hospital at Stanford Rehabilitation Center, 520 Willow Road, Palo Alto, California, 94304, phone # (415) 327-4800 x560.

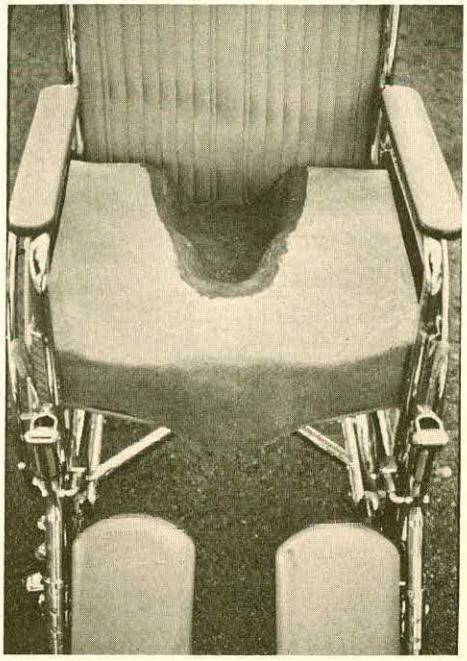

Figure 1

View of VASIO-P in an 18" wide wheelchair.

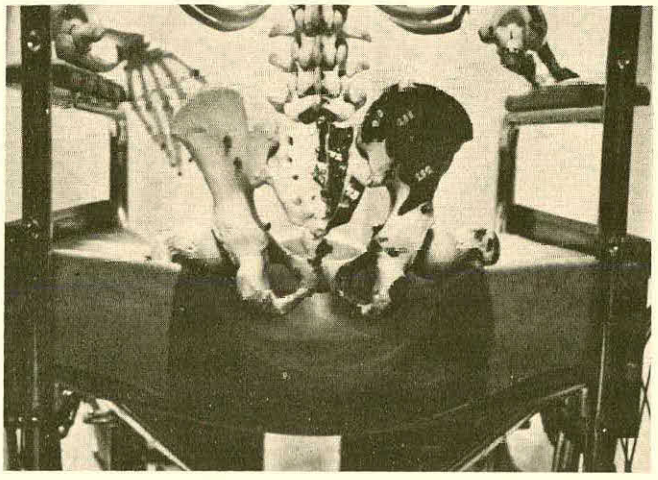

Figure 2

Posterior view of a skeleton seated on VASIO-P in a wheelchair.

PRESSURE SORE PREVENTION AND BIOMECHANICAL SUPPORT FOR THE PARALYTIC WHEELCHAIR-DEPENDENT PERSON

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Rehabilitation Engineering Center
Children's Hospital at Stanford

ABSTRACT

Many commercially available wheelchair cushions are adequately designed to prevent ischemia, but none afford body support for those individuals with neurological, muscular, or skeletal deficiencies. The objective of these authors is to provide patients with a "seating interface orthosis (SIO)", which diffuses pressure to prevent decubitus ulcers and supports the pelvis and trunk to prevent or arrest biomechanical malalignment. Over a one year period, 24 patients were provided with a SIO which incorporated the aforementioned objectives. 23 patients reacted positively to the approach.

INTRODUCTION

Two of the many problems faced by wheelchair-dependent individuals are decubitus ulcers and pelvic/spinal malalignment. The primary cause of decubitus ulcers is high pressure over the bony prominences of the sitting area. Pelvic and spinal deformities may have a variety of causes, such as muscular weakness, imbalance, or paralysis. Anaesthesia affects both problems detrimentally: it will not allow the patient to sense ischemic-producing pressure, nor allow full proprioception such that the patient cannot independently detect or correct malalignment. These authors have developed a seating system which sufficiently reduces sitting pressures at prominent osseous sites to prevent ischemia while maintaining a biomechanical influence on pelvic/spinal alignment, ischial/trochanteric registration, and postural balance.

Each of the aforementioned conditions will be examined in short discourse with specific attention paid to those aspects considered in the design of the SIO. Following this, a brief technical description of the cushion and results of clinical testing are presented.

BACKGROUND

Decubitus Ulcers

Central to the formation of a decubitus ulcer (bedsore, pressure sore) is ischemia, usually initiated by externally applied pressure or repetitive compressive insults, which later results in local necrosis. Of lesser importance to ulcer formation is autolysis following disruption of the cell membrane after a single compressive insult. A further factor is shear, a tangential rather than perpendicular stress. A sitting person is vulnerable to these forces at the ischial tuberosities, coccyx, greater trochanters, and sacrum. Those with sensation possess a positive neurological feedback loop which allows them to shift their weight and avoid ischemia. The asensory, however, lack this loop and are not aware of the ischemic-producing stress. The problem is further compounded by spasticity, lack of muscle control, or an imbalanced sitting posture. These ulcers are not limited to the epidermis. In advanced states they may progress deep to the bone and accompanying septicemia, osteitis, and pyoarthritis may be seen.

Pressure sore prevention or post-trauma management cannot begin without a thorough assessment of all the support surfaces to which a patient will transfer during the course of daily activities. In addition to the wheelchair seat, the unpadded surfaces of the commode, shower chair, and bathtub floor have a significant influence on initiating soft tissue trauma. Once an insult occurs it may later manifest as a pressure sore; or, the repair process may be retarded with inappropriate prophylaxis. The key to avoiding this cycle lies in reduction of both magnitude and duration of the external pressure. Seat cushions which employ air, gel, and fluid attempt equal distribution of pressure over the entire sitting area. However, the unstable, buoyant characteristics of these cushions may raise pressures higher than average capillary over the ischii, coccyx, and trochanteric heads, once active mobility is achieved. Furthermore, over the passage of time these same characteristics promote biomechanical deformities such as spinal curves, pelvic obliquity, and hip dislocations, or make manipulation of wheelchair-controlling mouth, head and shoulder switches difficult.

An alternative to equal distribution is "selective repartitioning", where designated portions of the sitting area receive high amounts of pressure while others are subjected to lower stress levels. In this way, the vulnerable ischial and sacrococcygeal anatomy is apportioned minimal stress. The bulk of the body weight is then transferred to the smoother and fleshier surfaces of the thighs and flanks of the buttocks, where higher levels of stress will not readily result in ischemia. This is most easily accomplished by use of a laminated foam cushion, which can be sculpted to the appropriate design.

Biomechanics

Disregarding congenital deformities, skeletal malalignment secondary to neuromuscualr deficiency is progressive without orthotic intervention. Conventionally, orthoses are considered for the appendages and trunk. Rarely is a seat cushion

considered an orthosis; however this term is fitting if the cushion accomplishes an orthotic task. In eupraxia, posture is maintained through the complimentary interaction of an intact skeleton and striated muscles, integrated with nervous control. Loss of nervous control, muscular power, or skeletal integrity may lead to a variety of biomechanical deformities. For instance scoliosis, when not idiopathic, may result from paralysis, muscular atrophy, or an imbalance of muscle power in the involved area of the spine. Orthotic intervention attempts to prevent or arrest the deformity by providing a compensatory exoskeleton for additional support. In like manner, the permanently seated person, especially with diagnoses such as spinal cord injury, myelodisplasia, or multiple sclerosis, may suffer from biomechanical deformities subsequent to the primary diagnosis. Permanent, intimate fitting devices for these patients are impractical. A viable alternative is the incorporation of pelvic and truncal stabilizing features into the wheelchair cushion.

In the sitting position, the pelvis is the primary foundation for postural control; it also supports the weight of the trunk and upper body, which comprises about two-thirds of the total body weight. It is important to stabilize the pelvis in all three planes of motion to deter biomechanical deformities associated with long-term sitting. Amputations, hip dislocations, fixed skeletal deformities, incontinence, and weight are other factors which dictate the final configuration of the SIO. Stabilization of the pelvis and trunk in a static position is the prime concern in the biomechanical aspects of design. For individuals exhibiting normal sensory feedback (e.g. muscular dystrophy, post-polio, or amyotrophic lateral sclerosis), provision of comfort plays an important part encouraging balanced pelvic positioning; otherwise the patient will assume a compromising postural attitude in an effort to avoid irritating stimuli. Design and fabrication of the SIO encompasses physical/occupational therapy assessment procedures and orthotic principles.

MATERIALS AND METHODS

Over the past year the authors have developed a cushion which is made from two commercially available foams, not simply laminated together but fabricated to a particular design to provide the desired support. These authors use a combination of Ethafoam-220 (1) and Temper-foam (2) in the fabrication of the cushion.

To relieve ischial and sacrococcygeal pressures, some commercial cushions employ a simple cutout in the perineal area, which relieves the pressure but cannot be considered to provide biomechanical support. The firm Ethafoam base reflects this relief but extends the cutout area forward to the groin to promote aeration. Biomechanical support is provided by the intimate contact afforded by contoured edges as opposed to a simple cutout (figure 1). The undersurface is shaped to match the sling of the wheelchair. Hip flexion beyond 90° can be accomplished by inserting a small wedge at (e.g.) 15° to horizontal. Doing so increases pressure loading to the thighs away from the sacroccoccygeal region and provides

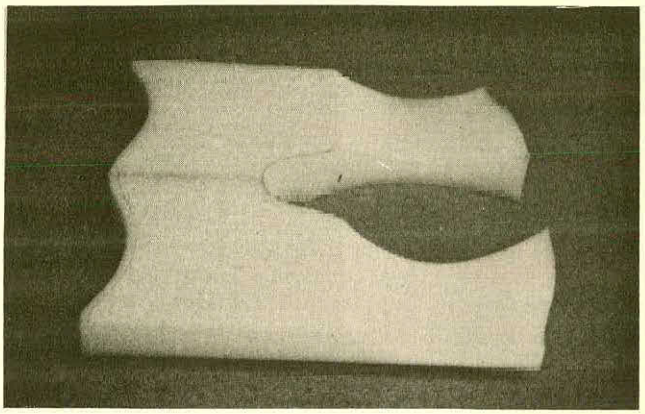

Figure 1

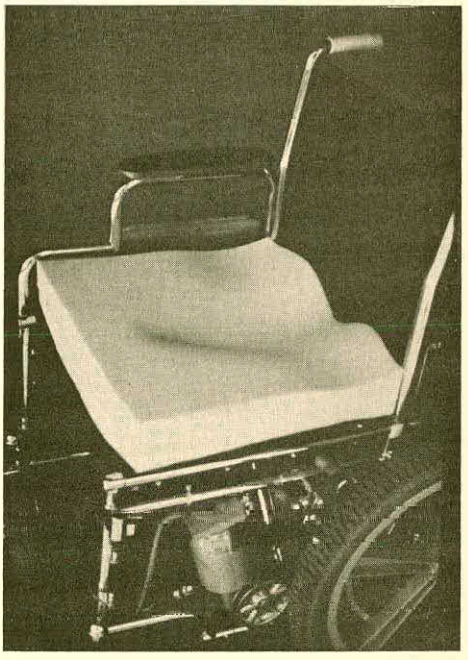

Figure 2

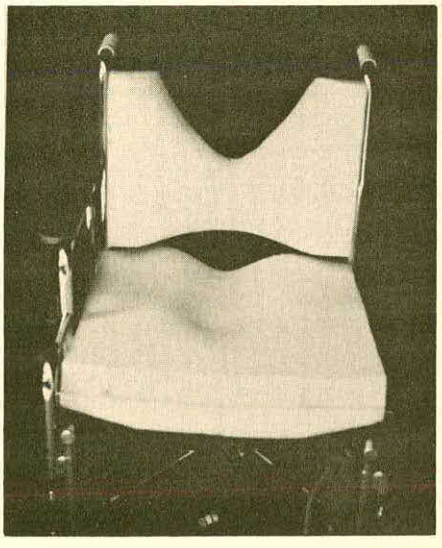

Figure 3

added anterior support to the trunk. The entire process can be completed by a skilled technician in less than 1 hour. This customizing process can also be used to accomodate any fixed asymmetry of the person's anatomy. Additional features, such as abduction pommels and thigh recesses can also be sculpted into the base design. The last step is to overlay this base with a viscoelastic or urethane foam (figure 2). The desired covering material is stretch cotton velour with a drawstring for easy application. The stretch quality of the material minimizes tissue shear, and the cotton fabric absorbs moisture to prevent skin maceration

Spinal relief or lateral truncal pads can then be added to reduce pressures in patients with say, a gibbous posture or a laminectomy (figure 3). As an extreme example, a spinal cord injured with extensive skeletal deficiencies requires skillful employment of orthotic principles in design of the support environment, including plaster casting and use of plastic materials. Nevertheless, selectively repartitioning the ischemic-producing load still provides the focal element for design of the SIO.

RESULTS

Effectiveness of the cushion is measured in the following areas: deterrence of biomechanical deformities, reduction of sitting pressures under bony pelvic prominences, healing of pressure sores (if any), increased sitting tolerance, and patient comfort. 23 of 24 patients on the cushion had favorable responses with regard to these criteria. Of these 23 patients, 10 had spinal cord injury, 3 multiple sclerosis, and the remainder an array of neurological, muscular, and skeletal maladies. The one patient who rejected the cushion had a spinal cord injury at C6, and was evaluating an earlier design. Since that time several changes have been incorporated and no additional problems have been encountered. Patients were recently interviewed within a two-week period in reference to the above criteria. All patients who initially reacted positively to the cushion were still using it at the time of interview. At the time of writing patients used the cushion for a maximum of 12 months to a minimum of 1 month, with an average use of 5.9 months. 11 of the 23 had tissue trauma at the time of evaluation. Since then three patients have completely healed and the remainder showed significant improvement. In each case pressure at the sacrococcygeal region was reduced to near zero. 10 of the 23 had biomechanical problems of significant magnitude to warrant special design of the cushion. When completed, all were supported to the satisfaction of physicians, therapists, and most important, themselves. All of the 23 patients either maintained or increased their daily sitting tolerance and rated the cushion high in regard to comfort, increased truncal stability, and enhancement of postural attitude.

Though certainly not an experiment conducted under rigidly controlled conditions, these results are encouraging and indicate that a seating interface orthosis can be designed to prevent decubitus ulcers as well as provide orthopedic advantages, regardless of the lack of biomechanical integrity.

CONCLUSIONS

Mathematical analysis of the average sitting contact surface area in man shows that pressure levels (if equally distributed) cannot be reduced to less than 47 mm Hg. (3). Further, equal pressure distribution may indicate instability. To achieve both a trauma-free sitting environment and maintain sound musculoskeletal integrity the principles of selective repartitioning must be employed. The above described principles of the SIO achieve this goal but it is stressed that the ultimate degree of success is restrained by the quality and completeness of the inital needs assessment.

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DEVELOPMENT AND EVALUATION OF THE ARROYA DOWNHILL SKI-SLEDDING SYSTEM FOR PERSONS WITH DISABILITIES

PETER W. AXELSON

Rehabilitative Engineering Research and Development Center
at the Palo Alto Veterans Administration Medical Center

ABSTRACT

The ARROYA is a sled like device contructed of reinforced fiberglass. Stainless steel edges on the bottom surface allow for turning and stopping on varying terrain and in varying ski conditions. The objective of this research is to continue the development and evaluation of a downhill ski-sledding system for persons who cannot use traditional skiing equipment. Just as important, downhill ski-sledding methodologies must be devoloped to facilitate the successful integration of this new sport into the existing ski population. The ARROYA addresses the neglected recreational needs of disabled persons who would benefit from integration into the whole of society. The responsible application of technology toward ski-sled design development and the establishment of downhill ski-sledding protocall will allow ski programs for the disabled to offer integrative downhill skiing to just about everyone.

NEED

The field of rehabilitation engineering has generally ignored the recreational needs of disabled individuals. There is a need for equipment that will enable persons with disabilities to participate in an able-bodied manner in a variety of sports.

APPROACH

Downhill snow skiing is an ideal sport to allow the integration of disabled individuals into the mainstream of able-bodied recreational enthusiasts. A new downhill ski-sled for the disabled has been developed and has received preliminary field testing by paraplegics and instructors in several handicapped ski programs. This sled has proven to be safe, controllable and compatible with 97% of all ski chairlifts. An approach that unifies ski-sled development and program integration will help to assure participation of the disabled community in recreational activities.

STATUS

RERanD Center Program

The Rehabilitative Engineering Research and Development Center at the Veterans Administration Medical Center in Palo Alto, California is responsible for the coordination of development and evaluation of ARROYA ski-sled prototypes. RERanD core monies funded the construction of 15 ARROYA IV prototypes for the 1979-80 ski season and 10 ARROYA V prototypes for the 1980-81 ski season. RERanD also funded three ski-sledding instructor clinics during the 1979-80 ski season to facilitate program evaluation.

Field Testing and Clinics

During the 1979-80 ski season, the prototype ski-sled, ARROYA IV, was field tested at nine ski areas including Winter Park Ski Area at Winter Park, Colorado and Snoqualamie Ski Summit near Seattle, Washington. Instructor clinics were also held at each of the nine ski areas where ski programs for the disabled are utilizing a total of twenty ARROYA IV downhill ski-sleds. These clinics provide instructors, disabled ski program directors and users with knowledge on the safe operation of the ski-sled.

User Feedback

Information gathered from instructor and user questionnaires is facilitating the development of a better manual for use by ski-sled instructors and users. Questionnaire information was also used to develop the ARROYA V ski-sled which incorporates user feedback and suggested modifications from the 1979-80 ski season. For example, users indicated that while turn were easy to complete, they were difficult to initiate. This suggestion led to the use of four edges on the ARROYA V, two forward edges which allow skiers to initiate turns and two rearward edges which allow completition of a turn.

Public Awareness

Demonstrations of the ARROYA ski-sled at various instructor clinics throughout the United States and in Norway generated very positive publicity. Each clinic received local newspaper coverage and some received television coverage. The objective of this publicity was to make individuals aware of the opportunity for paraplegics to use the ARROYA ski-sled and to increase general public awareness of the disabled community.

disabilities. Slalom, giant slalom and freestyle events were offered in mens and womens classes A and B. The ARROYA was also demonstrated at the "Winter Olympics for the Disabled" in Geilo, Norway, where it was proposed that the ski-sled be integrated into international sports competition for the disabled.

1981 National Handicapped Ski Championahips

Ten ARROYA V ski-sleds were used in competition at the 1981 National Handicapped Ski Championships at Winter Park ski area in Colorado by 35 skiers with varying disabilities. The freestyle event was eliminated this year. However an unofficial downhill event was added. The competition was close and exciting for all of the racers involved.

National Coordination

During the 1981 Nationals, a meeting was held to exchange information and discuss the various issues associated with downhill ski-sledding programs. Present at the meeting were representatives from all of the RERanD ARROYA evaluation centers and three other ski-sledding programs. Among the issues discussed were:

A. Tethering of ski-sledders vs. non-tethering (Tethering is a buddy system whereby an able bodied skier trails the ski-sled with a line attached. This is an aid to the sled skier during learning and is often required by ski area management at all times).

B. Ski area insurance problems as related to the ARROYA.

C. Ski area personnel involvement with chairlift loading and unloading procedures.

FUTURE WORK

Continued development and evaluation of ARROYA downhill ski-sledding systems for persons with disabilities has been disapproved by the Veterans Administration merit review system. Immediate action is being taken to locate research oriented manufacturers who will continue the development and manufacture of ARROYA ski-sleds.

However, RERanD will:

A. Continue to monitor the evaluation of ARROYA V ski-sleds.
B. Seek funding for typesetting and printing of the ARROYA users manual.
C. Monitor the certification of Level II and III ski-sledding instructors.
D. Monitor the certification of "advanced" ski-sled users.

CONCLUSION

This work has benefits for both society and the individual. Because of the low pressure situation associated with recreation, integration of the disabled into the able-bodied population is facilitated. Able and disabled individuals benefit mentally and physically from skiing activities, and these effects can carry over into all aspects of life. We expect to demonstrate that anyone on the ski slopes is an able bodied skier.

The following programs are currently evaluating ARROYA V ski-sleds which are on loan from the Rehabilitative Engineering Research and Development Center at the VA Medical Center, Palo Alto, California:

Winter Park Recreational Association
Box 36
Winter Park, Colorado 80482
(303) 726-5514, ext. 179

Breckenridge Outdoor-Education Center
P.O. Box 697
Breckenridge, Colorado 80424
(303) 453-6422

Ski for All Foundation
Chris Colb, Executive Director
521 Wall Street, Suite 326A
Seattle, Washington 98121
(206) 623-2714

NHYSRA Lake Tahoe Chapter
Larry Young
Box 1636
Truckee, California 95734
(916) 587-3911

If you have further questions, please contact:

Peter Axelson
Rehabilitative Engineering
Research and Development Center (153)
Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, California 94304
(415) 493-5000, ext. 4473

ARROYA V ski sleds are available for $980 from:

Beneficial Designs
5858 Empire Grade
Santa Cruz, California 95060
408-429-8447

PUBLICATIONS

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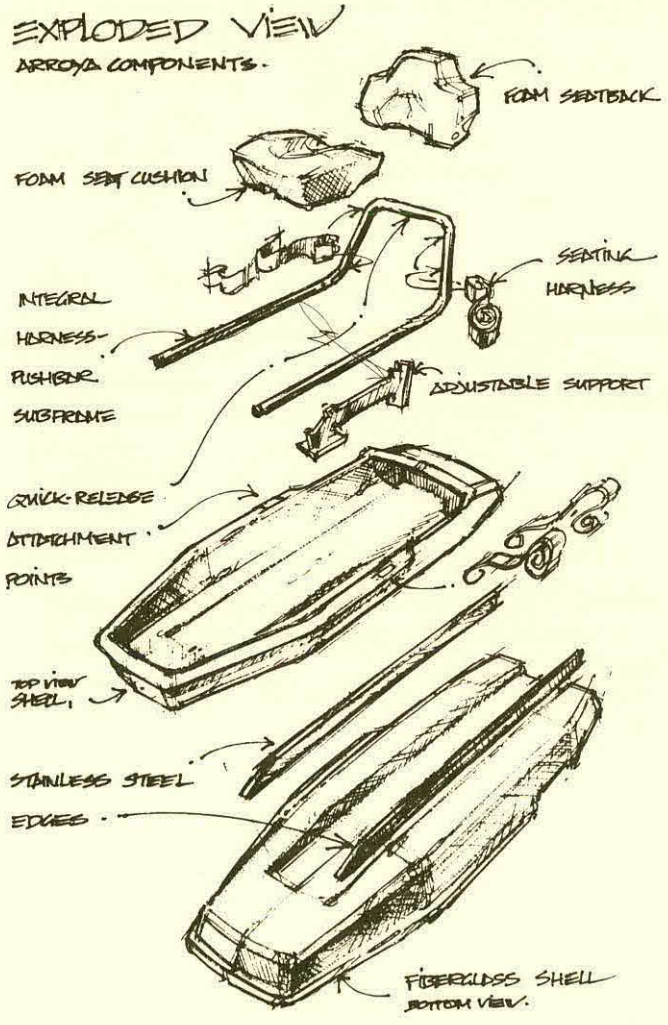
DESIGN FEATURES

The ARROYA ski-sled is unique. It has many downhill advantages over the Norwegian "Pulk", the "Smith Sled" and other sled-like devices that are available for skiers with disabilities. Most of these other devices can be used for cross country skiing. However, many requirements are necessary for a device to be safe and compatible with existing downhill ski area facilities. Ski-sledding devices must meet criteria with regard to the following issues:

a. standard chairlift loading procedures
b. standard chairlift unloading procedures
c. standard chairlift evacuation procedures
d. control over speed on busy ski slopes
e. control over direction on busy ski slopes

These five issues are of major concern to ski area management and must be addressed in order to assure a safe ski-sledding system that will be permitted at a public ski area.



Chairlift Compatibility

The ARROYA ski-sled has been found to be compatible with 97% of the chairlifts in the United States. With the aid of an experienced lift crew, an able bodied skier and an ARROYA user can load onto and off of a chairlift without stopping the lift. However, in all cases the chairlift is slowed during the loading procedure. Each sled has a securing mechanism which is designed for quick connect and disconnect. In addition, each sled is equipped with a built-in harness which enables evacuation of the user in the event of chairlift breakdown.

User Controlability of the ARROYA

The bottom of the ski-sled is concave and is similar to the design of a water ski. Stainless steel edges are attached to the inner vertical surfaces of the concave area as shown in the figure. These edges allow for controlled traverse on the ski slope. Preliminary field testing has demonstrated that users of the ski-sled have the ability to control their turns on "intermediate" ski slopes in a variety of snow conditions and on "advanced" ski slopes when snow conditions are most favorable.

Simple Design and Maintenance

A specially designed strap system secures the skier to the sled in a way that is analagous to a downhill skiers foot in a ski boot. A high density contour-molded seat cushion provides good skin protection over rough terrain. The seating system, developed under a RERanD contract to the Childrens Hospital at Stanford, is specifically designed to reduce sacral pressure. The snowskirt cover is made of nylon wet suit material and holds the skier snugly in the sled. Thus, the skier becomes a "part" of the sled and any movement or force exerted by the skier translates into motion of the sled.

Integration of the Disabled Skier with Other Skiers

Unlike many other sports and recreational activities available to the disabled person, the ARROYA allows a ski-sled user to interact naturally with skiers using other types of adaptive equipment (i.e. skies, boots, poles, etc.). This type of interaction between ambulatory and non-ambulatory individuals is not found in "wheelchair sports" (many recreational activities for paraplegics and quadriplegics tend to segregate them from their ambulatory friends). In fact, able-bodied individuals also enjoy skiing in the ski-sled. It is therefore possible that this ski-sled will be used by both ambulatory and non-ambulatory individuals. Such widespread usage could produce such a large market for ski-sleds that the cost of a sled would be significantly reduced.

1980 National Handicapped Ski Championships

ARROYA IV downhill ski-sleds were used in competition at the 1980 National Handicapped Ski Championships in Colorado by 14 skiers with varying

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DOWNHILL SKI-SLEDDING SYSTEM FOR PERSONS WITH DISABILITIES

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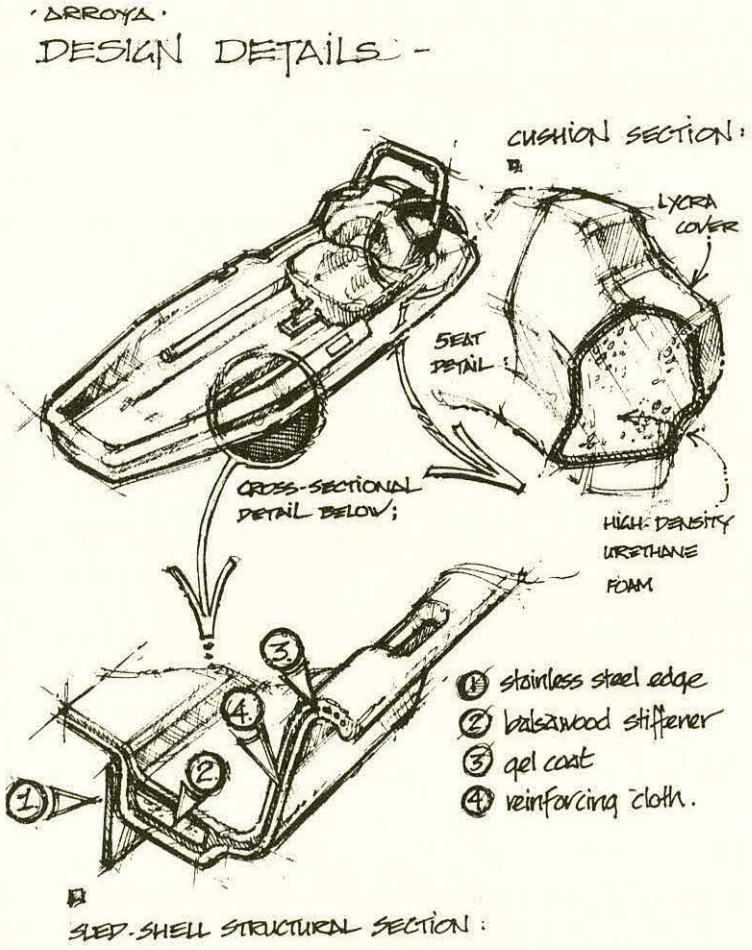

STUDENT PAPER

PARAPLEGIC RECREATION AND EXERCISE VEHICLE

Craig Forsyth, Ronald Rob, Jonathan Lexier

University of Manitoba in Mechanical Engineering

ABSTRACT

The purpose of the project was to design and construct a recreation and exercise vehicle for paraplegic persons that took into account most of their physical limitations. Heavy emphasis was placed on the design of features being "tailored" to accommodate their disability and capabilities.

A vehicle has been designed that is both functional and simplistic. It incorporates special features and is meant to be an economically viable alternative to present vehicles on the market.

The vehicle designed, we feel, meets the needs of paraplegic persons and is better constructed, component-wise, than anything currently available on the Canadian market.

INTRODUCTION

Our project attempts to surmount the barriers that paraplegics can encounter in their efforts to enjoy recreation and exercise. These two basic human needs are traditionally geared to using legpower and ultimately exercising the cardiovascular system. Many paraplegics, depending on their degree of paraplegia, have restricted use of their legs and are, therefore, limited in the number of activities in which they can participate where equipment does not necessitate the use of one's legs. It is for these needs of recreation and exercise that our group decided to design and construct a vehicle for these people's use.

Knowledge of existing vehicles aided us considerably as the advantages and disadvantages of each could be noted. Ratchet driven wheelchairs, wheelchairs with attachable front wheels and hand cycles presently being manufactured in the United States were all looked into.

We proposed to put as many of the advantages together in one vehicle as possible, as well as our own ideas. The styling was based on the popular ten-speed bicycle. The Paraplegic Recreation and Exercise Vehicle (PREV) would be of a hand powered, front wheel drive tricycle nature. Provision for five speeds, a length of five to six feet and a weight range of fifty-five to sixty-five pounds constituted the vehicle's numerical specifications. The idea of using this type of vehicle is a rather imaginative one and interest has been shown on the part of possible users. The fact that we are dealing with a limited market points toward a cottage industry type of product. PREV is meant to be used in the normal summer cycling season under the same conditions as regular bicycles by persons who have, as a minimum, upper body muscle control.

DESIGN APPROACH

Since none of the group members were knowledgeable in the area of disabled persons, we consulted some who were. A representative of the Canadian Paraplegic Association and members of the Physically Handicapped Concerns on Campus group provided us with the user specifications regarding the seat, leg supports and foot rests. With this in mind, a set of design criteria was established that included: (1) minimization of weight; (2) accessibility; (3) stability; (4) utility; (5) overall dimensions; (6) storage and transportability; (7) user comfort; (8) aesthetics and (9) economics. These design criteria provided the groundwork upon which the structuring of a realistic design was based.

DESIGN FEATURES

Swivelling Mid Frame

Our tricycle utilizes a swivelling mid frame that has been incorporated to aid in the mounting and dismounting from the vehicle. In our research, we found that many of the presently available vehicles of this nature contained a rigid frame that connected the entire frame structure. In our efforts to take the paraplegic's condition into account, we decided to depart from this norm and use a mid frame that swivels; thus allowing the wheelchair to be brought closer to the bike. Ours will swivel to either the left or right, so the user has a choice as to how he gets on the bike. The swivelling bar will be contained in a restrictive slot that will control the side-to-side movement of the bar. The swivelling concept will greatly fulfill the accessibility design criterion. A locking mechanism to constrain the swivel frame while the vehicle is in motion has been developed also.

Front Frame

The design of this component was made to conform as closely as possible to those shapes found on existing bicycles. The front frame utilizes a five-speed derailleur system that is driven by a chain and sprocket assembly. The unique feature of this particular drive system is that it is not the standard circular pedal drive that is conventionally used for a hand-driven vehicle. Ours is a ratchet driven chain and sprocket assembly. The hands of the rider move in essentially the same plane, moving simultaneously in opposite directions. One can visualize the motion by placing his arms straight out in front of him and simultaneously pulling back on one hand while the other moves in the forward direction. The ratchets turn a driving sprocket and motion is transmitted to the front

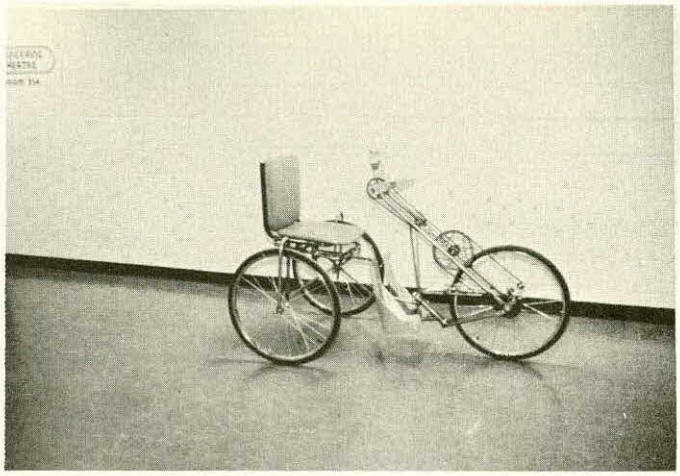

Figure 1: Vehicle without armrests

driving wheel of the bicycle via gears and chains.

Rear Frame

The last major component of the bicycle is the rear frame. It is this section that the rear wheels fasten to and also the section of the vehicle where constraints resulting from the design of the previous two sections does not allow for a great deal of originality. It must support the person using the bike and not contribute significantly to the weight. A basic frame utilizing twin axle support members and a rectangular seat support was employed.

Minor Components

The seat was chosen with a special purpose in mind. It has sides or arms that contain the rider giving a greater feeling of security when riding the vehicle. Padding on the seat and back could be increased according to the needs of the individual user. Leg supports with velcro straps were chosen. These leg supports have foot rests and foot tiedown straps which are a must for a paraplegic because of the way their feet tend to flop forward and hang limply if not supported properly. A lap belt to hold the rider in would be of the quick release type used in automobiles. Most of the other smaller components used on the vehicle, like the caliper brake assembly and gear shifting arrangement, could be salvaged from a ten-speed bicycle, or purchased at a bicycle repair store.

This description basically completes the ideas conceived thus far for the "Paraplegic Recreation and Exercise Vehicle."

ADDITIONAL COMMENTS ON DESIGN

The desire to design something that could be easily reproduced by the average, machine shop oriented person necessitated the use of various simplifying procedures. Straight pieces of tubing were utilized as much as possible. The tubing that was bent was done so by packing the tube with silica sand and effectively transforming it into a "solid" piece of material. Aluminum for weight savings was used where strength was not a factor. The aluminum leg supports have since been redesigned out of ABS pipe – molded to the contours of the human leg. The present vehicle has an overall length of sixty-nine inches and weight of approximately sixty-four pounds. The thirty-one inch wheel width makes it possible to go through most standard sized doors. A turning radius of eight feet can be achieved and gearing ratios are being experimented with to find the optimum range. Standardized parts and sizes were used wherever possible to cut down on the cost. A preliminary cost estimate to build such a vehicle would be $450.00 plus labor. However, the cottage industry approach and purchasing materials at quantity discounts would reduce this figure (which was arrived at using all new retail prices), quite significantly. A guesstimate of the labor time involved on the prototype would be in the range of 140 – 160 hours. Average construction time could be minimized to approximately one-quarter of this value.

CONCLUSION

In our conversations with members of the Canadian Paraplegic Association and Physically Handicapped Concerns on Campus, the point was made that a general nature vehicle of this sort should not be built. It has to be designed for a particular group with a particular use in mind. We heeded this advice, and have designed a better vehicle, we feel, for the purpose it is serving, that is, recreation and exercise for the paraplegic person.

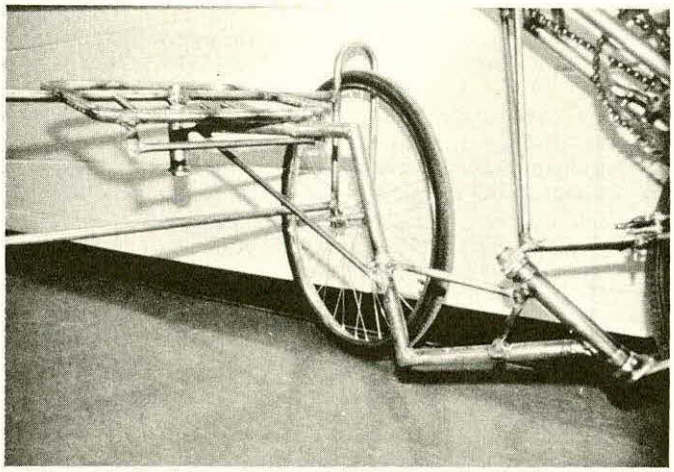

Figure 2: S–Bar mechanism which allows front of vehicle to swing away and facilitate mounting/dismounting.

PREV Project Team

PARA-BIKE - A RECREATIONAL BICYCLE FOR INDIVIDUALS WHO DO NOT HAVE THE USE OF THEIR LEGS

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Rehabilitative Engineering Research and Development Center
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ABSTRACT

The Para-Bike, a low riding bicycle for individuals who do not have the use of their legs, is being developed at the Rehabilitative Engineering Research and Development (RERanD) Center, located at the Veterans Administration Medical Center in Palo Alto, California. As part of an active recreational device development program at the RERanD Center, a working prototype of the Para-Bike has demonstrated the feasibility and potential of a two wheel cycling alternative.

INTRODUCTION

Enjoying Life

A disabled individual is entitled to enjoy life, and the rehabilitation engineering community is in a position to help assure a fully meaningful existence, unmitigated by disability. The Rehabilitative Engineering Research and Development (RERanD) Center has approached this need with an active program to develop recreational devices for the disabled.

Bicycling

As a recreational activity engendering both physical and emotional vitality, bicycling is particularly appropirate for an individual endeavoring to overcome difficulties in mobility and participation. Depending upon the interests and specific needs of an individual, the bicycle may be used for a wide variety of recreational and therapeutic purposes ranging from exercise, improvement of balance and relaxation, to the excitement of competition, the pleasures of interacting with friends, and the exploration of the countryside and one's independence.

With the further development of the Para-Bike, a low riding two-wheeled bicycle, people without the use of their legs will have the opportunity for the first time, to share in the physical and emotional benefits of bicycling.

Development Of "Para-Bike"

Now undergoing a testing and prototype development phase at the RERanD Center, the Para-Bike began as a design project for Candy Mintz and myself in the Stanford University Design Division masters program (as a VA sponsored, RERanD Center administered project). Professor Phillip Barkan was the program instructor, and Professor Larry Leifer, director of the RERanD Center, served as faculty advisor. Biomedical engineer, Peter Axelson, was the RERanD Center liaison on the project. The challenge was to provide a creative alternative in paraplegic recreational cycling. The program culminated in a working prototype (see Figure 1 above).

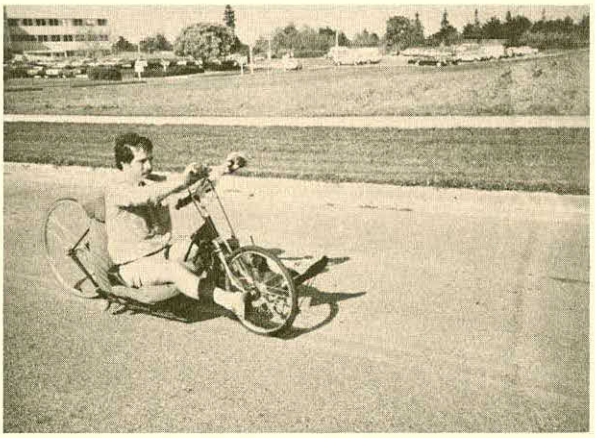

Figure 1. The low riding two-wheeled Para-Bike shown in action.

RELATED CYCLE DESIGNS ON THE MARKET

Tricycles

Hand pedaled tricycles have been around for years, including one report of a trike custom built in the 1920's at a bike shop in Bemidji, Minnesota. More currently, JanssenR of Englewood, Colorado, has been on the market for several years with a number of models of their Hancycle.

Several tricycles have been designed and built by individuals initially for their own needs and now available custom built. Bill Warner of Brookline, Massachusetts, who has ridden hand-powered tricycles in the International Human Powered Vehicle Association (IHPVA) Championships for three years in a row, is now marketing a design with his recent improvements. Ron Grismer of Charlo, Montana, and George Cunningham of Seattle, Washington, have ridden trikes of their

own design on a five day 200 mile camping trip. Daniel Gould of Missoula, Montana, who built Ron Grismer's tricycle, now has a custom building service.

Wheelchair Conversion

Orthopedic Systems of Nelsonville, Ohio, markets their Unicycle, an attachment which converts a wheelchair into a tricycle.

FUNDAMENTALS

Bicycle vs. Tricycle or Multi-Wheeled Vehicles

The bicycle holds a very special niche among vehicles. It is lighter more compact than vehicles with three or four wheels.

The dynamics of a bicycle are also unique. The bicycle becomes an extension of the rider's motion. As Stanford Professor Thomas Kane put it during an informal discussion with us on cycle dynamics, a bicycle has the remarkable quality of moving in unison with the rider, leaning into turns. More wheels improve the stability at slower speeds, but around curves the rider must be fighting the vehicle's tendency to tip.

There is another characteristic specific to the bicycle. When released while at rest, the bicycle will fall to one side or the other. However, once rolling, the tendency to remain upright and self steer increases with velocity.

The existing tricycles have begun to meet the needs of the disabled cyclist, and yet the push for a two-wheeled alternative has led to the more exciting Para-Bike concept.

PARA-BIKE DESIGN FEATURES

The Para-Bike has reshuffled several of the features found on standard bike designs, including the drive mechanism and position of the cyclist. A hand-cranked chainwheel and chain linkage to the front wheel replace handlebars, combining the propulsion and steering mechanisms. The pedaling axis is offset from the steering axis to enhance steering control. Back pedaling activates a caliper brake on the rear wheel.

Balance And Support

The natural tendency of a bicycle to balance and self steer diminish at slower speeds. People who have the use of their legs may drop a foot to help balance when coming to a stop on a standard bicycle. On the Para-Bike, the low-slung profile allows the rider to be within arms reach of the ground. The rider wears protective wrist and hand guards and comfortably uses a hand as a support when starting or stopping (see Figure 2). As a precaution, a spherically shaped rollerskate wheel is mounted on the frame to either side of the rider ready to touch down at the point of maximum desirable lean. Although useful as training wheels and convenient as a third wheel when desired, the side wheels tend to limit the turning radius as tighter turns may require a greater lean. For this reason, the side wheels may be shed as the rider gains proficiency.

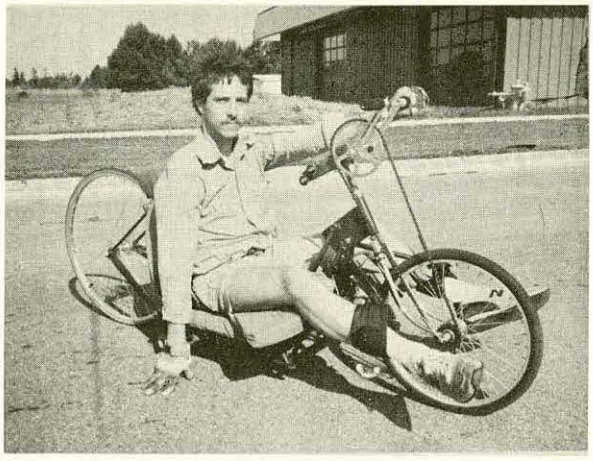

Figure 2. Para-Bike at rest with the rider using a hand for support. Side wheels are visible on the seat frame below the rider.

Seating

A web and cushion seating arrangement responds to the special needs of the paraplegic, who is highly susceptable to decubitus ulcers caused by prolonged pressure over the coccyx and the ischial tuberosities. Elastic material is woven to form a mesh stretched between the tubes of the box-like frame.

A cushion developed in conjunction with Stanford Children's Hospital for the ARROYA (a downhill skiing sled, designed by Peter Axelson and developed at the RERanD Center) is placed on top of the elastic suspension. The cushion is shaped to redistribute the support away from the pressure sensitive areas.

The rider sits upright, the legs suspended in cushioned, quick release slings from either side of the front end of the frame.

Adjustable Steering Geometry

A first prototype (without appropriate seating) was fashioned out of discarded bicycle parts to establish the feasibility of the low riding concept. However, the wobbly steering tendency, resulting from the coupled steering and pedaling, led to the incorporation of an adjustable steering geometry on the current prototype. By allowing fine tuning of the variables influencing steering, the optimal arrangement may be determined experimentally.

Other Features

Fashioned out of 3/4 inch thin walled, high strength chromium-molybdenum tubing, the Para-Bike weighs 42 pounds, which is less than the hand-powered tricycle designs (and yet including the

extra weight involved in the adjustable steering apparatus). Only about 20 inches wide, doorways are no obstacle. Built by Peter Johnson of Palo Alto, who has designed, built and raced his own "streamline" cycle in the IHPVA, the Para-Bike is a showpiece of craftmanship.

PERFORMANCE AND EVALUATION

Peter Axelson, a T-10 paraplegic, was the first individual to ride the Para-Bike, and he has gained considerable proficiency on level terrain. A wider gear range is needed to venture into hilly countryside.

Initial testing has shown that the Para-Bike gains in stability with increasing speed. However, even at lower speeds, it retains its controllability and may be maneuvered indoors, adding immensely to the usefulness of the device.

Out on the bike path, the low riding characteristic has another advantage. Closer to the ground, the sensation of speed is magnified adding to the excitement generated by the enhanced maneuverability of a bicycle.

Learning Phase

The learning process is characterized by an initial awkwardness, similar to that experienced on a standard bicycle, as the rider experiments with the new sensations of balance and directional control. Some coaching is helpful, as there are techniques which facilitate a more rapid mastery of the vehicle. However, the rider must essentially train by doing, developing the control by trial and error.

One technique which has shown considerable value is to instruct the rider in "turning into the fall". This action, when done smoothly, simply reestablishes the balanced tracking of the bicycle. As the rider's skill increases, this balancing technique becomes automatic, and is virtually undetectable. By using the steering to maintain balance, the rider does not need to depend as much upon shoulder and back muscles for adjustments in the lean of the bicycle. This is an important feature for the individual with more limited control of back muscles.

Level Of Paralysis

The extent of paralysis for which the Para-Bike is appropriate will become more obvious with further user evaluation, but is expected to vary significantly with the individual. The further development of the Para-Bike will concentrate upon improved performance and accommodating higher levels of paralysis.

A more comprehensive field testing program is getting underway with the upcoming selection of an optimal steering configuration and design of the next prototype.

FURTHER DEVELOPMENT

Approach

Our approach is to first develop a competition prototype of the Para-Bike. The excessive stringencies in design criteria for competition equipment will foster rapid advances in the design evolution, providing valuable information for the design of a subsequent improved recreational version. The second phase of our work will incorporate the field testing results of the first competition and recreational prototypes into the development of comprehensive production oriented versions of the Para-Bike. We will work closely with potential manufacturers of the Para-Bike to ease the transition into the marketplace.

Current Progress

Work is underway on the first competition version of the Para-Bike, sponsored by the Telephone Pioneers of America - Sierra Pacific, George S. Ladd and John I. Sabin Chapters. This competition version, which will perform at the IHPVA Championships, will incorporate major changes in the frame configuration and seating. A single large diameter tube in line with the wheels will replace the box-like frame which holds the suspension seating on the current prototype, significantly reducing the weight of the frame. A hammock arrangement, secured from swaying and supported at key locations will form the seat bottom, with appropriate cushions placed on top of the hammock.

The pedal cranks will be placed so that they extend away from the pedaling axis in the same direction, instead of offset by 180 as on standard bicycles. Initial testing has demonstrated improved steering control as propulsive thrusts and pulls are applied symmetrical about the steering axis.

CONCLUSION

The Rehabilitative Engineering Research and Development Center is involved in applying recent advances in engineering science and technology to the direct benefit of disabled persons, in all aspects of life. The Para-Bike, a creative alternative in cycling for the disabled, has demonstrated its feasibility and is under further development at the RERanD Center.

PARA-BIKE PUBLICATIONS

Schwandt, Doug, "Para-Bike", Sports 'n Spokes, The Magazine for Wheelchair Sports and Recreation, Pheonix, Arizona, November/December, 1980, pp. 18, 19 and 21.

DC MOTOR CONTROL FOR REHABILITATION USE

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Medical Engineering Resource Unit of
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ABSTRACT

A versatile, analog DC motor controller is described. Pulse-width modulation techniques are used to provide proportional control. A center-off facility is present. The circuitry is adaptable at the input, to various analog transducers, and at the output, to different DC motors.

OBJECTIVE

National Health and Welfare, Canada have been funding a project to design and build an analog DC motor controller. Features which have been deemed important are: a) proportional control (ie. speed related to position of a joystick), b) center-off capability, c) high efficiency, d) high reliability, and e) adaptability (to different joysticks and different motors)(1).

THE DESIGN

In order to operate the DC motor control two 12V batteries are required. They must be connected in a series configuration to provide +12V, 0V, and -12V. The following discussion assumes the use of this power source.

The Logic Circuitry

500 milliamp regulators, +5V and -5V, power the logic circuitry. This ensures that the performance of the motor does not become erratic after the batteries become discharged. A schematic of the DC motor control circuit is given in Figure 1. The circuit shown is actually half of a circuit which has been used to drive two motors on a wheelchair, thus explaining the many unused pins.

In this design, a motor is driven by a control signal and its complement. The complementary signal, Va', is achieved by inverting the original motor control signal, Va. Va is a pulse-width modulated signal determined by an LM 747 (and its associated circuitry) from a DC level, Vj, provided by a joystick (or other form of analog transducer). As the joystick is moved, Vj changes, and the pulse-width of the motor control signal changes proportionally. Adjusting potentiometer P2 varies the pulse-width modulation over the range of the joystick. Thus, it is possible to supply to the motor an average voltage of anywhere from 6 to 24 volts when the stick is fully forward. The LM 747 is a dual op-amp and therefore can be used to provide two independent motor control signals.

Different joysticks can be interfaced with an appropriate selection of resistor R1. The frequency of the pulse-width modulation signal can be changed by altering capacitor C1.

To ensure minimum power loss while the joystick (or other transducer) is in the center position, the logic circuit has a dead band facility. The quad-comparator, LM 339, takes two voltages off potentiometer P1 and compares them with the voltage level, Vj, from the joystick. The comparison outputs are then ORed together to provide a control signal for the CD4066 analog switch. If the joystick voltage lies within the dead band, the analog switch is open and no signal passes to the motor. As soon as the joystick voltage leaves the center-off band, then the analog switch is closed and the pulse-width modulated signal, Va, controls the speed of the motor. The width of the dead band can be varied by adjusting potentiometer P1.

The Output Amplifier

The configuration of the output amplifier is shown in Figure 2. The circuit is symmetrical about the motor, except that one side is driven by the signal Va while the other is driven by its complement, Va'.

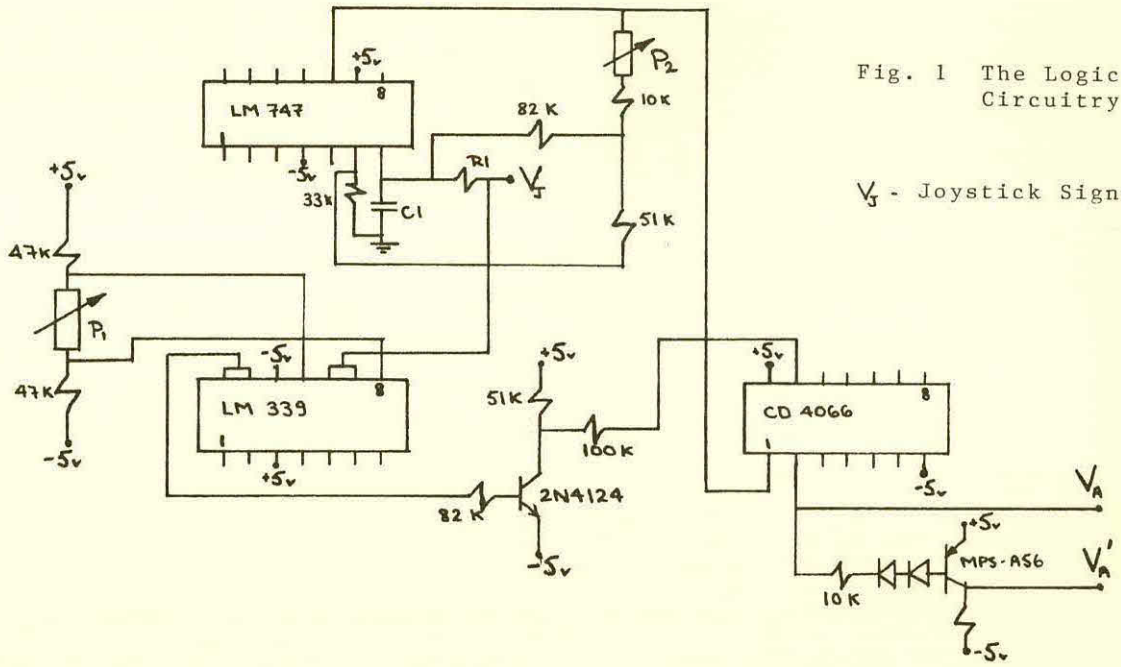

Fig. 1 The Logic Circuitry

V_J - Joystick Signal

Another feature of the amplifier is that the bridge configuration of transistors ensures that both batteries in the series combination degrade evenly. Regardless of which direction the motor is spinning, the current supplied by each battery is the same. This results in consistent behaviour of the motor in periods of low battery charge.

The amplifier shown was designed to have all transistors saturated for all motor currents up to 8 Amps. Both the 2N5883 and the 2N5885 transistors are rated to 20 Amps and can be used efficiently at that output if their base resistors, the 51 ohm - 5 Watt resistors,are changed. Therefore, the output amplifier is capable of delivering up to 20 Amps at 24 volts.

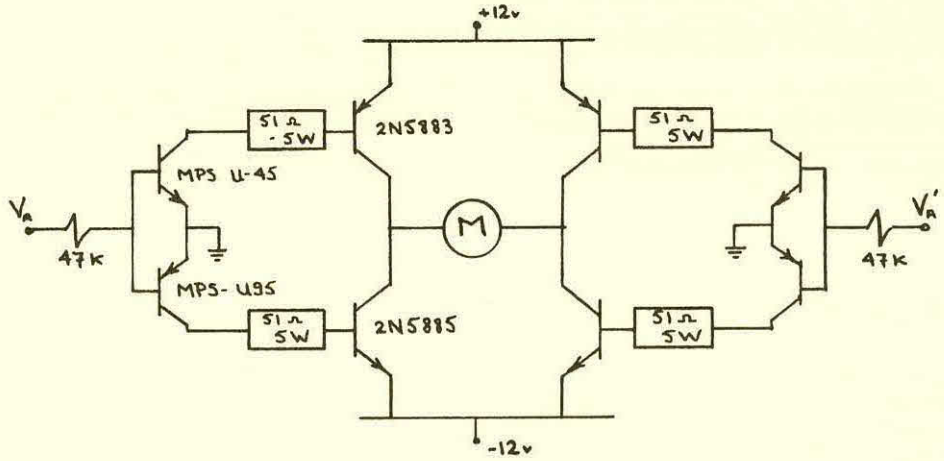

Fig. 2 The Output Amplifier

EXAMPLE APPLICATION

Two current applications of the DC motor controller include motorized wheelchairs and motorized lifting systems.

For the powered wheelchair, two friction-drive motors were available. Thus, two independent motor controls were needed. The circuitry in Figures 1 and 2 was duplicated and tests were subsequently performed. Very little heatsinking was required; currents up to 8 Amps resulted in minimal heating of the transistors. The voltage drop obtained at the motor was 23.2 V for a 24.0 V supply. The dead band worked with no noticeable jerking of the chair.

The controller has not been used on a lifting jack yet. However, if the output current requirement exceeds 8 Amps, the base resistances of the 2N5883 and 2N5885 will have to be decreased, and some more heatsinking will be required.

DISCUSSION

The DC motor controller described is adaptable at both the transducer and the motor end. Single potentiometers adjust both the maximum voltage at the motor and the center dead band. The attainable overall electrical efficiency exceeds 90%.

The limitations of the controller depend on the output requirements. Maximum voltages ranging between 6V and 24V can be provided. The maximum current is limited by the rating of the transistors - 20 Amps in this case. The critical element in determining the efficiency of the controller is the base resistances of the 2N5883 and 2N5885 transistors. These resistances must be chosen so that a) the output transistors are always saturated, and b) the power loss in the base circuit is minimized.

Maximizing the efficiency of the controller also means a minimum of heatsinking is required. Therefore, the physical size of the controller can be kept very small.

The Medical Engineering Resource Unit is currently having 25 DC motor control units manufactured for wheelchairs. Each unit is capable of controlling two motors independently. Twenty will deliver up to 8 Amps comfortably, and the other five will supply up to 14 Amps. The latter are expected to appeal to clients who wish to 'race' their powered chairs.

ACKNOWLEDGEMENT

The author wishes to thank the Vancouver Foundation and National Health and Welfare, Canada for initiating and sustaining this and other related projects.

A special acknowledgement is extended to Mr. J. Richards for his technical support and advice to this work.

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WHEELCHAIR BATTERY CAPACITY[1]

Vernon W. Ulrich[2] and James J. Kauzlarich[3]

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ABSTRACT:

The behavior of wheelchair batteries is being investigated through various types of testing. Bench tests and actual in use wheelchair tests are presently in progress. These different tests are being related using Miner's Rule. A development of Miner's Rule and the testing procedures are included. Preliminary results suggest that Miner's Rule is applicable to battery capacity calculations.

INTRODUCTION:

A wheelchair user's daily activities often demand more power than his chair batteries can supply. The purpose of this project is to gain knowledge about the behavior of batteries in wheelchairs. A combination of computer analysis and experimentation is being used in the investigation on bench and wheelchair usage tests.

THEORY

The computer analysis is dependent on development of an appropriate model of battery capacity. Batteries, beams under cyclic loading, and ball bearing fatigue are all governed by the same power law equation.

$$\text{Time} = C_1 \ (\text{Load})^{C_2} \qquad (1)$$

where C_1 and C_2 are empirical constants. Equation (1), for a Pb/acid battery, appears as a straight line on log-log graph paer as shown in figure (1).

Miner's Rule, which was originally developed for cummulative fatigue failure, allows equation (1) to be applied to non-constant load conditions. Consider a battery subjected to a given load for a given length of time (t) which is less than the time (T) required to deplete the battery charge at that load. The ratio of these two times represents the portion of the available battery

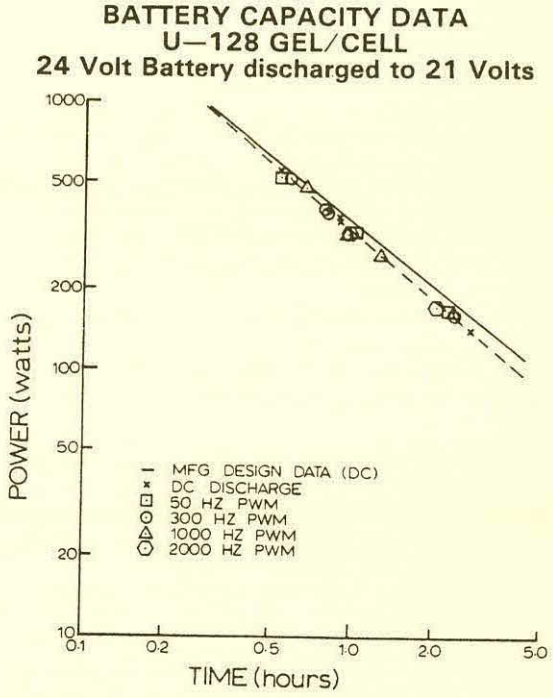

Figure (1)

energy used. As the discharge continues, Miner's Rule predicts that the sum of these ratios will be constant for a given battery. This can be expressed mathematically as:

$$\sum_{i=0}^{n} \frac{t_i}{T_i} = C \quad (\text{Miner's constant}) \qquad (2)$$

A mean value for Miner's constant reported for the fatigue failure of Aluminum alloy is 1.05.[2] Interestingly, the results of tests at the University of Virginia suggest that the appropriate constant for Pb/acid and Ni/Cd batteries is close to 1.05. Equations (1) and (2) have been programmed into the computer and are being applied the experimental data.

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[1] This work is supported by Grant #23-P-55960 National Institute for Handicapped Research.

[2] Graduate Research Assistant, Department of Mechanical Engineering, University of Virginia.

[3] Professor of Mechanical Engineering, University of Virginia.

BENCH TESTS:

Various single load bench tests have been run over the past two years, including both direct current and pulse width modulated discharges. The results, which have already been published, [7] show no difference in Pb/acid battery capacity between pulsed and direct current discharges, over pulse width frequencies ranging from 50 to 2000 Hz.

Present bench testing is centered about different variations of a two step driving cycle. A typical example, similar to one used by NASA, [6] involves direct current loads of 80 watts for 1 second and 600 watts for 4 seconds, followed by 7 seconds of off time. This cycle is repeated until the battery voltage drops below 21 volts. Data is collected by computer and then analysed with respect to Miner's Rule.

WHEELCHAIR TESTS:

An instrumented wheelchair, designed and built at the University of Virginia, Rehabilitation Engineering Center, [5] is used to record the power consumption for one charge of the batteries. The present instrumentation is mounted on a "Rolls" chassis manufactured by Invacare, with a drive system built by General Teleoperators, Inc. Two Sears Diehard deep cycle utility batteries are being used for the tests. The present study involves continuous chair use within an office building. An arbitrary route, involving different types of floor surfaces and obstacles, was selected and the chair was driven over the course repeatedly until a cutoff voltage of 21 volts was reached when traveling full speed on a level surface. Each lap of the four hour test required about five minutes to complete. Comments are recorded along with the data on the same tape. The resulting data tapes are played into the computer and analysed using Miner's Rule.

CONCLUDING REMARKS:

More bench and outdoor in use testing is planned, therefore only preliminary conclusions have been reached. It appears that Miners' Rule is applicable for predicting battery capacity. Final results and conclusions will be presented at a later date.

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CAPACITIVE TOUCHPLATE CONTROLLER FOR POWERED MOBILITY IN SEVERE MOTOR DISABILITY

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ABSTRACT

A system for persons with cerebral palsy has been developed whereby five individual capacitive touch plates can be used as a means for controlling a powered wheelchair. The rugged system is adaptable to a wide variety of individual motor patterns and targeting capabilities. The system philosophy, design criteria, aspects of construction and typical applications are discussed and described.

INTRODUCTION

Commercially available electric wheelchairs are generally joystick-controlled. Repositioning of the joystick may be necessary to enable the more severely handicapped person to effectively drive a wheelchair. However, not all handicapped individuals have the ability to control a joystick because of lack of motor control, limited ranges of movement or activating force levels, or combinations of these factors.

A capacitive touchplate controller was designed and developed to realize the following features:

i) The plate is actuated by body contact and can be made independent of applied force. Damage to either the subject or the plate resulting from large forces due to gross hand control will not be incurred.

ii) The actuating target area can be adjusted to suit the targeting ability of each intended user. Rectangular-shaped plates have been used to date.

iii) Placement of each control plate can be easily made to accommodate the motor patterns of each individual.

iv) The system is resistant to food spills and saliva.

A seperate power control unit interfaces the touchplates to the wheelchair by converting logic levels to power signals for the motors.

CIRCUIT DESCRIPTION

A five-channel touchplate circuit was developed to provide four directional movements (forward, reverse, left and right), and on/off or speed control options.

The circuit utilizes three CMOS hex Schmitt trigger invertors (CD 4584 or equivalent) as shown in Figure 1. U1A is a master oscillator whose output goes to the input of U1B to U1F. Since each channel operates in the same manner, a description of only channel 1 is given.

The output of U1B feeds to the parallel combination of diode CR1 and potentiometer R2 which form a peaking circuit with capacitance Cx presented to the touch plate. The discharge time-constant of this circuit is determined by Cx and R2 where Cx is the summation of all wiring capacitances and the capacitance presented by the subject's body. Hence R2 is adjusted to null out the effects of wiring capacitances so that a logic '0' appears at the output of U3A. The waveform shown in Figure 2(a) can now be observed at pin 5 of U2A. A DC offset exists due to stray capacitance but is below the threshold of the Schmitt trigger. Thus the output of U2A will switch with a pulse-width proportional to the DC offset on pin 5.

The output of U2A is fed to a second peaking circuit formed by CR4, R5, and C3 which maintain the input of U3A above its threshold level at logic "1", and hence the output of U3A is low.

When plate TCH1 is touched, the addition of body capacitance causes the DC offset level on pin 5 of U2A to rise above its threshold and pin 6 of U2A to go low. C3 is now discharged through R5 causing the output of U3A to go high.

The output from pin 5 of U2A under these conditions is shown in Figure 2(b). Interference between channels is possible due to insulation leakage of the cables and limits the distance between the touch plates and the circuit board to two feet. This distance is sufficient to permit the circuit board to be mounted on the underside of an individual's lap tray.

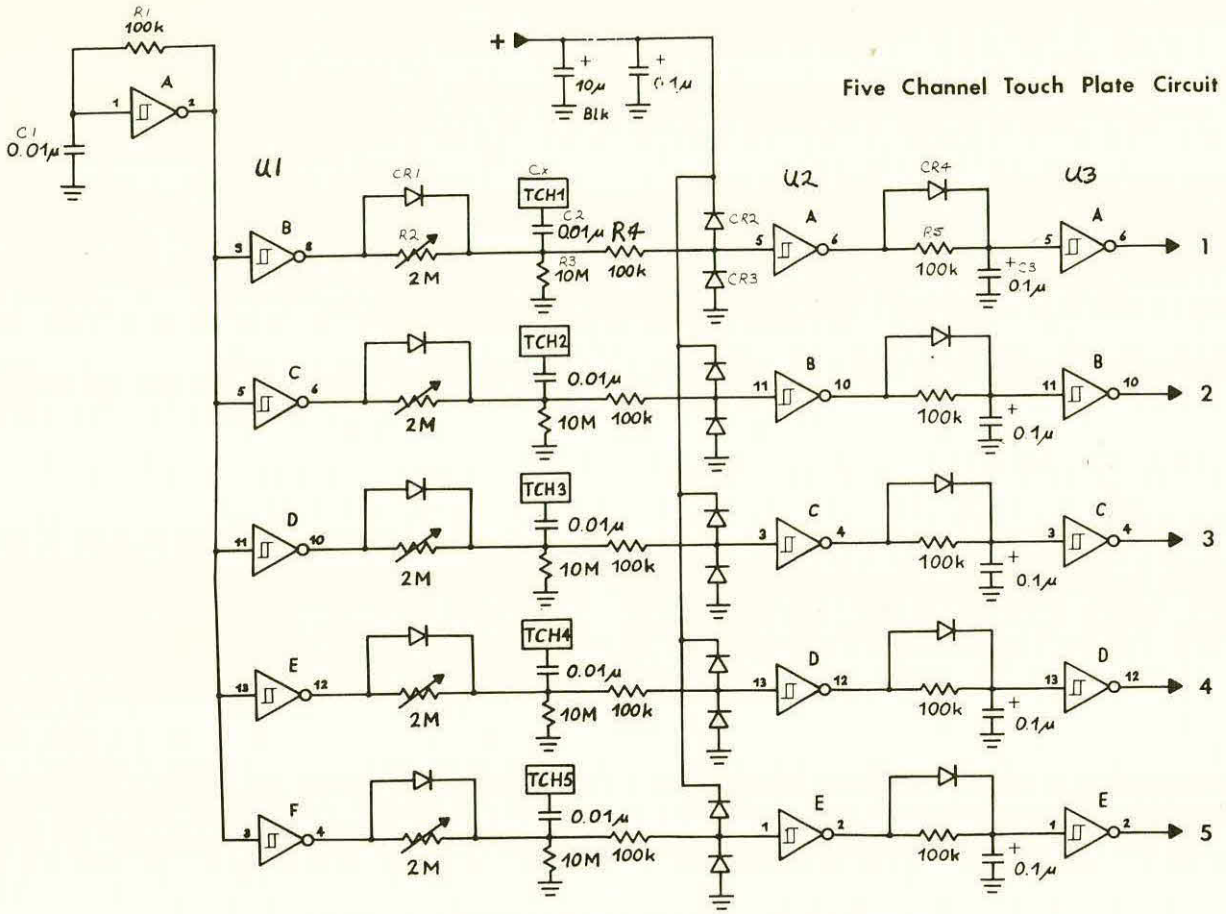


Figure 1: Circuit diagramme of touchplate system

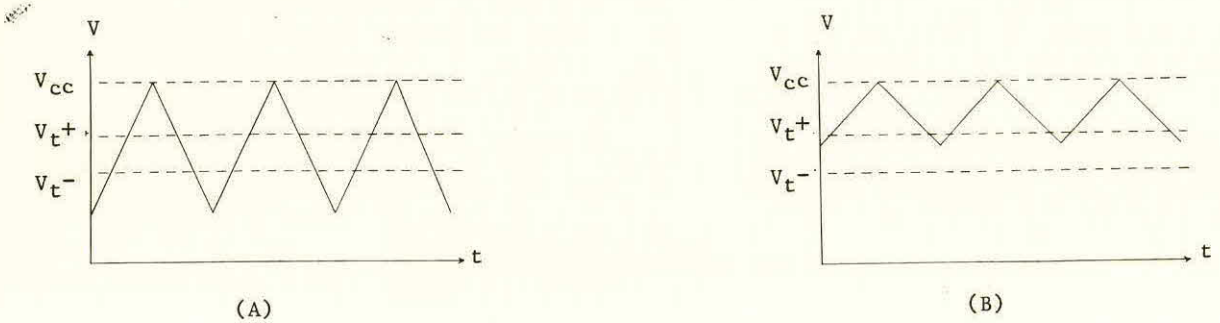


Figure 2: Output from pin 4 of U2A
(A) Nulling of cable capacitance
(B) Effect due to body capacitance

PHYSICAL CONSTRUCTION

In our experience, the majority of individuals requiring touchplate controllers already use trays fitted to the wheelchair. Trays provided by our Centre are made of 1/2" plywood with arborite surfaces. The outer edge is trimmed with a rubber moulding. Trays are custom-cut to fit each individual's body contour and, if required, to fit the contour of a seating insert.

Positioning and physical plate size are determined by a therapist and the technologist involved. This follows receipt of a medical prescription, based on a clinical assessment of each potential user. The technique for assessment is experimental and includes use of a computer-aided evaluation system and an assessment chair. With these aspects established, the plate centres are marked out on the tray and holes are drilled to accommodate 1/8" pop rivets. The wiring is laid

out on the bottom side of the tray which has channels cut into it using a router to accommodate the leads between the touchplates, the circuit board and the power control unit.

The plates are made from 0.04" thick stainless steel sheeting. All sharp edges are removed and a centre hole for mounting is drilled. A rivet is placed through the touchplate and the tray. A lug from the connecting wire and a backup washer are then riveted in place. The accommodating channels are then filled in with plastic wood and sanded flush. A strain relief is provided at the point where the cable to the power control unit exits from the rear of the tray.

The touchplate circuit board is housed in an OKW plastic case mounted on the underside of the tray. A completed touchplate system is shown in Figure 3.

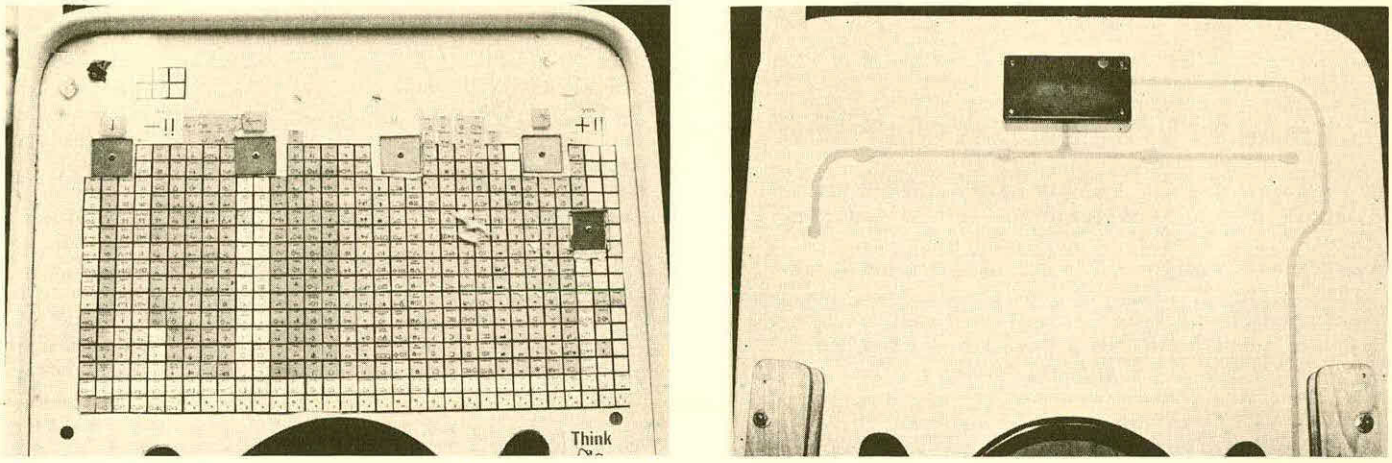
CONCLUSION

Over the past year the touchplate system has been satisfactorily fitted to the chairs of six children with cerebral palsy. A miniaturized version, as shown in Figure 4, was provided to an individual with muscular dystrophy who has limited range of movement and force output. Touchplates have also been provided to non-speaking children with athetosis for the control of communication aids. To date, maintenance has been necessary only to effect repairs on two output cables.

ACKNOWLEDGEMENTS

The author thanks Sam Chung and Gilbert Chau for aid in the initial design of the circuit, and Drs. M. Milner and S. Naumann for their editorial comments.

This work was supported by the Metropolitan Toronto Police Association.



(A) (B)

Figure 3: Completed touchplate system
(A) TOP
(B) BOTTOM

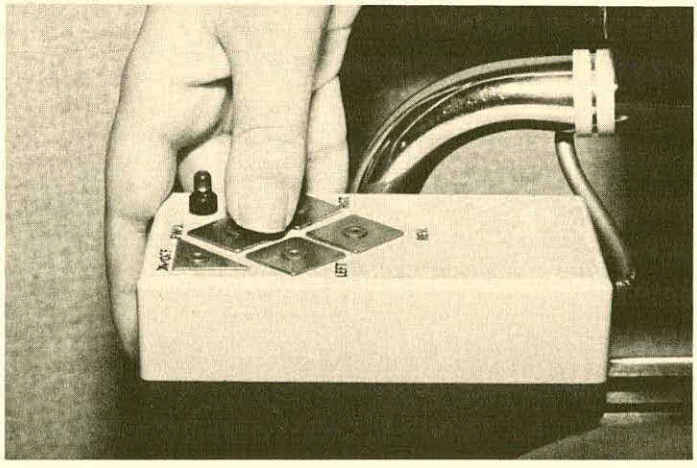


Figure 4: Miniaturized touchplate system

NEW DEVELOPMENTS IN PROPORTIONAL INTERFACE RESEARCH

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Although proportionally-controlled interface systems offer many advantages for use with assistive devices for severely disabled people, they are underdeveloped and underutilized. In order to take full advantage of their potential, basic research must be coordinated with development of simple and effective interface systems that are designed for high quality and low-cost production. One approach to such a program is described.

BACKGROUND

Since disabled people are limited in their control of the environment, it is important to take full advantage of whatever controllable movements remain. If a single movement--for example, head, limb, or breath pressure against a sensor--is available, it may be used to control a simple on-off switch. This allows the selection of either of two output values: ON, or OFF. However, the same pressure may be applied to a continuously variable or proportional control, whose output can take on any of an essentially infinite number of different values between zero and maximum.

For tasks involving the selection of one item out of a large range of possibilities, a proportional control would therefore allow a person direct access to a large number of different choices with a single movement, compared to the restricted range of only two choices offered by a switch for the same movement.

Since non-vocal communication aids generally operate by allowing the user to select the desired choice out of a large array of items, it would be very appropriate to use proportional controls in this application. Yet this has very rarely been done. Switch closures are almost universally used instead.

In everyday practice the term "interface" tends to be restricted almost entirely to simple switches when evaluating severely disabled people for assistive devices. For example, the Trace Center's comprehensive "annotated, illustrated profile of the different types of input interfaces" contains only switches (3). And CONTROLS, a "reference catalog to aid physically limited people in the operation of assistive devices," mentions only one control that provides a proportional output signal: the standard E&J joystick (4).

Even in the standard human-factors literature, very little attention has been paid to proportional control by any part of the body other than the hand or the foot (1).

There are historical, economic and psychological--as well as technical--reasons why proportional control has not yet played a strong role in the development of assistive devices. One major problem is that the wide range of differences among disabled people calls for a great deal of customization in the matching of interfaces to people; yet quantity production of standardized items appears to be the only feasible way to keep prices affordable and to make equipment available to the people who need it (5).

In the past, proportional sensors have been much more expensive and less readily standardized than switches. Now, however, the commercial availability of several families of reliable, standardized, low-cost transducers (Hall effect, electro-optical, and semiconductor pressure transducer) opens up new possibilities for some exciting developments in proportional systems.

THE TUFTS INTERFACE PROGRAM

A group of rehabilitation engineers and clinicians at Tufts-New England Medical Center's Biomedical Engineering Center have been working on a program of proportional-interface research and development, in an effort to demonstrate some of the potential benefits of this approach. The program includes basic research on the ability of disabled subjects to produce and control proportional output signals; careful development and human-factors design of several families of interface systems suitable for eventual low-cost manufacture; devising of new evaluation techniques; training of clinicians; and the gradual evolution of entirely new families of communication aids and other asistive devices based on proportional control(2).

In our work so far we have defined a number of specific projects--involving proportional interface devices, techniques, or applications--that are of particular interest. In some cases we have completed test models for initial evaluation, or run pilot experiments to obtain

preliminary data. Other projects will require expansion of our interface staff and facilities before they can be initiated.

Results to date will be presented at the Conference, and some of the devices already developed will be shown. Areas of current interest include:

A. Actuators and Actuator/Transducer Systems

1. Low-profile joint position monitor for finger movements. Extends less than 6mm (1/4") from surface of hand and has no sharp projections, allowing safe use by cerebral palsied children with uncontrolled movements. For use with continuous feedback.

2. Mouth control (intraoral) to provide two independent channels of proportional output plus one switch closure, for quadriplegics of level C_0 or below. Made entirely of acrylic and silicone rubber, to permit wearing 24 hr/day except during meals. Complete electrical isolation.

3. Isometric joystick controller built into end of wheelchair armrest. Plug-in replacement for standard E&J joystick. Very rugged; one moving part. Entirely contained within armrest for protection from obstacles and weather, and to permit passage through narrow doorways.

4. "Press-anywhere" controller for people with cerebral palsy. Consists of a flexible strip approximately 25mm wide x 12mm high (1" x 1/2"), running the full length of a laptray or table edge. Its output remains electrically centered until a hand is placed on the strip at any point; then any small rocking movements of the hand produce corresponding voltage changes in two independent channels (left/right, forward/backward). Voltages are maintained as long as the hand remains in place, but automatically reset to neutral when the hand is lifted. Provides precise control for people who have difficulty placing the hand accurately, but can control it better once the hand and arm are supported against gravity and only the hand is being moved. Very simple, low-cost device.

5. Low-profile fingertip "joystick" in the form of a disc 6mm (1/4") thick, for use on table, laptray, or armrest. Provides two channels of proportional output; simple construction with only one moving part. Movement required for operation is physiologically simpler than the motions and coordinations required for standard or isometric joysticks.

B. Transducers

1. Isometric vs. displacement joysticks.

2. Pneumatic pressure transducers.

3. Linear Hall effect sensors.

4. Electro-optical sensors.

5. Conductive elastomer pressure sensors.

6. Fingertip touch panels (proportional X-Y position output with only four wires).

7. Electrolytic tilt sensors (X-Y proportional output or single channel).

8. Digital "solid-state potentiometer" (fingertip differential-movement sensor).

C. Processing Techniques

1. Integration of transducer output.

2. Nonlinear shaping -- adjustable deadband, rapid slewing vs. slow "inching," etc.

3. Predictive feedback.

4. "Smart" processor to compensate for daily variations in user's range of control. Elementary pattern recognition.

5. Special techniques for controlling several independent channels when only one degree of freedom is physically available.

6. Special techniques for obtaining CHARACTER SELECT or PRINT commands when a separate switch closure is not available. Designed to allow proportional operation of a communication aid at relatively high speed by a person with very limited physical control.

D. Systems Using Proportional Control Inputs

1. Remote-control light pointer. X and Y control voltages from any interface allow a disabled person to instantly position a light beam anywhere on a communication board (laptray, wall, blackboard, projected slide, etc.) or on objects in the room. Multiple inputs allow a number of users to carry on interactive converations; each user's input signal automatically superimposes an individual "signature" pattern on the light-spot, to eliminate confusion. Extremely useful in testing speed and accuracy of various interface/communicator systems vs. direct pointing. Usable in direct sunlight.

2. Expressive communicator for totally paralyzed person, using galvanic skin response or skin potential response to produce audible response patterns. Could be particularly useful immediately following brain damage due to accident or severe stroke, when cognitive status may be unclear and expressive ability is greatly impaired; also for some degenerative neurological disorders.

3. Liquid crystal display unit converts slide projector to scanning, encoding, or direct-selection communicator. A slide of the desired letterboard or symbol array is sandwiched together with a special LCD unit and placed in a projector. Proportional signals to the control box select corresponding locations in a matrix of 16 rows x 16 columns (or 32 x 32 in the high-resolution

model). A light grey square then appears at the desired location on the projected image. No moving parts.

4. One- and two-dimensional audible "displays" for training, evaluation, and normal-feedback operation of proportional interfaces. Useful alternative or supplement to visual display for certain disabilities.

5. Electronic musical instruments controlled by multiple proportional channels. Allow non-verbal expression by quadriplegics, stroke patients, amputees, and people with degenerative conditions who have lost accustomed function; enable acquisition of new skills and means of expression by people with congenital disabilities such as cerebral palsy. An excellent training aid (self-motivating, intrinsically rewarding) for developing control skills in an immobilized person, for later immediate transfer to tasks such as wheelchair operation.

6. Low-cost linear readout display for pneumatic-actuator systems. Provides integration of input, adjustable damping, adjustable-speed scanning, spring-return or maintained-position modes, variable ratio of display movement to actuator travel, and other functions, without electronics or external power. Useful for field evaluations and for modular, low-technology communicators for people with reasonably good control over a single small movement but poor pointing ability.

7. Plug-in "superpaddle" for low-cost video game units. Converts voltage changes, obtained from any proportional transducer, into the varying resistance required to operate the game. Adjustments allow matching of a wide range of transducers and different brands of video games, and permit compensation for variations in the user's range of motion or control. Video games have certain advantages as a proportional-control training aid, but cannot be controlled by a direct voltage input.

E. Experimental Studies

1. Compare non-vocal communication rates of CP subjects alternating between a switch-input scanning aid and a proportional-control aid.

2. Compare speed and accuracy of small finger movements in CP subjects with speed and accuracy during pointing with entire hand and arm. Use remote-control light pointer to select items on subject's laptray letterboard in response to signals from fingertip-position sensor; compare speed of text transmission to the speed achieved when the subject uses direct pointing with the same letterboard.

3. Test comparative performance of isometric and displacement (standard) joysticks with CP subjects, for both tracking tasks and wheelchair control. How do results compare to existing human-factors data for able-bodied subjects?

4. Mount standard wheelchair joystick perpendicular to its normal orientation (shaft horizontal and pointing toward user). Test hypothesis that this arrangement provides better control for some people with CP by eliminating oscillation due to acceleration/deceleration motion coupling, and by simplifying manipulation of the stick.

5. Measure the extent to which immobilization of the hand and/or arm alters the controllability of finger movement, using both fingertip-position sensor and joint-movement transducer. Apply results to design of finger-operated controller built into molded handpiece.

CONCLUSION

The imaginative use of proportional output signals and interfacing techniques makes it possible to provide some severely physically disabled people with faster, more flexible, or more rewarding ways of interacting with the people and things in their environment than they can achieve when restricted to simple switch closures. It also opens up a wide range of new possibilities for the development of proportionally-controlled communication aids and other assistive devices.

The Interface group at the Tufts Biomedical Engineering Center is actively involved in a program of research and development designed to further explore the potential benefits of this approach to interface design. Results to date are very encouraging.

ACKNOWLEDGEMENT

This work has been supported by Grant #16-P-57856/1-05 from the National Institute for Handicapped Research, U.S. Dept. of Education.

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TOWARD TOTAL MOBILITY: AN OMNIDIRECTIONAL WHEELCHAIR

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ABSTRACT

Conventional powered wheelchairs allow two degrees of freedom mobility: translation fore and aft and rotation about a vertical axis. Based on the push-pull principle they have limited mobility in close spaces. Wheelchairs which would supply simultaneous lateral motion are desirable. A novel design for a chair which allows true omnidirectional motion is presented. This device is comprised of a chassis mounted on three independently driven wheels fixed in their orientation. Each wheel has passive perimeter rollers. A radio-controlled scale model and full scale test rig are described. Plans for an attractive prototype are also presented.

INTRODUCTION

Many disabled people depend on an externally driven wheelchair for their mobility. The most common designs have two driving wheels actuated by electric motors and two caster wheels for stability. They have limited mobility and are difficult to maneuver in tight spaces. Their propulsion system is based on the push-pull principle: steering is accomplished through differential rotation of the driving wheels. This method provides only two degrees of freedom of motion: translation in the longitudinal (fore-aft) direction, and rotation about a vertical axis for steering. A wheelchair which is also capable of simultaneous sideways motion, i.e., translation in the lateral (left-right) direction would possess total freedom of motion, or omnidirectionality on the ground. It would greatly improve mobility especially in conventionally built houses, apartments and work places. This paper describes our development of a wheelchair of this type.

PAST DESIGNS

Attempts at omnidirectional devices are not new. A great variety of mobility aids for the disabled exists. However, very few designs have true omnidirectional capability (1). Wheels with idle rollers were used at the Ontario Crippled Children's Center in 1975 (2), but no further development ensued. An electric wheelchair that can go off in any direction starting from a given rest position has been on the market for a few years. The LEM Chair, distributed by French-Italian Marketing Corp., Great Neck, New York, is equipped with one centrally located drive wheel connected to the seat. To select the direction of travel, this assembly, together with the rider is manually rotated on the vehicle base which has four stabilizing rollers. The direction of travel can be changed without moving the base, thus giving the appearance of omnidirectionality. However, the vehicle is analogous to a unicycle and can only travel according to the orientation of the operator, either forward or backward.

An indoor wheelchair with sideways moving capability is being developed by Finden and Lorentsen (3). In this vehicle two independently driven wheels are mounted on a beam that can be rotated around the central axis into two fixed positions, one for going forward or backwards, the other for going sideways. In either mode, the vehicle, stabilized by four casters, operates on the conventional push-pull principle. This scheme necessitates cumbersome repositioning of the drive assembly every time sideways motion is desired.

Only two existing methods, aside from our own, offer true omnidirectionality in an electric wheelchair defined for our purpose as simultaneously and independently controllable rotation and two translations. One design was patented by Ilon (4) of Sweden, and the other by Ziegler (5) of Germany. Both use four independently driven omnidirectional wheels fixed with respect to the frame of the vehicle.

In the Ilon scheme, the wheels are disposed in the typical automobile geometry, one pair sharing the front axis and the other the rear axis, the rollers being set at an angle on the hubs. The combined actions of all four wheels is crucial to the course stability of the system. For example, each wheel must rotate in an opposite direction in relation to its neighbors in order to effect lateral translation. Working prototypes of this vehicle have been built and commercial applications are planned.

In the Ziegler scheme, the wheels, which have normally-mounted rollers, are disposed tangentially with respect to the chassis, i.e., their axes intersect at the center. A variant of this design, in which the axes are very nearly vertical was built at the Naval Ocean Systems Center by Silva and co-workers (6). The ambulator platform, called the Stand-Aid, is reported by Silva as being very stable and working well. The design is

aimed at operation on a very smooth surface, therefore the step clearing ability is limited to about 1/4 inch.

The two truly omnidirectional designs discussed here have been realized as prototypes and are reported to perform satisfactorily. However, the omnidirectional function - three degrees of freedom - intrinsically requires only three drive wheels. Using four independently driven wheels to accomplish three modes of motion is tantamount to using four independent equations to solve for three unknowns. Granted that the drives are effectively coupled by the control electronics, it remains that any imprecision in the power applied to each motor cuts energy efficiency due to differential conflict between the wheels. The use of a fourth wheel and its associated circuitry therefore is not only wasteful in terms of capital and maintenance costs, but it also indroduces the potential for higher operating costs.

THE CURRENT DESIGN

At the Rehabilitative Engineering Research and Development Center in Palo Alto, we are developing a wheelchair based on a novel omnidirectional mobility platform (7). This system, shown in Figure 1, consists of three independently driven wheels disposed along the sides of a triangle. Each wheel is equipped with a number of idle peripheral rollers which allow it to move sideways under an external axial force, while retaining the ability to provide positive traction in its customary direction of travel. The combined actions of the three wheels result in a smooth, course-stable motion of the vehicle along any arbitrary path at any relative orientation, without the skidding of any part and without the possibility of any direct conflict between the actions of the wheels. Control by the rider is accomplished with a three-axis joystick. Direction of travel is selected by moving the stick in the desired direction; speed is proportional to its displacement from central position, while pure or combined rotation is set by correspondingly twisting it. The obvious conformance between joystick manipulation and wheelchair response makes its operation straightforward and easy to learn. Naturally, users with special conditions may require specially adapted input devices. At the present time we have completed the construction of a 1/2 scale radio controlled model of the chair and are nearing completion of a full scale prototype test rig based on a conventional wheelchair frame. The radio controlled scale model (Figure 1) is 16 inches wide with eight-inch-diameter wheels. Powered with a 7.2 V, 1 AH fast-charge nickel-cadmium battery, it travels at 1.2 MPH on level terrain with a range of 1,600 ft. and stalls on an incline of 20° under a total load of 31 lbs. The model has proved that the concept of true omnidirectional motion is attainable with the three wheel design. Even with open loop control and no acceleration-limiting it shows good course stability. It has elicited very positive responses from wheelchair users, engineers and medical professionals to whom it has been shown.

The full-scale test rig uses three direct-drive servo motors and omnidirectional wheels of a design similar to that shown in Figure 2. Seating is accomplished through the mounting of an automobile-type bucket seat. An on-board microcomputer processes the sensory inputs to the system, which consist of the following signals: a three-degree-of-freedom joystick is manipulated by the user to produce an indication of the direction and speed he wishes the chair tc pursue; a set of attitude sensors provides two additional analog signals that indicate the orientation of the inertial frame; battery voltage and motor currents are also monitored. The computer produces reliable motion control of the chair with feedback loops, while implementing additional safeguard functions such as joystick damping, stall current limiting, and stability preservation. The control system outputs three pulse-width-modulated signals to the power bridge circuits which drive the motors, along with system status signals to visual and audio indicators that inform the user of battery condition and system malfunction or motor failure. In addition, the on-board circuitry can shut down the entire system in case of computer malfunction. The operator can also quickly turn off the system by using the on-off button on the joystick chassis.

One of the primary design challenges involved in this effort is that of coming up with a wheel design which is durable yet relatively inexpensive to produce. This is essential if the omnidirectional chair is to be realized as a commercially available device. For this reason, a number of different wheel designs are being investigated. The wheel design shown in Figure 2 is comprised of a central hub made of aluminum and eight spokes constructed from high strength aluminum extrusion. The spoke and roller assemblies can be easily removed independently of one another for repair or replacement. Each roller assembly is well supported by deep groove ball bearings. A design which incorporates end-supported rollers is also being evaluated on the test rig.

We have also begun the design of a first generation prototype of the omnidirectional wheelchair. One of the designs being considered is shown in Figure 3. This chair will be based on a unitized chassis of either cast aluminum or monocoque fiberglass construction. The goal of the prototype will be that of a truly omnidirectional mobility device which is of a relatively inexpensive and stylistically attractive design.

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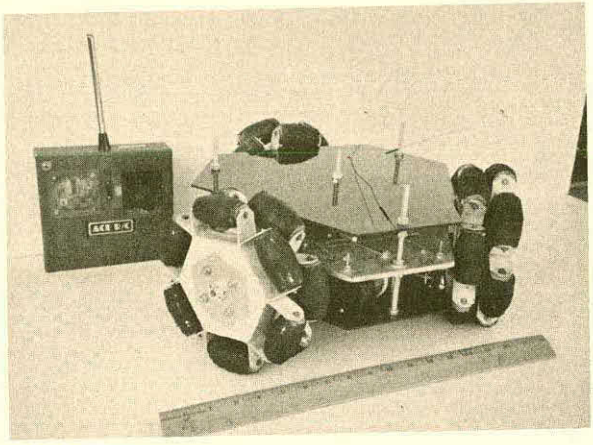

Fig. 1: Radio controlled omnidirectional device

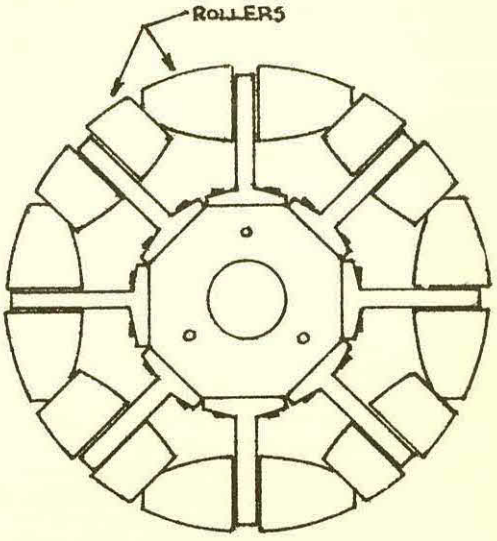

Fig. 2: Omnidirectional wheel

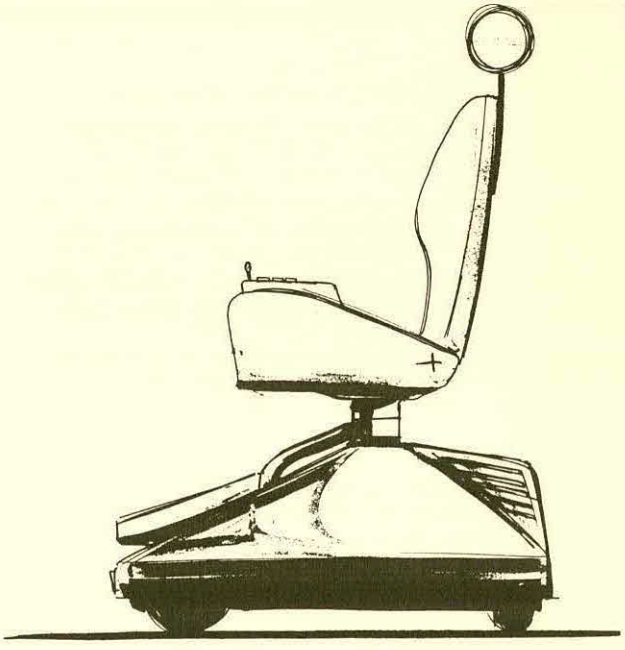

Fig. 3: Wheelchair prototype design concept

MOBILITY SYSTEMS FOR THE SEVERELY DISABLED THROUGH MODIFIED STANDARD AUTOMOBILES AND COMPATIBLE VARIABLE HEIGHT WHEELCHAIRS

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ABSTRACT

Although at present, vans provide satisfactory driving possibilities for some severely disabled persons, the majority of these drivers would prefer standard automobile-based systems because of lower initial cost, ease of parking due to smaller size and inconspicuous appearance. Three different automobile-wheelchair systems are considered: (1) A rear entry system for a special reclining and height-adjustable wheelchair to a Dodge Omni via a foldable ramp, (2) A system in which a modified Amigo chair gains access through the curbside door of an X-body automobile, and (3) A driver side entry system for a special wheelchair into a X-car. The last two systems are similar in entry principle. In both, the chair is attached to the door or a support arm extending from the car and the seat height adjusting mechanism is used to retract the lower section of the chair so that it fits within the door opening. The driver-side entry system appears to offer the best advantages and is being fully developed.

INTRODUCTION

At present, vans provide the only commercially available driving possibility for drivers with severe disabilities. These drivers, such as quadriplegics and bilateral amputees, must use wheelchairs and cannot transfer themselves or their chairs into an automobile without assistance. The most acceptable solution to their independent transportation problem is to allow them to enter, egress and drive a vehicle without leaving their wheelchair or requiring any human assistance. Examples of the commercially available systems are discussed by Peizer (1).

Although modified vans and associated transfer devices serve the needs of some disabled drivers, many would prefer the more practical and psychologically acceptable alternative of driving a small passenger automobile. Compared to vans, automobiles are easier to park, more fuel efficient and less conspicuous. Three automobile-wheelchair systems were designed and developed. The first system involves curbside door entry; the second provides access through the rear hatch door and the last is a driver-side entry system. Development of these systems was guided by two requirements: that any special wheelchair developed for use in the automobile must also serve as an ordinary wheelchair and that any vehicle modification must either be reversible or not interfere with the normal function of the vehicle.

The two major design problems in all three of the systems are the limited size of the door openings and the elevation of the floor of the car. These problems are addressed by providing a specially designed adjustable-height wheelchair and a suitable means of lifting the occupied wheelchair.

CURB SIDE ENTRY SYSTEM

The standard Amigo Wheelchair was modified at Amigo Sales Corp. by the addition of a height adjustable mechanism. This modification allows the occupied wheelchair to fit through the door opening of a standard automobile. The height adjustment feature also provides the lifting function. As shown in Fig. 1, the chair approaches the side of the car door which opens a full 90° by virtue of special hinges. The chair is then maneuvered onto a swivel arm mounted on the floor of the car near the door. With the chair fixed to the car, the height adjusting mechanism is operated to retract the lower portion of the chair and bring it closer to the seat. The prototype chair is complete, but car modifications and integration into the system have not been completed.

REAR ENTRY SYSTEM

This system provides automobile access for a specially designed wheelchair through the rear hatch door of a Dodge Omni. Transfer is accomplished via 56"-ramp. The ramp consists of two hinged sections, a mounting bracket and guide links arranged so as to form a four-bar linkage. The ramp is deployed or retracted when the upper ramp member is rotated. At the present the ramp is manually actuated, but automatic power actuation will be added if the concept proves to be suitable for further development. The ramp is equipped with two parallel racks that engage with two small gears mounted concentrically with the driving rear wheels. The rack and pinion arrangement enables the chair to climb the relatively steep ramp (initial inclination of 22°). The seat is lowered and reclined as the chair climbs the ramp to provide head clearance at the hatch opening (Fig. 2) Once the chair is in the car, it is guided to the driving site by means of a track system on the floor. Some minor difficulties were encountered

in initial engagement of the wheelchair with the rack and guidance of the chair both up the ramp and inside the car.

DRIVER SIDE ENTRY SYSTEM

A compact wheelchair with adjustable seat height was specifically designed with a small door opening in mind. The chair (Fig. 3) is composed of four sections: seat, footrest, cross member with seat guides and wheel-suspension assembly. A powered linear actuator (Motion Systems Inc., 6000 rpm, 12 VDC Universal Ball Screw with 10:1 gear ratio) slides the seat along two 5/8"-vertical guides via four linear ball bearings (Thomson 10-ADJ rated for 320 lbs radial load each). The guide rods are supported at their base by the cross member. Two additional bars extend from the top of the guide rods to the cross member to provide lateral support of the guide rods. The cross member and attachments are supported by two leaf springs that provide the necessary flexibility for riding on uneven terrain. The cross member is shaped in such a way that the seat is lowered to ground level between the springs and in front of the cross member. The arm rests enclose the springs when the seat is in its lowest position. Two caster wheels are attached at the front end of the leaf spring. The two 8"-driving wheels including their drive units (Everest and Jennings 3N motor drive, part No. PDR-3N-700) are bolted to the rear ends of the leaf springs.

The loading sequence proceeds as follows: the driver door is opened to about 85° by means of a linear actuator (Motion Systems Inc., 6000 rpm, 12 VDC Universal Ball Screw with 20:1 gear ratio). As the wheelchair approaches the open door, the footrest is raised so that the feet clear the door sill and are placed inside the car. The chair is then maneuvered into position so that the seat section is attached to a door bracket. The seat height adjustment actuator is operated in a lowering mode to retract the suspension section closer to the seat. This reduces the overall height of the occupied chair. Once the wheels clear the sill, the door is closed automatically to bring the chair and occupant into driving position. Near the end of the door travel, the action of the actuator is replaced by a power latching device (a modified Cadillac trunk closing unit with modified latch hook) which draws the door 1.5" to a locked position.

The footrest is constructed of bent tubes that are pinned to the seat section. Actuation of the footrest is accomplished by two cables pulled by screws placed inside the seat frame. The screws are in turn rotated by a chain and sprocket drive mounted within the backrest cavity.

This system requires modification of the door and its hinges to reduce the excessive deflection expected during loading. These modifications involve replacing the hinges and providing an additional chair support frame within the door cavity. The frame is bolted directly to the new hinges. This arrangement allows transferring the chair loads directly to the hinges bypassing the door itself. The presence of the support frame limits the extent of window opening.

CONCLUSIONS

Among the three different systems discussed, the driver side entry system is the most promising due to simplicity and minimal space needed for transferring the wheelchair. A full passenger and cargo load can be carried with the system. The major disadvantages of the rear entry system are difficulty in initial engagement of the chair with the ramp and the amount of space sacrificed for transfer and guidance equipment. The modified Amigo system for passenger side entry is still under development and no major conclusions can be stated in its regard.

ACKNOWLEDGEMENTS

This research is supported by Research Grant #G008005816 from the National Institute of Handicapped Research, Department of Education, Washington D.C. 20202. The authors are indebted to Chrysler Corporation and General Motors for donating the automobiles used in this research and to their students and associates without whom this research will not be possible.

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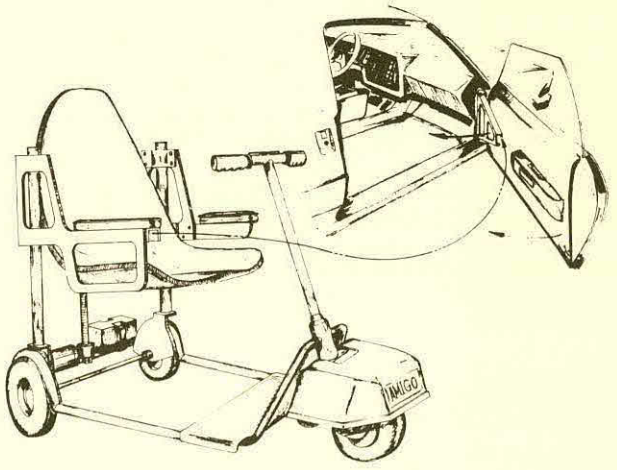

Fig. 1 Artist concept of the Curb Side Entry System

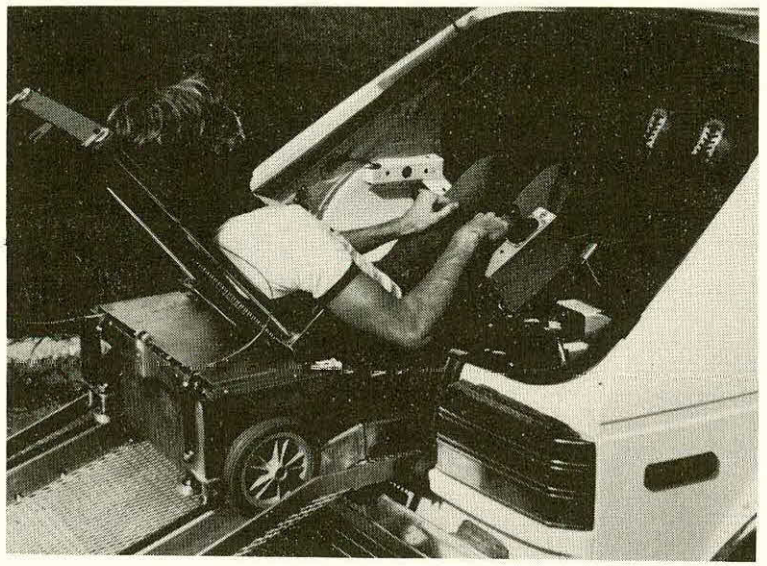

Fig. 2 In the Rear Entry System, the chair is lowered and reclined as the chair climbs the ramp to privide head clearance at the hatch opening.

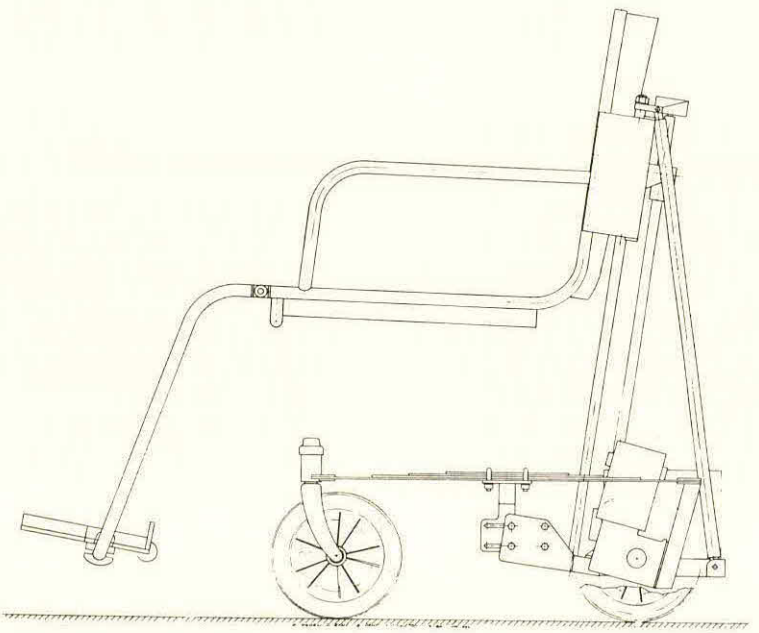

Fig. 3 Partially completed chair for the Driver Side Entry System.

STUDENT PAPER

MICROPROCESSOR WHEELCHAIR CONTROL: PROGRAMMABLE WHEELCHAIR CONTROL INTERFACE

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Control of motorized, electric wheelchairs commonly is effected through a joystick control which responds to a light push in the desired direction of travel. [1] Profound weakness of the arms or wrists and conditions in which fine control of movement is lost or unpredictable, such as cerebral palsy, make the wrist-actuated joystick difficult or impossible to use. A number of alternative control schemes have been proposed.[2-12] Only a few of these are commercially available. The chin-controlled joystick and the breath (puff-sip) control are used by high-level quadriplegics, but lack universal acceptance for functional and esthetic reasons. [13] People with severe cerebral palsy are more limited in their choices, with arm-slot control used on microswitch controlled wheelchairs.

For almost any device other than a joystick, a degree of customization usually is necessary to select and mount the switch system and to connect it to the driving electronics of the wheelchair. Engineering and labor costs for non-standardized hardware can be prohibitive: later repair service may be difficult to obtain. One source estimates that 4–5% of the wheelchairs sold every year in the U.S., roughly 4000 units, are electric.[14] If 20% need supplemental control electronics, the national cost for customization could approach $1 million.

TASK SPECIFICATION

The result of an engineering study of this problem has been the design of a modular Programmable Wheelchair Control Interface (PWCI) which will accept any common signal input, digital or analog, and will convert the input into the operating voltages used by a popular motor control unit, the Everest and Jennings 3P proportional controller. This system will extend the utility of proportional control to persons not now able to use it. In addition the hardware can be used in many different configurations with only programming changes needed to adapt the unit to persons of different functional ability.

The device is connected directly through the cable provided from the motor controller in place of the joystick, with no special wiring, and can be field installed. The display unit is interactive, and customized display and input switch configurations are achieved through software control. The system has sufficient capacity to permit more complex software tasks and expanded output control facilities for chair recliner and other environmental control functions.

SYSTEM DESIGN

The system is based on the CMOS RCA 1802 microprocessor, with all other chips in the circuit also CMOS to keep total power consumption well below suggested limits for wheelchair accessories. (ref. 3) Digital switch input is accomplished through a 20-key encoder, and provisions have been made for an analog multiplexer and analog-to-digital converter to process analog signals, such as those from a proportional pressure transducer.

The E & J motor control logic processes input voltages in a differential fashion with the speed of each motor increasing proportionately to the difference between the two voltages going to that motor's control logic. Direction of the motor is determined by which voltage is more positive.[15] These voltages are digitally generated by digital-to-analog converters and transmitted in the proper polarity by programmable switches. Safe operation is ensured by the inclusion of miniature relays which must be separately switch activated to electrically connect the output voltages to the logic inputs.

The single main circuit board fits in a cabinet of dimension 8" X 8" X 3.5" which piggybacks on the motor control box. The display used in the demonstration unit has LEDs arranged in a clock-face pattern for scanning functions. It is mounted in a triangular-prism box attached to a gooseneck bolted to the arm of the wheelchair. Rotary motion sensors are spring mounted next to the motor controller and are driven by the inside of the belt-drive rim on the rear wheels. All components are weather sealed. (Figure 1)

SYSTEM OPERATION

The first system was built as a demonstration unit; the operation described below can easily be changed by reprogramming. Software control of the demonstration system is based on a hierarchical series of control decisions. At each decision locus the system task is presented to the user by a lighted, task-labeled LED; LEDs on the clock face correspond to alternative actions within each task and are lighted sequentially as choices. For the demonstration system, 2 switches, SELECT and RESET, are used. To make a selection, SELECT is pressed; to restart the task RESET is pressed; to get to a previous task RESET is pressed repeatedly until the desired task is reached. (Figure 2)

The user initializes the system by selecting a display scanning speed (.5 to 5 seconds between changes in the display)[16], then the maximum forward speed (slow, medium, fast within the range of chair speed). A WAIT STATE is entered at this point which can be left with 2 hits on RESET (to go back to SPEED SET), or 2 hits on SELECT which starts the display scanning for the desired direction of motion. The WAIT STATE acts as a buffer between the two tasks;

it can be reentered at any time and acts also to allow the power to be left on while the user sits in the chair at rest without the danger of activating the chair motors with a chance switch closure. During the WAIT STATE, the "STOP" LED is lighted.

The "SELECT" LED is lit as the direction clock face is scanned. When the SELECT switch is hit, the LED with the chosen direction remains lighted and a warning LED is lighted. SELECT must now be released and hit again for motion to commence; it must remain pressed whenever motion is desired. The direction remains engaged until the RESET switch is hit, at which point the display again is scanned.

The maximum voltage output to each motor, and the polarity, are determined by the direction selected and the preset maximum forward speed. Reverse and turns in-place are always executed at slow speed. Release of the SELECT switch disengages the relays and sends a zero to the digital-to-analog converters.

SPEED AND ACCELERATION CONTROL: OPEN LOOP, CLOSED LOOP

Two modes of speed and acceleration control have been developed, open loop and closed loop. In both cases voltage to the motor logic is incrementally increased at a rate directly proportional to the forward speed previously chosen. This feature allows a user with a slower effective reaction time to use the system safely and it helps to avoid initiating a startle response in hypersensitive individuals due to a jerky start.

Closed loop control necessitates the use of rotary shaft encoders, each of which generates two channels of square wave pulses in quadrature at a frequency proportional to the speed of the wheel which drives it. These pulses are decoded for speed and direction information by the processor. Above a threshold speed, relative motion between the two wheels is compared and compensating changes in the output voltages are made. This feature allows the implementation of a tracking function in the forward mode to overcome the inherent tendency of the wheelchair to drift on slanted terrain due to its steering geometry.[17] In addition acceleration can be smoothed and turns made precisely. If pulses are not received by the processor after a certain period of time while the chair is in motion, an error signal is given and the system reverts to the WAIT STATE at which point components in the drive train and sensing system may be checked for mechanical failure or breakage.

FUTURE IMPLEMENTATIONS

At present the system is programmed for exclusively open loop or for exclusively closed loop operation. Software revisions will allow open loop to be selected as an override feature. Another feature currently being implemented on the closed loop mode is a HOLD state in which the chair motors will be used to maintain position on an incline while another direction setting is chosen. This will permit course corrections on ramps and hills, which can be dangerous if the chair starts to roll unpowered. A software technique to be studied at a later date is digital filtering which would allow a person whose movements have erratic, particularly athetoid, components to use a wrist controlled joystick safely.

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SYSTEM BLOCK DIAGRAM

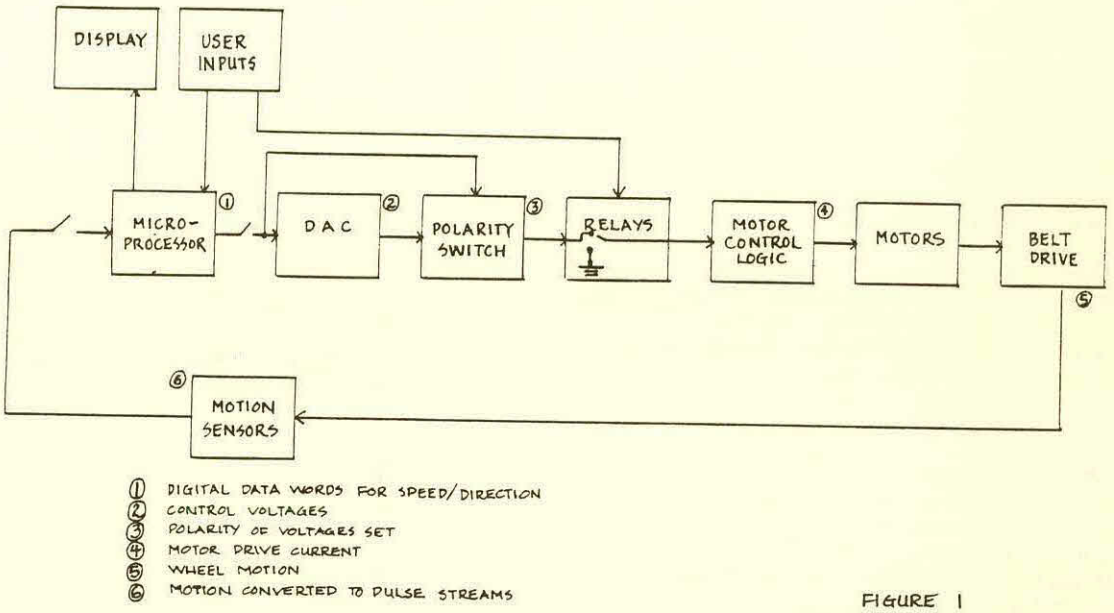

FIGURE 1

OPERATIONAL STATE FLOW CHART

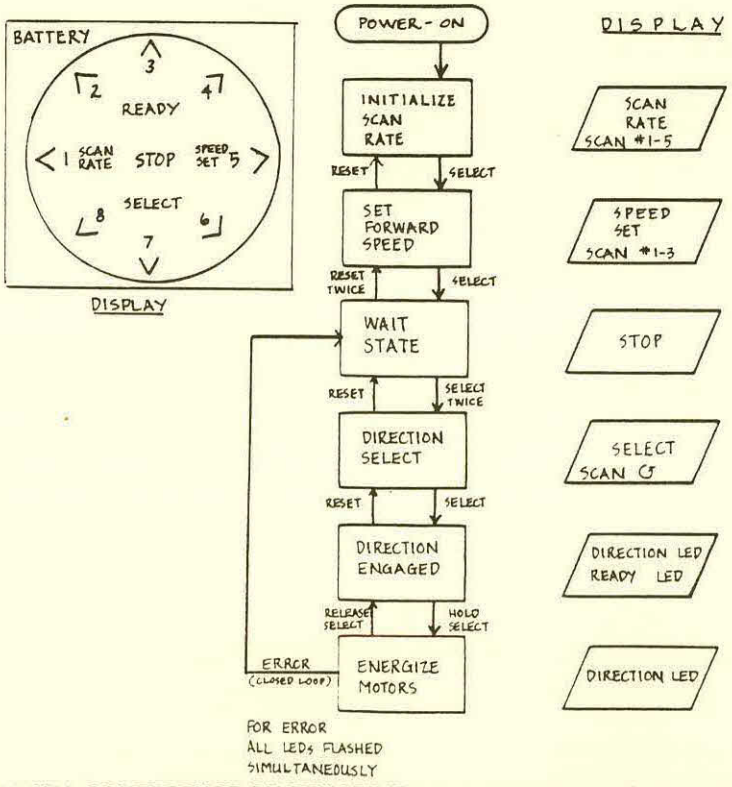

FIGURE 2

THE USE OF A MICROPROCESSOR AS A VERSATILE CONTROLLER FOR A POWERED WHEELCHAIR

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ABSTRACT

A microprocessor based controller for a powered wheelchair has been designed. The controller operates from four input switches that handle start, stop and turns of the wheelchair. An optional feedback system allows the controller to automatically correct deviations in azimuth when traversing uneven and inclined surfaces and to maintain the speed of the chair when going up inclined surfaces. The generality of the microprocessor based controller permits alterations in control strategy to be made in software, eliminating much of the previously necessary circuit redesign.

INTRODUCTION

By utilizing microprocessor technology, a wheelchair controller can be built with more flexibility in the control scheme than is possible with discrete logic controllers (1). The control scheme is coded as a string of easily altered software commands instead of hard wired logic components. The use of large scale integrated circuits reduces the number of physical parts and simplifies circuit design.

The controller presented in this paper has been programmed to handle operator inputs for starting, stopping, and turning. With the addition of wheel displacement sensors and their interface logic, it was possible to program the controller to compensate for deviations in operator selected azimuth and speed caused by the wheelchair's drive system and the terrain being traversed.

CONTROL FEATURES

Operator Interface

The controller is designed to be operated by four switches of almost any variety (pneumatic, hand, foot, head, etc.) selected to suit the control sites of the user of the wheelchair. The switch inputs can be programmed for either latching or non-latching modes. The latching input mode requires the user to initiate an action with one switch and terminate it with another, without needing to maintain the switch closure. An example would be pneumatic control for activating the chair to move forward or reverse. In the non-latching mode the action is maintained only as long as the switch is held closed by the user. This mode is often used for hand controls configured like a joystick (manipulandum).

The four switches control the initial direction of the chair; forward, reverse, right and left. One switch also serves for speed selection. By repeated activation of this switch, the user can increase the chair's speed through four programmed speed increments.

One or more safety switches are also provided to quickly deactivate the chair in emergency situations. These switches are independent of the controller and will deactivate the chair even in the event of a failure in the microprocessor.

Azimuthal Control

Alterations in the intended path of a wheelchair can be attributed to variances in the components of the drive systems of the chair and the effects of terrain on the alignment of the front casters (2). To compensate for these deviations, the driver must initiate corrections frequently if traversing an inclined surface such as a sidewalk (sloped for drainage) or a driveway.

It has been shown (2) that by forcing the drive wheels to travel equal distances when the operator intends to travel in a particular direction, the intended azimuth can be maintained. The displacement of each of the drive wheels is monitored by the computer which then adjusts the torque of the motors to keep the displacements equal. This is performed automatically whenever the operator has issued a forward or reverse command.

Speed Control

A wheelchair controlled by switches often has a number of pre-set speeds that the user may choose. The selected speed is generated by supplying a certain fixed average voltage to the motors. If the chair's controller does not include automatic speed control, the torque produced by the motors due to the applied average voltage will vary with the terrain. For example, the actual speed at which the chair climbs a ramp will be less than the speed of the chair on a level surface at the same "speed" setting.

With speed control, the user selects the desired speed and the controller automatically adjusts the motor torque to maintain it. This is accomplished by means of the same wheel displacement feedback interface as used with the azimuthal control.

The automatic control of speed is limited by

the maximum output torque of the drive wheels when going up an incline and by the braking produced by unpowered motors when traveling down an incline.

IMPLEMENTATION

An Everest & Jennings type 3P, 24 volt powered wheelchair was selected for implementation of the controller. The controller uses a Motorola 6802 microprocessor and includes a peripheral interface adapter, an EPROM for program storage, and the attendant bus interface circuitry. The peripheral interface adapter handles all I/O including operator switch inputs, speed selection, wheel displacement sensors, motor relay control, and motor duty cycle.

The torque of the two permanent magnet drive motors is controlled by adjusting the duty cycle of the pulse width modulated armature current. Each pulse has a maximum period of 3.2 msec which is divided into 16 intervals. By selectively controlling the number of intervals the current is on, the torque on each drive wheel can be adjusted to produce the desired action of the chair.

For purposes of speed and azimuthal control, displacement of the drive wheels is detected by optical encoders geared to each of the two wheels. Rotation of the wheels produces a train of pulses from each encoder, providing information on the chair's alignment and speed.

Figure 1 shows an information flow diagram of the controller.

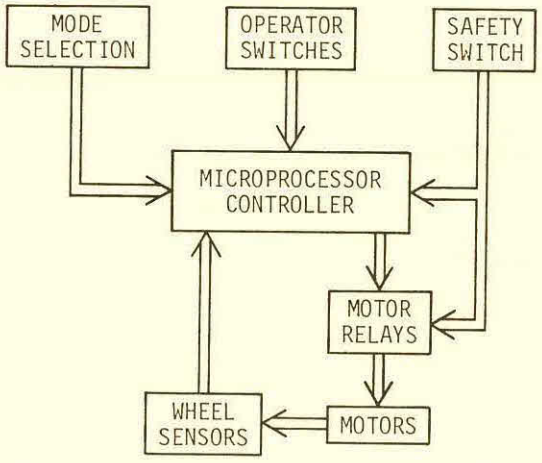

Fig. 1: Information flow of microprocessor-based wheelchair controller with azimuth and speed control.

To effect speed control, the number of pulses from each encoder is counted during a fixed time interval. The count is compared to an expected value based on the action of the chair selected by the operator. If the actual count is not equal to the expected value, the duty cycle of the current to the motors is adjusted. Monitoring is performed continuously and adjustments are made, if necessary, every 3.2 msec as long as the chair is in motion.

If the chair is moving forward, the operator can increase the chair's speed by reactivating the forward switch. With each reactivation, the controller smoothly accelerates the chair to the next speed setting.

Speed control is also provided during turns. By monitoring the turning speed, the response of the chair is made essentially independent of the surface conditions.

It should be noted in all instances where speed control is used that the maximum speed of the chair is limited by the maximum torque which can be produced by the motors. Therefore, the chair may not be able to travel at the same speed on a steep up incline as it traveled on a level surface. In such a situation, the motors may be full on but the torque is not sufficient to achieve the selected speed.

The minimum speed of the chair when going down a ramp is also limited. The E&J type 3P chair has relays to control the polarity of drive current. Because of this, active braking cannot be implemented smoothly as it would involve rapid switching of current polarity. Therefore, automatic braking is limited to the drag of the drives in an unpowered state. Consequently, speed control may not be possible on a steep down incline if gravity overcomes the drag of the unpowered motors. In such a case, the operator must manually brake by activating the reverse switch.

Azimuthal control also uses the encoders but a different software counter. The pulses from the encoder of one wheel increment the counter while the pulses from the other encoder decrement it. The controller checks the value of the counter every 3.2 msec during forward or reverse actions, and as long as it has a value of zero, the chair is maintaining the desired azimuth. If the count is non-zero, the drive current duty cycles are adjusted to return the count to zero. This procedure keeps the total displacement of each wheel equal, thus holding the chair to the original azimuth.

The circuitry of the controller has been implemented on a board which replaces one originally installed in the E&J controller. If the options of speed and azimuth control are selected, the only additions to the chair are the encoders and their gearing to the drive wheels.

RESULTS

The microprocessor-based controller was programmed to duplicate all of the functions available with the presently used commercial controller, the NU 805B. With such programming, the response of the chair to operator commands was not significantly altered. However, the microprocessor-based controller was much more versatile and allowed the addition of automatic speed and azimuth correction without major redesign of the controller.

The controller was evaluated for three months by a member of the laboratory staff who is disabled. She had extensive experience with the

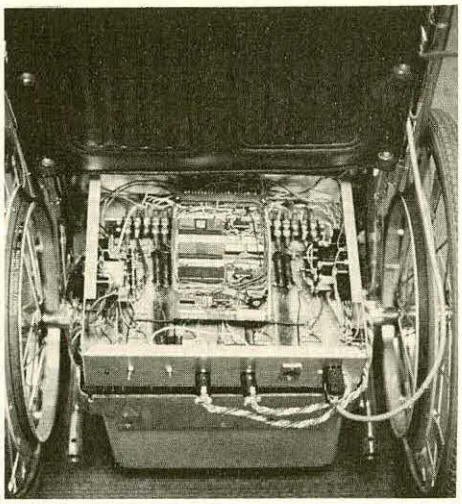

Figure 1. System Hardware

with the outputs of the D/A converters providing two drive signals which are, for normal operation, equal in magnitude but of opposite phase. The drive signals are amplified by a darlington/power transistor combination to produce the needed drive current through the motor. The polarity of the drive signals determines the direction of the armature current and thus the direction of the motor. The only power source requirement is a dual-battery system with a center tap ground. Varistors are placed across the motors to prevent transistor damage due to motor transient voltages.

Velocity feedback from each of the motors is generated by a tachometer mounted to the shaft of the motor. This generated voltage is then input to the computer through the A/D converter.

CONTROL STATEGIES

The utilization of a microcomputer as the central control element allows a wide variety of user input mediums to be accomodated. As mentioned before, the major portion of the interfacing required for the different input devices may be accomplished with software, thus allowing for a minimal hardware system, and also allowing for the system to be easily reconfigured to meet the needs of any particular user. The microcomputer also facilitates any preprocessing that may be necessary in order to provide acceptable drive signals to the wheelchair's motors.

The wheelchair control system described in this paper can presently provide the user wth a choice of three types of input devices as well as a flexible preprocessing unit. The three inputs include a standard joystick, a specially designed digital joystick, and a hum control unit. The special preprocessing package provides for the filtering of the user's input in order to eliminate "noise" due to spastic hand movements [2].

Standard Joystick

When operated using a standard two dimensional joystick the microcomputer system will sample the signals generated by the joystick, and process them so as to produce motor drive signals which are proportional to the desired velocity and the desired direction. Even in this simple configuration the flexibility offered by the microcomputer is apparent, since the accomodation of joysticks having more than two dimensions is simply a matter of expanding the system's software. One application of this flexibility would be in the control of four wheel drive chairs, where a multidimensional joystick is utilized to control the independently driven motors. One additional area where the microcomputer flexibility is advantageous is in the control of wheelchair peripheral devices such as manipulators and environmental control systems. For these applications the microcomputer is used to automatically transfer control from the device to the wheelchair, thus allowing a single input medium to control several devices [3].

Digital Joysticks

The inclusion of the analog-to-digital converter allows for the use of a standard joystick, but since the system is using a microcomputer it seems proper to investigate the use of digital transducers, thus eliminating the conversion process. In addition to eliminating the A/D converter, many of the undesirable properties of conventional joysticks may also be eliminated. Examples of these poor properties include the frictional wear and the resistance to movement found in most analog potentiometers. One likely alternative to the analog potentiometer is the optical shaft encoders.

As an initial investigation into the use of digital transducers the authors have constructed a joystick which utilizes two incremental shaft encoders. The use of incremental encoders was required at this point because of the large size and high cost of commercially available absolute encoders. A photograph of the resulting joystick is shown in Figure 2. The basic operation involves decoding the outputs of the optical encoders to determine the direction of shaft rotation, and then either incrementing or decrementing the

eight bit counters each time an output pulse occurs. Sampling the position of the joystick involves simply reading the contents of each of the two counters.

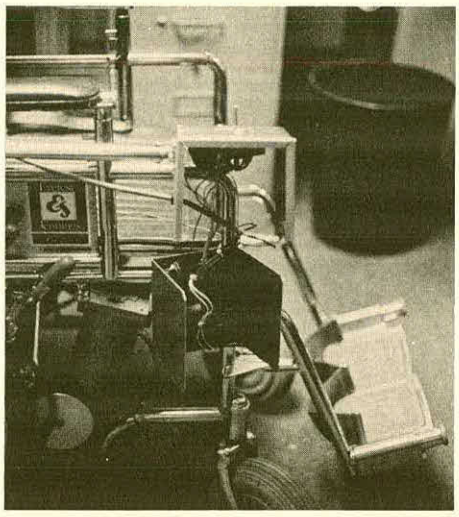

Figure 2. Digital Joystick

The use of the incremental encoders does result in one major disadvantage in that possible counter errors could result in a loss of reference and a resulting malfunction of the system. While this disadvantage may preclude the use of incremental encoders in commercially produced joysticks, it is hoped that the digital joystick described in this paper will provide a research tool through which to study the feasibility of using optical shaft encoders. Through such research one could gain insight into the resolution required for wheelchair applications, and hopefully design and fabricate a customized absolute encoder having a reasonable size and cost.

Input Preprocessing

One major problem encountered by many joystick users, regardless of whether the joystick is analog or digital, is the presence of spasticity in their hand movements. A useful technique for eliminating this problem is to lowpass filter the output of the joystick. This process essentially extracts the average value of the hand's oscillations and provides the system with a useful drive signal. With the microcomputer being used to process the joystick signals it seems practical and advantageous to implement the filter digitally. This allows for the programmability of the filter characteristics, thus allowing for easily tailoring the filter to meet the needs of a particular user.

Deriving the filter's difference equation begins with the desired analog lowpass filter given by

$$G(s) = \frac{K_1}{s + K_2}$$

Using standard techniques this may be transformed into the Z domain where the difference equation

$$y(nT) = A \cdot u(nT) + A \cdot u((n-1)T) - B \cdot y((n-1)T)$$

where

$$A = \frac{\frac{K_1}{K_2} \tan \frac{K_2 \cdot T}{2}}{1 + \frac{K_2 \cdot T}{2}}$$

$$B = \frac{\tan \frac{K_2 \cdot T}{2} - 1}{1 + \tan \frac{K_2 \cdot T}{2}}$$

may be derived. T is the sampling period and K_1 and K_2 specify the filter parameters. By varying the parameters A and B it is very easy to modify the characteristics of the lowpass digital filter to meet the needs of any particular user. As you can see the filter equation is recursive and may be very easily programmed in the microcomputer.

Hum Control

The final input option available to the wheelchair user is hum control [4]. This type of input enables those persons unfortunate enough to have lost complete use of their arms the option of controlling the wheelchair by selectively humming one of four possible tones. Under the hum control option, each of the available tones is detected by a tone decoding circuit. The state of each of the decoders is examined at a specified rate by the microcomputer and the changes in state produce corresponding motions of the electric wheelchair. The system is surprisingly easy to use and can be completely adjusted to match the vocal characteristics of the handicapped person. The use of the microcomputer reduces the hardware of the system while at the same time increasing the capabilities. For example, the microcomputer may be used to detect tone

sequences, tone volume, or the length of time a tone was hummed in order to give the user additional input variables.

MOTOR CONTROL OPTIONS

In addition to the wide variety of input devices available to the user, there is also a variety of motor drive options available to the design engineer. These options include both pulse width modulated motor control and linear continuous control, as well as the capability for velocity feedback compensation. In order to provide the system with the capability for both linear and pulse width modulated motor control, the analog motor drive circuitry has been designed to accept either; therefore making the selection process simply a matter of selecting available software. This enables the design engineer to easily experiment with both options, and quickly make comparisons concerning efficiency, wheelchair response, and user acceptance. The motor drive circuitry also allows for the implementation of dynamic braking through the independent control of each of the power transistors.

Through the use of tachometers, velocity feedback is also provided to the controller. This enables the research engineer to develop and experiment with a wide variety of velocity control schemes. One example of this would be the use of a proportional-integral-derivative (PID) controller to obtain the response specified by the user's joystick input. Having hardware and software of this type available gives the engineer an extremely valuable research tool.

FUTURE WORK

With the addition of the microcomputer to the wheelchair controller, the capabilities of the system increase dramatically. The intelligence offered by the microcomputer allows the wheelchair designer to incorporate such sophisticated schemes as collision avoidance, guidance, and battery monitoring. Two projects presently being pursued within the authors' laboratories include the design of a controller capable of automatically guiding the wheelchair using visual feedback, and the design of a microcomputer-based system capable of monitoring and displaying battery condition.

CONCLUSIONS

This paper has described a completely versatile microcomputer-based electric wheelchair control system. The system provides the user with a great deal of flexibility by allowing a variety of input devices and providing room for expanding to include many more. In addition to numerous input devices the user also has the option of selecting a special preprocessing package which can help overcome any difficulties experienced because of spastic hand tremor.

Possibly an even more important aspect of this controller lies in its value to the research engineer. The ability to change control strategies as well as experiment with feedback control techniques through the use of various software packages is a flexibility that will allow the design engineer to steadily improve on the properties of wheelchair controllers.

While the presently available options demonstrate the power of the microcomputer-based system, the future work described in this paper clearly defines the potential of such a system. Automatic guidance and battery monitoring are just a few of the many possibilities that exist.

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SMART WHEELCHAIR

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Abstract

To allow quadriplegics independent mobility, a 'smart' microprocessor based electric wheelchair has been developed by Stanford University and the Palo Alto Veterans Administration Medical Center. Ultrasound distance ranging technology is employed to track the user's head position in two dimensional space. This data is then used to determine the chair's direction and speed. This concept of motion control has be successfully demonstrated with a working prototype machine. Obstacle detection, wall-following, and cruise-control modes are other implemented features of the current design.

Need

It is well recognized that the lack of mobility is the most limiting disability quadriplegics face. It is their number one priority to be able to mechanically move around an otherwise unwilling body and to do so at their own command. Without a means to freely do so, they are totally dependent on a chauffeuring aide to push them around. A goal of independent living can not possibly be achieved without mobility.

Current Technology

The use of an electric wheelchair is the most obvious way to provide mobility to a quadriplegic. Attempts at making such a wheelchair compatible with the needs of quadriplegics presently involve some type of mechanical coupling of a speed/direction controlling unit to those parts of the body that the user could still control. A joystick manipulated by the chin or an apparatus attached to the headrest are two common current methods of operating the motorized wheelchair.[1] However, these interface devices are far from ideal, since intimate contact with them must be maintained at all times, and critical positioning of them is required to accomodate the user. Limited chin extension and marginal control of those movements aggravate the control problem and prove frustrating to use for many. Additionally, chair motion tends to be quite jerky due to the acceleration feedback effect of the chair on the user's chin position. Other chair designs utilizing pneumatic switches activated by the user puffing or sipping on a plastic straw[2] suffers from similar disadvantages as well the increased difficulty in mastering its control.

Goal

It was the aim of five graduate Mechanical Engineering students at Stanford University's Smart Product Design Laboratory to develop ideas that would enable quadriplegics to more efficiently maneuver their wheelchair in their life-space. A totally non-contacting scheme of user control of an electric wheelchair was envisioned. The problems of collision with obstacles and tracking along a straight path would also be addressed. With funding and electronic expertise from the Palo Alto Veterans Administration Rehabilitative Engineering Research and Development Center, the concept of a 'smart' electric wheelchair came into being.[3]

Solution

The prototype 'Smart Wheelchair' has successfully proved that those goals can be met. The current model utilizes Polaroid Ultrasonic Sensor technology.[4] to accomplish many of the objectives. On a Polaroid camera, this type of sensor provides the subject-to-camera distance required for focusing. A resolution of approximately one-quarter of an inch is possible at distances from nine inches to twenty feet. On the 'smart' wheelchair, a modified Everest and Jenning's Model 3P, a pair of these sensors triangulate the user's head position. Another pair of transducers face forward while others face to the left and right of the chair. The function of these sensors is explained below.

Operation

In operation, a center or rest head position is defined in an interactive computer training session. Deviations from this 'origin' in both the forward-back or left-right planes can be calculated from subsequent rangings of the two sensors.[Figure 1] This data is then transformed in such a manner as to provide information needed to proportionally drive the two motors of the chair. The magnitude of the data controls the speed and the difference between the two motor speeds steers the wheelchair. From the user's point of view, he directs the motion of the chair with his head. To move the chair forward, he would position his head forward of the 'rest' position. Similar operations perform motion in the remaining three directions; left pivot, right pivot, and backwards. Since combinations of these directions are allowed, a smooth right turn can be accomplished by positioning the head forward and to the

right. In effect, the user's head has become a proportionally controlled joystick. Since very minimal head motion is required to use this system and the control is quite easy to learn, this unique non-contacting scheme promises to be an ideal solution for quadriplegic control of an electric wheelchair.

Other Modes

The additional ultrasonic sensors are used in other operating modes. Two forward facing units detect the presence of obstacles in the path of the chair. When the distance between such an object and the chair becomes less than a preprogrammed value, the chair will slow and/or stop before colliding with it. This feature is designed to detect a sudden opening of a door or imminent collision with a walking person on an intersecting course. If the wheelchair encounters a slowly moving person in its forward path, the chair will 'follow' it at a fixed distance.

Side sensors serve to detect walls at the right and left of the chair. A 'follow-that-wall' mode enables the chair to travel parallel to the chosen wall without operator intervention. Open doorways are detected and ignored, but a discontinuity of more than a few feet disables this mode and returns total control to the user. Since a solid wall is not required in this mode, the chair will track a picket fence with equal ease.

A 'cruise control' mode utilizes wheel speed data obtained from two optical shaft encoders friction coupled to the two driven wheels. At 200 milliseconds intervals, twelve-bit binary counts (each count representing 1/1980 of a revolution) are made in the forward and reverse direction for each motor. This data is then used to maintain a constant chair speed and heading despite minor terrain changes.

Of course, there is also a mode that allows the user to freely move his head without activating any chair movement.

Mode Switching

Switching from one operational mode to another was initially performed by a Centigram voice recognition unit.[5] Although this system worked fairly well, it could not be made easily portable. As an interim solution, mode changes are signaled when the user positions his head to the extreme rear and then to one of the four quadrants.

Hardware and Software

The present hardware of the 'smart' wheelchair consists of a 'portablized' Zilog MCZ 1/05 Z80 microprocessor system with 64K of memory, three parallel I/O ports, a serial port, two D/A convertors, and a floppy disk system.[6] In the prototype system, Once the programs to operate the chair have been loaded into RAM from disk, the floppy and CRT terminal are disconnected and the user can drive away. The software executive is written in BASIC with a majority of the real-time program coded in 2300 lines of assembly language called from BASIC. Extensive use is also made of integer and floating-point routines from the Zilog math package.

The use of a microprocessor allows complex control of chair inputs and outputs, more than could be managed by a straight analog control system. For example, the motor speed is not permitted to change by more than a given amount from update to update. In this manner, acceleration limiting is performed and jerky motions of the chair are minimized. In a similar manner, head position is checked for out-of-bounds conditions. If such invalid data is aquired, it is ignored. Also, to calibrate the head position algorithm, a 'training' program is run. The user is asked to move his head to the center, and to the left, right, forward, and rear extremes. Sensor readings taken at each of these stages enable the control program to adapt to the particular user's extent of motion. Additional control parameters such as gain and 'dead-zone' can be adjusted to suit different users and changing conditions. This form of hysteresis further stabilizes the system from abrupt direction changes about the rest position.

Interface

The microprocessor - motor interface involves the generation of an eight bit data byte which is then converted to an analog voltage level by a Signetics NE5018 D/A converter. Introduced into the existing Everest and Jennings motor-speed control unit, it then drives the motor with a pulse-width modulated signal. The microprocessor performs the required linearization of the analog voltage versus produced motor speed function. Additionally, four motor power relays (two for each motor) are controlled by TTL signals output from the microprocessor. These relays perform current reversal for the DC chair motors with one activated relay producing forward drive and rearward motion resulting from both being energized.

Performance

In actual operation, the prototype chair performs quite satisfactorily. After a minimum amount of practice, controlling it can be mastered by anyone. The ability to accomplish fine maneuvers is limited only by the geometry of the chair and its caster wheel system. A slight 'over-steering' instability in straight-line travel has been noted, but a modification of the head position algorithm should cure this minor problem.

Current and Future Designs

The current design iteration phase is addressing the reduction of system physical size and memory requirements. New EPROM-based software is being developed to eliminate the need to load the program from disk storage. A DC bridge controller will be used for increased efficiency as well as to eliminate the bulky motor relays in the existing configuration. These high performance units feature motor current sensing resistors and a regenerative braking system that recharges the batteries during braking. In addition to its superior performance, the DC bridge circuit can be driven directly by the computer-generated pulse-width modulated output signal.

To increase the overall gain of the system, an inertial frame will be employed. This will also serve to minimize the effects of acceleration on the overall performance. As an added bonus, this device will indicate the approach of instability of the vehicle as well as inform the user of an attempt to climb a hill that is too steep. Visual and audio indicators will inform the user of a low battery conditon. A watch-dog circuit will shut down the entire system should a computer malfunction occur. Some type of accessable panic switch would allow the user to accomplish the same function.

The microcomputer software will be designed to dynamically adjust to the user. In such a system, one would merely need to transfer the user to the wheelchair and turn on the unit. From this point on, the computer system will learn the user's range of motion as well as his rest positon. The final design will attempt to capture the head-control features of the "smart" wheelchair on a single circuit board that can be fitted to an existing commercial wheelchair.

Conclusion

It is the goal of the Rehabilitative Engineering Research and Development Center to utilize state-of-the-art science and technology for the direct benefit of physically disabled persons. This device and others that will follow will endeavor to make their life more productive and free.

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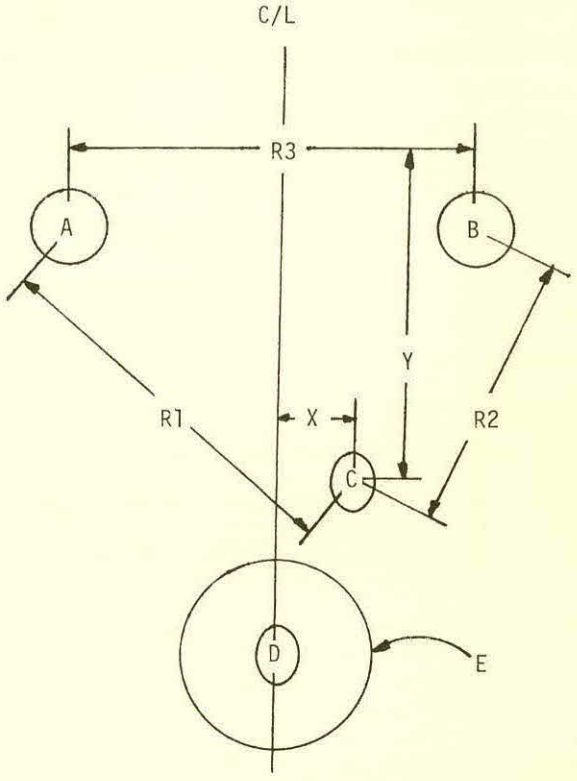

Figure 1: Top View of Head Control System

Legend

A,B	Ultrasonic Transducers
C	Typical Head Position to be Measured
D	Rest ("Center") Head Position
E	Outer Limit of "Dead Zone"
R1	Range Measured by Transducer A
R2	Range Measured by Transducer B
R3	Fixed Transducer Spacing
X,Y	Distances to be Calculated

Equations

$X = ((R1-R2)*(R1+R2))/(2*R3)$
$Y = Z/(2*R3)$
$Z = (S*(S-R1)*(S-R2)*(S-R3))\ .5$
$S = (R1+R2+R3)/2$

AN OVERVIEW OF THE BLIND REHABILITATION PROCESS

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The evaluation of rehabilitation programs has suffered from both conceptual and methodological flaws. We have focused on the basic issues underlying these flaws, and developed methods for addressing these problems in evaluation research.

The potential usefullness of rehabilitation has been undermined by the absence of systematic evaluation of program effectiveness. Evaluation of these programs in terms of goal-attainment and cost-effectiveness will lead to the most effective possible rehabilitation treatment, for the greatest number of people. In particular, blind rehabilitation is characterized by the absence of information on program effectiveness. The program selected for study, the Blind Rehabilitation Center (BRC) at the Hines V.A. Hospital, is chartered to undertake the rehabilitation of all applicants who meet the criteria for receiving services. Meaningful evaluation of this and other such programs must assess effectiveness in terms of outcomes, and must examine the role of patient factors in determining outcomes.

We have been unable to specify how a blind patient's participation in a rehabilitation program affects his general life state because we have been unable to identify just what changes occur in his life as a result of the acquisition of skills developed during the training. We must determine how the acquisition of skills has affected his ability to function in society by changing the quality of his life state. In addition, we must develop a model for the interaction between patient and treatment. We must assume that the patterns of psychological and social characteristics which the patient brings with him to the treatment setting will have significant effects on the quality of outcome. Accounting for these variables will allow more meaningful program evaluation and assessment of outcomes. But equally important, it will lead to program modifications which increase the success rate of low probability patients.

The outcome evaluation of the BRC brings into focus many of the issues involved in any evaluation process. The outcome criteria must be derived from program goals; the design must permit assessment; and valid measures must be developed.

One of the most basic problems that must be solved is the selection of relevant dependent variables, or outcome criteria, which define program effectiveness. Like most service programs designed to change persons' lives, the goals of the BRC are too broad and too task-oriented, to provide a basis for rigorous assessment. On one level, the program hopes to enhance the quality of life of the patient by increasing independence, strengthening psychological resources, and modifying attitudes. In this form, it is impossible to measure the degree to which the program achieves these goals. On another level, the BRC attempts to teach specific skills, such as the use of the long cane. Proficiency in these tasks is measurable; but their measurement would tell us little about the degree to which the higher order goals have been achieved. The acquisition of skills must be placed within the context of feelings, attitudes, and behavior in order to reveal in what ways it has improved a patient's life. In order to do this, we must have measurements of these feelings, attitudes and behavior along with measurements of skills. Thus a primary requirement of adequate research procedure is the translation of these goals into variables which can be measured with psychometrically valid instruments, the measurements from which can be realistically intrepreted as revealing change, or lack or change, in the lives of blind patients.

Another major difficulty centers around the

issues of research design and design limitations. The best design is a randomized controlled experiment (Campbell and Stanley, 1966; Cook and Campbell, 1975) in which participants are randomly assigned to an experimental group or a control group, so that any post-treatment group differences can be attributed to the experimental treatment. While this research model permits casual inferences and maximizes generalizability, it is impossible implement in the present case. When evaluating an existing program such as the BRC, the researcher has no control over the treatment administered to the participants, and only a moderate degree of control over the selection of dependent variables. More important, the creation of a control group would mean denying treatment to persons who both need and want it. Not only is this inhumane, but it would violate the service policy of the BRC.

Many other designs, while methodologically weaker, are also unacceptable for other reasons. For these reasons, it was decided that the most powerful and most appropriate design for the evaluation of program effectiveness of the BRC is a pre-test/post-test change score design, in which participants act as their own controls. Patients are assessed on a set of specific variables prior to entry into rehabilitation training, and again after training is complete. This approach permits the assessment of how much change, if any, is effected through the efforts of the program in question (2). The major weakness of this design is that it may permit competing explanations of outcomes. Thus to understand and eventually predict outcomes, it is necessary to also study the effects of factors which may intervene between treatment and outcome. These factors are primarily individual differences in the areas of personality and socio-economic characteristics.

In addition, past research (1, 3, 5, 6) has relied on simplistic measures of outcome, such as a general rating of travel ability. But the ability to travel is a very complex issue for a blind or partially sighted person. Accurate measurement requires an index which takes into account the places to which the person travels, the frequency and mode of travel, and the degree of self-sufficiency in travel. Thus a global rating of travel freedom is grossly inadequate.

A second problem is that none of the studies examine how the blind rehabilitation process affects the overall life of the blind person because they focus on one, possibly two, outcome variables (3, 5, 6). To do this is to defeat the purpose of evaluation by assessing skills outside the context of the rehabilitation goals. If the patient has been taught the requisite skills to permit him greater travel freedom, and yet he does not use those skills after returning home, then either the rehabilitation program has failed, or the patient himself is untreatable by the standard practices. Either way, the personnel and financial resources of the program have been wasted, and the patient is left unhelped. Thus outcomes must be assessed on the basis of specific variables which are grounded in the context of the patient's total functions.

Attempts to identify variables which predispose to successful rehabilitation of the blind patient have been plauged with the same problems. Research has examined patient factors on a piecemeal basis (1, 4, 7), producing results that are often contradictory and uninterpretable. Complex behavior is simply not explicable in terms of one or two variables. What is necessary is an examination of patterns of patient variables, including social, economic, and psychological factors.

Thus a multivariate model of both outcome variables and patient factors must be developed in order to examine the efficacy of rehabilitation treatment. The extant literature suggests certain personality and social factors which may be important; the goals of the rehabilitation program suggest relevant outcome variables. It is necessary that the relationships among all of these variables be examined in the same study, on the same sample, so that we may determine the ways in which patient factors interact with treatments to produce outcomes. Developing such a model of blind rehabilitation will then permit the application of the model to other programs, thus furthering the basic goal of enhancing the effectiveness and efficiency of rehabilitation systems.

One of the main problems in assessing rehabilitation outcome lies in the difficulty of translating impressionistic clinical definitions of improvement into psychometrically valid measuring instruments. The solution to this lies in collaboration between those who are best able to define the outcome criteria, practitioners involved in the clinical applications of rehabilitation, and those who create the measuring instruments, the psychometricians and evaluation researchers. These two groups of Professionals must work closely together to produce instruments which focus on the relevant outcomes, and do so in a way which is psychometrically valid. Any instrument which does not meet these standards will produce data which are misleading and uninterpretable.

Given that the test designers have received adequate clinical input about the variables to be measured, there are methods of test design which enable one to make statements about specific kinds and quantities of change. These methods can be applied to the problem of evaluating rehabilitation programs. The basic methodology for doing this has been developed by Wright and his associates (8). Generally, this method produces a scale of test items along a dimension ranging from best to worst, or most to least, or from hardest to easiest. Such a scale permits us to make precise measurements of the amount of an ability or quality which a person processes.

Using the concepts and methods discussed here, we have completed the first stages of our study of the BRC. We started with a series of conferences with the BRC staff to elicit from them as concrete

as possible an intrepretation of their treatment goals and desired outcomes. This included the specification of items of patients' skills, attitudes, and behavior believed to adhere in positive outcomes.

Based on this input from the staff, we devised four instruments. The Mood Scale assesses the patient's anxiety and/or depression. The Activities Schedule is a list of activities, scaled for difficulty, spanning the realms of self and home care, recreation, communication and finances. It assesses facility and motivation for improving skills. The Travel Inventory measures frequency, mode, and freedom in travel for various purposes. The Attitudes Questionnaire is a series of attitudes scaled from more to less extreme with which the person is asked to agree or disagree.

We have developed these instruments in accordance with the psychometric principles developed by Wright (8). The pilot testing has shown that they each define a consistent scale of difficulty that is independent of the person taking the test, and that produces a measure of a characteristic in terms of the amount of that characteristic which the person possesses. Thus, for example, the Travel Inventory yields a score which defines the amount of travel independence which the patient displays.

With instruments as powerful as these, we may now proceed to the major study. With these instruments, we will undertake the evaluation of the BRC, using a pre/post design. Thus we can precisely measure the types of change and the amount of change produced by the rehabilitation treatment. With the addition of socio-demographic data, we will also use the Attitudes and Mood Scales as independent variables, and thus eventually attempt to predict which configurations of mood, attitude, and social factors are associated with positive and negative outcomes.

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SURVIVAL THROUGH RESEARCH UTILIZATION

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ABSTRACT

Employability and quality of life of disabled individuals are enhanced through the use of technical methods and devices. Examples are presented herein. New, improved and less expensive assist devices are needed. Development of new technology, however, cannot be justified unless we utilize existing methods and devices. A resume' of research utilization activities of the IMPART program and suggestions for further rehabilitation research utilization effort is presented.

RATIONALE

"Research utilization" is not a romantic term to design engineers. But if we were to fully achieve our mission in rehabilitation engineering, we must develop an active love affair with "research utilization."

It takes too long for our innovations to reach the hands of disabled individuals. Our job is incomplete until our idea is converted to a real method or device that actually improves function, education or quality of life of handicapped individuals. Research utilization includes getting the device into the hands of the handicapped consumer.

A "tight" or austere economy will force us to give more attention to the research utilization or technology utilization process. Demands are now greater for more practical, inexpensive, and cost-effective products. We know there is less money available to public vocational rehabilitation service agencies which means there is less money available for the purchase of functional assist devices. When the need for an assist device arises, there is increasing pressure to acquire the least expensive, readily-available device. There is greater effort, and rightfully so, to avoid costly and time-consuming custom design. The climate is right for "research utilization."

Rehabilitation researchers must help those engineers and others whose primary concern is research utilization. He will be rewarded because an increase in demand for functional assist devices will inherently result in demand for more rehabilitation engineering research work. He will also be rewarded when he sees disabled persons overcome handicaps by using methods and devices that he and his peers conceived and developed.

Research utilization is vital to everyone concerned with rehabilitation. It is certainly a factor that effects survival of the rehabilitation engineering researcher.

CASE STUDIES

A review of actual cases where research utilization played a major role in successfully improving function, education, employment and quality of life of severely disabled individuals follows. In each case, these factors discussed: (1) disabilities of the client, (2) abilities, (3) job aspirations, (4) assist devices involved, (5) success achieved, and (6) current status of the client. Where possible, the source of technology and sponsoring agencies are identified.

CASE 1, HERBIE TAYLOR 34 YEAR-OLD, POST-POLIO QUADRIPLEGIC

Mr. Taylor is a trained electronic technician who uses a powered wheelchair. His productivity is limited because of poor vertical and horizontal reach. He has good hand dexterity and fair pinch.

A potential employer, Datapoint Corporation in San Antonio, Texas, was reluctant to hire him because they believed his poor reach would limit his productivity. IMPART research utilization specialists identified the "SCAT" wheelchair which is an electrically powered chair with a powered seat-elevating feature. One of these chairs, which belong to the Veterans Administration Prosthetics Center (now The Veterans Administration National Rehabilitation Center or VANREC) was demonstrated for the management of Datapoint who quickly responded by hiring the quadriplegic job applicant.

The client was placed on probation for two months and was hired permanently at the end of that time. A powered drive, power elevated "SCAT" chair was purchased for the client by Texas Rehabilitation Commission and the case was closed.

This was clearly an example of research utilization. VANREC had previously provided funding for development of the special chair which was developed and marketed by a private manufacturer.

CASE 2, MARTHA ARBUCKLE, 40 YEAR-OLD POST-POLIO QUADRIPLEGIC

Mrs. Arbuckle has been confined to bed and a reclining wheelchair for 17 years. She has a good voice and is a bright, cheerful lady who serves on the IMPART advisory committee. She has poor head and neck function and has very limited range of motion in the thumb, index finger and second finger of one hand. A special switch, utilized for operating the telephone while in bed, was previously designed and fabricated by local personnel. This switch was later redesigned and fabricated by the Rehabilitation Engineering Center at The Institute for Rehabilitation and Research.

Working with a Texas Rehabilitation Commission counselor, Ms. Arbuckle identified a job with the Texas Department of Human Resources which involves telephoning fathers who are delinquent in child support payment. The job involves, (1) dialing a telephone, (2) referring to notes, (3) recording information and (4) communicating with peers in her office.

Commercially available automatic telephone dialing equipment (the Prentke-Romich ADT-5B) and an environmental control device (Prentke-Romich ECU-2) was identified and discussed with the South western Bell Telephone Company. A "carousel-type" device which holds and displays names, telephone numbers and other information was designed and fabricated by a local engineer. The IMPART program loaned an automatic dialer and environmental control device to the Department of Human Resources to demonstrate feasibility for the client to perform the job. After a successful demonstration, the telephone company purchased an automatic dialer and environmental controller which was rented to D.H.S. and the client was employed.

Ms. Arbuckle has now been employed for eighteen months. The only concessions made for her at this time are the following: (1) a control switch is placed in her hand upon her arrival at work, (2) the equipment is turned on for her, (3) notes are clipped to her carousel device and (4) assistance in transferring calls is provided.

The equipment utilized by Ms.Arbuckle represents research and development work by many researchers and sponsoring agencies. It also represents applications work by an existing Rehabilitation Engineering Center funded by N.I.H.R. This case illustrates how research utilization activity can place the products of rehabilitation research into the hands of handicapped consumers. Ms. Arbuckle's performance and earning power, can be further increased by utilizing new products of research. That his, her ability to hold and transfer telephone calls and to type and to edit letters, can be enhanced by using the Rehabilitation Institute of Chicago-developed computer-based environmental control system.

CASE 3, A BLIND DISC JOCKEY

A blind disc jockey was about to lose his job because the radio station changed from single to long-playing records. The blind employee could not "cue" the records quickly enough.

IMPART recommended the use of a Paper Money Identifier (PMI) which enabled the client to locate and select appropriate bands on a timely basis. This saved the job of the client. The PMI was developed by Southwest Research Institute under NASA sponsorship.

CASE 4, A NON-VERBAL HIGH SCHOOL STUDENT

Speech therapy had been discontinued for a non-communicative high school student who was thought to be moderately mentally retarded. IMPART provided information on various communication aids to Tulsa University's Speech and Hearing Department and arranged for the staff to borrow and learn to use synthetic voice generators, small print-out devices, visual communicators for the deaf, and other apparatus. Subsequently, the staff evaluated the client and had him use these devices on a trial basis. An extended trial of the Canon Communicator, a device with a small keyboard and tape printout, was prescribed. The client quickly began using this communication aid in the classroom. Further, he began to talk in class, at home, and on citizen's band radio. The young man's performance in school improved markedly.

OTHER CASES

Numerous cases similar to those discussed above have been solved by the IMPART Program by identifing existing devices, methods, and resources. This, clearly, is researched utilization. In instances where design and fabrication was required, this effort was funded by case funds, resources provided through other programs, or funds provided by state rehabilitation agencies.

RESUME' OF IMPART PROGRAM ACTIVITIES
PROBLEM ACQUISITION

Acquisition of specific problems from vocational rehabilitation counselors and disabled persons has required extensive effort. It has been necessary to convince these people that, (a) technology can solve vocational and independent living problems, (b) costs will be reasonable, (c) most required devices exist, and (d) rehabilitation engineers are truly interested in handicapped individuals and wish to help solve their problems.

GEOGRAPHICAL AREAS SERVED

About ninety percent of the problem were received from Texas, Oklahoma and New Mexico, and distribution approximated the ratio of the number of counselors in each state. Administrators in these states endorsed the program and provided matching state funds for the federal funds.

The original intent was to serve the five states in RSA Region VI which consists of Texas, Oklahoma, New Mexico, Arkansas and Louisiana. Arkansas elected not to participate in the program. Louisiana elected to procure vocational rehabilitation engineering services and technical information support from Louisiana Polytechnic University.

PROBLEMS REFERRED TO OTHER FACILITIES

About twenty percent of the problems were referred to state-funded programs, Rehabilitation Engineering Centers, the Veterans Administration National Rehabilitation Engineering Center and local resources. Problems requiring engineering design and fabrication were referred to other grant programs within Southwest Research Institute (including a 3-year I & E grant program from Texas Rehabilitation Commission), the Institute of Rehabilitation and Research at Houston, Caruth Rehabilitation Center at Dallas, the Tulsa Rehabilitation Center in Tulsa, the Evaluation Section of Oklahoma Rehabilitation Services in Tulsa and local sources in Austin, San Antonio, Beaumont Houston, Dallas and Tulsa.

Very useful technical information and support was provided by all of the N.I.H.R.-Rehabilitation Engineering Centers and the Veterans Administration National Rehabilitation Engineering Center. Many state vocational rehabilitation agencies, other federally-funded programs, universities and equipment vendors provided significant assistance.

TRAINING PROVIDED BY IMPART

IMPART staff members have made many presentations to vocational rehabilitation counselors in order to, (1) explain the purpose of the program, (2) acquire problem submissions and (3) improve their knowledge and understanding of technical assist devices and methods.

FURTHER RESEARCH UTILIZATION IN REHABILITATION STATE AGENCY REHABILITATION ENGINEERS

Several state agencies have employed rehabilitation engineers and a number of others are considering means for acquiring such services via contractual arrangements. Presence of these rehabilitation engineers will improve, but will not satisfy, the national need for rehabilitation research utilization.

STATE AGENCY DATA BANKS

Texas and Oklahoma will have extensive rehabilitation device information banks at the close of the present IMPART program. Louisiana is accumulating a similar system through a contractual arrangement with Louisiana Tech University. Those states that acquire or contract for rehabilitation engineering services will presumably have access to their contractors' information resources.

THE NIHR ABLEDATA SYSTEM

In the near future, the Abledata System will be functional and will contain a very extensive collection of information on commercially available assist devices and methods, special and developmental devices, and information on use and evaluation of such devices. ABLEDATA will contain all the information collected by each of the NIHR-funded Rehabilitation Engineering Centers, the IMPART program, and various other resources. There is no doubt that this system will have great impact on rehabilitation research utilization and should further encourage state agencies to consider more extensive utilization of technical devices in vocational rehabilitation and special education.

ROLE OF REGIONAL IMPART PROGRAMS

The NIHR should consider establishment of ongoing, regional IMPART programs. These teams would utilize and promote utilization of the ABLEDATA System, vendor items, and local engineering, and fabrication resources. The NIHR-funded Research and Training Centers could play an effective role by conducting seminars that would improve the knowledge and utilization of assist devices by vocational rehabilitation counselors and disabled consumers.

CONCLUSION

The need for new and improved technical rehabilitation assist devices is predicated upon demands and use of currently available methods and devices. It has been clearly demonstrated many times that employment is made possible and quality of life is dramatically improved through the use of technology. Rehabilitation research utilization implies identification, promotion of use and prescription of appropriate assist devices. Research utilization, therefore, is vital to the survival of disabled persons, producers of assist devices, vocational rehabilitation counselors, rehabilitation counselors and rehabilitation research engineers.

TECHNICAL EDUCATIONAL AIDS FOR CHILDREN WITH HANDICAPS - TEACH

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&

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ABSTRACT

In July, 1978, the Bureau of Education for the Handicapped awarded a three year demonstration grant to the Memphis City Schools - Division of Special Education. One objective of this grant was to demonstrate that severely physically handicapped children could participate more meaningfully in their educational program with the assistance of technical aids designed to facilitate seating, communication, mobility, feeding and toileting. Technical services were contracted from the University of Tennessee - Rehabilitation Engineering Center and appropriate aids and training were provided. In addition a model for implementing a delivery system for technical aids in an educational setting was developed and an instrument to aid in the prescription of technical aids was designed.

PROCEDURES

Ten children were selected to participate in the Project. Each child exhibited some form of cerebral palsy and was non-verbal as a result of motor damage to the speech mechanism. Each child also demonstrated severe motor impairments which affected functions other than speech, i.e. trunk stability, head control, hand skills, or feeding.

The children attend Shrine School, a special education school for the physically handicapped which is part of the Memphis City School System. Shrine School is located on the Sheffield School Complex which consists of an elementary school, a junior and senior high school and a vocational technical center. This complex, conveniently, could be used for mainstreaming, provided that the problems created by the physical limitations of these children could be minimized.

Each child entered the Project participating in the educational program prescribed for him in the educational assessment meeting. A needs assessment for technical assistance revealed the specific areas in which technical aids could benefit each child the most.

Aids would be designed to permit easier access to educational materials to enhance communicative interaction and development, and to facilitate activities in daily living.

By the end of the first year all ten children had been evaluated to project technical needs. On an individual basis, training of prerequisite skills required to operate specific technical aids, was initiated by the occupational therapist and/or speech pathologist. Preliminary communication systems, seating and mobility aids, and A.D.L. (Activities for Daily Living) aids were then provided, based on the evaluation information. Initial training programs in the use and maintenance of technical aids were developed for teachers and parents.

All ten children in Project TEACH have been provided with an alternative communication system. Each communication system has been individually prescribed based on the information gathered by the Technical Aid Evaluation developed by Project TEACH. Five children have wheelchair trays that have been custom-designed to accommodate the individualized communication boards. Two children have an optical strip-printer scanner developed by UT-REC specifically for a Project TEACH child. This item is now commercially available. One student has a commercially available Cannon Communicator with a custom-designed belt attachment. One child has been provided a computer and another with binaural amplification.

Without these technical devices, classroom participation and the related learning activities would be minimal. These communication devices have enabled the non-verbal child to communicate with his teachers, peers, and parents and to develop the necessary language skills for more complex academic programs. For both school and home, seating systems have permitted safer transportation, provided proper work surfaces, and simplified other activities of daily living such as feeding. Wheelchair inserts have increased sitting comfort, the amount of time children can sit in their seats, i.e. wheelchairs, and have allowed the student to be positioned in a manner that would allow him to better attend to instruction.

Feeding aids have allowed children to eat without the necessity for an attendant to feed them.

Page turners and computers have permitted children to access educational materials faster and independently.

Theraputic aids have allowed the child to receive therapy without being removed from the classroom.

TABLE 1

TECHNICAL AIDS PROVIDED

Category	Source	No	Description
Communication Aids	CU -now CM	2	Optical Scanner Strip Printer
	CU	3	Etran Systems
	MCM	1	Cannon Communicator
	CU	3	Communication Bliss Boards
Mobility powered drives	CU	2	Child sized cart
	Mod	2	Amigo + A BEC-modified
	CU	2	3 PE & J + A BEC
A.D.L.	CU		Potty Seats
	CU	2	Ratchet Plate
	CM	1	Winisford Feeder
	MCM	1	CP Feeder
Educational	CM	1	Page Turner
	CM	2	Apple Computer
Therapeutic		2	Stand Tables
		1	Corner seat
			Control Training Devices
			Prone Wedges
			Side Lier
			Modified Toys
Seating		8	Individually prescribed wheelchair inserts

*CU - custom design
*CM - commercial design
*MCM - modified commercial design

MODEL DESCRIPTION

The need for a formalized approach in prescribing, delivering, and training of technical aids in the educational setting was recognized. (See Appendix.)

A team having broad representation from areas such as Speech Pathology, Occupational Therapy, Physical Therapy, Special Education, and Rehabilitation Engineering should be assembled to assess technical needs.

After the preparation of the referral criteria, a formal referral process should be initiated. The persons that would be most expected to make referrals (teachers, therapists and medical community) should be oriented to the referral criteria. Appropriate referral forms should be prepared, distributed and collected.

Selection criteria for those children assessed for technical aids should be established by this team. Important factors to consider are: 1) degree of physical impairment, 2) ability to perform functionally in areas of communication and/or Activities of Daily Living (mobility, feeding and toileting), 3) level of intellectual functioning, 4) amount of success that could be expected to be experienced by the provision of an aid, 5) school and home environment.

The team should periodically assemble to screen referrals in order to determine whether or not they meet the selection criteria and should be formally assessed for a technical aid at a later date. Before any formal assessment can be conducted, parent notification should be made and permission to assess secured.

The formal technical assessment should include input from the student, parent, teachers, therapists and representatives of any other discipline significantly participating in the management of the child. In the educational setting, once the technical needs of each child are prioritized, they will be incorporated into the student's Individual Educational Program (IEP).

Technical aids may be obtained from three sources. The most desirable option is to obtain a commercially available aid. This is generally significantly less expensive than customization. If this isn't feasible, then serious consideration should be given to the modification of a commercially available aid. In the event that neither of these options seem practical, the final alternative, of course, is to consult with the technical staff and explore the possibilities of customization.

For those items secured through commercial sources, the following procedure should be observed. An initial technical check will determine if the aid is functional. The IEP will be modified to reflect the use of the aid in the child's educational program. The teacher, child, and parent will be trained in the proper utilization of the aid according to each of their needs. Once the technical needs of the student have been met, periodic re-evaluation and on-going maintenance will be provided. If the aid should prove to be ineffective, then the student will be referred to the technical facility.

For those technical aids that have been either modified or custom designed, the following procedures will be followed. The design modification or custom design will be presented

to the team for validation (i.e. does it appear to be able to do what the team wants it to do?). A cost estimate is presented so that the team may decide whether or not the design is economically feasible. If the above are acceptable, the modifications and/or fabrication of the new aid are made. An initial operational check will be made and the aid placed with the appropriate school staff. Modifications are made to the student's IEP to reflect the acquisition of the aid. Professionals, children and parents are trained in the proper utilization of the aid. Once technical needs have been met, periodic re-evaluation and ongoing maintenance are provided.

In the event that these technical needs are not met, the child should be referred back to the team for re-evaluation.

CONCLUSIONS

The provision of technical aids through Project TEACH, in addition to the supplementary services of a Speech Pathologist and Occupational Therapist has clearly demonstrated this approach as an essential supplement to the Individualized Educational Program of each of ten children involved in the Project. The following conclusions have emerged.

Seating Aids

Seating Systems enable severely physically handicapped children to sit with greater stability in dynamic sitting postures in a classroom. As a result of the more stable posture, severely handicapped children are better able to use available hand skills.

Communication Aids

With communication systems children were able to increase expressive vocabulary and sentence length and complexity. Communication systems enabled the students to express concepts and feelings. Children were now able to respond to instructional tasks and participate in social interaction.

Mobility Aids

Technical aids enabled children to become more independent in following their daily school routine, thus freeing teachers and aids for other activities. Mobility systems enabled children to independently initiate motion and so develop more initiative in general.

Activities of Daily Living Aids

Feeding aids enable several children to feed themselves and so free teacher aids for other responsibilities.

Adapted commode seats made toileting easier and safer for the children. It enabled several children to become toilet trained.

Theraputic Aids

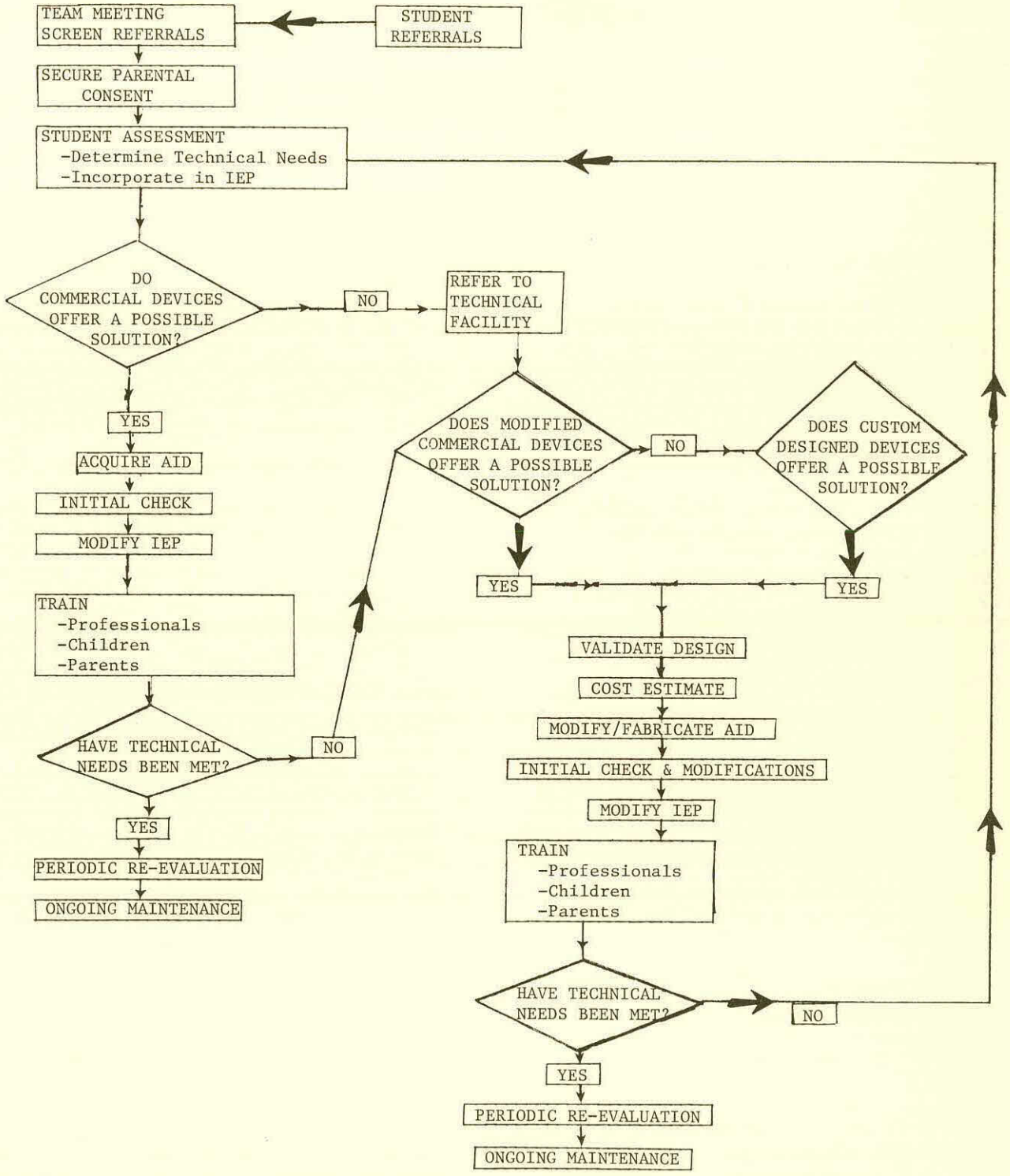
Theraputic positions can be maintained without removing children from classroom.

Control Training Aids

Allow to learn to operate switches necessary to drive cart, and wheelchairs.

MODEL FOR REHABILITATION ENGINEERING SERVICES IN SPECIAL EDUCATION CLASSROOM

FLOW CHART



PROJECT THRESHOLD - THE PROGRAM AND ITS APPLICATION

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ABSTRACT

Although the transition process of the handicapped individual into the home and community is recognized as important and addressed during the initial rehabilitation process, the individual's priorities at that time may not be on making long range goals. Often, as the individual becomes more aware of his capabilities, he may begin to actively pursue long range goals such as independent living, further education, or vocational plans. In many instances, it is at this stage that rehabilitation engineering can be particularly beneficial in contributing to the successful pursuit of these goals. This paper describes Project Threshold, a resource which utilizes rehabilitation engineering as well as other allied health professions to solve problems of the severely disabled.

BACKGROUND

In answer to a demonstrated need for a more efficient method of applying rehabilitation engineering and technology to the problems of disabled individuals, service delivery programs such as Project Threshold have been developed. The idea for Project Threshold originated within the Rehabilitation Engineering Center at Rancho Los Amigos Hospital and was established with an innovation and expansion grant in 1976. It has been supported since that time through case service contracts with the California State Department of Rehabilitation. The Project Threshold Client Service program was designed to meet the unique needs of severely disabled clients who require specialized assistance in performing tasks of daily living, assistance with management of attendant time and activities, and/or performance of school and job related tasks.

APPROACH

Project Threshold staff consists of a core team of four individuals who are responsible for implementing an evaluation process which is structured to meet the client's needs by identifying problem areas and then systematically working out solutions to the problems with the goal of increasing the client's level of independence in the most simple and cost effective manner. The process begins with a referral from a rehabilitation counselor. The clients that we see are generally severely disabled representing a wide variety of disabilities. The problems that they present with usually fall into one of two categories:

1) Independent Living Analysis

2) Evaluation of Equipment Needs

The first category includes individuals with attendant management problems and/or complex independent living needs which require further definition. The second category is applicable to clients who may have a need for equipment and/or home or work site modifications. After receiving a referral, a systematic analysis is performed to identify the client's functional abilities and limitations and specific independent living problems or equipment needs. Most evaluations are conducted in the Model Home (a building designated as a Rehabilitation Equipment Demonstration Unit which is stocked with numerous assistive devices for trial use), unless a home or work site visit is required. A team approach is used in order to draw upon the varied backgrounds and expertise of the core staff and various consultants as well as to involve the client and counselor in the evaluation process. The evaluation consists of trying possible solutions to each of the problems which were identified. The least expensive and simplest approach is tried first, such as the use of adaptive behavior. If this solution fails, then commercially available assistive devices are tried. Custom designed equipment is considered only when there is no commercial source.

Following the evaluation, a written report is prepared summarizing the evaluation and listing specific recommendations including need for further training and/or equipment. Information on equipment availability and approximate cost is included in the report. A comprehensive file on commercially available equipment is used to obtain this information. This file is part of

a computerized information system entitled Abledata.

During the fiscal year July 1979 to July 1980, a total of 118 clients received services from Project Threshold. It is interesting to note that in addition to providing services to this large number of clients, Project Threshold has been able to device economical solutions to problems in 65% of the cases at an average cost of $447, through recommendations of adaptive behavior and commercially available equipment rather than custom design and fabrication of equipment which is more costly (average cost $1,521 for 28% of the cases).

SUMMARY

In summary, a service delivery program which utilizes adaptive behavior, commercially available equipment and custom design and fabrication of devices as possible solutions to the problems presented by the severely disabled has been described. The major focus of the presentation will be a case history which illustrates how these three types of solutions were implemented. This case further shows the importance of involving the client in the problem solving process which increases the client's awareness of his/her functional abilities and encourages the client to match these abilities with adaptive behavior or equipment in other situations.

EMPLOYMENT APPLICATIONS OF COMPUTER RELATED SENSORY AIDS FOR HANDICAPPED PERSONS

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Sensory Aids Foundation, under a grant from Projects With Industry section of the Rehabilitation Services Administration, is offering a program to expand employment opportunities for physically disabled individuals in computer related jobs throughout the State of California. The number of computer related jobs is expanding rapidly in business, industry and government. Two computer-based sensory aids used by handicapped employees are presented in this paper. These are the second generation TSPS (long distance telephone operator) equipment, and the Maryland Computer Systems synthetic speech terminal with automatic form writer program.

INTRODUCTION

Sensory Aids Foundation has been developing new areas of employment for blind and visually impaired persons throughout the State of California since September, 1975. Operating under a grant from Projects With Industry (PWI) section of the Rehabilitation Services Administration, which has provided partial funding to Sensory Aids Foundation, job development services have been expanded to include persons with any physical disability. Many of these innovative jobs require the use of technologically advanced sensory aids to allow access by a handicapped person.

Projections by the Department of Labor foresee a rapid expansion of computer related positions through 1985. As a result of this expanding industry trend, Sensory Aids Foundation's PWI program has focused on this broad job category for the past one and one-half years, and has completed over 50 placements in computer related jobs. Job titles in these placements include: insurance claims representative, computer programmer, word processing operator, data entry terminal operator, telephone switchboard operator and communications technician. The approach to innovative placements includes the following.

The staff professional builds a base of knowledge about each client consisting of information on functional abilities, skills and interests. When the client has identified an employment area of interest, and meets the qualifications, staff members explore jobs falling within the indicated area. This exploration is multifaceted. It consists of working closely with industry personnel representatives to overcome procedural barriers, working with all industry personnel to overcome attitudinal barriers, performing a comprehensive analysis of the tasks required for performance of the job and functions involved in completing each task, identifying appropriate modifications to existing equipment and/or recommending aids and devices which would enhance the client's performance on the job, and providing follow-up support services to both employer and client to aid in solution of any ensuing problems.

Many technological aids are presently available which, when applied in employment situations, significantly reduce the effects of handicaps, and assist handicapped individuals to perform competitively with non-handicapped peers. In many cases, existing equipment can be modified to accomplish the same goals. Sensory Aids Foundation staff uses both stand-alone equipment and equipment modifications in job placements.

COMPUTER RELATED EQUIPMENT IN JOB PLACEMENTS

Insurance Claims Representative. Sensory Aids Foundation applied the Maryland Computer Services TIM-2 (Talking Information Management System) with the automatic form writer software in an employment situation at the Automobile Club of Southern California. A totally blind person is working as an insurance claims representative using this equipment. An insurance claims rep has the responsibility of gathering claim information from an insured claimant, and then must complete one of approximately 45 different forms. In addition, the claims representatives must access computer information concerning the claimant's policy status. The blind employee has already developed excellent telephone communication and keyboard skills which are required to

perform this job.

The Equipment. The automatic form writer is available from Maryland Computer Services (MCS) in Bel Air, Maryland. It enables a blind typist to fill out forms with the speed and accuracy of a sighted person. Hardware consists of an HP 9825A desk top computer (which contains an internal cassette tape drive). It has been modified to contain a spelled speech electronics board and speaker. The board provides vocal output of the HP visual display either in its entirety or in a shortened form. The audio vocabulary includes the alphabet, numerals, punctuation (spoken and full word), a set of complete words, and upper and lower case verification. It generates spelled speech at approximately three characters per second. The face of the computer consists of a standard typewriter keyboard, a calculator keyboard and a number of command keys. In addition, an HP-compatible ink printer or a hard copy braille printer, such as the Triformation Systems LED-1, may be added as a peripheral to allow a blind user complete independence in all areas of information management.

Software consists of the information management program stored on a cassette tape, along with the data bank. Items of information in the data bank may be added, deleted or edited at the user's command. The system can duplicate tapes for back-up purposes and can form new tapes for use in expanded data banks. A separate disc drive is available for large data bank storage.

Initially, a sighted person must set up each form format and enter instructions into the form writer for correct completion of each form. The process is simple. The computer asks the operator questions which prompt "building" of the form. When the sighted operator completes all form building entries and has reviewed them for accuracy, the entries are stored on the automatic form writer tape or disc. Once the computer has been instructed in completion of a form, and that information has been stored in the program, the blind user can fill in the actual forms automatically whenever required.

Traffic Service Position System (TSPS long distance telephone operator). The primary engineering project initiated by Sensory Aids Foundation between 1975 and 1978 was the development of prototype interface equipment for blind TSPS operators. A second generation of equipment has now been completed and is in the evaluation stage. The new system incorporated the voice output system by Telesensory Systems, Inc. (TSI) with the braille system developed by M.I.T.

Equipment. The special equipment developed by TSI to enable blind operators to use a standard TSPS console is designated the TIPS (TSPS Information Processing System). The TIPS system consists of three parts, designated the TIPS Console, the MPU (Main Processing Unit) and the Printer/Interface package which prints out ticketing information. The TIPS converts visual information, such as lighted pushbuttons on a TSPS console, into other media accessible to a blind operator. The system connects to the TSPS central computer by means of a TSPS/TIPS Interface developed by the Bell System, and a cable.

TIPS Console. The TIPS console sits on the shelf of the TSPS console within easy reach of the blind operator where it does not interfere with access to TSPS keys. A second headset (in addition to the TSPS headset for communicating with the customer) is plugged into the MPU. It announces the status of lighted call buttons on the TSPS console. Using this information, the trained operator can complete the call in the same manner as a sighted operator.

The TIPS console contains: (1) A 7-key standard braille keyboard used for note-taking, entering ticketing information, and for generating commands to the MPU, (2) A 20-character braille display which displays in braille on command the numerical information shown on the TSPS numerical display. It also displays for review braille notes and ticketing information previously entered by the operator on the braille keyboard in order to check for accuracy and completeness. Twenty (20) lines of 20 characters each may be stored in the memory of the MPU and recalled one line at a time for review. (3) The blind operator may replay the synthesized voice call announcements on demand, and to repeat as needed to complete the customer's call. A "Ticket" key tells the printer to print out the ticketing information after it has been entered at the braille keyboard and/or reviewed on the 20-character display. (4) A volume control allows the operator to adjust the level of the synthesized speech call announcements.

MPU (Main Processing Unit). The Main Processing Unit contains the TIPS computer electronics, the memory where braille keyboard and other information is stored, the speech board for producing synthesized speech call announcements, and the logic/electronics to drive the TIPS console and printer and to communicate with the TSPS/TIPS Interface. The MPU uses standard AC power and must be plugged into a socket before use. It sits on the floor beside the TSPS console when in use.

Four switches provide Power ON/OFF; a test mode to insure operational integrity; a Ticket Retransfer switch which causes reprinting of all tickets entered into the TIPS since power was turned on at the beginning of a shift, and is used as a backup in case of loss of the printer tape or printer failure; and a reset switch which resets all electronic buffers in the system and clears all ticket information stored since the last time the system was turned on.

Printer/Printer Interface. The Printer prints out ticketing information entered into the braille keyboard. The MPU converts the braille signals into ink print signals and prints out on the printer located on an administrative desk. The ticketing information is subsequently entered on the proper form. A second printer is available for backup.

The Printer Interface sits beside the printer. This box is designed to receive data from many TIPS units and print it out on a single, common printer. The Printer Interface runs on the printer AC power.

CONCLUSION

The sensory aids and adaptive devices discussed in this paper have provided handicapped people with the capacity to become productive, contributing members of our society. Computers will increasingly become more evident in the job market, and now handicapped persons have the ability to perform these jobs competitively through the use of sensory aids such as the Maryland Computer Services TIM-2 System, the TIPS console for the TSPS, and other microprocessor based systems.

ACKNOWLEDGEMENTS

The authors wish to express appreciation to the following persons: M. Mason, D. Wells, D. Van Horn, and D. Congor for providing technical assistance. This project has been supported by grant no. 13626-892 from the Department of Education, Rehabilitation Services Administration, Projects With Industry, Washington, D.C.

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ABLEDATA -- A REHABILITATION PRODUCT INFORMATION SYSTEM

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ABSTRACT

ABLEDATA is an information bank for rehabilitation products. The computerized data retrieval system is designed to provide information on commercially available aids and equipment used by disabled persons. The inclusion of both formal and informal evaluation data is unique to ABLEDATA, as compared to other product index systems. The system is also being designed as an on-line national network available by subscription, but during the experimental phase direct access is limited to selected sites.

INTRODUCTION

The need for a national information system on rehabilitation equipment has been identified by many groups with interests in the field of rehabilitation; including disabled individuals, health professionals, state rehabilitation agencies and other related services and agencies, researchers, developers, educators and manufacturers.

ABLEDATA, supported by the National Institute of Handicapped Research, is being developed as a national system to assist in documenting and disseminating resource information concerning rehabilitation equipment. More than fifteen programs nationwide have been assisting to coordinate and compile the data entries for ABLEDATA, many of these are the Rehabilitation Engineering Centers. Many private individuals and agencies have also offered to share collected data to be input to ABLEDATA for dissemination. The Rehabilitation Engineering Service Delivery Project of the State of California Department of Rehabilitation has also provided support to the project, with all technical assistance provided by the National Rehabilitation Information Center.

ABLEDATA, designed as a national data base, is maintained by a data base vendor, Bibliographic Retrieval Services (BRS) in Scotia, New York. It may be accessed by persons with subscriptions to BRS and approved ABLEDATA passwords through special telecommunication lines (i.e., Telenet, Tymnet). In addition to the BRS subscription each participant must have access to a computer terminal with an acoustic coupler, and agree to participate with the national system, including attending the training sessions and compiling use statistics.

DATA BASE FILES

The content of each data entry in the files includes the following fields:

NM	Generic Name
BN	Brand Name, Model Number
MN	Manufacturer
CD	Code Number
AV	Distributors
CT	Cost
DE	Description
CM	User Comments
EV	Evaluation
ID	Identifiers

Generic Name, Brand Name, Manufacturer, Distributors, Cost, and Description are self explanatory and must be completed for each data entry. A Code Number is assigned to each manufacturer and distributor and is used to access a separate file to obtain the addresses of desired companies. Presently the fields, or paragraphs, for User Comments and Evaluation are not completed for all data entries , these are only completed as the information is submitted or otherwise available. User Comments include informal use evaluation from disabled individuals, health professionals, or anyone desiring to share information regarding products. All data submitted is reviewed before input to the system, and verified if necessary. The Evaluation field is for formally documented evaluation results from research programs. The results may be reproduced in total or summarized if lengthy, with references for obtaining the complete results.

The Identifier field is the only paragraph using a controlled vocabulary. These terms are assigned from a list of broad categories, in which all rehabilitation equipment, aids and devices are divided into 13 categories, with appropriate sub-

categories. It is this terminology which forms the basis of the thesaurus, and is also used to do initial searches of broad equipment categories. The thesaurus for ABLEDATA is being developed simultaneously with the data entries.

SAMPLE DATA ENTRY

NM REMOTE CONTROL TYPING SYSTEM
BN PMV MINIMUM 5500. PMV SOLENOID 6500
MN PMV AB.
CD 315
AV MANUFACTURER
CT $3,210.00, 1979
DE MINIATURE KEYBOARD SYSTEM WHICH PERMITS REMOTE CONTROL OF AN IBM OR OLYMPIA ELECTRIC TYPEWRITER OR A FACIT PRINTER VIA TOUCH OF AN ELECTRIC PENCIL TO A MINIATURE KEYBOARD. CONSISTS OF A SOLENOID UNIT, REMOTE KEYBOARD AND ELECTRIC PENCIL. OPERABLE BY FINE HAND, HEAD OR OTHER CONTROL WITH A 4 BY 5 INCH RANGE.
ID COMMUNICATION. TYPING.
CM THE OVERKEYBOARD SOLENOID UNIT PREVENTS STANDARD TYPING ON THE TYPEWRITER. UNIT CANNOT ROLL THE TYPEWRITER PLATEN BACK TO PERMIT CORRECTION OF ERRORS ON PREVIOUS LINES.

SEARCHING THE DATA BASE

Searching the system is done through free text searching, there is no coding or keyword system involved. Free text searching is simply searching for words or phrases in names, descriptions or other parts of a data entry which are not necessarily taken from the controlled vocabulary of the thesaurus. Trained but inexperienced searchers can usually obtain the same required results as experienced searchers. Searches are initiated by requesting the computer to locate the number of citations for a specified word. As this can result in a large number of citations, the search can be limited in two ways: 1) by limiting the fields of searching (i.e., generic name only), and/or 2) by using the system identified limiters (i.e., and, or, with, not, adjacent). By using limitations properly product searches can be narrowed considerably, resulting in minimal extraneous printout for pertinent information. Since the vocabulary is not controlled, allowance must also be made for variant spellings, plurals, and synonyms when initiating a search.

The following is an example of a search for page turners showing the use of limiters. A query is typed into the computer terminal for the number of data entries with "PAGE ADJ TURNER$" (page adjacent to turner(s) anywhere in the files), result equals 15 entries. If the same request is made but limited to the generic name field only, "PAGE ADJ TURNER$.NM.", the result equals 12 entries. Further limiters are possible as follows: "PAGE ADJ TURNER$ AND (AUTOMATIC OR ELECTRIC)", result equals 10. "PAGE ADJ TURNER$ AND (FORWARD AND REVERSE)", result equals 6. "PAGE ADJ TURNER$ AND (SIP AND PUFF)", result equals 1.

GRAPHICS

While it is recognized that the addition of graphics with the description would enhance the information provided by ABLEDATA, it is too costly to include in the development of the system at this time. To provide an alternative to programmed graphics the Information Brokers maintain a file of catalogs and brochures which can be reviewed or duplicated as needed for specific information inquiries.

SYSTEM IMPLEMENTATION

To provide optimum assistance for users and the most accurate feedback regarding the use of ABLEDATA, a network of Information Brokers is being planned for implementation of the system. Information included in ABLEDATA is freely accessible to anyone through these information brokers by telephone, mail or in-person requests. Individual Information Brokers are responsible for accessing, interpreting and disseminating the information stored in ABLEDATA files and will also collect feedback comments and other information that can be placed into the files to benefit all users. However, the brokers will not have the ability to enter the data base and change the data file entries directly, all changes or new information collected will be submitted to a central coordinator for review before being input to the files.

All resources listed in ABLEDATA files are either a manufacturer, a national distributor with a unique catalog, or a sole distributor. One very important part of the role of an Information Broker is the development of local and regional resource files for obtaining products listed in ABLEDATA, and related services.

In the future it is anticipated that ABLEDATA will be available to any center or agency wishing to sponsor an Information Broker and participate in the program. During the development of the experimental project, direct access has been limited to selected sites, but anyone may access ABLEDATA through the identified Information Brokers.

FUTURE ACTIVITIES

The product data base is considered the first phase of ABLEDATA. Future planning includes a design data base for one-off designs or custom modifications to commercially available equipment. This design data base can potentially document problems and failures, as well as successes to assist developers or direct service delivery providers with their future efforts. It is also anticipated that eventually ABLEDATA will be available for international sharing with other compatible data bases.

As stated previously a thesaurus is now under development. Also, the development of a training program for Information Brokers is projected for the next year. With the completion of both the thesaurus and training program it is anticipated that the number of Information Brokers with direct access to ABLEDATA will be expanded.

A demonstration project of maintaining the local and regional files on a microcomputer for the Information Broker will be developed. It is anticipated that a program will be developed which can be shared with any future information brokers who have access to a microcomputer for storing their files. This will not be a requirement to participate with

ABLEDATA, however, as all local files can be maintained manually.

SUMMARY

A rehabilitation product information retrieval system, ABLEDATA, is accessible to anyone through an Information Broker. As of May 1981 there were more than 4,000 data entries in ABLEDATA. There will be a continual increase in the number of data entries by continued cooperation and contributions of more than fifteen state and federally funded centers nationwide. The ABLEDATA thesaurus and training program will be developed in the coming year, with the resulting expansion of the Information Broker network. During the formative months ABLEDATA can be accessed only through the following Information Brokers:

Carol Clerico
University of Virginia
Charlottesville, VA
(804) 977-1378

Paige Finnerty
Rancho Los Amigos
Downey, CA
(213) 922-8116

Rosemary Murphy
Children's Hospital at Stanford
Palo Alto, CA
(415) 327-4800

Jim Christenson
California Department of Rehabilitation
Sacramento, CA
(916) 323-2959

PROVISION OF ASSISTIVE EQUIPMENT FOR HANDICAPPED PERSONS - A RETROSPECTIVE STUDY

J. G. Kohn, M.D., M.P.H.; S. Enders, O.T.R.; J. Preston, Jr., M.S.W.; W. Motloch, C.O.; B. Allison

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ABSTRACT

The effectiveness of mobility-postural seating devices was evaluated in a study population of 196 patients who were referred for devices between May 1, 1975 and May 1, 1978. 138 (70%) returned a questionnaire, and 49 families who appeared to be demographically representative of the larger group were personnally interviewed. Recommendations based on the study were: 1) evaluation should be related to a) functional needs,b) psychosocial factors and c)the environment where used. 2) team approach and consumer participation in decision making is essential 3) goals should be clearly stated 4) documentation should be possible of success of device and 5) follow-up should be incorporated into service costs.

OBJECTIVE

This clinical research study was an attempt to determine if it is possible to: 1) define and document the benefits of assistive devices; 2) relate benefit to cost; and 3) develop an initial assessment procedure that identifies accurately both technical and psychosocial requirements of the client. An additional objective was to identify economic aspects related to provision of devices: costs, source of funds, time sequences from requests for funds to authorization to payment, and financial obstacles to provision.

INTRODUCTION

It has been the impression of rehabilitation engineers, physicians, and therapists that provision of assistive devices must satisfy technical performance requirements and must also consider the clients's lifestyle, physical environment, interaction with family, friends and fellow workers, and the effect on the client's self-image. The benefit of an assistive device is, therefore, both objective and subjective: objective in terms of professional assessment of optimal technical and functional performance, and subjective in terms of the client's satisfaction with the device in home and work surroundings on a day-to-day basis. Measurement of benefit has been difficult to document. Effective evaluation of devices has been frequently identified as a major gap in the rehabilitation engineering service delivery system. Clinical evaluation begins with the initial assessment procedure, follows along through provision of the device and continues through a follow-up process which documents technical performance and client satisfaction. Clinical evaluation is therefore a crucial component in research utilization.

In order to develop a clinical evaluation model which could be used prospectively in the evaluation of new items, it was decided by the advisory committee and the grant staff to conduct a retrospective study, taking advantage of the Center's service delivery history to broaden the elements of clinical evaluation beyond technical and engineering specifications. It was felt this would provide an important input in planning comprehensive services, research activities and clinical evaluations.

Since seating and mobility devices for severely physically disabled individuals have been a primary area of service delivery at the Center from its inception, it was decided to focus the follow-up study on people who had been evaluated at the Rehabilitation Engineering Center (REC) and for whom the recommendation had included a major mobility device with a significant control and/or interface in the system.

STUDY TECHNIQUE AND RESULTS

The study technique consisted of making contact with all study participants (196). Seventy percent (138) responded, and of this group 36% (49) were interviewed in their home environment by an evaluation team. Demographic characteristics of the nonrespondent, the questionnaire group and those given home visits were comparable.

A point system was used to quantitate the daily use aspects of equipment use, change in life style through equipment use and reasons for nonuse of the prescribed equipment. Eighty-one percent of the devices were found to be in working condition and 50% of them were being used an average of nine hours per day at the time of the study. Twenty-two percent of the devices had been outgrown and the average life span per device was 30.9 months. Since the average cost per device was $1,650.00, the cost per day for use of the device through its life span was $1.50. Although the psychosocial values and changes in life style which derive from an ability to

enlarge environmental horizons are somewhat intangible, assistive devices do enable many persons with severe motor impairment to achieve educational and employment opportunities, and the overall cost-benefit ratio appears to be satisfactory. The study has been completed and the report prepared. The assessment and clinical evaluation instruments will be field tested during the next grant year.

DISCUSSION

The figures below show results of this study compared to a national survey.

	CH@S Rehab. Engr. Ctr.	National Survey*
Device is ineffective	21%	38%
Device is effective	79%	61%
Device is mechanically unreliable	19%	30%
Device is mechnically reliable	81%	70%

*T. B. Grall. 1979. A feasiblity study of product testing and reporting for handicapped consumers, p. 67, Consumers Union of United States, Inc.

While the above figures indicate a better mechanical performance record for the REC, the review team felt that a 1/5 unreliability recond was unacceptable over a long period of time. Since the REC had opened in 1974 and the study dates were 1975-78, some mechanical problems were felt by the rehabilitation engineer to be due to internal problems in getting materials and training new personnel. Of far greater importance, however, was the finding that a number of the interviewed group had not made the REC aware of mechanical problems, and had not returned for necessary repairs or reconstruction. This is a strong argument for regular REC-initiated follow up and education of clients to report malfunction and other problems.

UTILIZATION OF RESEARCH

As a result of this study, six major recommendations were made:

1. Evaluation of an individual for an assistive device should be related to: a) functional needs; b) psychosocial factors, and c) the environment in which it will be used. Evaluation forms should be available to document that such factors were considered.

2. A team approach is indicated; the basic team recommended is an occupational or physical therapist and rehabilitation engineer, with the client /family considered as part of the team. An expanded team consisting of physician, medical social worker, speech pathologist, psychologist or other professional worker, is indicated if:

a. medical assessment is needed;
b. there is a lack of consensus among referral sources;
c. requirements are for multiple pieces of equipment;
d. mental ability status is unclear;
e. there are discrepancies in background/ medical information;
f. the core team decides for any other reason that consultation is needed.

3. Goals should be established for performance assessment of the assistive device: management goals or motor function goals, or both.

Management Goals are Directed Toward:

a. care, comfort, maintenance of health and prevention of ill health of the client, and
b. protection, support and optimal function of the caretaker related to activities with the client.

Motor Function Goals are Directed Toward:

a. maintenance or improvement of current motor activities, or
b. fostering new motor activities.

Goals should be identified, stated in the evaluation, and used in justification for funding request.

4. Consumer participation is an integral and essential requirement for successful provision of assistive devices. Active participation should be trained in interaction skills, and/or have a resource person (e.g., a social worker) who can assist in these areas. Psychosocial needs are an important aspect of success or failure in assistive devices.

5. It should be possible to document in the evaluation the goals, assistive devices recommended, estimated durability, and estimated costs. These should be stated in a form such that they are retrievable for evaluation of:

a. success in matching device to person-environment
b. process success--from evaluation to funding authorization to provision to payment
c. cost/benefit analysis: attainment of goals in relation to costs of assistive devices.

6. Follow-up should be incorporated into the process of evaluation and provision of a device. Time costs for fabrication should include time for follow-up at regualr intervals.

IMPACT

The assessment and clinical evaluation instruments developed are useful throughout the rehabilitation engineering field to broaden clinical evaluation beyond technical specifications and in-house trials to include more consumer-oriented measures of device effectiveness. Information on cost/time factors, and funding mechanisms adds much needed input to discussions of cost-benefit ratios, life expectancy of equipment and fee-for-service. Within the target

area, working relationships between rehabilitation engineering, therapists, parents and consumers have been enhanced; and the need for follow-up procedures has been documented. Copies of the complete study are available from the Center.

PERSONNEL

The study team was multi-disciplinary and covered four areas of concern:

Medical	- Jean G. Kohn, M.D., M.P.H.
Functional	- Sandi Enders, O.T.R.
Psychosocial	- John Preston, Jr., M.S.W.
Technical	- Wallace M. Motloch, C.O.
	Brian Allison

ACKNOWLEDGMENT

The work reflects the results of a research study supported by National Institute of Handicapped Research under Grant No. G008005817 under Department of Education.

SERVICE DELIVERY OF TECHNICAL AIDS - A STEP FORWARD

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ABSTRACT: A delivery system will be described which has been in place in the Province of Québec (Canada) since 1978. Specifically this paper will focus on two institutions that have participated with the Office des personnes handicapées du Québec (OPHQ) in providing the necessary technical expertise required to fulfill requests for aids that handicapped persons have made to the office. A case history will be described to show the steps in the process.

INTRODUCTION

In 1978 the Québec National Assembly passed a Bill which established the Office des personnes handicapées du Québec. The main intent of the Bill is to ensure handicapped persons full and equal recognition, and exercise of the rights and freedom shared by all citizens.

The OPHQ is empowered to grant subsidies to promotional organizations mainly devoted to the assertion of the rights and promotion of interest of the handicapped. The OPHQ may also issue "adapted work centre" certificates to associations or organizations employing, in majority, handicapped persons.

This bill provides various measures designed to ensure the educational, vocational and social integration of the handicapped person. For that purpose, the bill provides, in particular, for the formulation and carrying out of service programmes which must take account of the free choice of each person benefiting from such a programme. Where a service is not available locally, or regionally the OPHQ may grant material assistance to a handicapped person for carrying out of a service programme. The Office may also enter, with any employer and a handicapped person , into a contract for the vocational integration of such person into the labour market. Subsidies may be granted to an employer to allow him to adapt job openings to the capacities of a handicapped person or to otherwise promote his employment.

The Service Programme

One of the measures provided by the Act is the formulation and carrying out of Service Programmes. This programme, conceived by the Office, assures a better co-ordination of the resources available to the handicapped in the locale in which he or she resides to more adequately serve the needs of the individual. Nevertheless, this co-ordination is only possible if the Office represented by the case worker, the local or regional resource, and the handicapped person collaborate very closely and continuously toward the successful delivery of a request for service.

To this end a form has been prepared to clearly outline the steps taken to reach the objective which is the global integration into the society of the handicapped person. As experience is gained in this programme the needs of the handicapped in general will be identified, and the resources that satisfy these needs will become clearly identified. It follows that the missing services will become more evident so that this can be overcome.

Because the role of the OPHQ is one of co-ordination of existing services, other institutions are called upon to evaluate the needs of the client, to advise the Office on technical aids if required, the installation of these aids including special interfacing to make the best use of the persons abilities, and finally the training and follow-up.

The client must meet three requirements for admission to the program; that he or she is limited in the performance of normal activities; is suffering significantly and permanently from a physical or mental deficienty; or regularly uses a prosthesis or an orthopedic device or any other means of overcoming his handicap.

The admissibility to the services having been established, the Office sets forth three stages in the progression towards the solution of the handicapped person's request. These are:

Identification of the needs of the Client

This process begins with the identification of his or her abilities based on clinical evaluations. This may have already been done, but if not arrangements are made to have this done. The evaluation will take into consideration the potential of the client, his or her aspirations, the socio-economic situation and finally the age of the person. This is the point at which the Office will seek help from local or regional resources to conduct an evaluation. In the case of

Mr. Custeaux, which is a typical case, a review meeting was called which was composed of the agent for the Office, an occupational therapist and a physiotherapist who were familiar with his abilities, a biomedical physician from the Montreal Rehabilitation Institute, who had previously designed an interface for the client's powered wheelchair, a member of the Medical Engineering Section of the National Research Council of Canada, and of course the client. This first meeting focussed on the requirements to fulfill the request from the client for a technical aid to permit him to pursue a career in journalism. Options were discussed in relation to his abilities from a simple interface coupled to a typewriter to a complete text editor. The role of the National Research Council was advisory in nature, that is informing the members of the team of the availability of equipment, its function and suitability.

It was decided that a home computer with a word processor software package would best fit his needs. The keyboard would be replaced by a "Target" interface which is a mouth-operated direct access keyboard and an "Encoder-80" which would couple it to the micro-computer. This system would provide him with the means to write and store large amounts of text and to print out a finished product suitable for classwork and later employment.

Formulation of Objectives

The Office is then in a position to define the objectives to enable the client to develop to a maximum his or her physical and mental abilities. The philosophy of the Office is to treat the client's needs globally. The programme must satisfy four elements:

1) Medical and functional rehabilitation.
2) Social integration: residential, socialization, transport.
3) Professional integration.
4) Continuity in employment.

Delivery of Services

At this time the Office will take action to provide, in this case, the technical aids that have been decided upon. Maximum co-ordination between the resources and the Office is of the utmost importance at this point. Resource persons are identified for each institution or agency involved so that a close liaison can be established. In the case where a resource cannot be found to provide the necessary service, the Office is empowered to purchase this service temporarily since the mandate is also to discover these deficiencies and work towards establishing these resources on a permanent basis.

A formal agreement is drawn up by the OPHQ and signed by all parties concerned in the delivery of the service. This protocol outlines clearly the objectives agreed upon, but more importantly clearly defines the responsibilities of each resource person.

In this case, the National Research Council of Canada was to make the necessary connection between the microcomputer and the interface, which was provided by TASH Inc.(1) Secondly, the National Research Council would assure a continuing evaluation of the progress on a monthly basis. This was felt necessary at this time since the parties involved have not had very much experience in the total delivery system. This case is considered a pilot project by the National Research Council of Canada.

The responsibilities of the Rehabilitation Institute were: to purchase the equipment (the cost being borne by the Office); to install the system which also entailed proper positioning of the interface and to train the client on the use of the word processor. Lastly, it was agreed that they, along with the client, would provide the Office with an evaluation report at the end of one year.

The client in turn would find an assistant experienced in micro-computers that would carry on the training begun by the Rehabilitation Institute once the equipment was installed at his residence. He would also furnish an evaluation of the technical aid to the Office. This evaluation would cover the technical aspects of the aid,and its usefulness in fulfilling his requirements.

A form has been prepared to help the Office during the progressive steps in the delivery of services. It is general in nature given the great variety of requests, but nevertheless would contain the information required so that problem areas can be eliminated as experience is gained. In the case of the client mentioned here, the request for services was made in September 1980. The equipment was delivered and training started in December 1980.

REFERENCES

1) Technical Aids & Systems for the Handicapped Inc. (TASH Inc.) c/o Sunnybrook Medical Centre, 2075 Bayview Avenue, Toronto, Canada. M4N 3M5.

TASH Inc. is a non-profit technical aids supply centre. The objective of this centre is to market, service and encourage Canadian manufacture of aids to the handicapped which are unavailable through other means.

EVALUATION PROGRAM AT THE VETERANS ADMINISTRATION REHABILITATION ENGINEERING CENTER

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New York, New York 10001

The Veterans Administration Rehabilitation Engineering Center conducts a systematic evaluation program as an essential ingredient in the development and delivery of technical rehabilitation devices for disabled persons. The VAREC's Evaluation Program supplies the necessary information to prescribe, procure and deliver devices, to guide applied research and development programs, and to aid manufacturers in producing useful products.

The evaluation procedure employed depends on the complexity and the novelty of the device. It may encompass structural analyses, safety and functional tests, biomechanical analyses and the ultimate test-trials by users in appropriate environments. Over the past 25 years VAREC has been evaluating devices including prostheses and orthoses, wheelchairs, walkers, special beds, wheelchair cushions, sensory aids, communication aids, environmental controls, driving system, standing devices and many others.

The Veterans Administration Rehabilitation Engineering Center (VAREC) undertakes the evaluation of a broad range of devices intended to improve the rehabilitation and activities of veterans with skeletal or neuromuscular disabilities, such devices as braces, artificial limbs, wheelchairs, lifts, driving adaptations, too numerous to list them all here. The primary purpose is to provide the Veterans Administration with an intelligent basis for the selection, procurement and application of those devices which can benefit disabled beneficiaries. This Program also serves to guide developers' efforts in areas of particular interest to the Veterans Administration. Evaluations may range from a simple analysis of design and materials to a full-scale biomechanical analysis in the laboratory, complimented by a field study in several medical centers and clinics around the country. Below are illustrations of some typical VAREC evaluation procedures.

Orthopedic braces and artificial limbs, for both upper and lower extremities, have been the subject of evaluation programs since the close of World War II and extremely useful methods and techniques have evolved. The parameters which provide the most useful assessment of these devices are very well established. In addition, there exists a body of basic data on normal human locomotion from which useful criteria for evaluating performance can be drawn. Nevertheless, every orthosis or prosthesis is evaluated in accordance with written Protocols and an established set of data collection instruments.

A different situation prevails in the approach to the evaluation of wheelchairs. There is available very little basic information about wheelchair performance factors, and until several years ago, the VA wheelchair standards offered little help. They were descriptive in nature and related primarily to dimensions and materials. We believe that to be meaningful, an evaluation should depend on tests not only of hardware, but also of the human factors that enter into effective and efficient use. In the VAREC scheme, the user is an integral part of the evaluation process. The evaluation of a device requires more than a check for compliance with a set of procurement specifications that often only describes a leading manufacturer's product. This may assure the purchase of a quality product; one that has stood the test of time at a reasonable price. If this were all we were concerned with, there would be no need to "evaluate" devices other than to conduct periodic simple compliance tests.

Evaluation should help improve the quality of devices such as a wheelchair. We want to improve that product to make it safer, stronger, lighter and more efficient. We can do this through a systematic evaluation program that addresses itself to questions like:

1. Are there significant differences among commercially available "conventional" wheelchairs?
2. Is it possible to "idealize" the design of a wheelchair by synthesizing the best features of known wheelchairs?
3. Are the lightweight wheelchairs of

sufficient general utility?

4. Should the advantages of lightweight wheelchairs be available to all?
5. Are lighter materials the principal factor in the design of useful lightweight wheelchairs?

During the past 25 years the VA Rehabilitation Engineering Center has developed an evaluation program that provides a basis for assessment of devices and aids, a program that takes into account the man-machine combination and is both descriptive and functional. The heart of the Program consists of test procedures designed on the basis of long experience, to provide information on:

1. Analysis of mechanical design, adequacy of materials and durability.
2. Convenience and ease of operation.
3. User acceptability in relation to appearance, utilization in the home (and/or other appropriate environments) and the availability of similar devices.
4. Stability and safety.
5. Force and energy requirement.

A careful analysis of the design of any device indicates the extent to which the fundamental idea or purpose has been translated into appropriate "mechanical" features. Consideration of the mechanical design in relation to all aspects of the intended application often discloses serious and unforeseen limitations.

All this is necessary because, for example, the materials used in wheelchair fabrication strongly influence comfort, safety and durability. Durability is determined by means of cycling tests. Convenience and ease of operation are especially critical factors for persons of limited strength and mobility who must operate them, for example, when 7 wheelchairs weighted with 150 lbs. were started from a dead stop, their starting forces ranged from 3 lbs. to 6 lbs.

Use tests are also needed to assess these matters. In some cases, observation by trained personnel of a few appropriately selected users may suffice. In other cases, long-term, in-hospital, home, work, or school use provides the full scope of data needed for sound judgement.

User acceptability is essential. Even the most ingeniously designed device is useless if users resist it. Therefore, the reactions and opinions of users are obtained to form the basis of judging acceptability. The method may consist of a few direct, specific questions in one case and a formal questionnaire answered by several users in another, or complete batteries of questionnaires designed for users, families and clinical personnel is a third.

Safety and reliability are obviously of paramount importance in devices to aid the disabled, as for example, when the user's balance is impaired and he depends on the aid (wheelchair, walker, brace) for stability. Maintaining a condition of stability depends on the relationship between the vertical projection of the C.G. and the area of the base support. This is specifically tested under various use conditions.

The amount of energy required of the user to operate a device such as a wheelchair is a major consideration in any evaluation of the man-machine combination. The significance of energy costs and efficiency of operation are known to increase with the severity of the disability.

In the early years of the Evaluation Program, VAREC physiologists designed and conducted energy studies related to wheelchair propulsion, locomotion with prostheses and other areas. Devices that provide locomotion require energy inputs from the user. The distribution of this energy between purposeful motion and friction is a key factor in the efficiency of a wheelchair. To study these matters in relation to new and complex devices, VAREC has contracted with the Laboratory of Applied Physiology, School of Medicine, Wright State University (Ohio) to conduct metabolic and cardiorespiratory responses of disabled persons using wheelchairs and similar devices.

Classical methods from the fields of work physiology and mechanics have proven useful for calculating energy costs of propulsion. Some are based on the determination of oxygen uptake rates. Others are based on mass and velocity ($E=\frac{1}{2} m v^2$) of the man-machine system in operation. For evaluation purposes both methods can be related in a more meaningful expression than either alone.

Our program of wheelchair evaluation has produced a set of functional Standards for wheelchairs. These Standards have become a blueprint for the evaluation of wheelchairs and are used throughout the world. They are based on carefully established specifications required to meet these standards. Other Standards developed include: Automotive hand controls, wheelchair lifts for vans, powered wheelchair; Environmental Control systems, among in-house standards for stump socks, sach feet, powered hands/elbows and others.

The term "Standards" refers to value judgements on what is useful, what is good and what is to be avoided in terms of poor workmanship, durability, comfort, etc. These judgements must be reliable and rest on experience, professional training, and understanding scientific limitations. These Standards should serve to screen out poor quality of materials, inadequate function, safety hazards, excessive costs and a high maintenance potential. We believe that our Standards will not stifle design creativity. They should not reduce the capacity for customization, for making adaptations and modifications, for specific needs.

Specifications relate to such things as dimensions, weights, and performance factors which are required to attain the standard. These requirements are translated into appropriate hardware and

functions. The selection of materials, fastenings and the design of components are specified only to the extent necessary without undue restriction in creativity. These items are specified by "functional statements" related to safety, comfort, ease of operation and function. Compliance with these specifications must be checked periodically to ensure that changes in manufacturing technique or the use of substitute materials have not reduced quality below standards.

The VA Standards developed by VAREC are, to the best of our knowledge, the first attempt anywhere to develop performance standards for these devices.

In conclusion, the VAREC strongly feels a systematic evaluation program is essential to promote availability of needed and useful devices for the disabled. The evaluation program supplies essential information to select (prescribe), procure and deliver devices; guide applied research and development programs and aid manufacturers in improving their products, as needed, to ensure that the products are safe and useful. Over the past 25 years the range of devices has expanded to encompass beds, automotive aids, manual and powered wheelchairs, standing aids, lifts,...etc., and the complexity and uniqueness of the device, determines the protocol for evaluation.

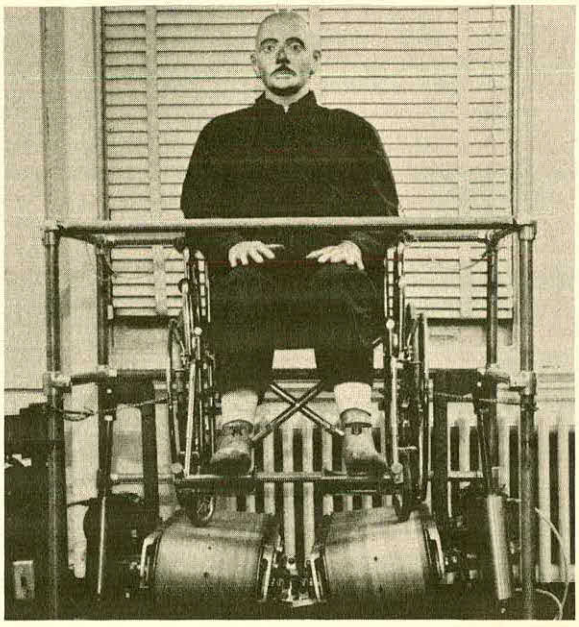

Figure 1: Wheelchair use simulation on treadmill with alternating surface angulation.

APPLICATION OF DIMENSIONAL ANALYSIS IN DETERMINING COST/BENEFIT OF HANDICAPPED DEVICES

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This paper presents a generalized method of performing cost/benefit analysis on aids and devices for the handicapped using dimensional analysis. The utility of the method presented is that both objective and subjective selection factors influencing the cost benefit analysis can be considered simultaneously. Additionally, this analysis method allows dissimilar devices or aids designed to compensate for the same loss of function to be compared with each other or against a chosen benchmark.

Introduction:

Organizations and individuals whether consumers, government, researchers and investigators or third party payers have expressed the need for coherent plans for product evaluation and cost/benefit analysis of devices and aids available to the handicapped (1). Though existing product evaluation efforts are able to develop a considerable amount of information concerning technical attributes and dollar costs there is little information available to potential buyers as to which product offers the best value, that is, the best cost benefit ratio. In a time of restricted government funding and given the limited financial resources of many third party payees and consumers the need for appropriate cost benefit analysis becomes more apparent.

Consideration of a device's technical merits, costs and other objective selection factors is not sufficient to perform a proper cost/benefit analysis. Subjective factors such as user acceptance, social acceptance, adaptability, and aesthetic appearance need to be considered. Handicapped devices and aids possessing exceptional technical quality with reasonable financial costs are of little value if they do not satisfy the needs perceived by the user.

A technique which has proven useful in other fields when objective and subjective selection factors must be considered simultaneously is dimensional analysis (2). Dimensional analysis was originally developed by P.W. Bridgman (3) for application in physics and has been adapted and used by others in fields as diverse as aircraft manufacture, facility location and biology (2,4,5).

Rationale:

The dimensional analysis technique as applied in device selection involves the calculation of a dimensionless number ratio, R, which is defined as:

$$R = \frac{\text{Preference for Device X}}{\text{Preference for Device Y}}$$

where:

- $i = 1,2,\ldots.n$
- x_i = numeric value associated with the i^{th} selection factor for device X
- y_i = numeric value associated with the i^{th} selection factor for device Y
- w_i = numeric weight value of i^{th} selection factor
- R = the selection factor such that
  - if R 1, device Y is superior
  - if R 1, device X is superior
  - if R = 0, devices are equal

subject to:

- x_i is greater than 0
- y_i is greater than 0

Consider two hypothetical devices X and Y with the same intended use (e.g. blind mobility aid, reading machine, etc.). Using the dimensional analysis technique and possible selection factors and weight the procedure is as follows:

Factors	Device X (X_i)	Device Y (Y_i)	Weight (W_i)
1. Manufacturing cost	$50	$100	3
2. Distribution cost	$200	$ 50	3
3. Maintenance cost for life	$ 10	$ 50	3
4. Training cost	$200	$300	3
5. Aesthetic appearance	5	7	4
6. User acceptability	6	4	5
7. Size of potential user population	1/100,000	1/50,000	4

Factors	Device X (X_i)	Device Y (Y_i)	Weight (W_i)
8. Product life	1/5 years	1/8 years	3

$$R = \left(\frac{X_1}{Y_1}\right)^{W_1}\left(\frac{X_2}{Y_2}\right)^{W_2} \cdots \left(\frac{X_8}{Y_8}\right)^{W_8}$$

$$= \left(\frac{50}{100}\right)^3\left(\frac{200}{50}\right)^3\left(\frac{10}{50}\right)^3\left(\frac{200}{300}\right)^3\left(\frac{5}{7}\right)^4\left(\frac{6}{4}\right)^5$$

$$\left(\frac{50,000}{100,000}\right)^4\left(\frac{8}{5}\right)^5 = .0134$$

Since the value of R is less than 1, choice X would be considered superior. It should be noted that all dollar costs are given the same weight and that the selection factors which can be readily assigned a dollar value equivalent such as factor 8 (product life) are given the same weight as dollar costs. Factors 5 and 6 which are subjective selection factors use a rating scale of 1 (best) to 10 (worst). The weights use a scale of 1 to 10 where factors which are of greater relative importance are given a higher numeric weight. Note that the inverse of potential user population and product life are used for selection factors 7 and 8. If additional positive selection factors were considered, that is those where a high numeric value is desirable (as for selection factors 7 and 8), the inverse must be used to match it with other selection factors which are generally negative where a higher numeric value is less desirable.

In practice, a well-accepted, widely distributed device would be selected as a benchmark device (X). Several competing devices would be compared against the chosen benchmark one at a time. The dimensional analysis giving the largest R value greater than one would be chosen as best or if no dimensional analysis yields a R value greater than one the benchmark device would be considered the best available.

Discussion:

The utility of the dimensional analysis procedure outlined, greatly depends on the care with which weights are chosen and the validity of the rating scales used for the subjective selection factors. Additionally, care must be exercised that all relevant selection factors are included in the analysis. Failure to properly weigh, rate, and include all selection factors will considerably diminish the value of the procedure or invalidate it entirely. However, it should be noted that methods for assigning ranks and weights on a well reasoned basis are currently being developed by RER&D Center investigators.

The dimensional analysis procedure outlined is admittedly biased, however, it provides a structural framework for comparison so that rational choices can be made. Furthermore, the weighing scale can be tailored to reflect the preferences of various groups who may place differing values, for sound reasons, on the selection factors.

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MAXIMIZING BENEFITS OF ASSISTIVE DEVICES
PSYCHOSOCIAL CONSIDERATIONS

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ABSTRACT

There are many physical, social, emotional and environmental factors which might prevent the individual and family from utilizing an assistive device. This study examines: (1) certain life-style changes that occur after receiving an assistive device (2) how these changes may impinge upon successful use of the device and finally (3) emphasizes the importance of emotional adaption as well as physical adaption to the device.

INTRODUCTION

There are many physical, social, emotional and environmental factors that should be considered in the design and manufacturing of devices to be utilized in the rehabilitation or adjustment process of the disabled.

The task becomes that of balancing the disabled persons environmental physical as well as personal strengths against the debilitating forces of the physical impairment. This is especially true in the provision of an assistive device whereby there is a real need to reduce complications that tend to exacerbate those unusual problems that are created by the physical disability.

For disabled and non-disabled alike, a life-style of homeostatic balance is maintained unless stress is overwhelming. Part of the adjustment process of the disabled person involves learning to live in satisfying equilibrium with one's surroundings. In this context, provision of an assistive device constitutes a change in the support environment, and should result in a change in life style, with the additional stress requiring further adjustment toward equilibrium.

Life-style as a concept encompasses participation in daily activities, social interaction within the environment, perception of life tasks, aspirations and values, and one's self-concept of success or failure in these areas. Much of our understanding regarding the rehabilitation of the disabled has been seen as a medical problem. However, more emphasis is now being placed on the role of an indivudual's life-style in relation to disease and the rehabilitation process. Thus, the emphasis on intervention is not aimed at the emotional response to the disability per se, but on the adaptive response to the stress involved in the adjustment process. It is my opinion that there is a significant amount of stress involved with the introduction of an assistive device into the person's life-style.

STUDY METHODOLOGY

Concern about the relationship between successful use of an assistive device and psychosocial factors related to them was brought into sharp focus by an opinion survey study of two hundred manufacturers, researchers, clinicians, and users of assistive devices. (1). The data presented here are derived from questionnaires to 49 families selected from 138 who responded to an inquiry about use of mobility postural seating devices recommended at the Rehabilitation Engineering Center, Children's Hospital at Stanford (hereafter REC) between May 1, 1975 and May 1, 1978. The 49 families completed a structured opinion survey which focused upon changes in the individual's life-style, family relationships and how provision of the device affected the activities of other members of the family (Table 1).

RESULTS

Forty-three percent of the group studied indicated that use of a wheelchair in the family environment required structural modifications of the home, such as ramps, wider door openings, bathroom modifications, elevators or stair glides.

Nearly 1/3 (31%) of the group were aware of the need for additional help from family members or attendant care because the increased mobility achieved, markedly enlarged the disabled persons environmental exploration and confronted them with new types of limitations which required additional assistance with activities such as wheelchair transfers on the home and coping with architectural barriers outside the home.

The enlarged horizons of mobility led to changes in occupational roles in only 18% of the recipients. However, a very positive result was that in some instance the homebound mother felt sufficiently relieved of continuous care of her disabled child to secure part-time employment or engage in other activities. A negative factor in the responses was that nearly 1/3 (32%) of the respondents were concerned about the frequency of visits to REC facility for maintenance of the device.

Use of the mobility device did not significantly affect the respondents eating, sleeping and toileting habits and was not one of the expectations for the device. The most important

Question Area	Agree (%)	Disagree (%)	Neither Agree Nor Disagree (%)
Family enjoys more social life	81	10	9
More independence	71	21	8
Increase in social activities	67	26	7
More contact with peers	67	23	10
Allows more normal function	62	22	16
Increased activities in school	56	27	17
Sitting habits changed	56	28	16
Likes device's looks (self concept with device)	54	27	19
Family living habits more ordered	54	30	16
Restructuring of physical surrounding required	43	48	9
More time required of others for physical support	40	49	11
Frequent trips to medical facilities required	32	47	21
Increased need for help in management	31	53	16
Changes in occupational role	18	76	6
Changes in health of others in family	17	67	16
Sleeping habits changed	8	89	3
Toileting habits changed	8	89	3
Eating habits changed	6	90	4

finding was that more than three-fourths (79%) of the respondents believed that use of the mobility device had initiated significant change in their life-style. This was the same group which in a retrospective study by Kohn, et al., believed that the device met all or most of their needs (2).

DISCUSSION

Rehabilitation Engineering settings are sensitive to the physical needs of the severely disabled. Although we have witnessed significant technological advances, there is a tendency to be less sensitive to the emotional and social components related to the uses of an assistive device. Katz suggests that many of the new technologies do little to improve the life adjustment of the disabled, but simply extend their lives (3).

The relationship of psychological stress to physical disability has been extensively studied; however, the relationship of psychological stress to utilization of assistive devices by disabled persons is less well known and documented. This discussion focuses on changes in a person's life (stimulus) when disabled person obtains an assistive device and the effects (response) it has upon the person and/or family to the life-style changes. For the purpose of this study, the stress was involved with the introduction of an assistive device into the person's life style.

Thus, stress becomes the primary focus in the assessment process. Bracht feels that two important areas need to be considered when anticipating possible life-style changes, (1) the changing of daily living habits in order to manage a medical regimen and (2) the changing of deleterious living habits that have been casual factors in the illness, or in this case the disabled person's life-style (4).

As this applies to assistive devices, service providers must ask what events, such as modifying the home, maintaining the device, etc. might create internal or environmental conflicts/stress for the individual or family?

In addition to technological considerations that impact on life style changes, one must realize the emotional reactions of the family or person to the device itself is a factor that will affect maximal integration of the device into the disabled person's life.

It is important to note that life style changes can be a result of using the device or can have causal effect in changed requirements for assistive device(s). Using one device can cause increased demands for other devices or support systems. For example, stable positioning can lead to exploring independent mobility, simple communication boards can lead to complex communication systems. In relation to other support systems independent mobility can lead to increased need for outside accessible transportation; a more comfortably seated child can allow a parent to seek outside employment, which increases the need for attendant care for the child.

If the person and/or family has not been prepared for the implications of acquiring greater

mobility or other function, the new skills may be regarded in a negative way and as an additional problem to the family.

SUMMARY

There is no simple approach to resolving the problems associated with maladaptive responses to an assistive device. Effective intervention requires resourcefulness and ingenuity by all involved, professional and personal alike. This point should be stressed, because as Siller points out, although specific specialist - physician, social worker, rehabilitation engineer, occupational therapist, and others may enter at particular stages in terms of specific focus, all must consistently and responsibly attend to the particular needs of the person (5).

The practical approach advocated here views the introduction of an assistive device as involving an acute change in a person's life-style which creates a new set of life circumstances. The individual or family is faced with the problem of immediate adaption to this change in order to come to terms with the device as well as new responsibilities and problems imposed by the device resulting in the new life-style change.

The results of the present inquiry indicate that life-style changes do occur when devices are introduced into the disabled person's life-style. In other words, a psychosocial change has taken place, with the adjustment process which is always required with change. It appears that assessment of psychosocial factors during the initial evaluation of a disabled client may facilitate acceptance and incorporation of an asssitive device into an altered life-style.

These changes require the disabled person to make rapid accommodations in order to come to terms with the new set of requirements imposed by the device. Consequently, the device should have the characteristics of overcoming as many physical barriers as possible and the flexibility of enabling the person to cope with those that inevitably remain, architectural or attitudinal.

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ACKNOWLEDGMENT

The work reflects the results of a research study supported by National Institute of Handicapped Research under Grant No. G008005817 under Department of Education

DEMONSTRATION OF THE SPA-SYN-COM COMMUNICATION AND CONTROL-AID CONCEPT

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A Subsidiary of The Austin Company

The SPA-SYN-COM communication and control-aid concept has been demonstrated using a military head-tracking unit (SHMS), a microcomputer, and a CRT terminal. A "target board" depicting alphanumeric symbols is placed in front of the user, who wears an eyeglass frame containing a simple sighting device and a magnetic SHMS sensor. The user selects symbols by moving his/her head to view the desired symbol in the sighting device. The microcomputer requests the position and orientation of the sighting device from the SHMS system and resolves those measurements into symbolic output. The CRT screen is used as display for several lines of output.

Several handicapped persons participated in testing the demonstration unit. The reactions were favorable and the users quickly learned to operate the system. The handicapped users provided valuable comments concerning: speed, feedback, alignment, calibration, and maintenance.

1.0 INTRODUCTION

The lack of an adequate means of communication bars many severely physically handicapped persons from effective participation in the job market and normal participation in society. While a number of communication and control aids have been developed and some have been marketed, existing aids generally achieve low communication rates and are inflexible and nonportable. However, many of these problems can be overcome by a new input device.

2.0 THE SPA-SYN-COM DEMONSTRATION UNIT

2.1 System Configuration

The SHMS source was mounted on a nonmetallic post attached to a small table, placed directly behind the user's wheelchair. The sensor and sighting device were mounted on an eyeglass frame worn by the user. The target board was mounted over the upper portion of the CRT screen, and placed directly in front of the user. The Northstar microcomputer and the SHMS system were positioned on an adjacent table.

A yellow cross superimposed over the "H" was used for initial calibration of the system. Symbols were arranged as on an ordinary typewriter keyboard. Sighting of a particular symbol in general produced the symbol depicted in the next available space on the CRT screen. However, four symbols had special functions:

- . RET Begins new line of output
- . ← Backspaces and deletes one symbol
- . \ Deletes entire line
- . @ Stops operation for speed change

Sighting of areas outside the boundaries of the target board produced a "no-operation" condition, allowing the user to pause without producing additional output.

A plexiglass platform was mounted on the side of a standard eyeglass frame. The SHMS sensor was mounted on top of this platform. The sight used an opaque disk with a hole in its center. This disk was held at a distance of approximately 12 cm from the front of the eyeglass frame. A safety band was attached to ensure that the assembly stayed in place on the user's head. Some tests were conducted with a sensor and a light-beam-pointer flashlight fastened to a visor. The computer programs were written in Microsoft FORTRAN-80. Programs used by the demonstration system were stored on disk and loaded for use.

Position and orientation measurements were made by a SHMS Helmet-Mounted-Sight system (SHMS III, serial number 5) with software revision 3. (This system uses a carrier frequency of 10.6 kHz and updates measurements at approximately a 50 Hz rate. Measurements are determined to 12 bit accuracy.) Normal filtering (including a rate limit of 20%) was active, but built-in compensation for field distortion was disabled by command from the Northstar. An RS-232 interface was employed to facilitate computer-to- computer communication.

The system block diagram (Figure 1) depicts system operation. During operation, the Northstar repetitively requested current measured sensor position and orientation from the SHMS unit. These measurements were decoded as received and then converted into the coordinates of the points sighted on the target board. The

3.0 User Reaction

After a brief familiarization session, in which the theory and use of the unit was explained, a number of trials were conducted with each user. (All tests were conducted at the Physical Therapy Unit of the Medical Center Hospital of Vermont.)

Each subject was identified as a person with good head-pointing skills who needs a communication device. No attempt was made to test the unit on persons with reduced head-pointing skills. None of the users had prior experience with a communication aid. Two subject were high level quadriplegics and the third was a non-vocal stroke victim (left CVA with right hemiplegia).

Following introduction, each subject was able to access character blocks on the target board. Each required approximately fifteen minutes training in head-pointing strategies before beginning to communicate with accuracy and some speed. Speeds of 20-25 selections per minute were observed after 30 minutes of use.

A number of changes in SPA-SYN-COM, based on subject reaction and operation observation, were recommended:

Sighting device

The demonstration unit utilized a sighting device composed of a pair of spectacles, upon which were mounted a mechanical sight and the magnetic sensor. The configuration was functional, but not particularly comfortable and produced eye strain. Vision was partially obscured by the sight and all three subjects experienced some difficulty in viewing output letters on the CRT screen while focusing the sight on target blocks. The use of light beam is favored because it eliminates the need of a sight.

Feedback

Immediate feedback was seen as an essential requirement, even for those with excellent pointing skills. It was also regarded as an important factor in improving communication rates. The user wanted to know where he or she was looking and to receive a real-time indication of symbol selection. The lightbeam approach enables the user to follow his/her line-of-sight and correct for drift and tremor. It also allows an unrestricted view of the target board.

Target board

The typewriter keyboard was effective in showing the feasibility of the concept. It did not, however, facilitate high-speed communication. Users expressed the belief that an expanded board with blocks for syllables and frequently used words would be benificial. The need for special blocks for environmental controls was also expressed.

Alignment

A manual alignment was used for practical reasons (i.e., multiple users and types of wheelchairs). An automatic alignment procedure is recommended (i.e., the user looks at three separate points). This procedure should be designed so that communication can begin within 20-30 seconds after system initialization.

Parallax

The user's sighting device was adjusted so that it was accurately aligned with one of the axes of the sensor. The SHMS-system accuracy was better than 0.5°, and the angle between the mid-point of two symbol blocks was 2.28° with a distance between the source and the target board of 0.78 m. The flashlight was placed on the side of the head, opposite the sensor. The axis of the beam was then adjusted to be parallel with the sensor axis.

CONCLUSIONS AND RECOMMENDATIONS

The SPA-SYN-COM concept has been successfully demonstrated. The development of the SPA-SYN-COM communication and control aid using a commercial 8-bit microprocessor and a standard bus (e.g., S-100) will require a redesign of the proven military head tracking system, SHMS (2). While rigorous military specifications dictated the SHMS design, the need in this application is to design and develop an inexpensive commerical system that is flexible, portable, and capable of greatly improving communication rates. This also includes the use of the faster two-state algorithm (3).

4.0 ACKNOWLEDGMENT

The SPA-SYN-COM system was invented by James C. Krieg and a patent application has been filed. The work reported here is the result of an IR & D project sponsored by Polhemus Navigation Sciences, Inc., A Subsidiary of The Austin Company, and carried out while the authors were employees.

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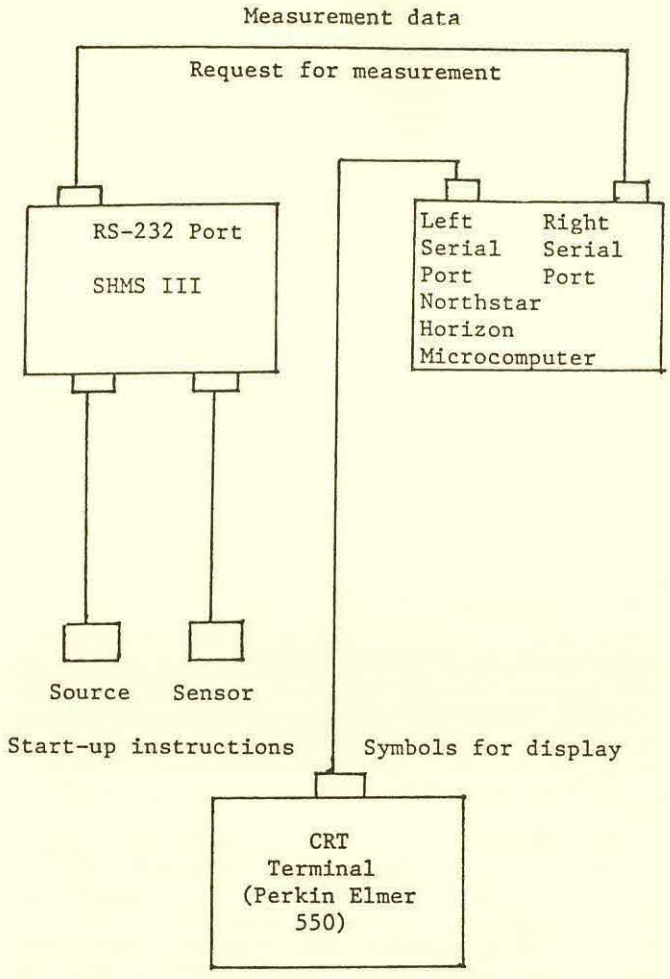

Figure 1. System block diagram.

Northstar resolved the target board coordinates into a symbol and output the symbol to the CRT display.

The demonstration system was capable of a 92 character-per-minute output rate or approximately 15 words per minute. However, half of the Northstar's time was spent in communicating with the SHMS. Improvement of the communication interface can therefore, provide significant increases in speed.

2.2 System Operation

Alignment

An operator manually aligned the axis in the source-coordinate system to be parallel with the axis in the target-board-coordinate system. The operator also measured the relative coordinates (X_{13}, Y_{13}, Z_{13}) between the two coordinate systems. The source was placed so the distance to any metallic scatters was larger than or equal to the distance between the source and sensor. No field distortion compensation was therefore needed (2).

Turn on

The operator turned on the SHMS, CRT terminal, and the Northstar. The SPA-SYN-COM program was executed while the user looked at the yellow cross on the target board.

Speed adjustment

When the user looked at the "@" he or she could decide on the delay for repeating the same letter and the delay for selecting a new letter.

2.3 Mathematics Behind The Algorithms

The geometry of the system is shown in Figure 2. The SHMS system provided upon request from the Northstar, the position and orientation ($\alpha, \beta, \rho, \psi, \theta, \phi$) were was in inches. A conversion into rectangular coordinates ($x, y, z, \psi, \theta, \phi$) was accomplished. A simple transformation converted the LOS (line-of-sight, parallel with the sensors x-axis) into a point (u,v) in the target-board-coordinate system where

$$u = (-\sin\psi)(x_{13} - x)/\cos\psi + y_{13} - y,$$

$$v = \sin\theta(x_{13} - x)/\cos\psi + z_{13} - z.$$

Symbol selection

Symbol selection required the system to maintain two running averages: average position and average squared position change.

The average position coordinate was obtained by first-order low-pass filtering of the individual screen coordinates; i.e.,

$$\bar{u}(k) = w\,u(k) + (1-\bar{w})\bar{u}(k-1),$$
$$\bar{v}(k) = w\,v(k) + (1-w)\bar{v}(k-1).$$

Note that k indicates the sample number and w is a weighting constant. $w = 0.5$ for the first average of position and $w = 1/(1+s(k)^2)$ for $k>2$.

The instantaneous (sample-to-sample) squared screen position change was

$$s(k) = [u(k) - u(k-1)]^2 + [v(k) - v(k-1)]^2$$

This was also low-pass filtered to produce the average squared position change

$$\bar{s}(k) = ws(k) + (1-w)\bar{s}(k-1)$$

After each sample input, the system compared s(k) with a present s_{max}. If s(k) was less than s_{max}, here $s_{max} = 0.1$, the system decided that the user was dwelling on a particular location. The average screen position (u(k),v(k)) was then resolved into indices by scaling and truncation. The appropriate alphanumeric symbol was then obtained from a 6 X 11 table. Note that in this algorithm, RET, ←, \, and @ are regarded as alphanumeric symbols. Three or more measurements are required to make a symbol selection.

ACCURACY AND LINEARITY MEASUREMENTS OF A CCD VIDEO CAMERA FOR USE IN A LINE OF GAZE COMMUNICATION DEVICE

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This paper discusses the experimental procedure and results of a calibration scheme to determine the accuracy and linearity of a charge-coupled device video camera. The camera is used for the detection of reflected light from the cornea of the human eye.

INTRODUCTION

The concept of ocular communication for the nonvocal has been approached in a number of papers published in recent years (4) (3) (2) (1) (5) (6). Various techniques have been employed to make efficient use of controllable eye movements as a means of producing coded messages, or in directly selecting letters and words. Efforts at Tufts have been devoted toward developing a complete line of gaze communication device which tracks both eye rotation, and head position and orientation. The sum of these is the line of gaze of Subject (4).

The Tufts project employs two independent monitoring systems to provide the necessary data for the computation of gaze. An ultrasonic ranging device monitors head position and orientation. A custom charge-coupled device video camera monitors the movement of the eye with respect to the head. This paper deals with the calibration of that camera for both linearity and accuracy.

Corneal Reflection Technique

The basic principle employed in the detection of ocular rotation in this project is the monitoring of the corneal reflection. The human eye can be thought of as consisting of two attached spheres of unequal radii. The larger sphere is the eyeball which rotates about its own center. The smaller sphere (or partial sphere) is the cornea of the eye. It is attached in such a way that it rotates about the center of the eyeball rather than its own center.

Young and Sheena (7) explain that the cornea is approximately spherical in its middle 25 degrees. In this range the cornea can be seen to be a convex mirror from which reflected incident light forms a virtual image. If the center of rotation and the incident light source are fixed relative to one another, the virtual image can be moved by rotating the convex mirror. In anatomical reality, the cornea (mirror) is rotated about the center of the eye. The reflection of incident light (the virtual image) is referred to as the corneal reflection. The movement of the reflection can be expressed by the relationship

$$X = A \sin E \qquad (1)$$

where X is the displacement, A is the distance from the center of curvature of the cornea to the center of the eye, and E is the angular rotation about the center. According to Young and Sheena (7), 12 degrees of rotation results in approximately 1.0mm of translation.

The CCD Camera

In order to detect the movement of the corneal reflection, a small video camera has been designed. The camera employs a Fairchild CCD 202 charge-coupled device image array. The array consists of a 100 X 100 matrix of photosensitive pixels (4mm X 3mm).

The array is mounted in a small housing which also contains appropriate lensing and focusing apparatus (Figure 1). The camera can be adjusted such that the excursions of the corneal reflection can be imaged on all or part of the photosensitive matrix. An infrared light emitting diode, producing collimated light provides the source of the incident light.

The camera is connected to a Z80 microprocessor which monitors the video output and stores the X-Y addresses of the illuminated pixels.

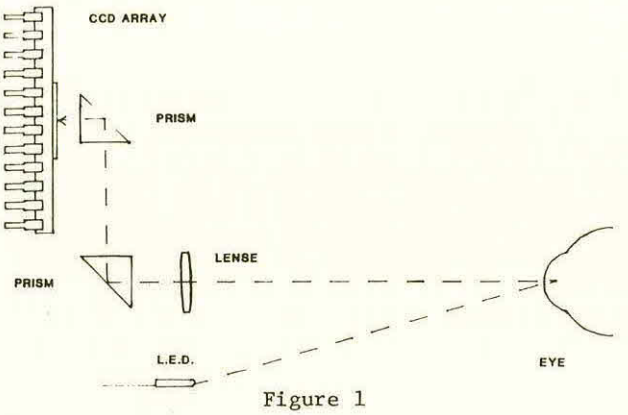

Figure 1

The Experiment

Young and Sheena (7) report that the geometry of the eye allows the corneal reflection to be used to monitor movements of ±.5 degrees or larger. For movements of smaller magnitude, other techniques must be employed.

The video camera must accurately detect the movement of the corneal reflection to at least ±.5 degrees. It is also important (although not essential) that the optics image the reflection on the array in a way that produces a linear detection of the movement.

The experiments for measuring linearity and accuracy were performed on a test bench with a model "eye" and a mechanical calibration instrument. A glass hemisphere with diameter chosen to be close to that of the human cornea (Diameter = 12mm) was attached to a 2 dimensional gimbal with dimensions again approximating the anatomical values (the gimbel represents the eyeball). The gimbal was attached to a 50cm arm which swept an arc which was subdivided into .25 degree units. Movement of the gimbal was constrained to one plane. Within that plane, the mechanical eye was capable of rotating ±30 degrees from center.

The camera was adjusted so that the full ±30 degrees would traverse along a line of pixels along the entire CCD array. The effect of this would be that the Z80 computer would read out the changing address along one row of the array as the mechanical eye was rotated. Since the movement was in one plane only, the address of the column within the array would ideally remain constant.

Experiment #1. The mechanical eye was rotated from one extreme to the other, with the addresses recorded at each one-degree interval. This would provide data on the linearity of the camera over a range that is much larger than would be required for actual corneal reflection detection.

Experiment #2. In order to determine the ultimate resolution of the camera, a five degree segment of the arc (from -10 to -15 degrees) was sampled at .25 degree intervals. This was the minimum measurement possible with the mechanical calibration instrument. Again, ±.125 degrees is considerably better than would be required for actual reflection monitoring (±.5 degree).

Experiment #3. Since many potential users of a line of gaze system would possibly wear corrective eye glasses, some measurement of the effect of the eyeglasses is necessary. Experiment #1 was repeated (at 5 degrees increments) with an eyeglass lens in the optical path. The particular lens was intended to correct for 20/40 vision.

RESULTS

The intention to sweep the entire ± 30 degrees was compromised by the mechanical apparatus and the actual range was from -29 degrees to +23 degrees. This movement covered 92 of the 100 pixels in the CCD row. The ability of the instrument to maintain the single plane motion was shown to be rather good. From one extreme of the sweep to the other, the reflection moved only 3 pixels in the column. This movement can be represented by a straight line, and can be accounted for by slight misalignment of the CCD array in the plane of the test instrument.

The output of the camera in response to the reflection of the camera's infrared source was a cluster of illuminated pixels. The size of this cluster is determined by the size of the virtual image (a combination of the size of the infrared source, and the distance from the source to the "eye"), and the camera detection threshold. In general, the cluster spread over 2 to 4 rows and columns. It is possible to compute the center of the cluster by computing the weighted average of the addresses. This procedure produces the fractional pixels that are indicated in the data.

The results of Experiment #1 are shown on Figure 2. The data points are shown as the crosses. The straight line on the figure represents the expected values. These expected values were computed using a simplification of equation (1)

$$X = A\sin(E) = (\text{approx. for small } E)\ AxE$$
where E is expressed in radians. (2)

Using the statistic r^2 (the coefficient of determination) to understand the goodness of fit, it is found that the experimental data fits the equation (2) extremely well. In this case r^2 is computed to be .99923.

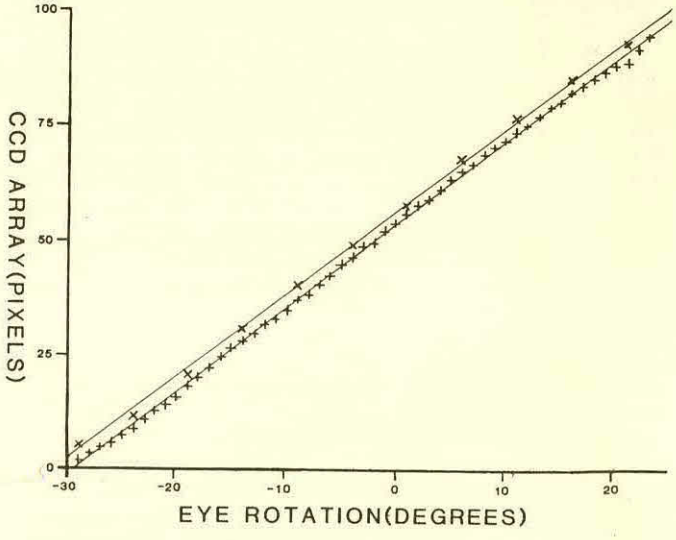

Figure 2

When a small section of the arc was examined in more detail, the samples taken at .25 degree intervals are shown in Figure 4. The sensitivity of the camera appears to approach the accuracy of the measuring instrument. The

sensitivity is ±.25 degrees. Using r^2 to determine the fit to the expected values from equation 2, the experimental data is again very representative; r^2 = .995798.

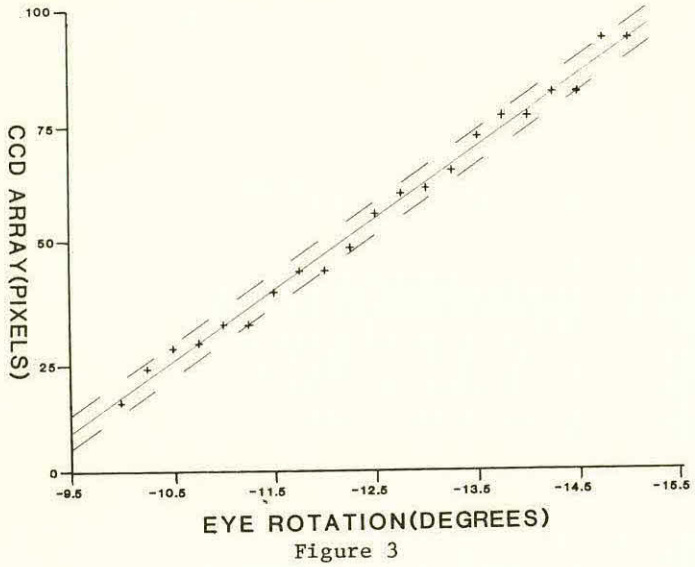

Figure 3

The data from the sample with the eyeglass lens in the optical path are plotted on Figure 2 as the X's. The data suggest the same slope as the expected values, with a different ordinate crossing. The image appears to be shifted on the CCD array. The value of r^2 for a line with this slope and ordinate crossing is .999566. One would have expected that the focusing qualities of the lens would interfere with the linearity of the imaging. From the value of r^2, no difficulties in linearity of the imaging are evident. This can be explained by considering the area of the eyeglass lens through which the corneal reflection is viewed.

The width of the area is on the order of 5mm. For any 5mm piece of the lens, the front and back surfaces can be assumed to be approximately parallel. Thus the effect of the lens reduces to that which would be created by a flat pane of glass. Since the lens has an appreciable thickness, the angle of the lense with respect to the viewing axis of the camera would create a problem of refraction. It is this refraction which can be assumed to be the cause of the constant shift of the image position on the CCD array. The refraction is only a function of the angle of the lens with the viewing axis of the camera.

DISCUSSION

The results of these experiments are quite encouraging. The CCD camera has shown that it can reliably and accurately acquire data on the position of a reflection from a spherical surface. The accuracy and the linearity over the +23 to -29 degree range are adequate for the purpose of observing the human eye. The fact that eyeglasses can be accounted for, is encouraging in that it makes it possible to consider the use of a final communication device with or without eyeglasses.

ACKNOWLEDGEMENT

Work supported by Grant # 16-P-57856/1-05 from the National Institute of Handicapped Research of the U.S. Department of Education.

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EYE-LINK FOR NON-VOCAL COMMUNICATION: DIRECT SELECTION BY EYE CONTACT

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A non-vocal communication technique and display board, Eye-Link, uses direct selection by eye contact between sender and receiver. The primary use of Eye-Link is seen in the early phases of hospitalization; however it may also find application in the chronic care setting as a low cost, indestructible, backup to electronic communication systems. Advantages include: simplicity, ease of comprehension, and speed relative to scanning and encoding techniques.

The non-vocal patient in the acute care setting has a need for a simple, low cost, communication device or technique that can be used in the early phase of hospitalization. This is the time, when there is a high level of activity directed at the complex aspects of medical management, that the patient feels fears and anxieties most strongly, but cannot express them adequately.

In many cases the need is for a brief period only, as for a patient who is intubated and being mechanically ventillated for respiratory insufficiency. Other patients, such as those with Guillian-Barré Syndrome, will have a longer period of need, lasting weeks to months, but are expected to recover their speech. Even the patient who has suffered prolonged, possibly permanent, loss of speech, and who ultimately will benefit from one of the more elaborate -- and expensive -- communication systems, will be helped by this early attention, because the practical issues of availability and cost can rarely be resolved in a timely fashion.

For the patient who has use of the hands, writing, or a printed message board is apt to be the best short-term solution. Many patients, however, cannot use their hands, particularly during the early critical period of illness, even though they are awake and desperate to communicate. For this group various scanning devices and strategies are reasonably effective, and we have had some success with an eye-movement encoding (Etran) board (1,2). Scanning communication, however, is excruciatingly slow, for both sender and receiver, while encoding strategies present intellectual challenges that many patients cannot cope with during this time of stress, when they are also apt to be sedated. The encoding scheme requires an abstract step which many patients cannot grasp, and it demands an effort to learn. From the practical standpoint the instruction and learning required of receivers -- primarily nursing staff -- reduces its applicability still further in the critical care setting. In general our best use of the eye encoding scheme is during the later stages of hospitalization.

Recently we had success in introducing a new technique -- direct-selection by eye contact -- for a patient who had failed in efforts to use the eye-encoding board. The patient was a 67 year old woman in the plateau phase of Guillian-Barré Syndrome. She was tracheostomized, on a ventilator, unable to move her hands, or to produce effective articulation. When first seen she was angry and depressed and, although sedated, at times very agitated. She was eager to be helped to communicate at more than a "yes/no" level.

METHOD

The technique, Eye-Link, (Fig.I), is based on the use of a transparent board, on which the selections are displayed in a rectangular matrix. The receiver holds the board, facing the sender, so that they can see each other through it. The transmission technique is as follows:

1. the receiver asks the sender, "word or spell?"
2. the sender responds with an eye movement

to the upper left or upper right.

3. the receiver then instructs the sender to fix on the desired letter/word.
4. the receiver, watching the sender's eyes, moves the board until eye contact is made through an individual square, indicating the desired selection. (For the sender with disconjugate gaze, the receiver must ascertain and follow the dominant eye).

WORD	A	B	C	D	SPELL
	HAPPY	COME	GO	UPSET	
E	F	G	H	I	J
NURSE	SUCTION	BM	YOU	I, ME	EMPTY
K	L	M	N	O	P
PLEASE	DRINK	FOOD	PAIN	ITCH	THANKS
QU	R	S	T	U	V
MOVE(ME)	TV	RADIO	MUSIC	BOOK	TIME
	W	X	Y	Z	
HOW	WHY	WHAT	WHEN	WHERE	DAMN
YES	ON	UP	DOWN	OFF	NO

Figure I. Eye-Link display board.

DISCUSSION

The board shown in Fig. I. was made from 1/16th inch acrylic plastic, 18 inches on a side, with the letters and words placed in 3 inch squares. The dimensions were set empirically, and should not be considered optimized (nor should the specific board layout). Consideration of dimensions must include both ability on the part of the receiver to discriminate differences in direction of gaze, and legibility to the sender, who may well be presbyopic and may or may not have spectacles available. (Do not neglect the basic step of determining the patient's visual acuity prior to any communication attempt!). The arrangement of 3 inch spacings proved adequate for use both by the patient, and between the authors, one of whom (S.K.) is experienced in being non-vocal during transitory periods of positive pressure ventilation via her tracheostomy. The word list was selected by S.K., in consultation with her occupational therapists and other patients at the New England Sinai Hospital.

The attractive aspects of Eye-Link are ease of instruction and understanding, speed of transmission (as opposed to scanning), and simplicity and low cost of preparation. As with all communication methods, however, limitations must be expected: ability to control gaze, cognitive status, and motivation to communicate, must all be assessed prior to introducing the technique.

ACKNOWLEDGEMENT

This work was carried out as part of the Harvard-MIT Rehabilitation Center Project, supported in part by Research Grant #23P-55854/1, from the National Institute for Handicapped Research, U.S. Dept. of Education.

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EYE BLINK INTERFACE

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ABSTRACT

The eye blink interface system was developed to enable non-vocal persons with a lack of manual dexterity to operate a communication board (Bliss, etc.). Sequential voluntary eye blinks control the system which consists of a transducer and a control circuit whose output is connected to the communication board. The transducer consists of an infrared emitting diode, a highly reflective surface affixed to the patient's eyelid, and a photo transistor to detect the reflected infrared beam. The electronic circuit is designed to disregard involuntary eye blinks, and can be adjusted or modified to accommodate different communication boards.

During the evaluation of a patient, K.R., a 20 year old white male, who sustained a craniocerebral trauma, it was found that he had voluntary eye movements. A suitable system to detect eye blinks and control the communication boards was not available.

The eye blink interface is a device that enables a severely disabled individual to communicate, by operating a communication board through the sensing of voluntary eye blinks that causes a switch contact closure at the input to the commercially available communication board (Zygo, Prentke-Romich). The interface includes an infrared sensor array, reflective tape, and an interface control unit (see Fig. 1).

The infrared sensor array is mounted on an eye glass frame so that it can be positioned from approximately 7 mm to not more than 13 mm away from the subject's eyelid. A small strip of reflective white paper with self-adhesive backing is placed on the subject's eyelid. The sensor is positioned so that when the eye is closed, the reflective surface of the paper comes into the field of the phototransistor on the sensor array. The reflective surface must be nearly perpendicular to the front surface of the sensor array. This alignment will vary because of the contour of the subject's eyelid.

The interface system uses a logic circuit that consists of three transistors, a Schmitt trigger, a decade counter, a hex inverter, a timer, a nor-gate, a dual monostable multivibrator, a double-pole-double-throw 5 V D.C. relay, and a 5 V D.C. power supply (mfg. Boston Tech.). These elements are mounted in a small instrument box that includes a buzzer for auditory signalling, and an indicator light.

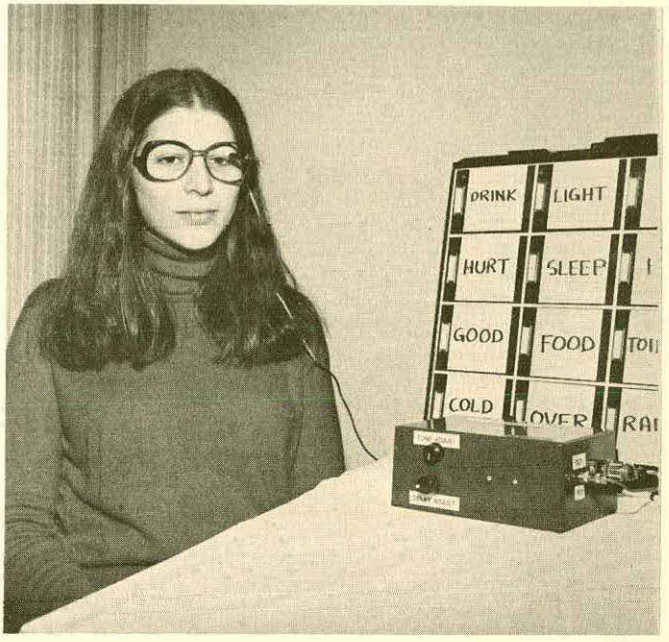

Fig. 1.

ELECTRONIC FUNCTIONS

The sensor array consists of an infrared emitting diode and a silicon NPN phototransistor. The axial intensity of the diode and the axial response of the phototransistor are both perpendicular to the face of the reflective tape. The phototransistor thus responds to radiation emitted from the diode only when a reflective object or surface is in the field of the phototransistor. When the reflective surface of the tape is placed in the field of the sensor by closing the eyes, approximately 30MA is generated by the sensor. This current is then amplified and converted to create a D.C. pulse at the input of the Schmitt trigger (see Fig. 2).

The interface logic circuit which controls a Zygo communication board follows. A second circuit for another communication board is described below. The output pulse from the Schmitt trigger is fed to a multivibrator with a range of delay

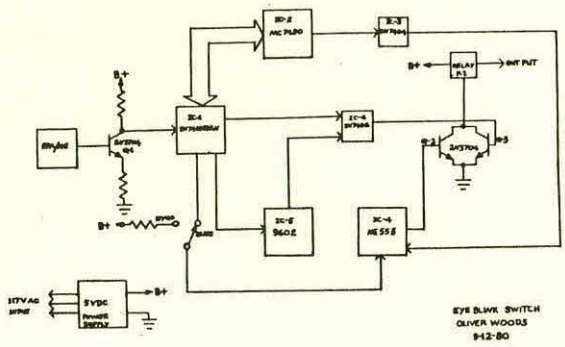

Fig. 2.

from 0 to 3 minutes. The delay is necessary to prevent activation of the device by involuntary eye blinks. It has been found that a delay of approximately 600 ms has been optimal in two patients. The delayed output from the multivibrator is then fed to the input of a nor-gate, which also receives the Schmitt trigger's output that is controlled by the eye-blink. If the two signals appear at the nor-gate's input simultaneously, the nor-gate produces a signal which turns on one of the output transistors which energizes the relay. The contacts of the relay have control of: 1) the communication board, and 2) the auditory and visual indicators on the control box. The first set of normally open contacts are closed by the first voluntary eye blink, which results in a switch closure at the manual input of the communication board. This closure puts the board in a "ready" state. The second set of normally open contacts are also closed by the first eye blink signal, which causes a visual display from an L.E.D. and an auditory output. These audio and visual indicators were found to be necessary to enhance the patient's concentration and also to attract the attention of the attending personnel in the room. Each progressive eye blink causes the indicator on the communication board to proceed to a following square. Upon reaching the desired square the patient stops blinking and this indicates the letter (or word) that is imprinted on the square.

This interface can also operate the Prentke, Romich communication board, however, a different type of logic is needed. The circuit functions as follows: the selector switch on the interface control box is placed in the "Bliss" position. When a voluntary eye closure is made, one of the outputs of the Schmitt trigger is fed to the input of the multivibrator. The same output pulse that was initiated by the voluntary eye blink is also fed to the input of the decade counter, which is programmed to count by fours. The same delay circuitry that was used in the Zygo mode is also used here. The first eye blink pulse triggers the relay via one of the output transistors which causes the communication board to operate in a continuous vertical scan of the first column only. When the second voluntary eye blink is initiated the vertical scan stops and starts to scan on the horizontal row selected. The third voluntary eye blink causes the scanning to halt at the desired square, and generates a pulse to the decade counter and the timer, latching the counter, and producing a steady level at the second input to the Schmitt trigger. The second output of the Schmitt trigger drives the timer, which delivers a steady pulse to the second output transistor. The output of the second transistor activates the relay and causes a switch closure at the input of the communication board that halts the scanning at the desired square. The fourth eye blink pulse clears the logic circuit and returns the board to its ready state.

The cost of the interface system parts and labor is approximately $500. (in production).

ACKNOWLEDGMENT

The work was supported in part by grant #G008003003 from the National Institute of Handicapped Research.

VOCATIONAL REHABILITATION OF THE SEVERELY DISABLED: VOICE CONTROLLED COMPUTER PROGRAMMING

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ABSTRACT

Speech recognition technology has developed to the point where many activities can be controlled by voice. In recent years, this technology has been used to help the handicapped achieve better control of their environment. This paper describes a voice controlled programming system designed to make programming easier for the severely handicapped. The design decisions leading to the construction of the prototype are discussed as well as some of the problems which need further study in order to make the handicapped even more productive as programmers.

INTRODUCTION

This paper describes a joint study, between IBM and the Rehabilitation Engineering Center (REC) of the Institute of Rehabilitation Medicine (IRM) of the NYU Medical Center, to promote the vocational rehabilitaion of the severely disabled utilizing voice controlled computer programming. The goal of this study is to determine the design parameters for voice-contolled programming systems which enable individuals with severe handicaps such as quadriplegia, who cannot use a keyboard, to write computer programs of a complex nature quickly and efficiently. Success in this research would lead to practical systems which enable severely handicapped persons to compete as programmers on an equal basis with able bodied individuals.

It is not unreasonable to assume that a system which facilitates programming will also prove to be good for teaching programming. If the system resulting from this research is useful for programming, but not useful for teaching programming an attempt will be made to identify the additional or alternate features required.

While facilitating computer programming is the goal of this study, we expect that our results will have applicability to the more general problem of securing high quality access to computer systems for various classes of disabled people. As computers become more and more central in all aspects of contemporary life, including such things as information systems, financial systems and office systems, securing adequate access to computers becomes essential for the handicapped if they are to participate in a meaningful way in our society.

The problem of accessing computers complements work already performed at IRM [1-6], where systems using voice to control various devices ranging from wheelchairs to page turners and TV sets have been built. Thus, success in the current endeavor implies the ability to construct a very comprehensive environment supporting domestic activities and offering possibilities for significant employment in the outside world.

COMPUTER PROGRAMMING

Computer programming does not require great amounts of physical dexterity or strength (just that required to operate the access devices). It therefore appears to be a good choice of profession for people with limited physical movement. Furthermore, since most sophisticated human-machine interfaces make use of a computer, it seems reasonable to make the computer the chief focus of the interface. Finally, computer programming is an expanding profession characterized by fairly good pay and good working conditions.

There are a number of good reasons for utilizing speech recognition to control the computer. Computer programming is a sophisticated task requiring a large number of different inputs for efficiency. Speech recognition supports a very complex interface in a fairly natural manner. Furthermore, since most people are capable of speaking for long periods of time, speech recognition is an interface that can be used for long uninterrupted periods of time without undue fatigue.

Some consideration was given to using eye-tracking as an interface. However, the number of options simultaneously available in eye-tracking is limited and smaller than the number available in speech recognition systems. The number of options in eye-tracking is limited by the number of regions that can be designated on a target area. Furthermore, eye-tracking is sensitive to head position and ambient light level. Eye-tracking requires a distracting, constant shifting of the eyes between work area and target area which is fatiguing. Finally, it also requires considerable practice to achieve proficiency. These reasons coupled with the positive features of speech recognition systems caused us to opt for speech recognition.

In attempting to make computers more accessible, there are two sets of problems which must be overcome. The first deals with the human-machine interface, i.e., the means by which a human obtains the necessary response from a machine. These problems have already been discussed briefly. The second set of problems deals with the difficulty of actually composing programs and getting them to run correctly.

Most programmers make extensive use of program printouts to help them debug programs. For severely handicapped individuals, such as persons with quadriplegia, handling physical objects such as printouts is a nontrivial problem. As a first step, APL was selected as the language of the system to help minimize the size of programs.

As is well known, APL is a very compact and powerful language - many useful and high level operations, (e.g., sorting) are primitive operators expressed by a single symbol in APL. This and APL's ability to handle vectors and higher dimensional arrays easily, often allows programmers to write programs very

quickly and compactly. The compact nature of APL also reduces the amount of entry that must be accomplished, thus reducing to some extent the severity of the problems associated with the human-machine interface.

In all fairness, it must be acknowledged that many critics of APL charge that it is difficult to learn and use because of its terseness. However, the use of speech recognition enables one to use APL without the need to be conscious of many of its conventions, e.g., one can name the functions in such a way as to facilitate their use and help one clearly remember their nature. This point will be discussed again in the section dealing with research questions. A more detailed discussion of this point is in preparation.

Finally, another useful feature of APL is that it is interactive. Having powerful operators easily available allows much useful manual manipulation of data both as an aid in composing programs and debugging them. It also provides a very natural approach to the teaching of APL programming by presenting a program as a record of a sequence of operators applied to data.

SYSTEM DESCRIPTION

It was decided to use commercially available equipment with a minimum of modification to initiate this study. There are three main reasons for this decision. First, this allows testing available devices and reduces initial cost. Second, the use of commercially available equipment would allow us to replicate the system easily as well as assemble the prototype quickly. Third, commercially available equipment is generally more rugged and reliable than prototypes assembled in a laboratory.

The initial system, which became operational in mid-March of 1981, consists of an IBM 5100 minicomputer dedicated to APL, a Threshold Technology 680 speech recognizer and a Rockwell Aim 65 microcomputer acting as an interface between the 5100 and the 680. There is a head operated switch which allows one to turn off the microphone so that general conversation does not produce gibberish on the system. The system is arranged so that the 5100 can be controlled either from its keyboard or the 680 acting through the Aim interface. This enables the system to be used effectively for teaching with the student using the speech recognizer and the teacher the keyboard.

The Threshold 680 has been programmed to recognize about 155 words and initial tests of the entire system have gone very well: every aspect of the 5100 operation has been brought under speech control; the error rate has been fairly low; and the flexibility of the system has been excellent, in many cases exceeding the performance of the pure keyboard system.

A compelling reason for selecting the 5100 was to ensure that the system be portable and stand-alone. It was the only portable minicomputer supporting APL which was readily available to us. Although its capabilities are significantly less than that of a mainframe, it is still adequate to teach the rudiments of APL and to provide an adequate test of the capabilities of voice control.

TEACHING PROGRAMMING

The first group of patients will begin using the system in early April of 1981. Tutorial sessions will be held twice-weekly, arranged to not interfere with the regular rehabilitation program. A second group will participate in June.

RESEARCH QUESTIONS

The results of this study have important implications for the able bodied as well as the severely disabled. We hope to produce evidence useful in deciding whether speech recognition can compete with keyboards in general as a method of computer access.

Another question we hope to answer is whether the extra flexibility of voice control can enhance the teaching and use of APL and other languages. In particular, we want to know what special problems, may arise in teaching computer programming by voice control.

We also expect to understand more fully the nature of the difficulties presented by relying on printouts as aids in the programming process. Hopefully, ideas will develop on ways to minimize the impact of this problem.

ACKNOWLEDGMENT

The following individuals have been of great help in getting this project going: from IBM, Dave Bantz, Adin Falkoff, Bob Federico, Dennis McBride, Don Orth, S. S. Soo and Tom Worthington; from IRM, Ruth Dicke.

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MICRODEC-BASED KEYBOARD EMULATOR FOR THE APPLE II COMPUTER

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ABSTRACT

This paper describes an interface system that makes it possible for disabled persons who can not operate a keyboard to access and use an Apple II personal computer. The interface essentially acts as a keyboard emulator, allowing a user controlling two switch inputs to select alphanumeric and control characters that are presented to the computer in such a manner that they appear to be coming from the computer keyboard. Of key importance in the concept of this interface is the fact that it gives the disabled user access to all of the capabilities of the Apple II computer system while requiring no software and very minimal hardware modifications to that system. The interface was incorporated with the commercially available MicroDEC environmental control system to facilitate development and reduce overall system cost.

SYSTEM CONCEPT

We are currently involved in a project devoted to the development of interface systems that would make it possible for disabled persons with very limited motor function to access and use existing computer systems. With most computer systems, control and data entry are performed by the user via a typewriter-style keyboard. The proposed interface would provide an alternate means of input entry for disabled persons who cannot operate a keyboard. In essence, the interface would act as a keyboard emulator, providing signals to the computer that are directly analogous to those normally provided by keyboard operation.

Of fundamental importance in the concept of the proposed interface approach is the fact that minimal hardware and no software modifications of the host computer would be required. This is a very important aspect when considering vocational situations where the disabled user may be accessing a large and complex computer system along with many other persons. It is also an approach valuable for personal computer applications, as it would make it possible for the disabled user to have direct access to all of the capabilities of the host computer.

To demonstrate this concept, we have developed an interface system to be used with the Apple II personal computer, one of the most popular and widely used personal computer systems currently available. The interface system makes it possible for a user controlling two switch inputs to select alphanumeric and control characters that are presented to the computer in such a manner that they appear to be coming from the computer keyboard. No modifications to Apple computer software are required to use this interface and the only hardware change required is connecting the output from the Apple keyboard in parallel with the interface output.

HARDWARE CONFIGURATION

To facilitate development and reduce overall system cost, the Apple II computer interface was incorporated with the commercially available MicroDEC environmental control system. The MicroDEC system provides a disabled user with the ability to control up to 16 peripheral devices or appliances and a single telephone line. Device control is achieved by transmitting coded signals over the power mains to receiver modules located at each peripheral. Details of this system are given by Gibler et al [1].

A photograph and block diagram showing the basic elements and interconnection scheme for the MicroDEC-based Apple computer interface system are shown in Figs. 1 and 2, respectively. The primary control element in the MicroDEC system is the MicroDEC control unit, which contains a single-board microcomputer based on the Motorola 6802 microprocessor. The inherent software flexibility associated with control unit function made it possible to implement computer keyboard emulation control without necessitating extensive hardware modifications.

The most extensive modification involved upgrading the control unit's 7-segment LED display to a 14-segment alphanumeric LED display. It was also necessary to provide additional computer memory. The program controlling normal MicroDEC operation is stored on a single 2K EPROM. To implement interface control, it was necessary to add another 2K EPROM and increase the system RAM from 128 bytes to 256 bytes.

Two parallel ports are already included on the microcomputer for basic MicroDEC input/output. Through software multiplexing, the same ports are used to provide both basic MicroDEC I/O and the transmission of emulation data in the modified unit. Thus the only hardware modification associated with I/O was wiring the output port to a socket on the back panel of the control unit.

In the Apple II computer, the keyboard is

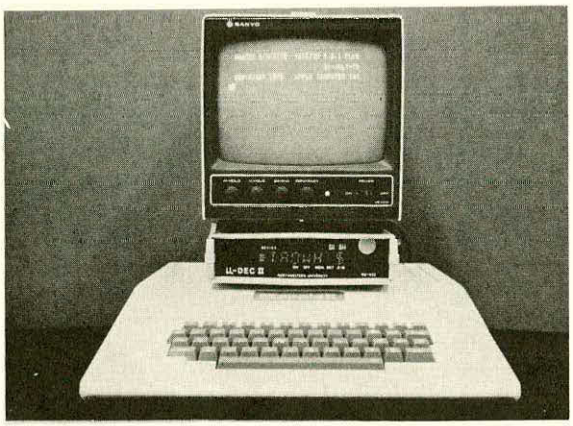

Fig. 1. Modified MicroDEC control unit and Apple II computer

connected to the computer by a ribbon cable that plugs into a 16-pin DIP socket, called the keyboard connector, on the computer motherboard. The pinouts and signal specifications for all aspects of keyboard connection and operation are given in the Apple II Reference Manual [2]. To connect a keyboard emulating system to the Apple computer, it is only necessary to unplug the cable from the keyboard to this connector and in its place plug in the cable from the keyboard emulation system.

For the emulation system described here, however, a custom designed input multiplexer circuit has been built that provides electrical isolation between the output circuitry of the interface and keyboard and allows the interface and keyboard to function in parallel. The input multiplexer consists of a single board that can be plugged into any unused back slot on the Apple computer motherboard. The emulator output from the modified MicroDEC control unit is connected to the multiplexer by a cable, as is the output from the Apple computer keyboard. Another cable connects the multiplexer circuit output to the Apple keyboard connector. Note that it is necessary to replace the ribbon cable that normally connects the Apply keyboard to the motherboard with a longer cable to make the connection to the multiplexer circuit.

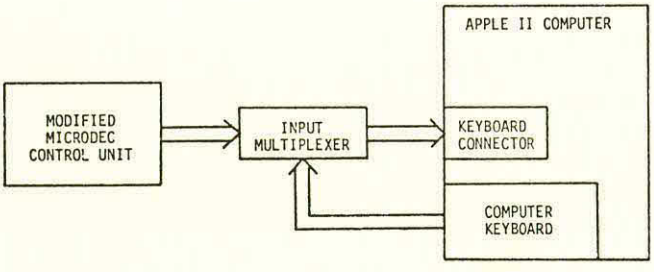

Fig. 2. Block diagram of keyboard emulation system

An important feature of this interface system is that, unless actively transmitting data to the Apple computer, the system is completely transparent to the computer and data can be input from the keyboard in a normal fashion. When data is to be transmitted from the interface to the computer, a control signal from the interface to the input multiplexer isolates the computer keyboard and strobes data from the interface into the computer's keyboard buffer. Note that only while the interface is actually transmitting a character, which takes approximately 10 msec, is input from the keyboard inhibited.

SYSTEMS OPERATION

The MicroDEC-based interface system utilizes a scanning method of operation requiring two switch closure input signals, one for advancing the device scan and the other for selecting or activating the specified control function. In the environmental control mode of operation, the system functions in precisely the same manner as the standard MicroDEC environmental control system (see Gibler et al [1] for details). As the user activates the switch advancing the device scan, numbers corresponding to each peripheral device being controlled are presented in sequence in the control unit display. Also presented in this basic scanning sequence are selections that allow branching to telephone control routines and user programming features. For the computer interface system, a channel has been added to the sequence of user programmable options that, when selected, puts the user in the Apple computer keyboard emulation mode of operation.

In the keyboard emulation mode, alphanumeric characters are selected by the user from lists presented in the eight position display. One such list is shown in Fig. 3. Selection of a character causes the appropriately coded representation of that character or desired control function to be transmitted to the connected computer or modifies the interface state in some prescribed manner.

The character or function indicated by the symbol on the extreme left in the display is that which will be acted upon if the selection or activation switch is actuated. Actuating the advance switch shifts the displayed selections from right-to-left in a rolling manner, with the characters falling off the left end of the display added to the right.

When the emulation mode is first entered from the environmental control mode, lists are displayed that allow the selection of letters to be 'typed' to the computer. The letter choices are displayed in groups of 5 with a space, such as shown in Fig. 3. If the desired letter is not in the displayed group, new groups may be obtained by selecting the character '*'.

To increase the speed with which the user can generate input to the computer, this system employs an anticipatory method of letter presentation in which the order that the letters are displayed is based on their conditional probabilities of occurrence given the knowledge of the preceding letter. The most probable letters are located in positions requiring the least number of scanning

and input operations to select. This anticipatory scanning method is equivalent to that described in detail by Rombola and Childress [3], which was based on principles developed by Crochetiere et al [4].

Selecting the last character in a letter selection list causes another list, called the command sequence, to be displayed. This list allows for the selection of various different functional options. One option provides for branching to an operational submode in which lists of numbers, punctuation marks and other symbols are presented for selection and output to the computer. Another option allows the presentation of a list representing editing functions, such as backspace, carriage return and tab, and the special computer control commands, reset and escape.

Selections are also presented in the command sequence that make it possible for the system user to generate keyboard upper case and control characters analogous to those obtained by depressing the shift and/or control keys on the Apple computer keyboard. These functions together with the selections presented in the letter and symbol lists make it possible for the user to generate any input to the computer with this interface that can be generated from the standard Apple keyboard.

Another choice in the command sequence allows selection of a specialized direct switch input control option. Selection of this option activates a control mode in which actuation of either of the input switches causes a character to be immediately typed to the computer that indicates which switch was actuated. This control option allows disabled persons to utilize specialized Apple computer software designed specifically for two switch input control.

DISCUSSION

We feel that the Apple computer keyboard emulation system described in this paper represents a practical and efficient approach to interfacing disabled persons with existing computer systems. A fundamentally important feature of this system is that it gives a disabled person access to all of the features and capabilities of the Apple II computer system and also provides the ability to use specialized programs written specifically for the disabled.

Basing the interface system on the MicroDEC environmental control system greatly simplified system design and also makes the system potentially much more cost effective since the hardware required essentially serves double duty. This aspect also clearly demonstrates the inherent flexibility of microprocessor-based designs and the advantage of their use in systems for the severely disabled, where hardware development and manufacturing costs are so high.

Further development work is planned to finalize the hardware and software characteristics of this system. We also plan to investigate the development of such interface systems for other personal computers and also the potential for the use of such interfaces by disabled persons in vocational settings. Although it must be noted that a strong demand for interface systems such as these has not been demonstrated to exist, the consensus among those involved in rehabilitation engineering appears to be that the rapid technological advancement in the computer field and the proliferation of the use of computers in our society provides the potential for significantly improving and expanding the educational and vocational opportunities available to severely disabled persons. We believe that the demand for interface systems such as the one described here will increase as this potential is realized.

Fig. 3. Modified MicroDEC control unit display

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ACKNOWLEDGEMENT

This research was supported by NIHR Grant No. 23-P-55898.

PROVIDING ACCESS TO COMPUTERS FOR PHYSICALLY HANDICAPPED PERSONS: TWO APPROACHES

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ABSTRACT: The potential benefits of computers will only be realized when the physically handicapped can gain universal access to these devices. This paper describes two contrasting approaches which are being undertaken at the National Research Council of Canada to provide some physically handicapped persons with access to computers. In the "hardware" approach, two devices are described which replace the computer's keyboard, in effect. In the "software" approach, a joystick input program is described which uses part of the screen of an Apple II computer. Joystick selection of user-programmed words and phrases is provided in order to facilitate computer programming and text editing. The relative advantages and disadvantages of each approach are discussed.

INTRODUCTION

Many workers in the field of rehabilitation engineering, and many handicapped persons themselves, have recognized the potential value of small computers as aids to written communication, education, vocation, recreation, etc., etc. The list of potential applications is almost endless, which is of course why everyone is getting so excited about computers (1,2,3). The problem is to convert potential applications to reality. For many physically handicapped persons, the computer is yet another problem of inaccessibility.

This paper will discuss our two separate approaches to the problem of accessing a computer for those who cannot manage the conventional keyboard, even with a keyguard. We call these the "hardware" and "software" approaches.

THE HARDWARE APPROACH

In this approach some alternative device is provided to replace the computer's standard keyboard, in effect. One of the major advantages often cited for personal computers (as aids for the handicapped) has been the fact that these are commercial products which are widely available and for which servicing is also readily available. Admittedly, using a specially designed device to replace the computer's keyboard violates this principle of universal availability. Others (4) have acknowledged this problem, also, for which we see no simple solution. Hence our two approaches.

A specially designed and self-contained "alternative keyboard" has many advantages, on the other hand. By generating all standard ASCII codes, in both serial and parallel format, a hardware interface will work with almost any make or model of small computer. No changes need to be made to the computer itself, either in hardware or software, so that the computer can still be used for all of its original applications. This approach is advantageous in vocational situations where a company already has considerable expensive data processing equipment. It would not be realistic to modify the company's equipment or software for the benefit of a few of their employees who happened to be handicapped. For those few, an alternative keyboard which simply "plugs in" to the company's computer system is much preferred.

The need for specially built hardware is not seen as a serious problem. Many physical interfaces for handicapped persons require special mechanical components to be manufactured in any case. By adding some encoding electronics, these interfaces then become universally applicable, stand-alone products which can be manufactured and sold in reasonable quantities. We are fortunate in Canada to have a new marketing agency established expressly for making such special purpose items available to handicapped consumers (TASH, Inc.).

Expanded Keyboard

Shown in Figure 1 is our expanded keyboard, a general purpose keyboard suited to persons with moderate hand and upper limb disabilities. As a stand-alone, ASCII-encoded keyboard, it embodies many of the design requirements outlined above. In addition it has latching CONTROL and SHIFT keys, to ensure one-hand operation. An optional synthetic speech module can provide feedback of each selected character for visually impaired users. By changing internal jumpers, keys can be reprogrammed. The expanded keyboard will also work directly with teletypewriters and teleprinters.

"Target" Mouth-operated Keyboard

A second alternative keyboard has been developed by the National Research Council of Canada's Rehabilitation Technology Unit, Toronto, Canada. This device, shown in Figure 2, is based on an original design by the Biomedical Engineering Unit, Queen's University, Kingston, Ont., Canada (5). Called "Target", the mouth-operated typing unit was originally designed to operate an electric typewriter by means of a bank of solenoids mounted over the keys of the typewriter. The device is suited to quadriplegics and other

persons with some head control and no functional use of their hands or arms.

If it is to be used with a computer or teleprinter, the Target requires an encoder unit to translate the key closures into ASCII codes. A prototype encoder unit, called "Encoder-80", has been built and is under limited field testing. A few other hardware interfaces are planned in order to accommodate different handicaps.

THE SOFTWARE APPROACH

Having given many reasons for using an external "alternative keyboard" as an interface to the computer we now describe the other side of our own work, in which a given computer is adapted to certain physical handicaps without the need for expensive external interfaces. In the "software approach" what we want to do is to take advantage of a small computer's own display and processing capabilities to reduce the need for external electronic hardware. There are many situations where a handicapped person may be purchasing his/her own computer, for example, and cost rather than universality is a more critical factor. Of course, in this approach we are restricting the handicapped to one particular make and model of computer. The other major disadvantage with this approach is that the special software will often interfere with applications programs the user may wish to run.

CRT Screen Character Input Program

Despite the limitations of the software approach, we have developed a useful program for the Apple II personal computer which gives a severely handicapped person access to the computer with very little additional cost or complexity. The interface for this application is a 4-position joystick, plus one additional switch for the Select function. It simply connects to the Apple's "Game I/O" connector. The physical configuration is shown in Figure 3, with a typical joystick available from TASH, Inc. Other makes of joysticks could be substituted. In fact any combination of suitable switches, paddles, or touch plates could be used in place of the joystick; so long as a minimum of two directional switches are provided, plus the Select switch. This type of interface is most suited to persons with spastic motions due to cerebral palsy or other causes.

The "CRT Screen Character Input Program", as the name implies, displays the complete keyboard character set on the lowest three lines of the computer's display screen (see Figure 3). Selections are made from this character array by causing a second cursor ("display cursor") to scan orthogonally over the array under control of the joystick. Once the display cursor is on the desired character, touching the Select switch will enter that character into the computer's operating system (or user's text) at the position of the main cursor.

In essence, all this is accomplished by revectoring the Apple "keyboard soft switch" (KSW) to the beginning of a new input program, written in 6502 assembly language. The Apple monitor's GETLN routine is still used, but KEYIN is replaced by our program, located in higher memory at 8CØØ to 95FF (hexadecimal). The character matrix and word/phrase file (described below) are stored between 87ØØ (hex.) and our input program.

Since a scanning interface is by nature rather slow, our Screen Character Input Program has a number of features designed to enhance the speed of use of the computer. The major feature is provision for user-created word and/or phrase files. One of these files, selected from disk, is appended below the character matrix and is accessed through the three-line "window" on the bottom of the screen. The user can scan through the word/phrase file the same as through the character matrix. The cursor stops only at the beginning of a word or phrase, skipping over remaining letters and blanks to stop at the beginning of the next word/phrase. Once the cursor is on the desired word/phrase, touching the Select switch just once enters that item in its entirety into the user's text.

The Screen Character Input Program can be used to generate all commands to the Apple Disk Operating System (DOS) and Applesoft BASIC. Hence programming the Apple computer is one major activity which is accessible to the handicapped by means of this program. For computer programming, the user would keep the DOS and BASIC commands which he uses frequently in a separate word/phrase file.

In our opinion, a major use of small computers by the handicapped will be for the writing and editing of text. To this end the Screen Character Input Program has been combined with a modified version of the Apple Writer copyright © text editing system. It was necessary to modify the Apple Writer to use only 20 lines on the screen for the user's text and to accept input from the Screen Character Input Program instead of from the Apple's keyboard. (Apple Writer does not use the standard GETLN routine, apparently because Apple Writer redefines the functions of the escape key.) Having a full word-processing system at the user's disposal is very powerful, especially with the added word/phrase capabilities. For example, the text editor can be used to create or modify the word/phrase files themselves!

Preliminary testing of the joystick input routine (without the word/phrase capability) with young cerebral-palsied children at the Ottawa Crippled Children's Treatment Centre has been promising. They are learning elementary computer programming by starting with commands to put designs on the Apple's low-resolution graphics screen, all by means of the joystick. Four students are using the joystick input and two are using the expanded keyboard, described above. Another two students can manage the standard Apple II keyboard.

This input program will work with some commercially available Applesoft BASIC programs, including games. Many others will work if slight modifications are made, usually to the initialization routines.

CONCLUSIONS

In order to provide access to computers for handicapped persons, the two different approaches

presented here are both necessary. The hardware approach, while more costly and complex, provides the ultimate in accessibility and is much less vulnerable to obsolescence....an important factor in this rapidly changing field. For certain handicaps and certain (limited) applications with the Apple II computer, the screen input software described in this paper provides a simpler, lower cost, approach. We will never be able to write or modify enough software, however, to be able to rely entirely on the software approach for making computers accessible for the handicapped.

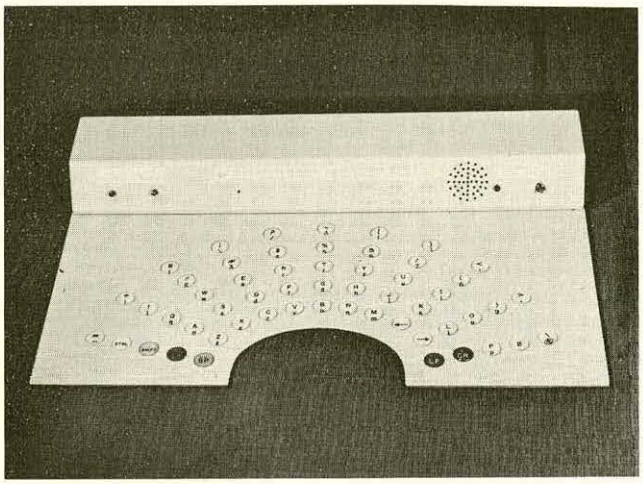

Figure 1. Expanded keyboard with flexible membrane keys.

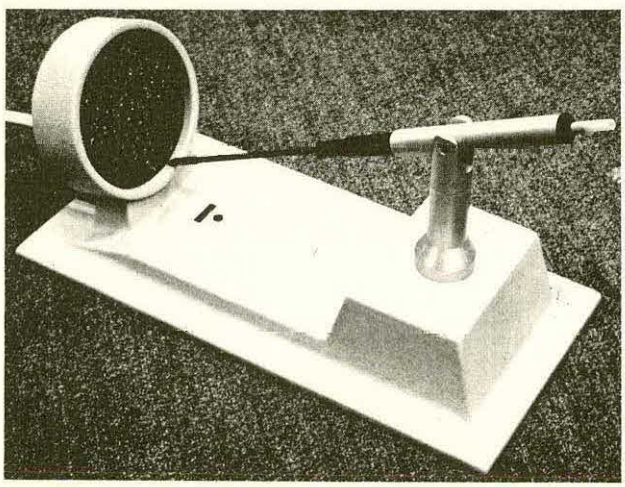

Figure 2. "Target" mouth-operated keyboard.

Figure 3. Apple II computer with joystick input.

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AN INEXPENSIVE HEXADECIMAL ENCODING KIT TO REPLACE COMPUTER KEYBOARD

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ABSTRACT

A system has been assembled which enables an individual with severe dystonia musculorum deformans to interact with a personal computer. The main element of the system, the input device, is an inexpensive, commercially available hexadecimal encoding kit. We will describe the function of this device, how it is used in this particular case, and its potential benefit to other persons with severe physical limitations.

BACKGROUND

Jim, a personable nineteen-year-old, completed his high school education with the assistance of an attendant. He has labored speech and is unable to write, but has above-average intelligence according to WAIS testing. As preparation to establishing a more independent lifestyle, Jim moved into Courage Residence, a transitional living facility, to develop necessary management skills. During his stay, Jim enrolled in the Technological Work Evaluation program, also housed within Courage Center, to explore the potential of a career as a computer programmer.

The Technological Work Evaluation program evaluates a severely disabled individual's potential for a career as a computer programmer. A major component of that evaluation is rehabilitation engineering. An individual's physical ability to interact with a terminal is assessed by rehabilitation engineering and equipment recommended or an individual system designed and constructed. Jim is an example of the latter approach.

Jim presented sitting in a powered wheelchair maximally restrained in a sitting support orthosis with an anterior closure. A head restraint assisted in maintaining his head in the midline. Jim's left arm was held by a single leather strap and his right arm was secured in a bivalved orthoplast splint along the wheelchair armrest. This positioned his right hand over the wheelchair control box in a functional position allowing him to operate his wheelchair.

Perhaps ironically, his right hand is the only body member over which Jim has relatively good control. It was this motion which we harnessed as the input mode. One of the original criteria established was that Jim be able to independently approach his system and begin operating without setup assistance. This meant removing the wheelchair joystick as it interfered with maximum right hand motion. Simply creating a keyed joint in the joystick allowed Jim to raise the upper section and fold it over out of the way.

KEYPAD INTERFACE

Our initial approach was to consider a scanning device which would be controlled by two switches. However, with the joystick removed, Jim was able to access an array of keys approximately 3½ inches square when they were placed immediately in front of his joystick box. Our search then for a suitably sized, easy to operate keypad led to the hex encoding kit, complete with keypad. This eliminated the need for a scanning device as the hexadecimal code for each character could be entered directly through the keyboard connector.

The kit, distributed by Jameco Electronics[1], consists of the following:

- -full 8 bit latched output
- -debounce circuit
- -LED verification of entries
- -standard 16 pin IC connection
- -3 user defined keys with one being bistable operation
- -LED indicating state of bistable switch
- -5 VDC only required.

The basic keypad operation prior to the modification was as follows:

1) Each key closure produced a hexadecimal digit output to the first quad latch.

2) Subsequent key closures transfer data from the first register to the second quad latch, then loaded the first register with the keyed hexadecimal digit.

3) Each key closure causes an output strobe.

Several minor changes were required but could be accomplished with the hardware supplied in the kit. Modifications to the keypad to make it compatible with an Apple computer keyboard input were as follows:

1) Lengthen the keypad strobe from 2μs to 10μs required by the Apple.

2) Use the bistable switch flip-flop to generate the keypad strobe on every second key input. (Bistable switch LED now indicates first key entered.)

3) One of the extra keys is used to clear first entry by resetting the first key flip-flop.

4) The second extra key is used as a repeat key by toggling the strobe flip-flop generating the data transfer pulse.

5) A reset key was added in an inconvenient location to prevent accidental closure.

With these changes, the sixteen-pin connector from the keypad is able to plug directly into the sixteen-pin keyboard connector. Charts indicating the hex code for each keyboard character facilitate code entry.

The Division of Vocational Rehabilitation has purchased an Apple computer for Jim to continue his educational and vocational program. As Jim is now able to maneuver his chair into a position from which he can access the keypad, he is able to pursue independent study. This ability to study independently was further enhanced by the purchase of a Gewa page turner, available from Zygo Industries[2], Inc., for him. Using the computer game port, we designed an interface permitting Jim to control the page turner with his Apple.

Jim's system now is complete and he is on an independent study program. The use of the encoding keypad opened up the world of computers for him, including the ability to follow manuals while learning to program the computer and taking notes on his computer while reading educational texts.

CONCLUSION

We have demonstrated the use of an inexpensive, commercially available hexadecimal encoding kit. It can replace the standard keyboard on several different minicomputer systems. We have demonstrated using a specific case but feel it could be used in many cases where range of motion is extremely limited and other methods, such as voice, of input have been eliminated.

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THE DEVELOPMENT OF THE AMBULATION PATTERN IN PERSONS HAVING LOWER EXTREMITY AMPUTATION: PRELIMINARY FINDINGS

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ABSTRACT

Although there are many descriptions available of deviations displayed by persons having above or below knee amputations, there is no information on how the gait pattern is acquired, or the effects of prosthetic fit and alignment, training strategies, and time on the eventual walking performance. The purpose of this study is to document changes in the kinetic and temporal-distance parameters throughout the learning period. Preliminary findings are discussed for six below knee amputees. Step time shortened and became more symmetrical; single support time of the involved extremity increased; and step lengths changed but remained asymmetrical. Of greatest interest were the changes in the force patterns which appeared more related to alignment changes than to practice.

INTRODUCTION

For a majority of persons having an amputation of the lower extremity the rehabilitation goal is restoration of ambulation using an artificial limb. As the person begins to walk with a prosthesis, instructions as to the length of steps, time spent on each limb, amount of weight to be taken through the limbs and speed of walking are given by the physical therapist. Except for velocity, these performance measures are usually assessed descriptively and subjectively.

Descriptions available in the literature of the gait patterns of persons having an above or below knee amputation center mainly upon the various compensations and deviations that occur (1,2, 3,4,5). Another approach has been to discuss the temporal-distance measures seen in the experienced walker in relation to energy costs and gait efficiency (6). How the walking pattern is acquired, and the effects of training and prosthetic alignment in the learning period has not been reported. One group of investigators has suggested the use of a visual representation of the force pattern to monitor progress throughout the gait training period (7). However, other temporal-distance parameters were not discussed.

The intent of this study is to monitor selected kinetic and temporal-distance parameters of walking performance daily throughout the period when a person is first learning to use a prosthesis. By also documenting training strategies and adjustments in fit or alignment a better understanding should be achieved of how these variables interact to affect the acquisition of the walking pattern. It is anticipated that eventually information from this patient data base will allow the investigator to compare the utility of various treatments or innovative prosthetics as techniques to enhance the gait acquisition process.

METHOD

This study is limited to persons with a unilateral above or below knee amputation who have not previously walked using a prosthesis. All subjects are in-patients at Moss Rehabilitation Hospital at the time of acceptance into the study. Subjects must be alert, able to follow simple instructions, and have no additional complications that limit the gait training program such as cerebral vascular accident or severely impaired vision. It is anticipated that the majority of the persons accepted to the study will be over 60 years of age.

Instrumentation used to collect objective data on walking performance includes a gait mat and force plates. The gait mat consists of four left and four right sections which are assembled into a walking substrate four meters long (Figure 1). A series of pressure sensitive switches (ribbon switches) are sequentially arranged and scanned by a microprocessor. The time and the location of each switch is recorded and stored to operate a lighted foot fall display, record computations, and print the results. Accuracy of recording foot contact time and placement is within $\pm$20 ms and $\pm$2 cm. Control buttons allow the operator to start and end data collection, to print out data, and to reset and clear the device to prepare for another pass by the subject (8). Parameters measured from the gait mat will be bilateral step length, step time, single and double support times, and average velocity.

Paired strain-gauge force plates each two meters long, placed longitudinally side-by-side on a 13 meter walkway are used to measure vertical ground reaction forces. For this application the vertical forces under each foot are collected to determine the peak vertical force bilaterally and the loading rate during double support time. Measurements are expressed as percentages of body weight to allow for comparison among subjects. The force data is collected on a PDP 11 minicomputer at the rate of 100 samples per second, and the print out is available to the investigator within 5 minutes of the test time.

Each subject is monitored daily for 5 days

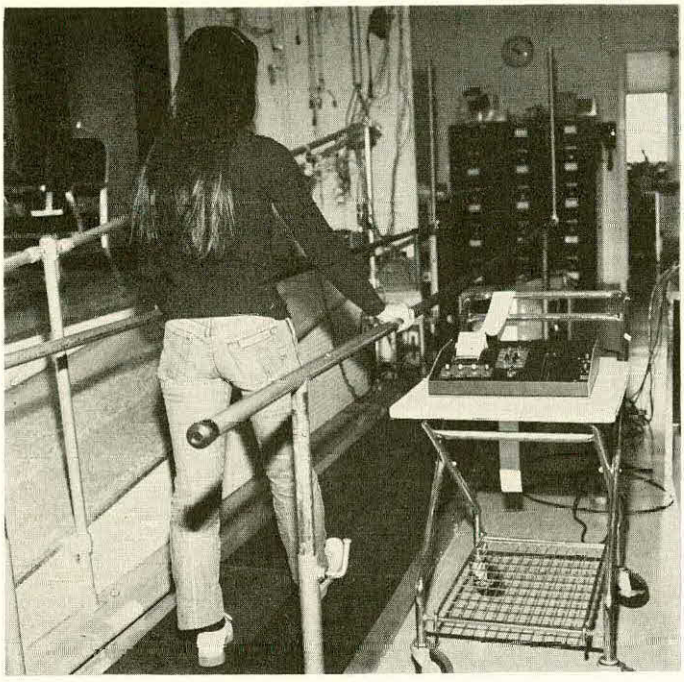

Figure 1. Subject on gait mat; control box to the right.

from the first day he is able to walk a distance of 4 meters between parallel bars. Subjects walk twice across the force plates, rest, and then walk twice across the gait mat with a 3 minute rest between passes. From this data forces for 4 left and 4 right steps are calculated. Temporal-distance measures are calculated using the middle 3 steps from each pass on the gait mat (6 left and 6 right). Following the fifth daily assessment, measurements are taken every third day until discharge and then at each follow-up visit to the physician (approximately two week intervals). Follow-up is planned to continue until six months after the definitive prosthesis is received.

RESULTS

To date six subjects have completed the in-hospital testing program; follow-up testing continues each time they return for a medical examination. The subjects range in age from 56 to 78 years. In all cases the need for amputation was related to peripheral vascular disease.

Comparisons of temporal-distance data at the beginning and end of in-hospital training illustrate that although step time decreased and became more symmetrical for all subjects, actual step length remained variable among subjects. Step length became more symmetrical for three subjects; more asymmetrical for two subjects; and maintained the same asymmetrical relationship for one subject. In all cases except one the step length of the involved leg was longer than that of the sound leg. Single support times became more symmetrical through the training period, with the involved leg increasing the time of independent support. Double support times showed no consistent trend in this small number of subjects.

At discharge, the mean peak force applied through the involved leg was 67.6% body weight (range 47-74%). During the training period, three subjects increased weight-bearing ability on the involved extremity; two remained at the same level; and one decreased weight-bearing. Most interesting were the day to day fluctuations of this parameter (Figure 2). As seen in this figure, there was no increase in weight-bearing between Day 1 and 9 although there was an increase in walking velocity. Several alterations were made in the prosthesis following Day 9 and the subject did not use the limb until Day 13 when a dramatic increase in weight-bearing ability was documented. Four days later, further small alterations were made to the prosthesis prior to discharge and the weight-bearing returned to a level below 50% of body weight. It is unclear at this time whether these changes were related to prosthetic alterations, fatigue at the end of the week, or both.

Early follow-up tests on three subjects, two weeks after discharge, also suggest interesting trends in the force data that are possibly related to the amount of walking done at home.

CONCLUSIONS

These preliminary findings are suggestive of the possibilities of kinetic and temporal-distance measures being useful to therapists and prosthetists as indicators of progress during the gait training period. Specific knowledge of the particular gait parameters of a patient at any point in his training program should lead to the generation of more specific remediation techniques or prosthetic adjustment and, hopefully, accelerate the acquisition of a stable pattern.

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ACKNOWLEDGMENT

The assistance of Barbara Cozzens, BS, for computer data programming is gratefully acknowledged. The work was supported in part by grant #G008003003 from the National Institute of Handicapped Research.

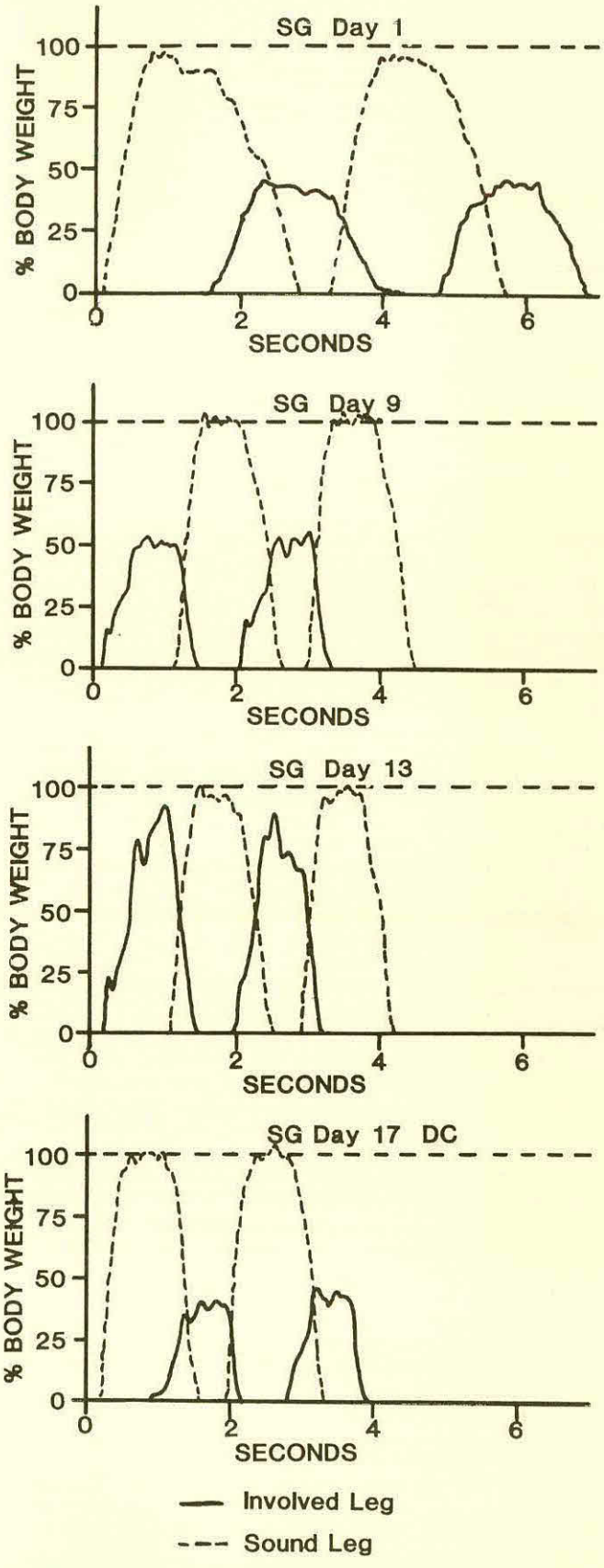

Figure 2. Force patterns for a below knee amputee at selected time periods from Day 1 to discharge.

QUANTITATIVE ANALYSIS OF MASS AND MASS DISTRIBUTION IN PROSTHESES USING A BIOMECHANICAL MODEL SIMULATION OF GAIT

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ABSTRACT

The effects of mass distribution in prosthesis for above knee amputees was investigated using a mathematical model simulation of the leg during the swing phase of gait. Weights were added to light weight modular prostheses to bring the prosthesis segments up to normal limb mass. Four weighted cases were investigated: distal and mid-segment placement on the "thigh" and "shank". Complete gait studies which measured subject motion, myoelectric signal and foot floor reaction forces were performed. Model simulations were then used to identify what compensatory mechanisms, if any, the subject used in response to the added weights.

Anatomical weighting of the shank near its normal center of mass produced the most favorable results by giving the amputee the ability to stabilize the knee prior to weight acceptance. It was found that the subject always compensated for added weight despite the fact that the model simulations showed that mechanically, in some cases, such compensation was not needed.

INTRODUCTION

The purpose of this investigation was to quantitatively determine the effects of mass and mass distribution of above knee (AK) and below knee (BK) prostheses and of long leg functional braces on patient gait. Current practice in prosthetic and orthotic materials selection is to use lightweight synthetics and alloys. This has decreased the average weight of an AK prostheses from 16-18 pounds for an all wood model to 6-8 lbs. for an endo-skeletal modular design. Using acrylics, BK prostheses have been made weighing less than 1 lb. In functional bracing, lightweight casting materials now offer alternatives to plaster of paris, lowering the weight of a brace from about 6 lbs. to about 4 lbs. This report will be concerned only with those aspects of the overall investigation relating to the effects of prosthesis mass distribution on gait.

The use of lightweight materials for prosthesis is not universal and is not always endorsed by the patient. Yet little quantitative information exists on the relative merits of light vs. heavy prostheses. From previous model simulations of swing leg motion (1) we have shown that decreasing, relative to normal, the mass and moment of inertia of lower extremity limb segments has a strong adverse effect on the predicted swing leg motion. It was further shown from model simulations that active muscular control of the thigh and shank was not necessary for the execution of a normal swing leg motion. Rather, the minimum conditions for the execution of a normally appearing swing phase were normal limb inertial properties and hip trajectory and the angular velocity of the thigh at toe off, a knee constraint to prevent hyperextension and a moment to prevent plantarflexion of the ankle. These results of the model simulations indicated that an above knee (A/K) amputee should be able to execute a normally appearing swing leg motion using a prosthesis whose mass and moment of inertia were the same as a normal leg. The model simulations also indicated that a prosthesis whose mass and moment of inertia were considerably less than normal would require major alterations in the normal pattern of muscular control.

This investigation was undertaken to help assess the relative merits of using lightweight or heavyweight prostheses in so far as the controllability of the prosthesis is concerned.

METHODS

Gait studies were perfromed on each subject. Motion picture film of each walk was taken and manually digitized to yield the hip trajectory and angles throughout the gait cycle.

The subjects first walked with a lightweight modular prosthesis. Weights were then added to the thigh and shank. The magnitude of the weight was chosen to bring the mass of each prosthesis segment up to that of a normal leg for the subject. Weights were placed distally and near the normal anatomical center of mass of the thigh and shank yielding four distinct weighted conditions. For any given walking trial weights were placed in only one position.

The mathematical model was then used to simulate the weighted walking trials using the unweighted walk as a reference. The moments acting on the thigh, shank and foot, of the lightweight modular prosthesis were computed using the model programs, taking the digitized film data and calculated masses, centers of mass and moments of inertia of the lower limb segments as input.

Simulations of the actual weighted cases were then performed. The segment moments determined for the unweighted case were always used to drive the limb whose inertial properties were calculated to be the same as those of the weighed prosthesis.

RESULTS

The simulated resuts for distal and mid-shank weighting showed that the subject would have to change the pattern of active muscular moments used in the unweighted case in order to execute an acceptable swing leg motion. In the case of weighting the distal shank, the amputee was not able to produce a level of knee stability that he was satisfied with. However, when the shank was weighted near its anatomical center of mass, the subject was able to produce a stable knee at heel strike. The criteria for stability was the ability to produce the same retrograde angular velocity in both the thigh and shank at the end of swing.

Unlike shank weighting, when the thigh was weighted the simulations showed that the subject could execute an acceptable swing leg motion without changing the patterns of muscular moments from those used in the unweighted case. However, for both cases, of thigh weights the gait studies showed that the subject compensated for the thigh weights by using an entirely different pattern of muscular moments from those used when walking unweighted. The addition of thigh weights also caused the subject to compensate with the musculature of the trunk and contralateral leg.

DISCUSSION AND CONCLUSIONS

One of the major criteria for the above knee amputee during gait is to obtain a stable knee at heel strike. Weighting of the prosthesis has shown marked effects on the subjects ability to execute an acceptable swing leg motion which allows for knee stability. Adding weight near the anatomical center of mass of the shank produced a limb that could be controlled by the amputee to yield a stable knee at heel strike as demonstrated from the biomechanical analysis, and this particular case drew strong approval from the subject. Distal shank weight did not enhance the subjects ability to control the limb and was felt to be less desirable than the lightweight prosthesis alone. Thigh weight was shown to be incompatable with the subjects ability to control the prosthesis and was percieved by the amputee as being the most work to control.

Thus, for an A/K amputee, a lightweight thigh segment coupled with an anatomically weighted shank was found to yield mechanical stability and a strong endorsement from the subject.

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ACKNOWLEDGEMENT

This work was supported by NIH grant number AM22165.

A SYSTEMATIC APPROACH TO DATA ACQUISITION IN THE GAIT LABORATORY

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ABSTRACT

A flexible system of computer software has been developed around a data base management system to permit analog data acquisition to be easily adapted to the requirements of an experiment and to facilitate access to the data that is generated. A user created dictionary, which defines experiment specific terminology, is utilized to construct two forms, one for patient information and one for sampling information. These forms are stored permanently and may be reused. Immediately prior to the data collection, the forms specified by the user are recalled, and they are updated with information relevant to the current experiment, (e.g. the subject's name or the voltage offset of a gait monitoring device). The revised forms and the data that are subsequently acquired are stored in a single file that allows all information to be retrieved easily.

INTRODUCTION

The gait laboratory presents a demanding environment for a computer; typically large amounts of data must be managed facilely. Each experiment is unique in some aspects necessitating that data acquisition software must provide reasonable flexibility. Our concern was to implement a flexible system for analog data acquisition that would be easy to use yet be capable of storing and manipulating large amounts of information. The list below identifies some of the salient features of the system that was developed. These points emphasize that data acquisition is part of a continuum of data management, that it is preceded by experiment specification and it is followed by data analysis.

1) The software system can be utilized to implement many different experiments.
2) The system takes advantage of redundancies that often occur in the specification of similar experiments by recording initialization data on forms. Two forms are used, one for patient data and the other for sampling information.
3) To accomodate each of the different types of experiments that are frequently encountered, forms may be created and stored for later use.
4) When a form is created, a blank (no response) is inserted when a question cannot be answered in advance of the experiment. At the beginning of an experiment, the desired forms are recalled, and initialization is completed by entering a response at each occurance of a blank. Our system has been implemented so that for most experiments, the form can be completed in a few minutes by modestly trained personnel.
5) The revised forms, raw data, and comments are stored employing a specially designed data base management system. This has the benefit of allowing all information associated with an experiment to be stored in a single file. The data management system supports some general utility programs and serves as a basis for future software development.
6) The method of data storage permits automated data analysis, because all information that may be required by a data analysis routine is stored permanently in addition to the raw data.
7) Data analysis programs and raw data can be shared among different users because the data management system provides a 'common language' for the transfer of information.

The following presents an overview of the techniques that were incorporated to permit a user to define his own experiment utilizing a set of general tools that are provided by the data acquisition system. The software has been implemented on a DEC PDP 11/45 computer running under RSX-11M V3.2. Specific details of the software implementation have been described elsewhere (1,2). It is assumed throughout this presentation that the computer can collect analog data when the proper information is supplied (e.g. the number of channels to sample and the sampling rate) and that it can store the acquired data.

CHARACTERIZATION OF A GAIT EXPERIMENT

Utilizing this automated system for data acquisition, a typical gait experiment proceeds as follows. Initially, the computer accepts the patient data (e.g. the patient's name and age). Instrumentation is mounted on the subject and the corresponding signal lines are connected to the computer. If the instrument configuration is non-standard, or if any gains or offsets are calculated, then this information must be recorded on the computer. The subject then crosses the instrumented gait walkway as the computer records

the digitized analog signals, and stores the information in a file. It is common practice to produce a quick plot of the data of the first pass to ensure that all equipment is operative. The remainder of the data is collected, and is then plotted in a strip chart like fashion to permit qualitative analysis. When the experiment is completed, the computer is utilized to assist in the data analysis procedure.

AN EXPERIMENT FILE

All information that is associated with and generated during an experiment is stored by the computer in a unique file, which is analogous to a file cabinet drawer. In a file, every storage unit or RECORD (folder in the drawer) contains data (papers) and identification information (a printed index tab that allows you to check the contents of the folder before it is withdrawn). A standard file protocol (system for indexing different folders) facilitates location and identification of any desired record. Records in a file are ordered chronologically as follows: the patient form, the sampling information form, and the raw data ordered sequentially by pass number. Comments that are entered during an experiment are also included. As an example, an abridged listing of the contents of a file that was produced during a gait experiment is shown in Fig 1. This sample experiment is detailed throughout the remainder of the text.

The first record in an experiment file contains the patient data form. Because the form was completed at the start of the experiment, it does not contain any blanks. A patient form contains all of the patient data (Fig 1, NAME and AGE) that is relevant to the experiment and may contain other information as well.

The next two records store the two part sampling information form. The first part specifies the A/D sampling parameters that are used to determine how the data was collected. Shown in Fig 1, the sampling rate (SRAT) was 100Hz, and the number of channels sampled (NCHN) was 3. The second part of the form is labeled Channel Assignments and defines what information was recorded on each respective A/D channel, in addition to the instrument voltage gain and offset. For example, the left knee angle (abbreviated LKNA) was monitored with a goniometer that was connected to analog channel 0. In reconstructing the goniometer signal, a gain factor of 1.1 and a signal offset of 0.23 will be applied.

The raw data associated with the experiment is stored as a sequence of serial data samples from each channel that was sampled. Because it is possible to collect a very large amount of data, and because each record is limited in size, many data records may be produced. Also, comments pertinent to the experiment may be entered at any time. They will be interspersed with the raw data, but are stored in separate records.

EXPERIMENT SPECIFICATION

A novel feature of the system for data acquisition is the implementation of a dictionary, which is used when initialization forms are first created and again immediately prior to an experiment when the blanks on each form are filled in. Use of a dictionary: 1)allows the user to create an experiment utilizing his own terminology, 2)enforces consistent application of the terminology and 3)allows the user to check the definition of any word. The dictionary can also contain HELP words, words whose definitions provide the operator with assistance or step-by-step instructions. Defined formally, a dictionary is an alphabetized list of words or mnemonics (4 characters or less) and their definitions. Figure 2 is a listing of the dictionary that was used in the sample experiment, Fig 1,3 and 4.

FIG 1

PATIENT DATA
NAME : JOHN SUBJECT
AGE : 35

SAMPLING INFORMATION
- SAMPLING PARAMETERS
NCHN : 3
SRAT : 100

- CHANNEL ASSIGNMENTS

		GAIN	OFFSET
CHAN 0:	LKNA	1.1	0.23
CHAN 1:	LFTS	1.0	0.
CHAN 2:	RFTS	1.0	0.

RAW DATA

LKNA	LFTS	RFTS
0.393	3.478	0.038
0.398	3.476	0 029
0.403	1.218	0.028
0.408	1.217	0.035
0.413	1.221	0.035
0.417	1.222	1.167
0.420	1.219	1.171

COMMENT
DURING THE LAST PASS, THERE WAS ONE BAD STEP.

Both the patient data and sampling information forms are bipartite, i.e. they consist of both user prompts, and responses. Correspondingly, the dictionary stores two different kinds of words: 1)user prompts and 2)channel assignment responses. Figure 4 depicts a sampling form that has not been filled in. The use of the prompt 'SRAT' is an abbreviated way of stating 'Enter the desired sampling rate in Hertz'. In case the operator is uncertain of the the equivalent long form of a prompt, the dictionary may be consulted. All permissible analog channel assignments are represented as words that are stored in the dictionary. At run-time, as the sampling form is being completed, consistency is enforced because each user supplied channel assignment is automatically verified with the dictionary.

FIG 2 A DICTIONARY

1)	AGE:	Age of the subject.
2)	LFTS:	Left footswitch signal.
3)	LKNA:	Left knee angle in the sagittal plane measured with a goniometer.
4)	NAME:	Name of the subject.
5)	NCHN:	The number of analog channels to sample.
6)	RFTS:	Right footswitch signal.
7)	SRAT:	The sampling rate, expressed in Hertz.

Employing a dictionary, a patient information form may be created. The patient form used in the sample experiment is shown in Fig 3. Blanks to the left of NAME and AGE indicate that responses must be provided by the operator at run-time. Both NAME and AGE are defined in the dictionary Fig 2.

The two part sampling information form that was used in the sample experiment is shown in Fig 4. Because the sampling parameters (NCHN=3 and SRAT=100) were specified previously, these values need not be entered as part of initialization when this form is selected. The channel assignments, gains and offsets are specified on the second part of the form. Note that since the offset associated with channel 0 is left blank on the form, this value must be provided before the experiment can begin. Only information that is likely to change on successive experiments should be left blank. It is most time efficient to create an initialization form with as few blanks as possible.

Once initialization forms have been created, they can be reused on successive experiments. Immediately prior to actual data acquisition, the initialization forms must be completed, and this procedure is usually straightforward. In the sample initialization forms (Fig 3 and 4) the patient NAME and AGE are entered into the corresponding blanks, and the offset of the goniometer placed about the left knee must be determined. An automated calibration procedure facilitates calculation of the gain or offset. When either of the forms are being completed, it is possible to modify a previous response. The completed forms are written to the experiment file. The data collection program reads the sampling information form to ascertain how many channels are to be sampled and the sampling rate, following which data acquisition can begin. As data are collected and comments are entered, they are added to the same output file.

CONCLUSION

It is possible to reduce the amount of information that the user enters prior to an experiment by utilizing initialization forms. In this way it is possible to achieve sufficient flexibility and at the same time provide a system which takes advantage of the majority of the cases where the present application is very similar to a previous experiment. Use of a dictionary enforces consistency in the manner in which initialization forms are completed, and simplifies the initialization procedure. Because all information needed to reconstruct an experiment is stored with the raw data, it is possible to support automated data analysis. A typical analysis program extracts information from the patient data and sampling information forms prior to data analysis to discern the specifics of each experiment. Because this information can be obtained independently without user assistance, the analysis processes can be highly automated. Although this discussion has focused on acquisition of analog data, the system could be extended to collect data in either digital or mixed digital and analog formats. Further, the system would be suitable for applications outside of the gait laboratory.

FIG 3

PATIENT DATA FORM

NAME: _____

AGE : ___

FIG 4

SAMPLING INFORMATION FORM

-SAMPLING PARAMETERS

NCHN: 3

SRAT : 100

-CHANNEL ASSIGNMENTS

		GAIN	OFFSET
CHAN 0:	LKNA	1.1	___
CHAN 1:	LFTS	1.0	0.
CHAN 2:	RFTS	1.0	0.

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ACKNOWLEDGEMENTS

This work represents a collaborative effort between the Rehabilitation Engineering Center at CWRU and The Motion Studies Laboratory of the Cleveland VA Med. Ctr. at Wade Park. Support was furnished by the National Institute of Handicapped Research Grant No. G001005815 to the REC and by funds to the Motion Studies Laboratory provided by the VA Rehabilitative Engineering R&D Program.

TEMPORAL MEASUREMENT OF THE PATTERN OF FOOT-TO-FLOOR CONTACT DURING GAIT

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ABSTRACT

Employing a partially conductive black rubber floor mat, a new system has been developed to measure the temporal components of foot-to-floor contact during walking. Three conductive tapes affixed to the soles of each of the subject's shoes are connected to a small monitor box worn by the subject. Contact of the footswitches on the rubber matting is detected by monitoring the resistance from each foot tape to the floor mat which is fixed at ground potential. The status of foot-to-floor contact is transmitted digitally over an umbilical cord to a control box that displays the resultant patterns of foot contact. Signals are also relayed to a digital computer for storage and processing.

INTRODUCTION

A footswitch is a contact sensitive transducer that is worn on the sole of the shoe or foot to permit temporal resolution of the pattern of foot-to-floor contact. Using a single footswitch affixed to each foot it is possible to resolve the gait cycle into its three fundamental components: single support, double support and swing. To obtain a more precise picture of the way in which the foot bears contact on the ground, the number of transducers can be increased.

Schwartz (1) was the first investigator to document an electrical system for recording simultaneously from three footswitch electrodes attached to the sole of each shoe. The osseous triangle was identified by placement of conductive metal dots less than 2cm in diameter over the first and fifth metatarsophalangeal joints and the heel. The subject walked on a grounded metal surface. Contact was sensed by completion of an electrical circuit and was indicated by illumination of a light associated with each footswitch. A seventh light driven from a metronome provided a time base. A photographic equivalent of a chart recorder, driven at 5.3cm/s provided a permanent record. The resultant "electrical footprints" allowed resolution to hundredths of a second. Schwartz has stated that the primary assumption which underlies the application of such a system is that "Any alteration of normal pressure on one or more of these three points will necessarily be accompanied by a change in the normal sequence or duration of time spent on the other points of the respective feet." He provided evidence to indicate that the test was repeatable, and that alterations in gait were reflected in the resultant footprints.

Leavitt (2) employed a relative weighting system whereby each of three external shoe switches mounted at the heel, midfoot and toe was assigned a unique value of 1,2 and 4 units, respectively. On switch closures, the corresponding weighting factors were summated electrically to produce a composite staircase-like signal which specified the state of foot contact. This technique has the advantage of reducing the number of cable connections required to interface the patient and monitoring devices.

DESIGN CONSIDERATIONS OF THE NEW FOOTSWITCH SYSTEM

Previous experience in our laboratory using a metal screen and a conductive tape footswitch system had demonstrated that it was a viable tool for clinical analysis. However, some difficulties were noted as follows: 1) the metal screen had a tendency to buckle and stretch with use, thus permitting possible registration of false foot contacts. 2) A very thin aluminum foil tape was used ("Scotch" brand #425 made by 3M) because it did not impede the subject's gait. However, the abrasive surface of the metal screen sometimes caused premature failure of the tape. 3) Walking on a metal surface could be somewhat intimidating to the patient, and 4) the shiny metal surface of the screen produced reflected light which sometimes interfered with stroboscopic or video systems. These inherent difficulties were overcome by replacing the screen with a conductive rubber mat. Only one conductive matting material was found to be commercially available in an appropriate size and at a reasonable cost, (Conductive rubber matting material #5000, available from Buffalo Weaving & Belting Co. 260 Chandler Street, Buffalo, N.Y. 14207). The rubber is conductive because it contains carbon black.

This new material provided the basis of the design for the new footswitch system. The footswitch system consists of three major components: 1) the floor mat sandwich, 2) a small patient worn monitor box and 3) a footswitch control unit. Footswitch tapes are placed on the sole of each of the subject's shoes relative to the

anatomical landmarks depicted in Fig 1. The first and fifth metatarsophalangeal joints are located by palpation. Filament reinforced strapping tape is often applied under the metal tape for strain relief. This preparation requires only about 5 minutes. A wire connects to each foot tape with an alligator clip, and then runs in a fine cable to the monitor box mounted about the patient's waist. An umbilical cord suspended from an overhead trolly serves to connect the patient box to the control unit. This control unit provides outputs which are sent to the computer.

THE FLOOR MAT AND CONTACT DETECTION CIRUITRY

In order to implement the new system, a new contact detection scheme had to be developed because the conductivity of the new mat is significantly lower than that of the previously used metal screen. Assuming that the mat was grounded at a single point along its edge, the resistance measured would vary significantly as a function of the horizontal distance from that point, and the resistance far away would be so large that it would be difficult to measure. Because the mat is 12m long yet only a 3.2mm thick, the resistance of the mat measured in the horizontal plane is much larger than the resistance measured through the mat. Therefore, to decrease the effective resistance, a distributed ground was implemented by placing a conductive brass screen beneath the area covered by the rubber mat (Fig 2).

Contact of a footswitch is detected when the resistance from a foot tape to ground drops below 20Kohms. The circuit functions by applying a test voltage, and determining the amount of current that flows to ground. As the current increases, the Schmitt trigger changes state to indicate that contact has occurred. By adjusting the input biasing network, or by increasing the Schmitt trigger hysteresis, it is possible to adjust the threshold of the circuit. With about 100mv of hysteresis and the bias network depicted, the circuit is sufficiently sensitive to register the light contact of a tiny pin. Because the resistance measured through the rubber mat varies with both the area of foot tape in contact with the mat and the applied pressure, it is unreasonable to regulate the sensitivity of the detection circuitry such that only contacts which exceed some minimum force will be registered.

The output of the contact detection circuit is a TTL compatible digital pulse that serves as input

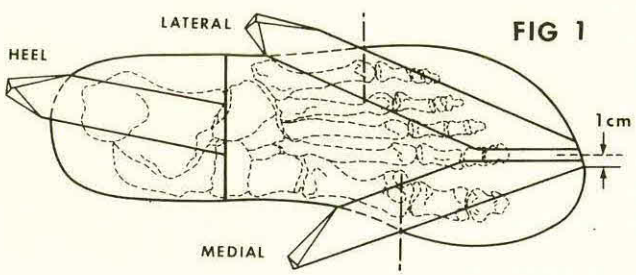

FIG 1

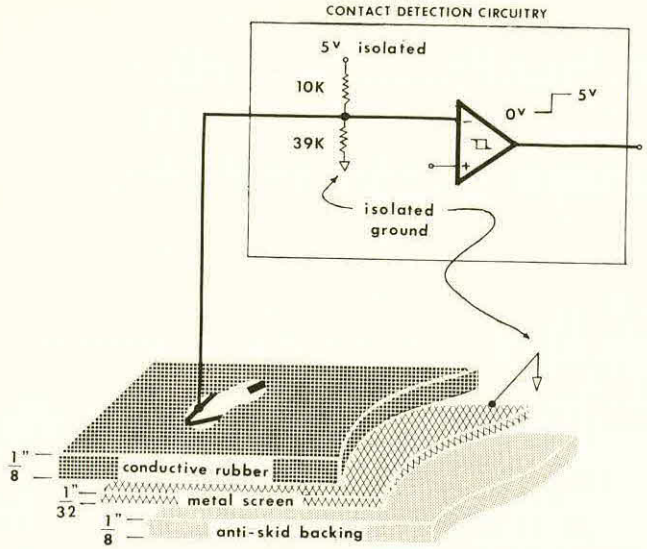

FIG 2

A highly conductive metallic screen is positioned beneath the partially conductive rubber matting to decrease the effective resistance through the ground path. The third and bottom layer of the floor mat sandwich is an insulating rubber mat which serves to prevent slippage of the screen over the floor, and to electrically insulate the screen so that a truly isolated ground is maintained. The Schmitt trigger contact detector circuit switches state from low to high when the resistance from any foot contact to the metal screen falls below 20Kohms. The circuit is sufficiently sensitive to register light foot contact applied over a small contact area.

to a data transmitter. The six bits of digital data (one for each footswitch) are relayed via an overhead umbilical cord to the footswitch control box. To decrease the number of conductor cables required to transmit the contact status, the signals are time multiplexed (with a UART) permitting all data to be transmitted across a single wire. The status of all contacts is updated every 0.5ms. Only two other cable connections are required, those carrying isolated power and ground. The circuitry can easily fit in a box 14x11x4cm in size, and is light weight.

FOOTSWITCH MONITOR BOX

A line powered control box, remote from the patient, demultiplexes the digital serial data, and encodes the six bits of information into several different usable formats (Fig 3). Each of the six foot contact switches controls a light on the front panel of the control unit. The lights are arranged on the front panel from left to right as follows: heel, medial and lateral of the left foot, and heel, medial and lateral of the right foot. This feature has proven valuable as it provides immediate feedback as to the integrity of the system. Even prior to data analysis, it is possible to ascertain a fair amount of qualitative

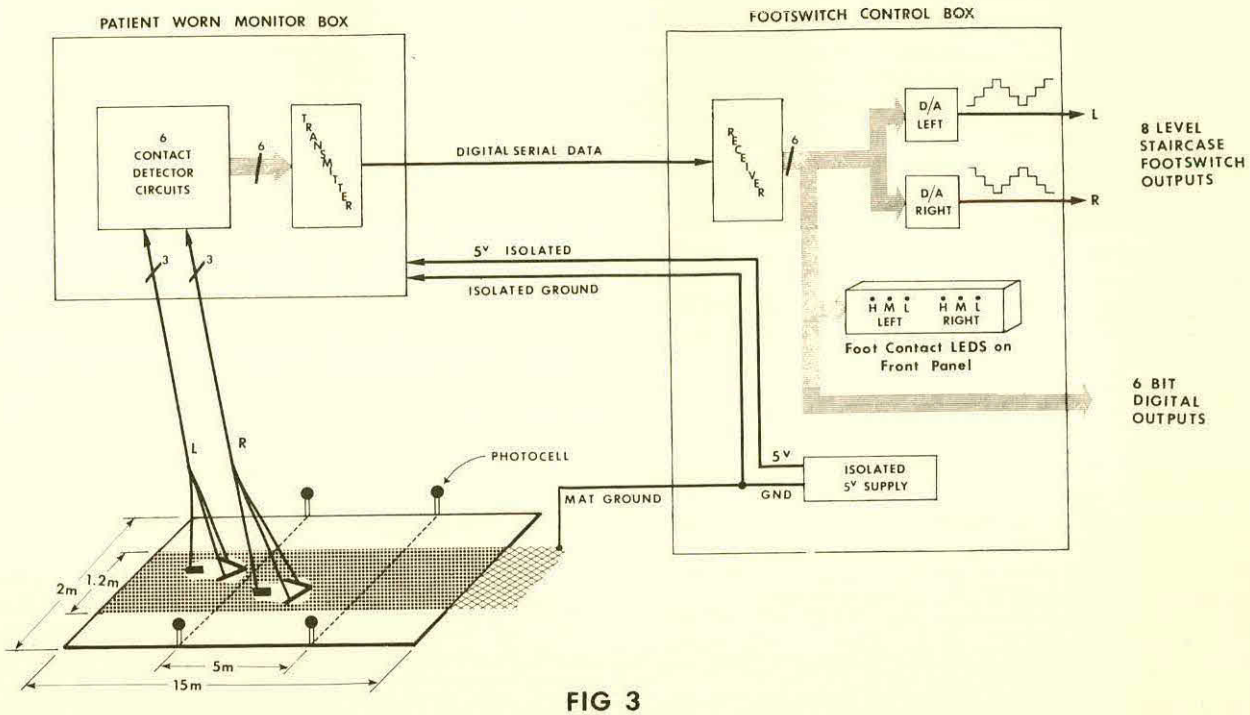

FIG 3

The gait walkway is 15m long and 2m wide. The floor mat is 15m by 1.2m and is centered on the walkway. The central 5m of the walkway is delimited with two photocells which initiate and terminate data acquisition by the computer, and permit calculation of velocity, average step and stride length, etc. The circuitry contained in the patient worn monitor box determines which footswitches are in contact with the ground. The six resultant signals are time multiplexed and transmitted across a single data line to the control box. The control box produces an isolated 5v supply (to assure patient safety) which powers the monitor box, and the ground is also attached to the metal screen on the walkway. The serial data passes through an optical isolator, and then to the data receiver which reconstructs the original 6 bits of data. A staircase signal is produced with a digital to analog convertor consisting of an R-2R network driven directly by the TTL output of the receiver.

information from observing the pattern generated by the lights. Each of the six signals is provided in TTL compatible format for interfacing with standard digital equipment.

The control box also contains circuitry to generate an eight level staircase representing the contact states of each foot. This is done because our computer software only permits sampling of analog data, and it is possible to use the A/D channels more efficiently by sampling the two composite staircase signals instead of the six individual contact signals. The data are reconverted to the six binary signals to produce a graphical display. The staircase output is also suitable for monitoring with a chart recorder.

CONCLUSION

By employing a conductive rubber floor mat, the deficiencies associated with use of a metal screen walking surface can be overcome. The system is electrically safe, accurate, reliable and inexpensive to construct. The actual testing procedure is inexpensive as the only materials consumed are the foot tapes. In addition to the amount of time needed to perform the actual walking, only 5 minutes are required for shoe preparation and thus the test is suitable for clinical applications. The mat tends to be non-reflective, thus making it suitable for applications requiring the concurrent acquisition of footswitch and stroboscopic or video system data.

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ACKNOWLEDGEMENTS

This work represents a collaborative effort between the Rehabilitation Engineering Center at CWRU and The Motion Studies Laboratory of the Cleveland VA Med. Ctr. at Wade Park. Support was furnished by the National Institute of Handicapped Research Grant No. G001005815 to the REC and by funds to the Motion Studies Laboratory provided by the VA Rehabilitative Eng. R&D Program.

GRAPHICAL DISPLAYS FOR FOOTSWITCH ANALYSIS IN GAIT STUDIES

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ABSTRACT

Several computer generated graphical displays for use with a tri-electrode footswitch system have been developed to enable rapid identification and quantitative assessment of abnormal foot placement patterns during the stance phase of gait. These displays are presented and their interpretation and utility are discussed.

Footswitch data are collected using three strips of aluminum tape affixed to the medial, lateral and heel portions of each of the subject's shoes as depicted in the insert of Fig 1. As the subject walks along a conductive walkway appropriate electronic circuitry registers the state of contact of each of the tapes with the walkway and transmits the data to a computer based data management system. (For hardware details please see Sutin et al. this conference.)

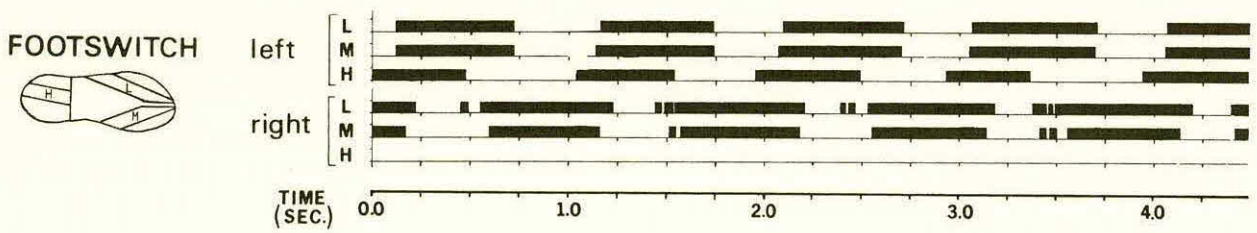
Figure 1 shows a "footprint" like display which indicates along a common time base the intervals when the respective aspects of the shoes (heel, medial, lateral) were in contact with the walkway. These particular data represent the gait of a hemiplegic cerebral palsy child. Essentially normal foot placement is present for the left foot where the stance shows the normal sequence of heel strike followed by forefoot contact (to achieve foot-flat), then toe only contact and finally the total absence of foot contact indicating the initiation of swing phase. The foot contact sequence on the right however, depicts a typical equinovarus foot placement, commencing with contact of the lateral forefoot and then followed by contact of the medial forefoot. The total lack of heel contact is strikingly apparent.

Other gross observations which may be gleaned from this simple plot include basic stride characteristics such as the relative durations of the stance and swing phases, and the presence of foot-drag on the right side as revealed by the incidental brief contacts of the forefoot during the swing phase of the right foot.

The ability to record foot placement information with high fidelity and high resolution (±5 ms) makes such records useful for documenting and objectively evaluating gait performance over time or before and after some intervention is performed. For example, if it were desired to compare the effectiveness of different orthoses in alleviating foot-drag, one could simply count the incidence of swing phase toe drag present in plots such as Fig 1. To provide more analytical information, the basic footswitch plot of Fig 1, can be annotated with numbers representing the "contact durations" produced on each step. We have also found it very useful to indicate the latencies of the various contact events (i.e. onset and offset times) as measured by a clock, initiated when the subject trips a photocell mounted near the start of the walkway.

The footswitch data shown in parts 'A' and 'B' of Fig 2 report this "latency" information for the gait of another cerebral palsy child having mainly left side ankle extensor spasticity which causes him to walk with a toe first stance on that side. This abnormality is clearly observable from inspection of the left footswitch data of part 'A'. The foot placement pattern recorded for the left foot as shown in 'B' differs in that the toe-first stance seen in 'A' has been converted to a more normal sequence of initial heel strike followed by forefoot contact. This correction of the child's functional equinovarus gait, was produced by having him walk using a functional electric peroneal nerve stimulator while the data in 'B' were being collected.

FIG 1



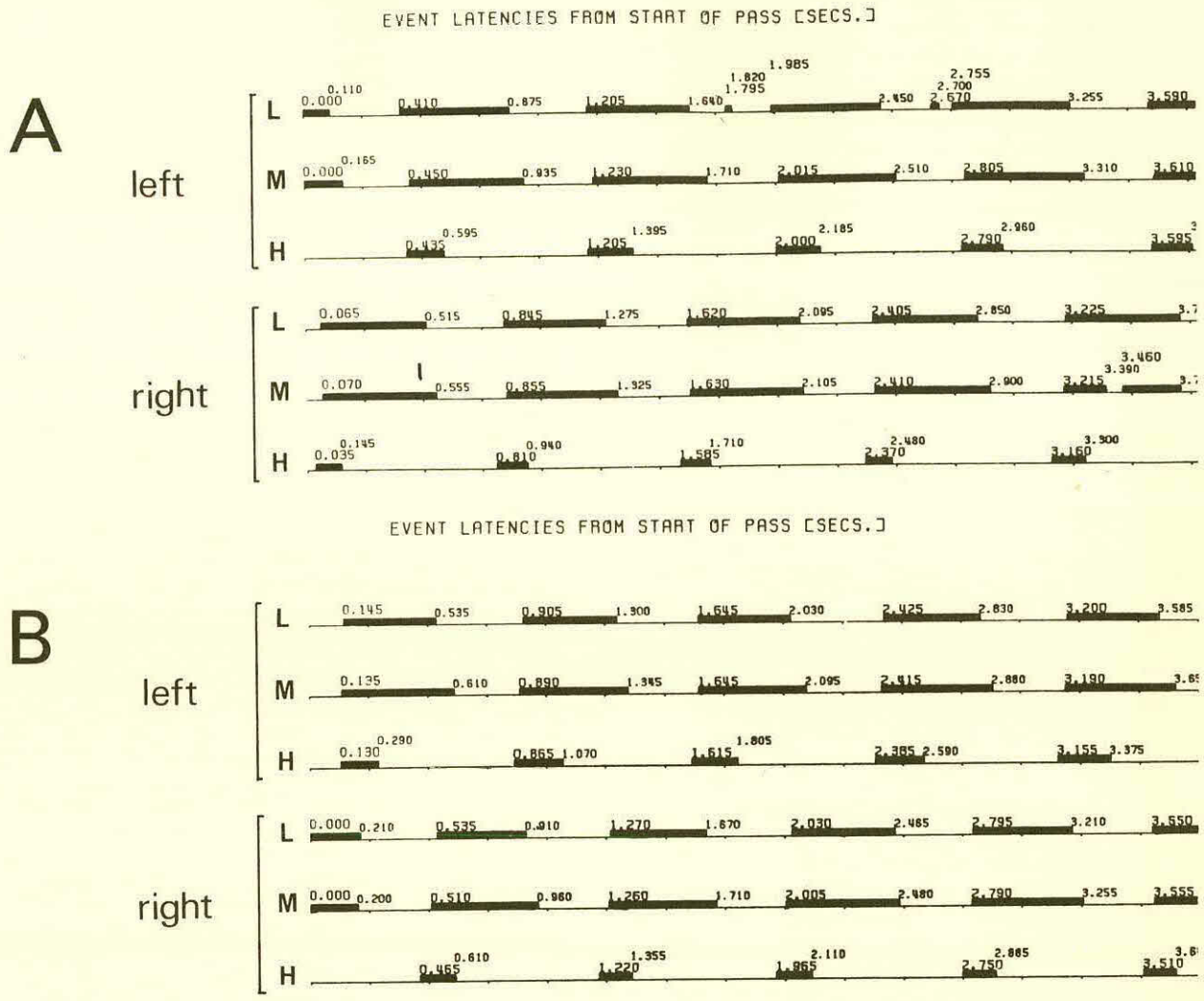


FIG 2

It was desired to determine if this correction of his equinovarus gait would persist after the electrical stimulator was turned off (i.e. was there any therapeutic or "carry-over" effect). For this purpose a special graphical display (see Fig 3) was developed to readily distinguish abnormal toe-first stance from normal heel-first stance. The parameter which is measured is the time delay (latency) between the stance events of heel contact and the initial contact of the forefoot. Each of the graphs (Sequences 1,2 and 3) consists of a group of 3 histograms compiled using all of the steps of a given "sequence". A sequence is a collection of usually 6 or more passes (traverses which the subject makes accross the walkway) which are of similar velocity and are performed under the same experimental conditions.

Consider for the moment only Seq 1. Stance events which began with a normal heel strike are plotted to the right of the origin. Steps in which toe-first stance occurred produce "negative latencies" since the forefoot contact preceded that of the heel, and these events are plotted to the left of the origin. With this representation more normal gait performance is indicated by a displacement of the data further to the right. A further refinement of the display permits registration of which aspect of the forefoot came into contact first (i.e. lateral "L" vs. medial "M" vs. lateral and medial simultaneously "M+L"). The small vertical tick marks indicate the distribution mean, and the horizontal bars show +/- std dev).

In Seq 1, for the majority of the steps stance began with contact of the lateral forefoot, and then contact of the heel followed (his equinovarus situation). For the foot contact data that were collected during Seq 2 the patient walked using the functional electric peroneal stimulator to correct his equinovarus. The immediate conversion to the normal "heel strike first" foot placement is readily apparent. The fact that after the heel strike, the first part of the forefoot to contact the floor was the medial side is a consequence of the slightly exaggerated eversion of the foot produced in this patient by stimulating the peroneal nerve using surface electrodes. In Seq 3 with the stimulator turned off, the patient reverted to his abnormal gait.

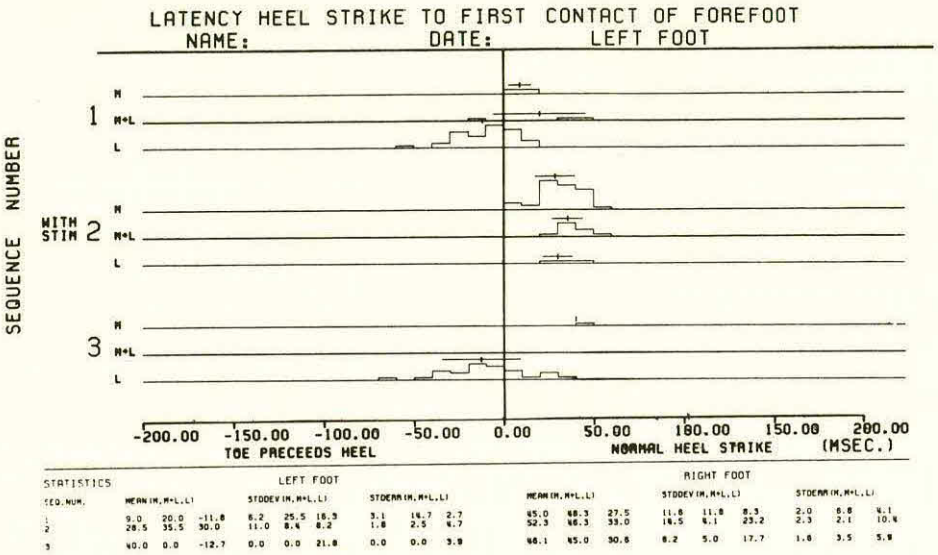


FIG 3

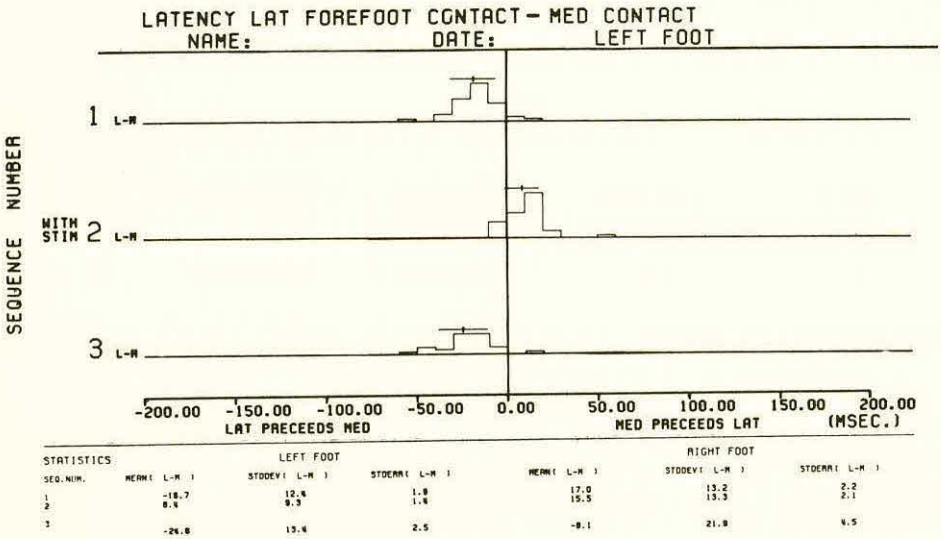


FIG 4

Another characteristic of foot placement which is a useful adjunct to that shown in Fig 3 is the time interval between contact of the lateral and medial forefoot or "roll" latency (if you will permit this neologism). The graphical layout (see Fig 4) is similar to that of Fig 3. A symmetric forefoot contact results in a roll latency of zero. In a typical varus forefoot, the lateral contact precedes the medial, and these data are plotted to the left of the origin. In valgus, medial contact precedes lateral and the data appear to the right of the origin. While in normal adult gait lateral forefoot contact usually briefly precedes medial contact, and in immature gait this sequence may be reversed (unpublished observations), for the "roll" display it is generally true that the data will be displaced further to either side of the origin with increasingly severe forefoot abnormality.

The same patient data that appear in Fig 3 were used to produce the roll display of Fig 4. The correction of the varus forefoot posture at the initiation of stance to a more symmetric forefoot placement (Seq 2) is apparent when the peroneal stimulator was in use, and the lack of a therapeutic or "carry-over" effect is indicated by the data shown in Seq 3.

The graphical displays presented here are just a few examples that demonstrate how tri-electrode footswitch information can be utilized to assess, quantify and document some specific aspects of abnormal foot placement. Other display schemes could be developed which are less analytical and perhaps less abstract but this mainly depends on what aspects of foot-to-floor contact the particular investigator wishes to assess. For example, simple bar graphs could be prepared of the average contact durations of the heel, lateral and medial aspects of the foot. In addition, the average durations of particular phases of stance such as foot-flat and double support may be calculated, as well as swing-stance ratios, cadence and stride length. Indices of asymmetry between the left and right feet for these parameters of foot placement could also be computed. Regardless of which parameters are analyzed it is frequently helpful to have a short length of video tape of each patient's gait available to assist in later interpretation of the footswitch data.

Precise footswitch analysis represents a powerful adjunct to the study of gait. We hope that the suggestions we have offered here may be useful both to those investigators who perform gait studies and to the many patients whose gait abnormalities we seek to understand and to correct.

ACKNOWLEDGEMENTS

This work represents a collaborative effort between the Rehabilitation Engineering Center at CWRU and The Motion Studies Laboratory of the Cleveland VA Med. Ctr. at Wade Park. Support was furnished by the National Institute of Handicapped Research Grant No. G001005815 to the REC and by funds to the Motion Studies Laboratory provided by the VA Rehabilitative Eng. R&D Program.

AN EVALUATION OF THE APPROACHES OF OPTIMIZATION MODELS IN THE PREDICTION OF MUSCLE FORCES DURING HUMAN GAIT

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+Children's Hospital Medical Center, Boston, MA

ABSTRACT:

Analytical optimization procedures for the study of human gait were investigated with the goal of determining individual muscle forces during a walking cycle. Improvements on existing approaches were found to be more crucially dependent on the accurate determination of joint angles and the calculation of joint torques than on the particular optimization criteria employed. Physiologically based information on the functions of, and constraints on, individual muscles supplemented the optimization procedures. The results of this study predict the temporal pattern and quantitative levels of muscle force in a walking cycle for a series of normal persons as a necessary precursor to future study of pathological gait.

The detailed diagnosis and correction of pathologic states of human mobility is primarily limited by an incomplete knowledge of the musculoskeletal system and the detailed and quantitative description of the activity of the individual muscles in the synergistic patterns which combine to produce movement. Commonly used techniques which employ myoelectric, force plate and kinematic gait pattern acquisition only provide a representation of the external manifestations of the underlying muscle physiology. There is no present method to study the actions of the involved muscles non-invasively. A model of the musculoskeletal system could, in principle, given kinematic data and with assumptions to mitigate muscle redundancy, predict individual muscle behavior.

Various experimental methods have been employed to acquire kinematic data during the gait cycle. [Eberhart et al. (1954); Winter et al (1972); Antonsson et al. (1979)] Joint angles are measured and combined together with inertial data to estimate the joint torques necessary to produce the observed motion. The problem of muscle redundancy relative to the available degrees of freedom is circumvented either by combining muscles into functional groups and/or optimizing some criterion such as the total muscle force or the mechanico-chemical output. [Crowinshield et al. (1978); Hatze (1976); Pedotti et al. (1978); Paul (1965); Seireg and Arvikar (1975); Hardt (1978a)] Such models do predict the general qualitative behavior of the muscle force gait pattern. Comparisons between the approaches and results of different investigators are difficult, however, because of the peculiar nature of each researcher's system for acquiring data and defining the individual parameters of his particular model.

This paper attempts to evaluate the significance of various factors which contribute to the formation of a muscle force optimization solution and to introduce appropriate improvements which provide a more accurate determination of the temporal patterns and quantitative levels of the muscle forces during gait. In the model, the body is viewed as a system of rigid links in which the muscles are treated as torque generators. The time-dependent torques and muscle moment arms about the joints are calculated from inertial information and kinematic data on the gait cycle from separately evolved gait analysis systems at M.I.T. and at the Boston Children's Hospital. [Conati (1977); Antonsson et al. (1978); Simon et al. (1978)] The indeterminant solution associated with a number of degrees of freedom smaller than the number of muscles are addressed by optimizing criteria such as the total force or mechanico-chemical energy of the muscles. Provisions exist to incorporate additional physiologic information.

Variations in the temporal patterns and quantitative levels of the predicted muscle force solutions are used to assess the significance of different modifications in the optimization model. The muscle force pattern shown in Figure 1 is found by optimizing the mechanico-chemical energy of the muscles and using values of joint torque which had been calculated without aid of a force plate. The forces are scaled by the body weight of the individual, and myoelectric signals, which had been recorded using surface electrodes, are displayed above some muscles. Serious problems are evident. Certain muscles exhibit inadequate force at time of maximal myoelectric activity or demonstrate activity inconsistent with negligible myoelectric signals. Moreover, the quantitative values of several muscles exceed their stress limits.

In Figure 2 is shown the muscle force pattern resulting from optimizing mechanico-chemical energy while using more precise joint torque values calculated with the aid of a force plate and allowing these values to be variable within the limits of their measurement error. The improvement in the solution is dramatic, especially in the reduction of the quantitative values to below the muscle stress limits. The muscle force predictions are then recalculated by minimizing the sum of the muscle forces instead of the mechanico-chemical energy output. (Figure 3) The differences in the muscle gait patterns between the two optimal

criteria are minor and limited to slight shifts on the muscle force distribution among functionally similar muscles.

The temporal pattern of myoelectric activity as reported by the University of California at Berkeley (1953) has been added as bars in the figures above the corresponding muscles. This was done to demonstrate the inadequacy of the optimization solution in predicting synergistic activity between functionally similar muscles. In order to correct this problem, additional constraints were imposed on the model so that functionally similar muscles would share the load in proportion to their cross-sectional area. (Figure 4) Temporal agreement with myoelectric activity is considerably improved.

The accuracy of a muscle force optimization model in determining a muscle force gait pattern was found to be crucially dependent upon the precision achieved in calculating joint torques and muscle moment arms and not upon the different mathematical assumptions of particular optimization criteria. However, the ultimate source of deficiencies in present gait models is incomplete information on the physiologic function and role of individual muscles during the gait cycle. Current research is addressing this issue, focussing on the joint of greatest uncertainty, the ankle.

ACKNOWLEDGMENT:

This work was conducted at the Harvard-MIT Rehabilitation Engineering Center under grant 23-P-5585411/1 from the Rehabilitation Services Administration.

Personal support provided by a fellowship from the National Science Foundation and in part from a fellowship from the Medical Engineering and Medical Physics Program of the Harvard-MIT Division of Health Sciences and Technology.

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FIGURES

1. Muscle force gait pattern found by optimizing mechanico-chemical energy without additional physiologically based constraints. The joint torques used are those previously calculated without force plate data and without the search procedure for relaxing torque values. Muscle forces have been normalized by the body weight of the individual. Myoelectric activity in the accessible muscles are displayed above the model prediction of that muscle activity.
2. Muscle force predictions produced by optimizing mechanico-chemical energy employing joint torque values using force plate data and the procedure for relaxing the torque constraints. No additional physiologically based constraints have been added. Figure 2 is for subject whose data are shown in Figure 1. Myoelectric graphs are as on Figure 1. Additionally, the temporal duration of myoelectric activity as reported by the University of California at Berkeley study is represented as solid bars.
3. The muscle force predictions found by optimizing total muscle force with joint torque values calculated using force plate data and the procedure for relaxing the torque constraints. No additional physiologically based constraints have been added. The data are for the first subject.
4. The muscle force predictions found by optimizing mechanico-chemical energy with joint torque values calculated using force plate data and the procedure for relaxing torque constraints. Physiologically based functional group constraints have been added, and the data are for the first subject.

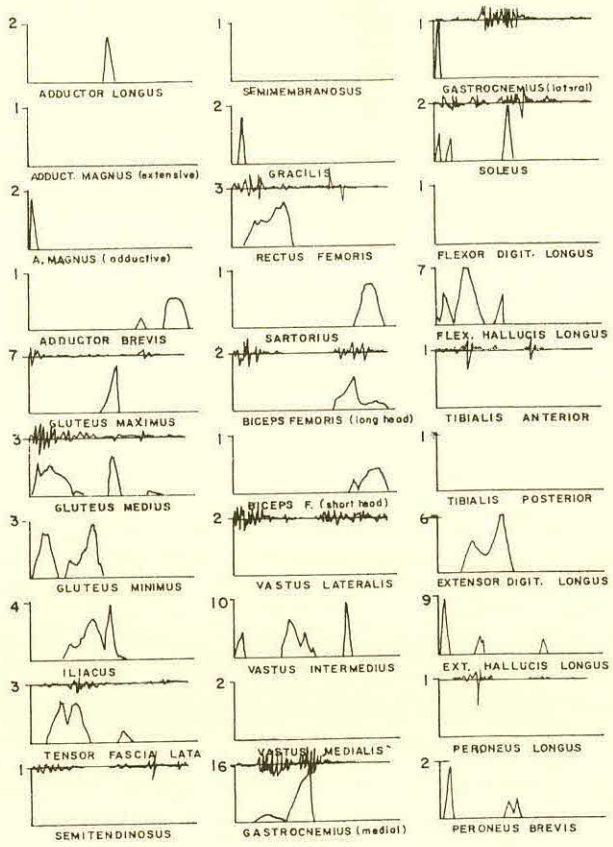

Figure 1

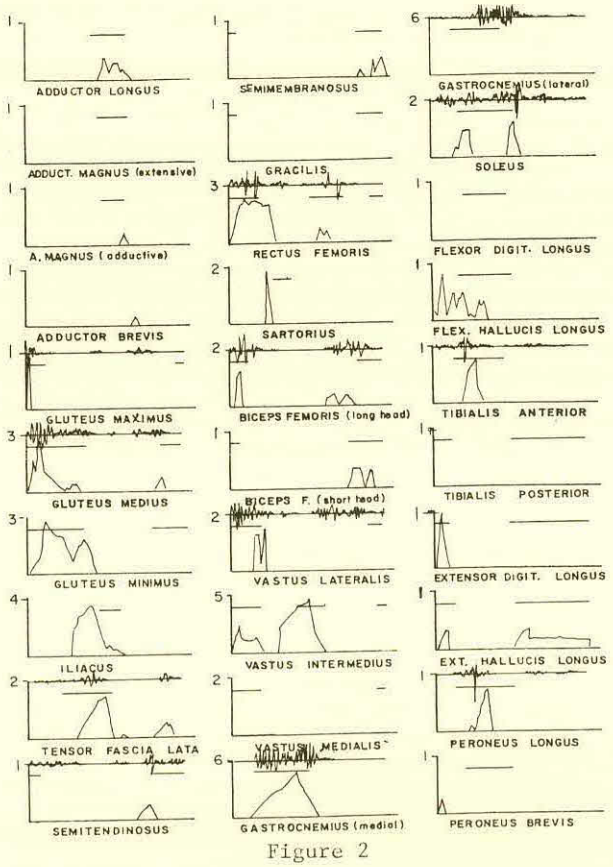

Figure 2

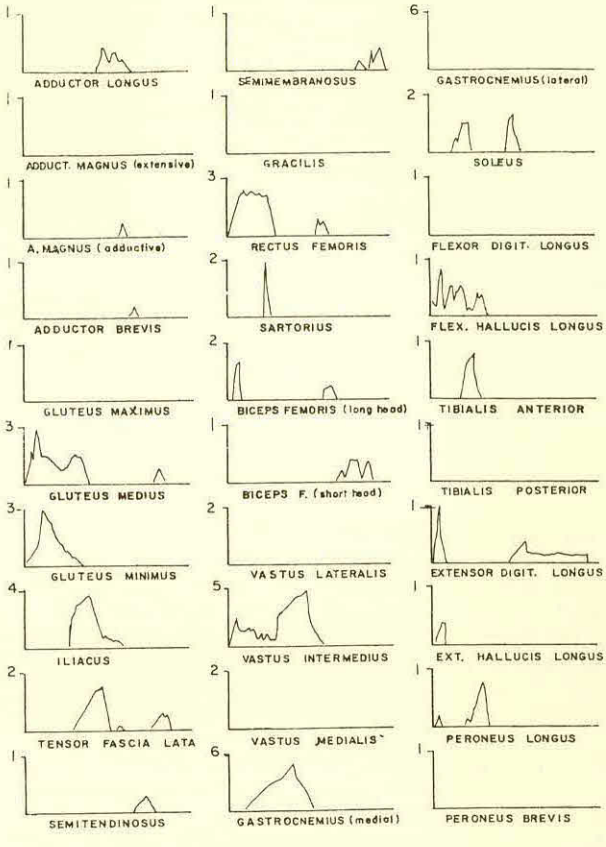

Figure 3

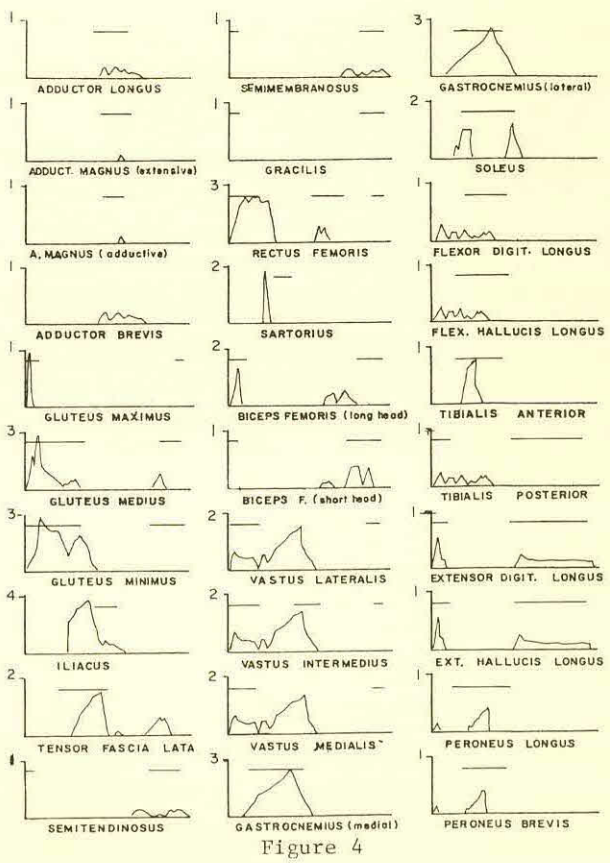

Figure 4

CLINICAL EVALUATION OF THE FOOT SWITCH STRIDE ANALYZER, MARK II

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The Foot Switch Stride Analyzer, Mark II, developed by Rancho Los Amigos Hospital, for the Veterans Administration, is a microprocessor based computer system which records foot-floor contact time, calculates all the significant gait parameters and provides the clinician with a permanent record.

The objectives of this evaluation were to determine the clinical value of this system in measuring and recording the gait characteristics of a variety of disabled people in five VA Medical Centers and one private institution.

The results of this evaluation indicate that this system is useful in measuring quantitatively certain gait parameters. Selected temporal and distance factors may be measured in a clinic with a minimal amount of equipment, space, and time.

INTRODUCTION

The Foot Switch Stride Analyzer, Mark II, developed by Rancho Los Amigos Hospital, Downey, California, for the Veterans Administration, is a microprocessor based computer system designed to record foot-floor contact data (obtained from foot switches) and calculate all of the gait parameters obtainable from this data. This system makes it possible to run patient tests in any convenient walking area and obtain printed records of the gait parameters immediately following each test.

This system has been designed to be used in a clinical setting to objectively measure principle gait parameters which are: velocity, cadence, stride length, number of strides, single limb support, double support, and swing and stance time. Each are measured in time as a percent of normal.

OBJECTIVE

The purpose of using this system in a clinical setting was to evaluate whether or not this device can quantify certain characteristics of gait that describe the gait pattern.

The primary objective of the evaluation was to explore if this system could be used to obtain selected temporal and distance factors in a clinic with a minimal amount of equipment, space, and time.

DESCRIPTION

The foot switch stride analyzer system consists of a pair of "Foot Switches", a "Start/Stop Controller", a "Recorder", and a "Calculator". The Recorder stores data generated by the Foot Switches and Start/Stop Controller as the patient walks. The Calculator accepts the data stored by the Recorder and calculates the gait parameters, printing the results on a permanent record.

INSTRUMENTATION (1)

Foot Switches

The Foot Switches (Figure 1) are worn as insoles in the patient's shoes and indicate the total time each foot is and is not bearing weight. The Foot Switches have the heel section separated from the forefoot section so that one pair of switches can accommodate a range of shoe sizes. As a result, three basic sizes of Foot Switches will fit the normal range of adult shoe sizes. The switches are situated at the heel, the first and fifth metatarsal, and the great toe. Each Foot Switch is connected to the Recorder by a five-foot cable.

Start/Stop Controller

The Start/Stop Controller is a light sensitive switch designed to be activated by special triggering lights set up at the beginning and end of a six-meter walkway (the velocity calculation is based upon the patient walking six meters) (Figures 2 and 3). The Start/Stop Controller is connected to the Recorder by a four-foot cable. It controls the Recorder, providing signals which determine the elapsed time of the

test, thereby making the velocity calculation possible.

An alternate control for the Recorder is a pushbutton switch (on a four-foot cable) which the tester would operate manually. If this switch is used in place of the Start/Stop Controller, the operator conducting the test must walk with the patient, pushing the button at clearly identifiable marks in the walkway to indicate the beginning and end of a six-meter distance.

Recorder

The Recorder is powered by a nine volt transistor radio battery and attaches at the patient's waist by a velcro belt (Figure 4). The Recorder records the elapsed time of a run so that the average velocity can be calculated. It also records the foot switch patterns and the times that these patterns change. A special routine in the Recorder program eliminates problems from "contact bounce" when the foot switches open and close. A battery test circuit is provided to insure that the system is always used with adequate power. When the Recorder switch is pushed to "Reset", the "Ready" indicator will light if the battery voltage is adequate to operate the Recorder.

Calculator

The Calculator is powered by 115 volt AC line current. It transfers the data (via the data cable) stored in the Recorder into its own memory, checks for irregularities in the data which would provide erroneous results, and calculates all of the gait parameters. (Figures 5 and 6). In addition to printing the numerical values of the gait parameters, the Calculator prints a record of the changing foot switch patterns (where H = Heel, 1 = 1st Metatarsal, 5 = 5th Metatarsal, and T = Great Toe). These are printed to look like footprints in time (with a new character being printed each 1/25 sec.) when viewed along the length of the paper. If the duration of the test is greater than seven seconds, then only the first seven seconds are printed.

The Calculator has been designed for ease of operation. The activation of only one of two pushbuttons (male or female) is required to perform the calculations. In addition to initiating the operation of the Calculator, these pushbuttons select the male or female "normal" data for determining the percent normal values. The "normal" data was established at Rancho Los Amigos by testing forty normal adults.

EVALUATION SITES

Five Veterans Administration Medical Centers and one private institution evaluated the system for a period of six months to a year. They were VAMC's New Orleans, Little Rock, Dallas, Biloxi, and Tampa. The Hospital For Special Surgery, Cornell Medical Center, New York, was the sixth evaluator.

Over 100 subjects with the following etiologies were tested with the system:

- Total hip joint replacements
- Total knee joint replacements
- Rheumatoid Arthritis
- Osteoarthritis
- Polymyositis
- AK amputations
- Low Back Syndrome
- Vascular Claudication (Peripheral Vascular Disease)
- Hemiplegia

RESULTS

The following is a summary of some of the results of the evaluation:

1. There were intermittent difficulties in processing the data from the Recorder. This manifested itself by misalignment of the printer format.
2. Footswitches required frequent repair of both the pin connectors and the internal connections of the foot pad switches.
3. There were difficulties in placing the footswitches inside the shoes of subjects who wear cowboy boots or tennis shoes. Problems with a single foot-switch can sway data and caution must be used. For example, single-stance-time on the unaffected side may be shortened by a sticking switch. Velocity may be calculated outrageously low.
4. In some cases, the wires leading from the foot-switch shoe inserts were not quite long enough to reach the back-pack Recorder.
5. The greatest value of the system is in the calculation of multiple parameters of gait. Data is provided instaneously and allows comparison with calculated normals. Since the data is calculated immediately, it permits determination of the value of canes, crutches, orthoses, and prosthetic alignment.
6. The system is particularly useful in measuring velocity and is a reliable indicator of lower-limb pathology. Patients with hip, knee or foot pathology have consistent reproducible velocities.

CONCLUSION

The Foot Switch Stride Analyzer, Mark II, is a useful tool to measure quantitatively the gait characteristics of a variety of disabled people. It may be used to document an initial patient evaluation and subsequent treatment program effectiveness.

The system is easy to use in a clinical situation. It requires a minimal amount of equipment, space, and time.

ACKNOWLEDGMENTS

The Technology and Performance Evaluation Service, VAREC, appreciates the

time and effort involved in evaluating this system by the staff of the Rehabilitation Medicine Services and the Departments of Orthopedics at VAMC's Little Rock, Dallas, New Orleans, Tampa, and Biloxi. The participation of the Hospital for Special Surgery, Cornell Medical Center, is also appreciated.

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This development was supported in part by the Veterans Administration Contract No. V101 (134) P - 538.

Fig. 1

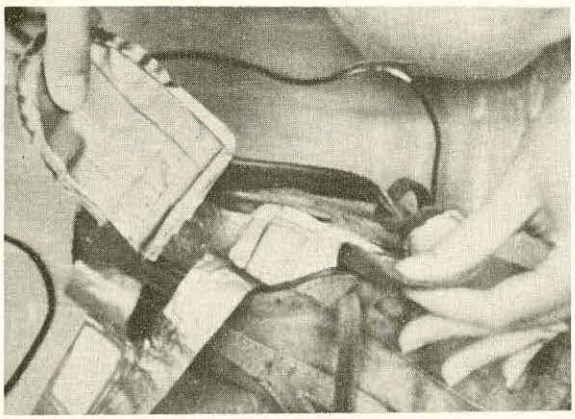


Fig. 2

Fig. 3

Fig. 4

Fig. 5

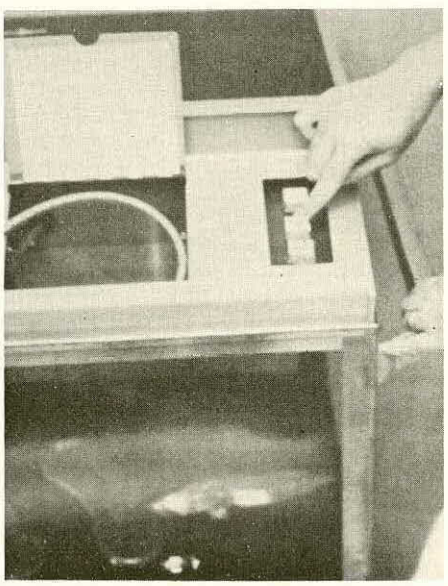
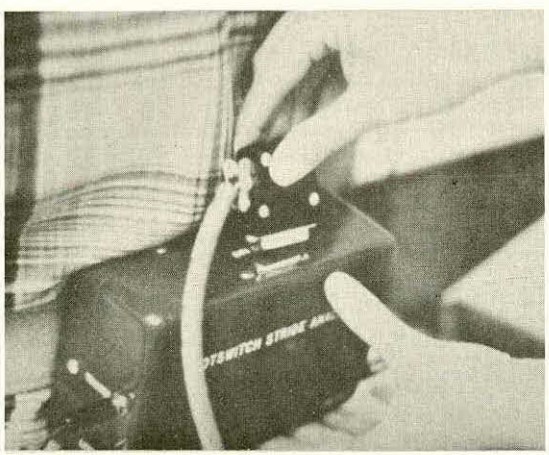


Fig. 6



ENGINEERING THERAPY: A CASE REPORT

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ABSTRACT

The case of a 62 year old woman who received a head injury is presented. As a result of her injuries she had severely limited functional capabilities and was unable to communicate or interact with her environment in any meaningful way. She participated in an intensive rehabilitation program but showed no significant improvement. She was transferred to a nursing home where we first saw her. We developed a microcomputer based communications system which she was able to use. There was significant improvement in her voluntary motor skills and motivation during the course of her "engineering therapy". Many of the improvements were not directly related to the operation of her communication system. Other benefits such as increased participation in her therapy by the nursing home staff were noted. The value of engineering therapy is discussed.

HISTORY

A 63 year old woman was involved in an automobile accident and received multiple injuries to the head, abdomen, and legs. A left frontotemporal depressed skull fracture required surgical elevation. Her neurologic impairment included severe quadriparesis, right worse than left, and perceptual-cognitive difficulties. She required a chronic tracheostomy and gastrostomy. She was described as alert but unable to communicate when she was transferred to a rehabilitation hospital three months after the injury. A cervical laminectomy was subsequently performed to relieve a mild spinal cord compression (C5-C6). No neurologic improvement was noted as a result of this procedure.

When she arrived at the rehabilitation hospital, she seemed alert and able to respond to simple commands (open or close eyes). She had no voluntary motion in the right extremities and almost none in the left. Communication abilities were minimal and she was inconsistently able to signify yes/no via hand motion or eye blink. Her speech was severely apraxic, dysarthric, and non-functional. During the course of her rehabilitation program there was a slowly progressive decrease in voluntary motion of the left extremities. She was transferred to a nursing home following five months in the rehabilitation program.

Two years post injury, the patient was referred to us by a family member. She was in the nursing home spending each day in bed and had not been in a wheelchair for months. Examination demonstrated almost no functional capabilities for control of any device. Her voluntary motions included: eye movement, side-to-side head motion, left elbow flexion, lateral pinch with the left thumb, and incomplete extension of the left knee. It was concluded that the patient might be able to develop enough functional capability to control a simple environmental control or communication system. The patient's family was informed of this conclusion. We were not extremely optimistic in view of the patients limited functional capabilities and the lack of information regarding her perceptual-cognitive deficits. Treatment was requested.

TREATMENT

We began by finding functional voluntary motions that could be used to operate switch controls. The extension of the left knee was determined to be the most consistent motion for this purpose. It was necessary to flex the hip to make use of this motion and even then the patient had difficulty initiating the movement. Lateral pinch was found to be the next best motion but was highly inconsistent and fatigable.

Knee and hand switches were designed and built to make use of the motions described above. A twelve channel environmental control unit (ECU) requiring two switches for control was used for initial evaluation and training (one switch to sequence through the channels and one to turn the individual channels on and off). Initial trials showed the patient could scan to a preselected channel using knee extension to activate the scan switch. Lateral pinch was not functional for switch operation initially. The patient fatigued rapidly and training sessions were brief. Improvement was noted over the first few sessions but the twelve channel ECU was too complex for initial training. A three channel scanning ECU-communication device was designed and built for training purposes. Incandescent display modules (with acetate overlays which could be written on with a marking pen) were plugged into individual channels.

Continued progress was made with training. Hand motion greatly improved and became more consistent than knee extension. Head motion also improved (allowing her to signify yes and no consistently) as did stamina. She was able to perform relatively complex tasks with her communication device such as selecting the composer of a given musical composition.

A speech-language evaluation showed the patient to possess basic language skills including reading and auditory comprehension. Difficulties included marked fatigability in comprehension, motor skills, and motivation.

It was decided that the patient had advanced as far as possible with the three channel system and would not be sufficiently motivated to improve further. The next step was to develop a more advanced communication system. Functional capabilities and motivation were still improving at this time. The patient was developing the ability to write her name using a marking pen with some assistance. She started to point to the display modules instead of using the switch operated scanning system. She was in a wheelchair daily and her sitting tolerance was improving. Improvement in other "non-related" areas, such as swallowing, also occured.

An Apple II microcomputer was chosen as the basis of her new communication device. The advantage of the microcomputer based system was its extreme flexibility. The first program developed for her displayed up to nine phrases on a television screen. The number of choices was programmable. Enlarged characters were used on the video display as it was determined that the patient could not read the normal sized characters. The system continually scanned through the choices and would stop upon activation of the control switch. A flashing arrow pointed to the current line and changed from white to black if the current line was chosen. The Apple was interfaced with a Votrax VSB voice synthesizer so that when a phrase was selected it was also spoken. Three menus of choices were developed dealing with dialog, feelings, and personal needs.

The patient was able to operate this communication system with little additional training. She could consistently "speak" any designated phrase and answer a direct question. She did not, however, spontaneously use the system for communication. Eventually, she started to use direct selection of the keys to spell out words and communicate spontaneously. A program was written which displayed her selection in double size characters on the television screen and provided some editing capabilities.

The patient demonstrated enough improvement that a medical evaluation for admission to our inpatient rehabilitation service was performed. The conclusion from this evaluation was that the patient was a marginal candidate for intensive rehabilitation. The goals of a hospital admission included: trial removal of the tracheostomy; training in swallowing, mastication and eventual total oral feeding; training in pulmonary toilet and effective cough; increased wheelchair sitting tolerance; correction of contractures and associated spasticity; and improvement of communication skills. The patient is currently awaiting admission to our rehabilitation service.

DISCUSSION

This case represents a somewhat unique approach to a rehabilitation problem. The patient initially participated in an intensive rehabilitation program including physical and occupational therapy but was unable to substantially benefit from it. In fact, she showed a decrease in her functional capabilities toward the end of the program. This left her rehabilitation team with no practical means for further interaction or training and so she was placed in a nursing home.

Initial evaluation by a rehabilitation engineer showed some limited potential for interaction and training through the use of technological tools. The direct benefit of the systems designed for her have yet to become of great practical use. The indirect benefits, however, have been great. She is more responsive and is interacting with her environment to a much greater extent than at any other time following her accident. The nurses and therapists at the nursing home have responded to this change and are working with her many more hours than before her "engineering therapy" began. There is now hope that she can achieve some of the limited goals stated earlier through a complete program on our rehabilitation service where she will work with physical, occupational, and speech therapists; physicians, nurses, psychologists, and engineers.

We believe that the technological tools available to the rehabilitation engineer provide numerous opportunities for a disabled individual to interact with his or her environment. These tools provide a useful supplement to the more traditional methods commonly employed in rehabilitation programs.

A MULTI-LANGUAGE, PORTABLE TEXT-TO-SPEECH SYSTEM FOR THE DISABLED

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Previous experience with speech output aids for blind and non-vocal persons has shown great promise. The need for individual adjustments and the relatively small market makes flexible, programmable aids necessary. We have developed a modular microprocessor text-to-speech system that is portable and battery operated. This prototype has been adjusted to several different users. Programs for different languages are developed. Connection of text sources are made simpler by standardized interfaces. One special attachment is a 500 symbol Bliss board and a related Bliss-to-speech program that transform the symbol string to well formed sentences.

INTRODUCTION

The advances in speech research and electronics have made a new class of aids based on different kinds of artificial speech available for the handicapped. The aids range from devices with a small fixed vocabulary of digitized natural speech to unrestricted text-to-speech systems. We are here concerned exclusively with aids of the latter type that transform any text to synthetic speech. Since many of the aids, such as speech prostheses and reading machines, offer new possibilities, the functional specification of the aids are in many cases still to be done. At our laboratory a minicomputer-based text-to-speech system was developed three years ago and has since then been used in different experimental applications for blind and non-vocal persons(1,2). This equipment was generally very well recieved, but in this context we want to focus on some of the negative reactions.

- Too space consuming, not portable.
- It has to be mains connected.
- Too noisy (fan noise)
- Spelling mode not available.
- Speech quality sometimes too low.
- Need for different text input devices.
- Production cost too high.
- Not in regular production.

The last remark is of course related to the preceeding. It has been shown to be impossible to engage any commercial company in production of this kind of aid. The general objections are that the market is too small and too uncertain, especially in a small language community such as Sweden, and that the cost of developing a production prototype is too high. This is a situation that we face in supplying different kinds of technical aids for the handicapped. Part of the answer to this dilemma lies in developing aids that are closer to produceable equipment at research institutes. Modular construction also give the possibility of using the same units in different kinds of aids. Standardization and sharing developing efforts internationally also gives a potentially greater market.

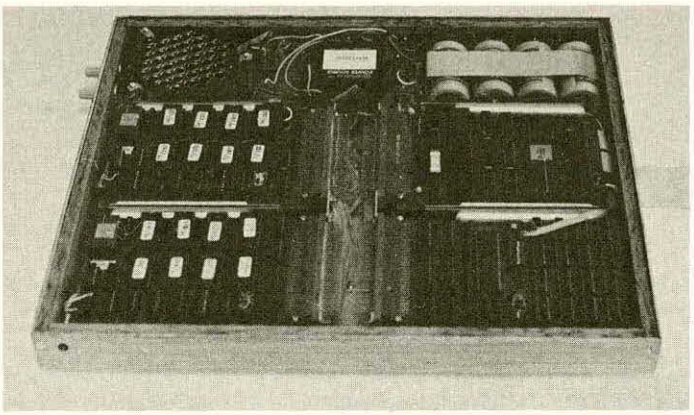

FIG. 1 Top-view of the text-to-speech system

Our present project is focussed on such a development and we have tried to accomodate as many of the suggestions for improvment as possible based on the experience from the previous prototype mentioned earlier. A substantial part of the work is also devoted to evaluations and application-oriented hardware and software adjustments.

TEXT-TO-SPEECH HARDWARE

The present text-to-speech system consists of a conventional formant speech synthesizer, a powerful microcomputer based on the MC68000 16-bit microprocessor and a variety of text input equipment. In the basic configuration the microcomputer consists of four eurocards; the processor card, one RAM memory card (32k byte) and two PROM memory cards with each 32k bytes of memory and one serial I/O port. The microcomputer box also contains rechargable batteries, loudspeaker and different kinds of controls (fig. 1). The synthesizer box is of the same size and fits under the microcomputer. As powerful signal processors become more available this component of the system will of course shrink drastically both in price and physical dimensions. These boxes

connected to any kind of text source, like a conventional computer terminal, operates as a general text-to-speech system. To make the system fully portable we have constructed a special "lid" to the computer box that contains a low profile keyboard and 16 character liquid crystal display (fig. 2). Other attachments include enlarged keyboards and a 500 symbol Bliss board which will be described later.

GENERAL SOFTWARE FEATURES

The text-to-speech program is initiated on "power on". It operates in three basic modes; spelling, word by word and sentence mode. An additional mode allows a combination of Bliss symbol and ordinary alphanumeric input. The principles for the text-to-speech conversion is described elsewhere (3). Unlike commercial synthesizers we do not operate with a fixed set of sounds (allophones), rather the sound inventory is fully under program control and the realization of the sounds are language dependent and adjusted according to the linguistic context.

It should be emphasized that the system accepts any kind of text, including numbers.

The talking speed is adjustable both by a knob and by keyboard commands. In sentence mode continuous reading at above 250 wpm (words per minute) is possible.

Besides the ordinary keyboard connection there is a possibility to connect to a host computer. This is neccessary in the talking terminal application but is also useful in other contexts.

Keyboard commands to the system consists of a command prefix plus a command character. Some of the implemented commands are;

- Change to spell mode
- Change to word mode
- Change to sentence mode
- Stop output from synthesizer
- Continue output from synthesiser
- Slow down speech
- Speed up speech
- Save last sentence
- Retrieve a saved sentence
- Reinitiate the program
- Write to a host computer

The text-to-speech system has been programmed for several languages. Versions now exist for Swedish, English, Spanish, Finnish, German and Chinese.

APPLICATIONS FOR THE BLIND

The generality of the text-to-speech system module makes it possible to use it in different kinds of aids for the blind. Some applications have already been explored.

Automatic "talking book" production

In cooperation with the Swedish Federation of the Visually Handicapped (SRF) we use the system to record different kinds of text material on audio tapes. The text is supplied

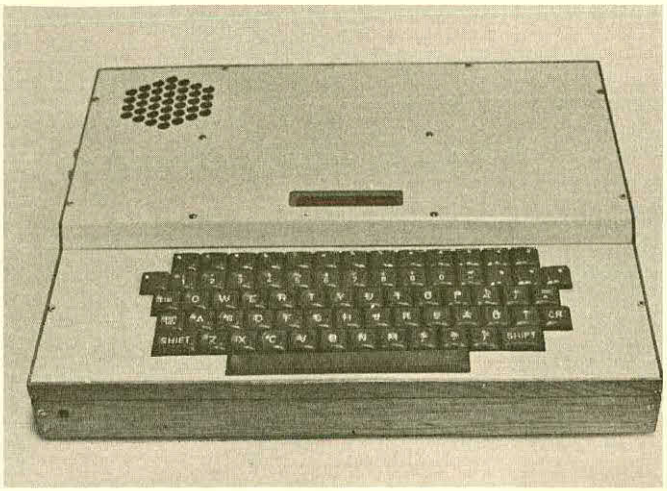

Fig. 2 Low profile keyboard mounted on top of the text-to-speech system.

from ordinary casette tapes which are used for text editing and printing of Braille books at the SRF printing office. In the future the blind person will be able to choose which kind of media he wants the text to be presented in; braille or synthetic speech.

Reading machine

So far we are missing a suitable OCR (optical character recognition) equipment to realize a reading machine for the blind. Special characters in the Swedish language make it necessary to develop special recognition schemes. Work is however under way in several places and we hope to be able to realize a reading machine for the blind within the next few years.

Talking terminal

In cooperation with the Swedish Institute for the Handicapped a special working place for a blind user will be developed during 1981. It will be equipped with a small computer and a talking terminal. The goal is to get experiences of how such an equipment should look like and what facilities are needed. Special emphasis will be placed on studying the ergonomics of a normal working situation. The computer will be used for both programming and editing of text.

Talking braille recorders

The recent development of braille recorders with editing and search capabilities has created a possibility for blind persons to interactively work with great volumes of text. Speech is in many cases a more convenient and fast mode of presentation than braille. Giving this kind of equipment a speech output option will greatly enhance its usefulness. This kind of interface will be implemented.

New kinds of information systems, such as TV-text, Viewdata and electronic mail, will be directly accessible by blind users through an appropriate connection to a text-to-speech system.

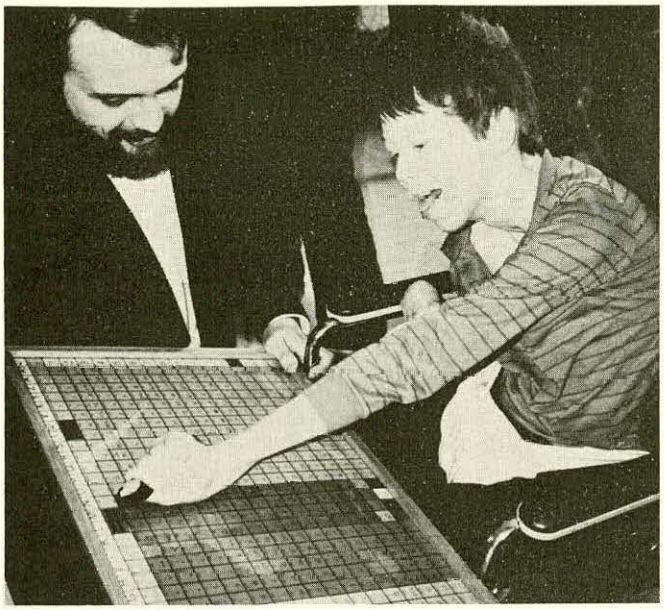

Fig. 3 Bliss board with speech output in use

APPLICATIONS FOR THE NON-VOCAL

Speech prosthesis with "typed" input

The previous prototype has been used extensively for non-vocal in both communication and language training. The smaller size and the possibility to run on rechargable batteries will make the use as a personal speech prosthesis feasible.

The main problem seems now to be on the text typing since the majority of the non-vocal have additional motor disabilities. Several different keyboards are interfaced to the system, such as a Canon Communicator and enlarged keyboards. Interfacing other kind of control devices are planned

Communication speed can be increased by storing whole phrases as 2-3 letter codes.

Bliss communication with speech output

A special attachment to the text-to-speech system has been developed for Bliss symbol users. A standardized chart containing approx. 500 symbols has been used. Symbols on the board are actuated by putting a magnet in the appropriate square. After an adjustable delay the code for that symbol is transmitted to the text-to-speech system via a standard RS-232C interface. The symbol set contains numbers and digits. By adding a few special symbols the whole capability of the general text-to-speech system , such as temporarily storing and quickly retrieving sentences is accessible from the Bliss board.

The Bliss-to-speech program is an expansion of the standard text-to-speech program. Therefore, Bliss symbols and spelled text can be intermixed to produce a spoken message. As each symbol is chosen, the synthesis system pronounces it as it were the only word in a sentence. When the user terminates the sentence with a punctuation mark the complete gramatically well formed sentence is spoken.

Each symbol on the Bliss board corresponds to a lexical entry giving its pronunciation followed by a code for its part-of-speech and other features such as declination category.

First the phrase structure is established, then rules for well-formed sentences are applied. The system has been successfully tested on several types of declarative and interrogative sentences including some with more than one clause. These sentence types can be composed of around 25 types of noun phrases and 25 types of verb phrases. This facility allows a user to compose many well formed sentences with flexibility of expression.

The possibility to spell words has already proved to be valuable in that it adds to the expressional capability. Many Bliss user have good language comprehension and this kind of device is judged to be of great help in language production training.

FINAL REMARKS

The presented text-to-speech system is still not in regular production. We feel, however, that trying the system out in many different applications is of primary importance. The experiences gained are necessary for a good specification of the final product. Some of the features of the present system are in this connection worth mentioning. The modularity has made it easy to adjust to different needs. Using state-of-the-art technology makes the system small and relatively cheap. The choice of a powerful processor makes future expansions and improvements of the text-to-speech program easy to accommodate without sacrifying speech rate.

Experience from the applications tells us that often the greatest problem in utilizing this kind of aid is the individual adjustments. This makes it even more important that the basic text-to-speech module is general enough to interface to a great variety of text sources and control devices.

Text-to-speech technology will, with improved quality, spread to more applications in everyday life. This will also implicate greater production volumes and lower costs and increase the availability for the disabled. It is important that the needs of the handicapped are well understood so that the demands could be considered in a commercial product.

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PRESENTATION OF COMMUNICATION PROSTHESES

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SCHNEIER COMMUNICATION UNIT

ABSTRACT

A virtual plethora of communication aids and devices representing a broad range of technological sophistication and capabilities is available for severely communicatively impaired individuals. This paper discusses the importance of the physical presentation of communication systems to facilitate accessibility and successful communicative interaction.

INTRODUCTION

Commercially available augmentative systems such as the Handivoice™ 110, Handivoice™ 120, Canon Communicator, and the Sharp Memowriter EL-7000 are each appropriate for certain non-speaking individuals manifesting a profile of strengths and needs commensurate with the aid's capabilities. Once a communication device has been selected, it then becomes necessary to discern a means of presenting the aid so as to increase its effectiveness and efficiency. Through this presentation process, a commercial device becomes a personalized aid. Each manufacturer packages their product for general distribution and acceptance however, the ultimate quality of the instrument is influenced by its accessibility to the non-speaker.

The manufacturer's level of interest is far removed from the concerns of application efficacy.

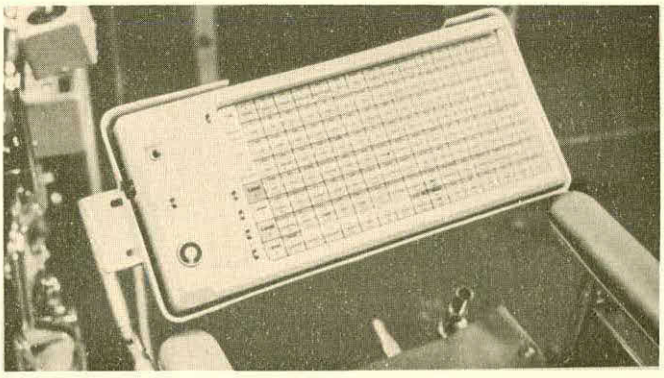

Figure 1. Tray for the Handivoice™ 110 which is capable of wheelchair mounting. In order to meet the individual needs of the clients using the Handivoice™ 110 the tray adjusts to a variety of vertical inclines. This adjustment can improve both visual and physical access to the keyboard.

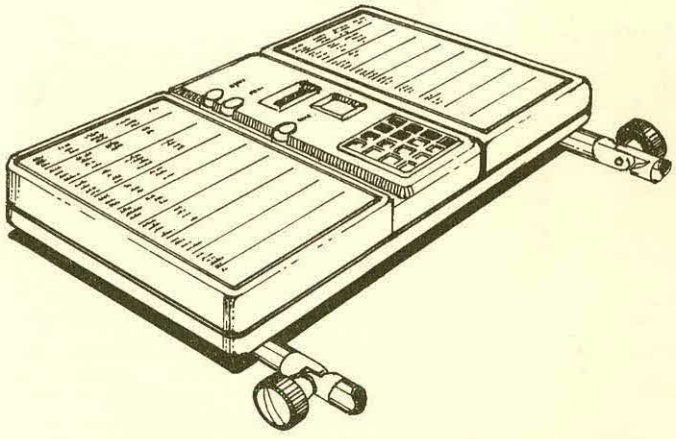

Figure 2. Rendering of Handivoice™ 120 wheelchair mounting. Tray has been designed to present numerical code display and adjust to various vertical inclines.

Combination Displays

The communication process in a young child is dynamic and synergistic. Expressive needs change relative to physical, cognitive, emotional, educational and social maturation and environmental demands. Often, the communication specialist recommends an augmentative system which combines a variety of outputs, modes, utilizes both permanent and temporary displays, may be used with more than one control movement, and is activated by a dual form of indication. Please refer to Figures 3 and 4.

Furniture Adaptations

Frequently, youngsters in educational settings employ a multiplicity of technical aids including communication devices, taperecorders, calculators, and typewriters. In order to facilitate the accessibility of these units, adapted tables and desks have been fabricated by the Rehabilitation Engineer. Please refer to Figure 5.

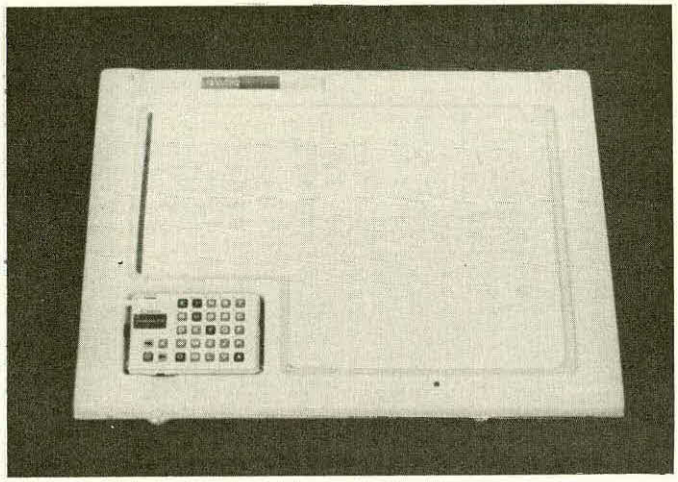

Figure 3. A system which combines a traditional word/phrase board with a Canon Communicator.

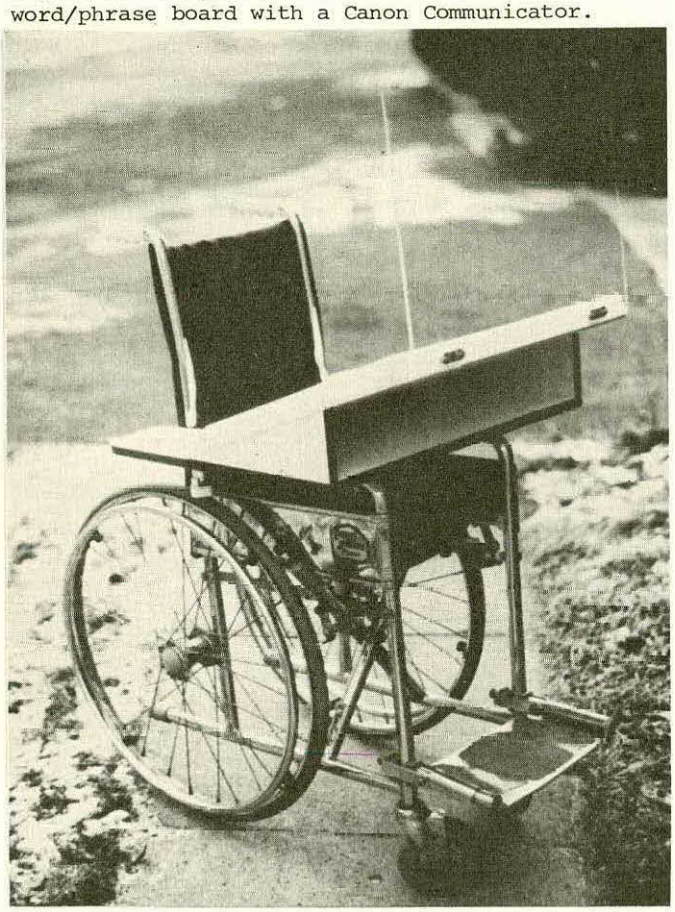

Figure 4. A system which combines words, Blissymbols, and pictures in a direct selection format, and also utilizes a vertical display for use either with an optical pointer and/or an ETRAN approach.

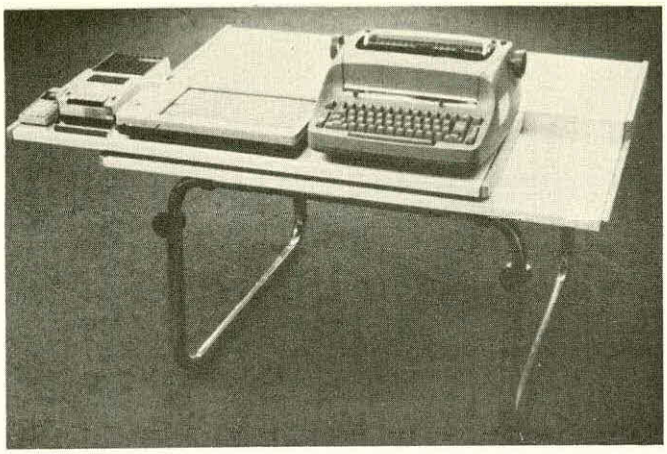

Figure 5. A classroom work surface that displays a variety of academic and communication aids. Shifts from side to side to increase visibility and accessibility. Table adjusts in height and angle to accommodate a wheelchair and a client's growth.

Vacuum-formed Displays

In order to produce the items depicted in Figures 1, 3 and 4, a mold constructed out of wood and polyester resin is constructed. A vacuum formable plastic such as kydex™ or uvex™ is used to produce the finished trays.

SUMMARY

Clients referred to the Schneier Communication Unit of the United Cerebral Palsy Association in Syracuse, New York receive a comprehensive communication assessment. Typically, one of three recommendations results from this evaluative process; the purchase of a commercially available device or the purchase of a commercially available aid requiring design modifications and/or a presentation format or, finally, an original fabrication such as the device depicted in Figure 4.

The Rehabilitation Engineer and Communication Specialist must unify their efforts to develop the most appropriate and efficient communication system which assumes a number of components including the instrument itself, that is, the hardware and software, the physical layout, and an examination of the interractive/integrative efficacy of the total plan.

NONVOCAL COMMUNICATION SYSTEM WITH UNLIMITED VOCABULARY USING APPLE AND SPEEC-SYLLABLES

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Biomedical Engineering Center
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A nonvocal communication system was designed using the Apple, with the Graphics Tablet as a lapboard and the SuperTalker for speech production. Language is represented by SPEEC-Syllables-300, a system which includes all single phonemes and the 235 most frequently occurring syllables in spoken English. The language system provides access to an unlimited vocabulary with high intelligibility for words made up of whole syllables, and reduced intelligibility for words requiring joining of single phonemes. The SPEEC-Syllables-300 system uses the SuperTalker phrase tables to store 275 items in memory (close to the maximum number the memory can contain at the sampling rates necessary for good intelligibility). Approximately three quarters of words are produced by means of syllable combinations, one fifth by joining syllables and phonemes and the remainder by joining only phonemes. Experience with a communication device that produces auditory feedback may be helpful in promoting phonological development.

INTRODUCTION

The availability of Apple computers in many schools opens up a new opportunity for enhancing nonvocal communication by making use of these devices. A system has been developed using two of the Apple options, the Graphics Tablet and the SuperTalker, as an interface and a means for producing an unlimited spoken vocabulary, respectively, in conjunction with a system, SPEEC-syllables, made up of frequently occurring English syllables. A demonstration of this system will accompany the presentation.

The Graphics Tablet as Interface

The Graphics Tablet is a device which electromagnetically senses the position of a special stylus to better than 1/100 of an inch over the roughly one square foot of its surface. Since, for all practical purposes, this defines a uniform and continuous space, flexible menus for selection of communication board units can be produced, tailoring shape, size and placement of menu items to each individual as desired from time to time. Direct contact of the stylus on the tablet is not necessary. Therefore, menus can be in the form of overlays that sit on the tablet, allowing easy modification of the system as a student develops more facility with it, and permitting the same equipment to be used by multiple students with different communication board needs. Thus, to vary both content and layout of a menu requires only a change in the overlay and a relatively minor change in software.

It is important to note that, as the Tablet concerns itself with only location, any function may be assigned to any location. Thus, while most locations are used to represent specific language units (e.g. "THE" "MYSELF"), some represent useful actions (e.g. "repeat last unit louder" "store sequence of units for later delivery").

The SuperTalker as Communicator

The SuperTalker enables one to record any sounds (though apparently optimized for speech) in chunks, ranging in size from very short (a single vowel) to lengths on the order of fifteen seconds, and then play them back in any desired order. The Vocal Production System (the software for the SuperTalker) provides for the creation of "phrase tables" (the collection of recorded entries, whatever their content). Only two tables can be resident in Apple's memory at one time. Others may reside on the floppy disk(s) available to the system. For multiple table usage, one table, containing the most frequently used units, is kept in memory permanently, while the second allowable table swaps in and out with others, depending on need. Swapping of the tables should be minimized, due to the delays inherent in the procedure (about 10 seconds for loading a disk).

The phrase tables of the SuperTalker are used to store high frequency, high intelligibility units of sound, as well as all single phonemes, which are strung together in order to produce English words with no vocabulary restrictions.

SPEEC-Syllables: Language System for Unlimited Vocabulary

The SPEEC-Syllables language system is a set of syllables chosen for their frequency of occurrence in combination, according to the SPEEC technique (Goodenough-Trepagnier and Prather, in press; Goodenough-Trepagnier et al., submitted). The SPEEC technique as usually applied generates lists of language units with

no size limitations (e.g. syllables, consonant clusters, parts of syllables, words). Discussion of the need for unlimited vocabulary and the relative merits of approaches to vocabulary production are beyond the scope of this paper (see Goodenough-Trepagnier and Prather, in press). For the purpose of providing a set of language units for the Apple, this technique was modified so that only units consisting of integer numbers of syllables, and, of course, all single phonemes, were allowed.

The basis of the SPEEC technique is to provide, for a given inventory size (N),those language units which allow all English words to be produced by means of the lowest possible number of selections per word (C). Allowing units of all lengths (from phoneme to word) is necessary to achieve the lowest C. For example, C=1.60 for SPEEC-400; C=1.74 for SPEEC-Syllables-400. This small price in additional unit selections per word (14 extra per 100 words) is compensated for by the greater intelligibility of units which are joined at rather than within syllable boundaries.

Rationale for Syllable Units - Coarticulation

Coarticulation is the term used to describe the fact that articulation does not proceed phoneme by phoneme in linear fashion. A more realistic description is that the articulatory organs are positioned at the beginning of a word in a way that is consistent with the articulation of the greater part of the word, and slight modifications are made as necessary, when possible. For example, the /s/ in "slip" and the /s/ in "sloop" are different, since the tongue is already positioned for the vowel which comes two phonemes later. This articulatory anticipation of the vowel can be done while producing the /s/ as it is not necessary to distinguish between the /ɪ/ tongue position and the /u/ tongue position during the /s/; /s/ with an [ɪ] flavor is not perceived as a different phoneme from /s/ with an [u] flavor.

While coarticulation can extend over a whole word (as in Turkish vowel harmony), most of it seems to be syllable limited. In other words, while the /sl/ of "slip" and the /uwp/ of "sloop" might sound odd, and be unintelligible if strung together on the SuperTalker, the /slɪ/ of "sliver" and the /pɚr/ of "purple," both whole syllables, can be joined to produce "slipper" with a much more acceptable and more easily interpretable result. Recorded digitized syllables, then, are readily combined with little problem of mismatched coarticulation.

Syllabification

Division of English words into syllables is generally treated with something less than unanimity. Some of the confusion in the minds of laymen is due to the fact that dividing a written word at the end of a line is often done on a morpheme basis (e.g. "help-ing"). For the purposes of consistency, ease of learning, intelligibility and efficiency (lowering C), the rules proposed by Kahn (1976) for 'citation-form'-type speech have been used to divide words into syllables for this system. All consonants which are possible as syllable-initial consonants or clusters are assimilated to the following vowel nucleus. The remaining consonants are assimilated to the preceeding vowel, e.g. /hel/-/ping/. The user may be taught these two simple rules, but failure to use the rules should have little effect on his success in communicating. Observation of users of a French syllable system over a two-year period support this prediction (Goodenough-Trepagnier and Prather, in press).

Intelligibility of SPEEC-Syllables on the SuperTalker

Syllables are perceptible and manipulable units of speech to a much greater extent than phonemes. Evidence of this is available from many types of work, including detection of target syllables and phonemes in the stream of speech (Savin and Bever, 1970), and studies of reading (Gleitman and Rozin, 1973). For these reasons as well as others (such as coarticulation, length and thus redundancy), most syllables are quite intelligible at digitizing rates which are unsatisfactory for consonant phonemes. The SuperTalker provides four digitizing rates, offering a trade-off between speech quality and the number of items which can be stored in memory. The highest level seems to be necessary for units such as single sibilants (such as /s/, /š/), restricting the number of units which a phrase table containing such sounds can hold. (Only one digitizing rate may be used in each phrase table). Other phrase tables hold larger numbers of units, recorded at lower digitizing rates.

It should be noted that consonant phonemes do not occur singly in speech, and are generally unpronounceable in isolation. They are necessarily accompanied by a vowel, so that /p/ is realized at best as something like [$p^h_{\ddot{\text{ə}}}$] (aspirated /p/ plus a voiceless schwa). With careful, practised recording, to achieve relative uniformity of volume and intonation, highly recognizable syllables can be produced which can be strung together into comprehensible words. (These words are however not 'natural' sounding because they lack word intonation. Each syllable is recorded with similar ("list") intonation and amplitude, to the best of the recorder's ability.) Words which need to be composed out of single consonant phonemes or some combination of phonemes and syllables are, of course, a different matter. The receiver needs to perform what is called 'auditory blending,' a task which seems to require extracting the intended phonemes from the perceived syllables ([$p^h_{\ddot{\text{ə}}}$], for example, is of course phonetically a syllable), mentally representing the word in phonemes, and pronouncing it. At best, phoneme strings are poor in intelligibility, particularly for women's and children's voices.

Intelligibility and Memory

Increasing the memory capacity of the device (e.g. through lower sampling rates, or better coding), would improve intelligibility since fewer words would involve any recourse to single phonemes. Selection regions on the Tablet are used for sequences of syllables recorded separately in memory. Similarly, sequences of selection regions could access a single digitized syllable in memory, e.g., regions marked /skuw/ and /l/ on the overlay could access the whole syllable /skuwl/ instead of a syllable /skuw/ plus the single phoneme /l/, if memory were enlarged to accommodate additional syllables. The following table gives some suggestion of how intelligibility would be improved by increasing the number of single syllables stored in memory from the 235 syllables (plus 38 phonemes, space and suppress-space) required for SPEEC-Syllables-300 to the 324 syllables (plus phonemes, space and suppress-space) needed for SPEEC-Syllables-400.

Percentage of Words Represented by:

	Syllables only
SPEEC-Syllables-300	73%
SPEEC-Syllables-400	78%

	Syllables plus Phonemes
SPEEC-Syllables-300	21%
SPEEC-Syllables-400	18%

	Phonemes alone
SPEEC-Syllables-300	6%
SPEEC-Syllables-400	4%

Use of a device offering formant synthesis would improve intelligibility of the words for which whole syllables are not available. The most effective mode of conjoining phonemes would require the use of linear predictive coding, so that coefficients could be gradually modified to smooth transitions between phonemes.

Delay between Syllables

In the real-time use of any device, there is a problem of time lag between units, during the time a user with limited motor ability is selecting the next unit, and/or a disk is being loaded. Pause between syllables is less disruptive to the receiver than pause within a syllable. Storage of the units in a buffer so that they can be output together is an option. (This does not enhance rate, however, as the receiver cannot take advantage of guessing.) Space between words in this system does not usually have to be signalled, as each unit carries the information that it is or is not word-initial. Space would be realized as a short silence in memory, accessed by selecting a location with a word-initial syllable. Space is represented word-initially because of its phonetic consequences on the following consonant. To fully handle phonetic features such as aspiration on syllable-initial /t/, and flapping of a medial /t/ beginning an unstressed syllable, the information that /t/ is or is not word-initial, as well as other information (such as stress, which is not represented in the system described here) would be required. The system described here allows selection of a phonetically appropriate /t/ in most cases.

While the Apple was not designed as a communication aid, and is far from ideal as a personal communicator, it is certainly desirable to use if it is available, to supplement nonvocal communication training. There is evidence (Goodenough-Trepagnier & Prather, in press) to suggest that practice with a sound-based language system with immediate sound feedback to psychologically and articulatorily real units of speech - syllables - may provide an invaluable type of experience with language which is very useful for phonological development, and is otherwise largely inaccessible to the non-speaking person.

ACKNOWLEDGEMENT

This work has been supported by Grant Number 16-P-57856/1-05 from the National Institute of Handicapped Research, U.S, Department of Education, and Grant Number PFR-8017163 from the National Science Foundation.

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SPECTROGRAPHIC MEASUREMENTS OF COARTICULATION IN A COMMERCIAL VOICE SYNTHESIZER

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In this paper the formant transitions between vowel pairs and vowel-consonant-vowel (VCV) clusters produced by a commercially available voice synthesizer are studied spectrographically. A comparison is made with natural speech utterances of the same combinations. Deviations from natural coarticulation are identified and discussed.

INTRODUCTION

The mechanical dynamics of the human vocal tract prevent the speaker from instantaneously changing the shape of the tract. In connected discourse, the speaker must assume a vocal tract shape in order to produce a phoneme and, over some short period of time, modify the shape of the tract to produce the succeeding phoneme. This transition between phonemes is accomplished by coarticulation. The speaker begins to move his articulators (lips, tongue, jaw, etc.) prior to the completion of a phoneme in anticipation of the vocal tract configuration required for the following phoneme. This movement continues past the end of the first phoneme, and does not reach completion until some time into the next.

The result of this process of accommodating the requirement for positional change is that the acoustic signal for each phoneme can be markedly modified. This modification of a phoneme will vary considerably depending upon the identity of the neighboring phonemes (1).

In figure 1, the spoken phoneme pair "u" (as in "due") and "i" (as in see) is shown when spoken in isolation. The first three resonant frequencies or formant values of "u" are 450 HZ, 1200 HZ, and 2250 HZ, while the "i" has these formants at 400 HZ, 2300 HZ, and 2800 HZ (6). The most dramatic difference in the pair is in F_2 (formant 2) with a required rise from 1200 to 2300HZ. The coarticulation is illustrated quite well with the F_2 of the "u" beginning to rise within the phoneme, and finally reaching the value of F_2 for the "i" within the "i".

Since it is thought that much of the information of the speech signal is contained in these transitions (5,7,9), it would be of extreme importance for a voice synthesizer to approximate this coarticulation. The remainder of this paper will investigate the properties of a commercially available voice synthesizer.

Commercial Voice Synthesizer

The Vocal Interface Division of the Federal Screw Works produces and markets a line of voice synthesizers under the Votrax product name. The synthesizer is a terminal analog model of the vocal tract with a hardware controlled phoneme repertoire.

This particular unit chosen for study was the VS-H which is a recent development in a single board synthesizer and is currently used in an electronic aid for the nonvocal ("the Handivoice").

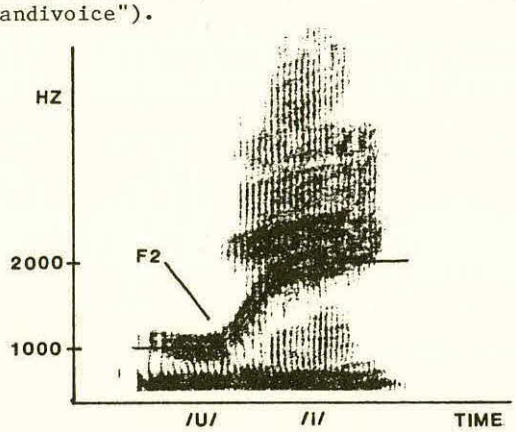

FIG. 1: F2 TRANSITION IN NATURAL SPEECH (LINE ADDED)

APPARATUS

In the two experiments described below, all spectrograms were made on a Kay model 6061B spectrum analyzer, with both the natural and synthesized speech samples received by a Sennheiser MD406 microphone. All samples were made using a single speaker and a single synthesizer with all adjustments constant for the duration of the experiment.

Experiment #1

In the first experiment, 13 vowels created by the Votrax were spectrographically compared with similar vowels naturally spoken. Phonemes in isolation were first compared to detect any dissimilarities in the two types of phonemes. Combinations of vowels were then created in order to study the coarticulation capabilities of the synthesizer. Vowels were chosen since they represent steadystate vocalizations with nearly constant formant values. Delattre, Liberman, and Cooper (2) point out that F_2 transitions

reflect articulatory movements from an acoustic locus to the steady-state of a vowel. This seems to be consistent in the transition from vowel to vowel. In this and the following experiment attention will be given to F_2.

RESULTS

The naturally generated a(hat), i(see), and u(due), were compared with synthesized counterparts. The steady-state values of F_1, F_2, and F_3 of the synthesized vowels appear to be in accordance with those of the natural speech, and with tabulated values (6).

A significant difference between the two groups of phonemes appears to be in the extremes of F_2. In natural speech, F_2 remains fairly constant, while often in the synthesized speech the beginning and endings of F_2 are different from the nucleus of F_2. An observation was made that a low F_2 would have a slight up-turn, while a high F_2 would have a slight down-turn. A mid range F_2 (e.g. a) has no modification. This feature is apparently part of the phoneme generation rules of the synthesizer. A low F_2 is likely to rise during coarticulation, and a high F_2 is likely to fall.

Further synthesizer rules came to light when two identical phonemes were merged. The F_2 modifications were omitted, allowing for smooth concatenation. This provides a mechanism for vowel lengthening without distortion.

Figure 2 shows a situation where F_2 must change value as two phonemes are joined. In the human speech the transition appears to be smooth while the same transition in the synthesized speech has a trace of discontinuity in F_2.

Close examination of the two types of transitions provides an explanation for the discontinuities. As stated earlier, coarticulation in natural speech begins in one phoneme, and ends in the next. Thus F_2 of each phoneme is affected by the combination. In contrast the coarticulation in synthesized speech occurs almost exclusively in the beginning of F_2 of each phoneme. The termination of the preceding phoneme is unaffected. The slight termination modifications discussed earlier provide a small amount of transition to the next phoneme.

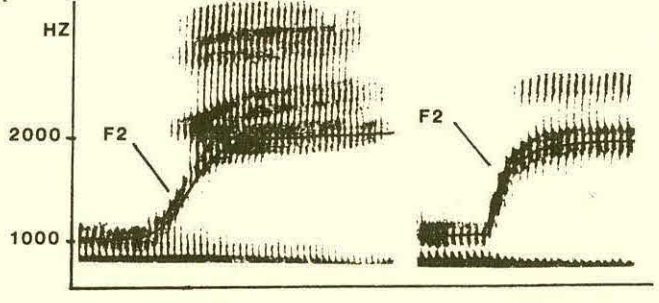

FIG. 2 COMPARISON OF NATURAL AND SYNTHESIZED /UI/ TRANSITIONS

This finding is rather significant since it is a deviation from true articulatory dynamics. In natural speech the succeeding phoneme affects F_2 of the preceding phoneme, and similarly has its own F_2 modified by the preceding. In the Votrax, the preceding phoneme affects F_2 of its successor, but is itself unaffected.

Experiment #2

In addition to the transition between adjoining vowels, transitions between vowels and consonants and consonants and vowels are of prime interest. Ohman (4) presented what is now classic data on coarticulation within (vowel-consonant-vowel) combinations where the intervocalic consonant was a /b/,/d/, or /g/. Ohman studied combinations of phonemes produced by Swedish, English, and Russian speakers. Work by Dematttre, Liberman, and Cooper (2) had already shown that such coarticulation in VC and CV pairs existed. Ohman showed that coarticulation transcended the intervocalic consonant. This is to say that the initial vowel affects F_2 of the final vowel, and the final vowel affects F_2 of the initial vowel.

In this experiment it was intended to reproduce the portion of Ohman's study which used English phonemes. The reproduction of the experiment included the production of all VCV combinations of /i/,/a/, and /u/ with the voiced stops /d/ and /g/.

Figure 3 shows the steady-state frequencies of F_2 for each of the three vowels when they are in different contexts. The data are presented with the phoneme in question printed on the left. It may be used in either initial or final position with each of the two consonants. The remaining vowel is then listed within the rows of data. Thus for example the frequency of F_2 for /a/ in the initial position of /aga/ in natural speech is 1000 HZ rising to a value of 1250 HZ at the consonant transition /g/. Following the consonant, F_2 is 1500 HZ and must fall to the steady state value of 1000 HZ.

Figure 3 shows the outcome of the experiment. Both the Votrax and natural speech are combined onto the same figure. The magnitudes of the changes in F_2 for the natural speech agree with Ohman's data. The magnitudes for the synthesized speech do not.

The F_2 transitions for the vowels are dependent only upon the vowels themselves. Whether in initial or final position, the vowel is unaffected by the presence of the other vowel. In fact, the data show that the F_2 transitions of the vowels are unaffected by the intervocalic consonant. This is most noticeable in the VC combinations /gi/ and /di/. The F_2 of /i/ should be rising to the steady-state in /di/ and falling in the /gi/. These utterances produced by the synthesizer show the transitions of both to be identically rising.

CONCLUSION

The coarticulation capabilities of the Votrax have been shown to be somewhat simplified from those of natural speech. In VV combinations, the transitions appear somewhat discontinuous due to the fact that nearly all coarticulation takes place in the final vowel with the initial unaffected by its neighbor. The transitions in VCV combinations do not have an effect across a medial consonant as does natural speech. In fact, there appear to be none of the consonant-dependent F_2 changes in CV and VC pairs that are evident in natural speech.

The significance of this is that there is increasing thought that the naturalness of synthesized speech is largely determined by the quality of the phoneme transitions (5), (8). It may be inferred from this discussion that a major contributing factor to the decreased naturalness of the Votrax is due to inaccuracies in the phoneme transitions.

		initial		final	
VCV		steady	transition	transition	steady
agi	N	a	1000--1250	i	2400-2400
	S	a	1000--1500	i	1750-2000
aga	N	a	1000--1250	a	1500--1000
	S	a	1000--1500	a	1300--1000
agu	N	a	1000--1100	u	1250--1000
	S	a	1000--1500	u	1300-- 750
ugi	N	u	500-- 800	i	2000--2000
	S	u	750--1200	i	1700--1800
uga	N	u	750-- 750	a	1400--1000
	S	u	750--1250	a	1250--1000
ugu	N	u	750-- 750	u	1000-- 750
	S	u	750--1250	u	1250-- 750
igi	N	i	2100--2100	i	2100--2100
	S	i	2000--1750	i	1750--1800
iga	N	i	2100--2100	a	1750--1000
	S	i	2000--1750	a	1250--1000
igu	N	i	2100--2100	u	1250-- 750
	S	i	2000--1750	u	1300-- 750
udi	N	u	750--1250	i	2000--2100
	S	u	750--1200	i	1700--1900
uda	N	u		a	1700--1000
	S	u	750--1250	a	1250--1000
udu	N	u	750--1250	u	2100-- 750
	S	u	750--1250	u	2100-- 750

FIG. 3: F_2 transitions of vowels in VCV clusters (N = natural, S = synthesized)

ACKNOWLEDGEMENT

This work has been supported by Grant Number 16-P-57856/1-05 from the National Institute of Handicapped Research of the US Department of Education.

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SAHARA II : SPEECH PROSTHESIS FOR THE NON-SPEAKING HANDICAPPED

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Abstract :

We present a work being conducted using a talking computer and a Blissymbol scanning board arranged with 500 lexical and syntactic calls.

The user indicates the desired sequence by pressing a button to start the scanner moving and by pressing it again to illuminate the desired symbols. Then with the selected symbols, the computer produces -with the aid of a grammar prepared especially for the purpose- both orthographic and phonetic, syntactically reconstructured strings. Then, the phonetic string is translated into a vocal output with an automatic prosodic processor and the orthographic string is printed on a small screen and on a type-writer.

Experiments are conducted in Readaptation Centers with disabled children. They will determine whether the goals of this study have been reached :
- to further the range of communication in an oral and/or graphic form,
- to encourage different ways of learning to read and spell, and of grasping the syntactical structures in French.

An operational synthesis system (1) for the French language has been developped at the CNET (Centre National d'Etudes des Télécommunications, The French National Research Center for Telecommunications). Vocal output of any message in the language may be obtained from input typed on a keyboard. The speech is intelligible and fairly natural : a linear prediction synthesizer - in the process of being integrated - is used - (10 coefficients, each linearly coded in 6 bits ; 6 bits PCM gain coding ; 7 bits pitch coding) with 1200 diphones as minimal speech elements and systematic prosody processing (intrinsic characteristics, accent and pitch) as a means of improving the quality (2).

Although text synthesis allows us to currently envisage realistic equipment for a population handicapped only in speech (for example, the mute and laryngectomee), the same is not possible for persons with both serious motor difficulties and oral expression deficiencies : cerebral muscular invalids.

A speech prosthesis system, "SAHARA II", has been designed for these particular users in order to indefferently address :

- a school population capable of spelling out messages,
- a population for which character by character message composition is too lenghty and difficult an effort to demand,

A pictographic selection panel has been used in order to meet this goal ; it is the Bliss system (3) which includes :

- a limited number of arbitrary pictographic symbols which represent word meanings in a simple manner. They can also be combined to create different, new meanings.
- a set of diacritical signs to indicate to which grammatical category a word belongs (object, action) and to take into account certain syntactical notions (past, present, future, plural...).

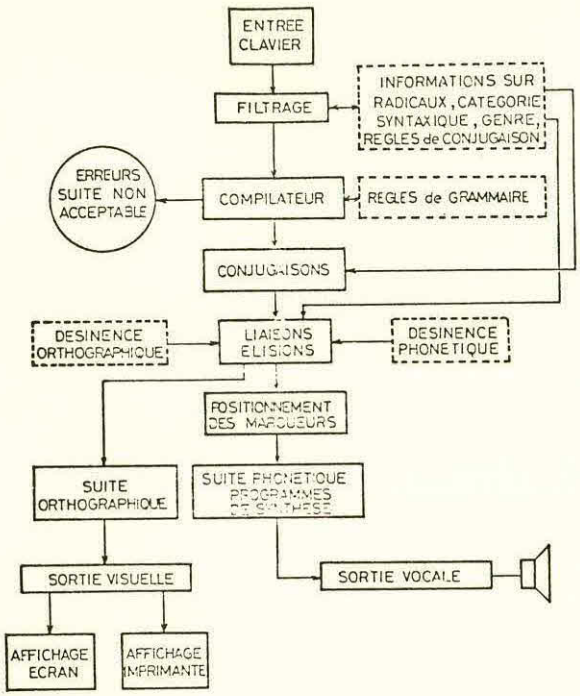
According to the directors of the Toronto Center for the Physically Handicapped, promoters of this symbolic communication system, "The symbols, as speech substitutes, can supply a prerequisite for the accomplishment of more advanced modes of communication, such as reading and writing" (4).

The 486 panel squares furnish a double representation for each linguistic unity :

- in its orthographical form,
- in an ideographic form whose meaning the user is familiar with.

As in the case of most already existing tools, a keyboard-relayed detector allows the user to select the squares containing the elements of his message : an indicator spot light moves from square to square ; pressing on the detector both selects and validates the square where the spot has arrived.

The selection panel itself is connected to the synthesis system whose software includes a grammar allowing for the transsformation of a series of selected squares (the key words) into a syntactically correct sentence.



In fact, a lexicon of all of the Bliss panel concepts is contained in storage ; all of the words are regrouped in the file according to orthographical and phonetic roots, lexical category, gender, for the substantives, and the numbers of both orthographical and phonetic ending rules.

Two additional files contain the orthographical and phonetic endings :

- A pre-filtering subroutine generates, based on the input string concepts, the actual word string for the syntactic analysis (compiler) : exceptions are processed and the definite article is generated.

- The compiler : the valid syntactic forms have been translated into a precedence grammar. It consists of 17 terminal and 12 non-terminal grammatical elements. This syntactic analysis supplies a complete tree for each sentence ; but the information given by the location of the four non-terminal end of noun phrase (enp), subject phrase (esp), complement phrase (ecp), and the verb phrase (evp) is alone sufficient to solve conjugation problems.

- The program for conjugation and agreement consists of supplying, for each non-invariant word, its retained ending format (number, gender and person). As for prosody processing, the markers which, for the synthesis of a written text, are normally entered on the orthographical chain at points considered syntactically pertinent, are either automatically superimposed at the output of the syntactic analysis on the four non-terminal elements (enp, esp, ecp, evp) or directly attached to words which, because of their lexical category, are only liable to accept one type of prosodic marker.

- Once the conjugation module has chosen the appropriate ending it remains to be concatinated to the root. At this stage, because the information is in the lexicons in the form of various markers, the problems of elisions, contractions (à le→ au, de le→ du) and certain grammatical exceptions (le bel enfant - le beau meuble, mon histoire - ma soeur) will be solved for the orthographical output. The problem of linking words will be solved for the phonetic output.

The system is currently operational on a minicomputer ; the program (approximately a thousand FORTRAN instructions) and the set of lexicons (diphones not included) take up about 65 k octets. It permits the generation of fairly complex sentences of about twenty words.

An output of the reconstruted orthographic string is enabled on a small alphanumeric screen and/or printer in addition to the output in synthetic speech ; this should allow the memorization of the spelling of words and therefore let the user establish the link between the ideogram and its written representation.

Other input possibilities are accepted :for example,we can substitute PAR LE SI LA B, a french syllabic method,(6) for BLISS. In this case, the co-ordinates of the squares refer to the corresponding syllables stocked under a phonetic form without reference to a program of orthographic to phonetic automatic conversion. In the same way, panel squares with pictures or photographes are easily usable without necessity to have recourse to supplementary software. The interchangeability of graphical elements allows an important flexibility in the use of such a system by non-speaking children at different levels of learning.

The system has been in use only since January 1981 in a rehabilitation center for cerebral muscular invalids. It would therefore be premature to make judgements at this point on the therapeutic and educational effects of such protheses.

Very similar types of equipment are currently being developed in the United States (5). The collected experiences give very diverse impressions. All indicate that much caution is necessary in both designing the tool and in the information given to users and to re-education personnel.

As a result, experience with various prosthesis prototypes due to begin in 1982 in different rehabilitation centers will be decisive in planning the development of true individual and portable prostheses.

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THE HANDICAPPED TYPEWRITER

BILL SMITH

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ABSTRACT

There are many severely disabled persons who cannot operate a typewriter keyboard even with a head or mouth stick.

A system is described which uses standard retail hardware: an APPLE II computer, one disk drive and a SILENTYPE printer together with a single switch designed to suit the user. An existing television receiver is used to display a large image of a typewriter keyboard. A scanning cursor allows the user to select, edit and send the result to a printer. The ability to select words and phrases as well as characters is also provided. In calculator mode the keyboard display is replaced by a calculator display which can also be operated by a singly switch closure.

The entire basic system costs about half that of its electromechanical predecessor and it has many additional features. It is expandable to provide environmental control and telephone abswering and dialing.

INTRODUCTION

A large number of severely disabled people exist who, due to accident, disease or birth defect, are unable to operate a typewriter or computer keyboard, even with the aid of a mouth or head stick. Many of these persons are also non-vocal, and the majority permanently institutionalized. Communication with most of these persons is by spelling board, though some more fortun ate ones have access to scanning systems connected to electric typewriters. These latter units, which tend to be of the elec tro-mechanical type,are physically large, require a special scanning display,and are also expensive. The large size causes problems in an institute and often interferes with routine patient care. Many of the severely disabled have impaired vision and due to their other disabilities cannot wear eyeglasses. The typed output is very difficult to see and error correction,when available is difficult. Because the typed output is not displayed in a large readable form,it is easy to lose one's place when interrupted.

THE BASIC SYSTEM

A system was required which was relatively inexpensive,small and unobtrusive and which would provide the disabled user with a readily available and easily operable communication aid and typing facility. Because most severely disabled persons already have access to a television set, it was preferable to use this as the scanning screen. Due to the relatively low cost of the small microcomputer, it was decided to use this to control the printed output. After investigating a number of such systems,the APPLE II with one disk drive and SILENTYPE printer was chosen as the most suitable. Visual display is sent to a standard television receiver using an R.F. modulator. All hardware is standard,unmodified off the shelf from the local computer store with the exception of one normally-open, custom designed switch to suit the user's particular needs. This switch is wired across the PB(0) input of the APPLE paddle control socket.

A program was written by one of us (Bill Smith) to display on the television screen, a large character replica of a typewriter keyboard. (fig. 1)

Figure 1 Upper Case Display

Because the scanning cursor described below does not return to the start position after each chosen characted as in the electro-mechanical version, a specially arranged character layout was not required.Additional special "keys" are provided for "FILE","left arrow","right arrow" and

"return". A large cursor scans horizontally below the keyboard display and on a single switch closure it changes to vertical motion. With a second switch closure it enters the chosen character at the bottom of the screen, with nothing sent to the printer at this time. Additional characters or spaces may be entered as required. The result is a line of type at the bottom of the screen which can be edited by means of the left and right arrow at any time. When the line becomes full (14 characters), the characters shift one position to the left and the lost character is printed on the printer. If the "return" is chosen, the whole line is printed and the small cursor set to the left.

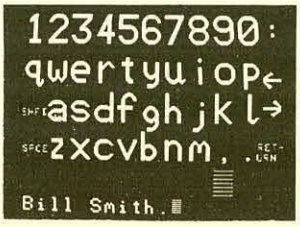


Figure 2 Lower Case Display

If the "shift" is chosen, the display on the television screen will change to lower case.(fig.2)Selecting "shift" again will return the display to upper case. The bottom line of chosen letters is not affected by the shift key. Provision is made so that when the printer line is full, the final word is not cut. If the user is interrupted or wishes to stop for a while, the scanning cursor will stop after 3 complete horizontal scans with no keypress. The scanner is reactivated again by means of a single keypress.

ADDITIONAL FEATURES

If the "file" key is selected on the upper case display,the screen will respond with "WHICH FILE? (A-Z)". 26 files are available which can be filled with words or phrases as required by the user. When selected by a single switch closure, the word or phrase will appear at the bottom of the screen, scrolling left and printing. At the end of the phrase the system returns to normal typing mode and additional characters may be added as required. The "Y" file comes pre-programmed with a series of commonly used sentences (fig.3).

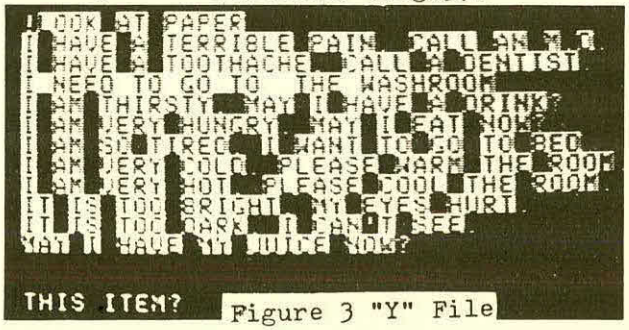


Figure 3 "Y" File

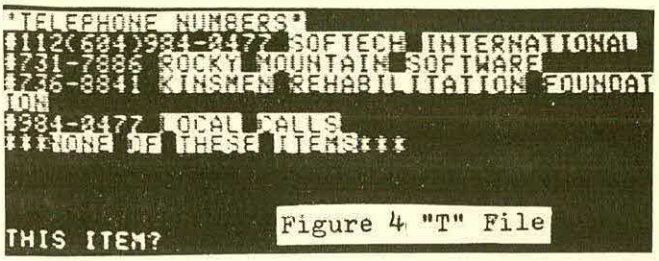


Figure 4 "T" File

and the "T" file is reserved for telephone numbers(fig.4). The "Z" file (fig.5) is a special command file from which the user modify, add to or delete from the other files; change the speed of the scan or select the environmental control mode or calculator mode (fig.6). This latter mode converts the system into a calculator operable by a single switch closure. In addition to the normal features of a calculator it also displays the last nine lines of the calculation plus a running total. A printer select key enables or disables the printer.

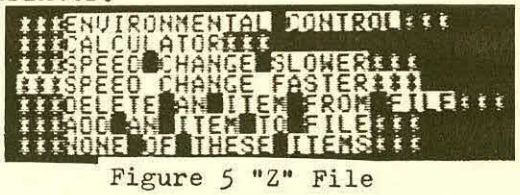


Figure 5 "Z" File

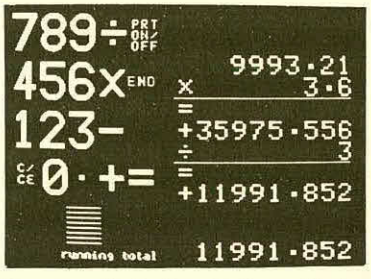
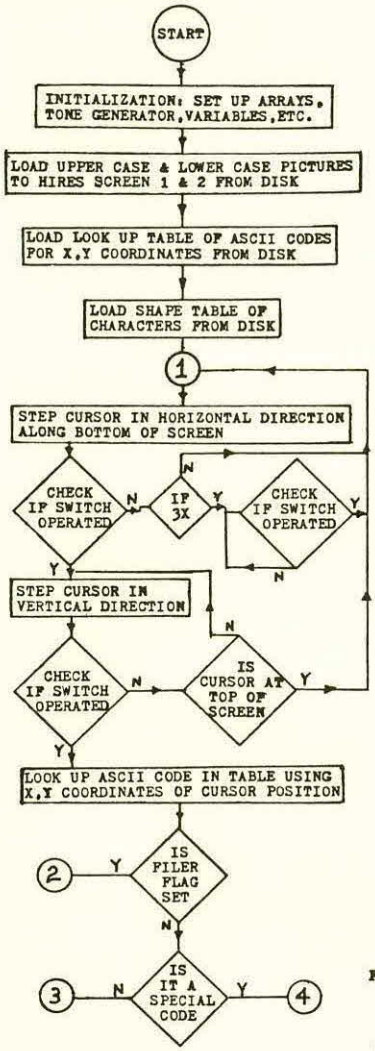
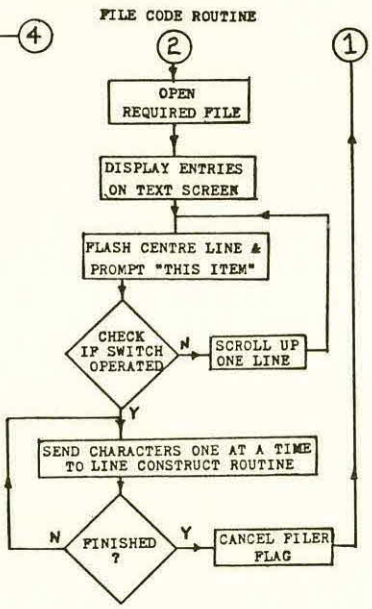


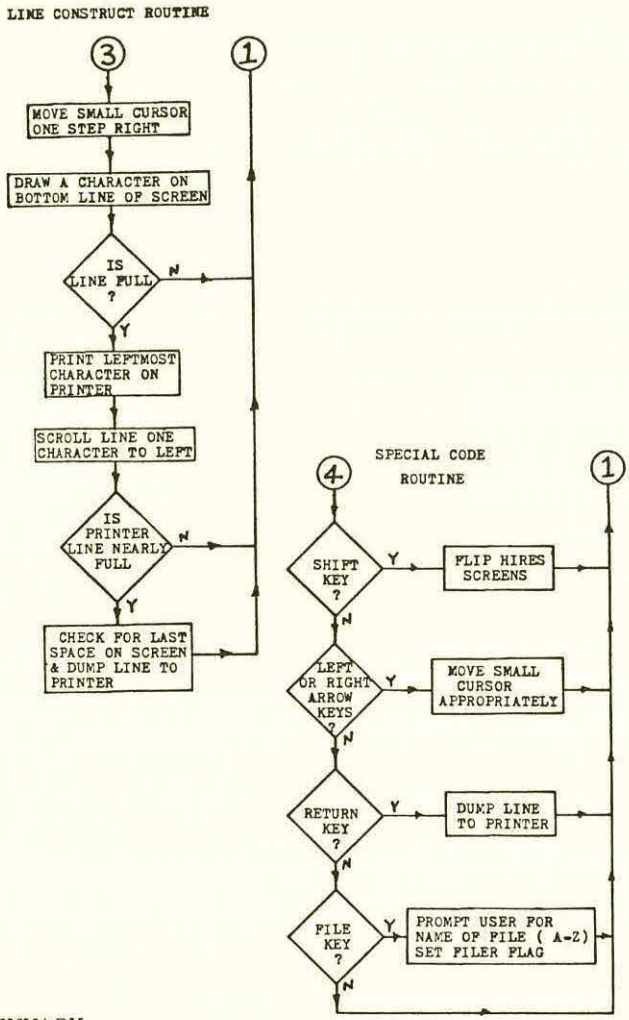
Figure 6 Calculator Mode

All of the above features require only the APPLE II computer with 48K of memory, one disk drive with controller and the SILENTYPE printer with controller. With the addition of an X-10 controller card and a D.C. Hayes modem, the environmental control and telephone dialing/answering features are also available. The software for these functions is included in the main program. If the hardware is not present the program recognizes this and returns control to the main program. The environmental controller controls lights and appliances, opens the doorlock, opens or closes the drapes etc. by means of B.S.R pulse coded units. The telephone dialer/answerer automatically dials any number stored in the "T" file. It also accepts incoming calls, saving the contents of the television screen, and notifying the user by displaying the message "TELEPHONE RINGING" on the screen. On hanging up (a single switch closure), the contents of the screen are restored unchanged.

A flow chart of the main program, line construct routine, special code routine, and file code routine is shown below.







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SUMMARY

The Handicapped Typewriter, which costs approximately half of its electro-mechanical predecessors, haa been installed in Queen Elizabeth Annex, where it is being used to teach cerebral palsied children. It has also been installed in Pearson Hospital, Vancouver and a number of private homes where it is being used as a communication aid. The preliminary results are encouraging and no problems have been encountered to date.

ACKNOWLEDGEMENTS

This work was supported by financial assistance from the Kinsmen Rehabilitation Foundation of British Columbia and the help full co-operation of Mr. Steve Egerton is gratefully acknowledged.

The program is available in diskette form in DOS 3.3, 16 sector from APPLE dealers or direct from

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CHARACTERIZATION AND EVALUATION OF AUGMENTATIVE COMMUNICATION SYSTEMS*

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ABSTRACT

Nine augmentative communication systems were evaluated to determine their effectiveness in meeting the needs of non-oral clients. The devices range from portable hand-held calculator type to stationary microcomputer-based systems. Each device is characterized in terms of its input, output and controller functions as well as general properties. A summary of evaluation findings is also presented.

Introduction

We evaluated assistive devices to determine reliability, maintainability, safety, and effectiveness. The device must be reliable if it is to be used as a communication aid. If the device breaks down, the person has lost the ability to communicate. It is necessary that the device be easy to maintain so that when it does break down, repairs do not require excessive time. It is important that the device be safe, both electrically and mechanically. It must also be effective in terms of meeting the communication needs of the user. Reliability, maintainability, and safety all have a bearing on the device effectiveness.

The approach to device evaluations developed by the California State University, Sacramento Assistive Device Center involves three main areas of study: technical evaluation, human factors, and clinical trials. The first phase is concerned with the technical aspects of the device: construction, layout, and design as they relate to reliability, maintainability, and safety.

The human factors evaluation determines the user skills required to operate the device. The clinical trials are concerned with how the device meets the capabilities of persons with various degrees of physical and cognitive disabilities.

With the information provided from the evaluation, clinicians are better able to match the capabilities of the user with the capabilities of a device. Another important result of these device evaluations is feedback to the manufacturer of the device. The result of this process is a better and more appropriate utilization of speech and language prostheses.

Characterization

The devices evaluated were the Canon Communicator (Telesensory Systems, Inc.), the Liberator 912 (Mulholland Company), the Zygo models 16C and 100 (Zygo Industries), the HandiVoice models 110 and 120 (H-C Electronics), the Communimate (EMS) Matrix (DUFCO) and Optical Headpointing Strip Printer (OHSP) (Prentice-Romich). Evaluation units were obtained from the manufacturers. The nine devices obtained for evaluation were available for two to four weeks, and the data presented were gathered in this limited time frame. This short time span is particularly significant in evaluating the clinical performance. Neither the degree to which people can learn to use the device, nor the long-term reliability cannot be assessed in such a short time.

The characterization of the devices is shown in Table 1. The Zygos and Matrix are classified as array communicators. The Zygo 16C output consists of sixteen display panels, each of which contains a light. The Zygo 100 and Matrix have arrays of 10 x 10 LEDS. The input is through a switch closure, and many interfaces which provide such a function may be used. The 16C controller provides three modes of operation: automatic scan, x-direction only scan, and x and y direction scans. The Zygo 100 and Matrix have either single switch or multiple switch operation. Single switch control uses a row/column scan in the Zygo 100, and an alternative right-down movement with the matrix. Multiple switch closures provide separate left, right, up, down, and data entry functions. For both units the "vocabulary" is determined by inserting words, letters, pictures, or symbols in the 16 or 100 squares.

The Liberator is an encoding communicator. The output is a twenty-column wide therman strip printer and an LCD. User input is via two switches. The controller provides two modes of operation: direct and scrolling. The units and tens digits are each controlled by a separate switch. Each letter, number, control character and punctuation mark has a two-digit code. The codes for the characters are ogranized by order of frequency of occurrence of letters in English text.

*This work supported in part by Office of Education Grant #G0079902261. Detailed evaluation reports covering each of the devices described here are available from the Assistive Device Center.

Once a two-digit code is entered, the character is printed--following a variable time delay that provides for error correction. The device is intended to rest on a lap board in a wheelchair or on a table in front of the user.

The Canon is a hand-held, fully portable aid. Its small size and low weight make it useful for ambulatory clients who are non-oral. The output is a 5 x 7 dot matrix thermal strip printer. User interface is via a twenty-six key calculator-type keyboard. A shift function provides full numeric capability, as well as some punctuation and mathematical symbols. Error correction is accomplished by a backspace key which obliterates the previously typed letter. The batteries are in a separate case with interconnecting cable. Provision is included for attachment of the device to the body through an ingenious strapping system.

Both HandiVoice units provide synthesized speech output (Votrax model VSH) employing "synthesis by rule." Both units utilize the Motorola MC6800 microcomputer system. The user interface for the model 110 is a 128 key panel of switches. Each panel may take on one of four functions through a level shift operation. The vocabulary consists of letters, number, phonemes, words, and phrases. Each successful entry is indicated by both a flashing LED and/or a tone. The model 120 provides two types of interface: a sixteen key keyboard and a switch input. This device employs an encoding scheme similar to the Liberator. In this case, a three-digit code is used to access all stored letters, words, etc. This may be accomplished by direct entry of a three-digit code or through a scrolling mode in which the three digits are scanned sequentially until the switch is closed. This latter mode is useful for users with severe motor disabilities. Error correction is possible only through a delay mechanism similar to that used in the Liberator. Both models provide for the storage of up to eighty entries, which may be replayed at a later time. Although both devices are labeled by the manufacturer as portable, the weight associated with the battery pack and synthesizer makes this difficult for many clients.

The Communimate is designed around the Sorceror microcomputer. Several hardware changes are made to the computer to allow single switch entry. Two "ROM" packs contain games and communication programs. There are 19 pages of vocabulary including words, phrases, control characters and alphanumeric symbols. The vocabulary is organized functionally. An optional printer supplements the standard TV display. Vocabulary is accessed by moving a cursor (left and right switches) and then hitting an enter switch.

The OHSP contains a matrix of 80 LEDS on an alphanumeric panel. The LEDS are scanned sequentially and a head mounted detector is aligned with an element of the LED panel. The unit detects when an entry has been made by a time coincidence circuit. A selected item may generate a tone, be printed on a thermal strip or both. The display panel is organized like a standard typewriter. A serial output option allows use of the OHSP as an ASCII keyboard triggered solely by the head.

Summary of Evaluations

Zygo 16C. The Zygo Model 16C is a useful communication aid for individuals with severe motor disabilities. The capability of using pictures or symbols as well as words is particularly valuable for clients with language disabilities. The major limitations are the slow speed and limited number of elements which can be used in the display.

Zygo 100. This is a relatively versatile communication device which can drive peripheral display, printing, and environmental control systems. Significant cognitive demands are required of the operator to use the memory. The array of switches provided by Zygo makes the likelihood of finding an appropriate interface quite high. The user may spell or select frequently used words, word parts (prefixes, suffixes), phrases, and sentences. The row-column scan can be confusing to brain-damaged or low-functioning individuals. The ability to use scanning requires a higher cognitive level than direct selection.

Canon. This device requires the motor capability of operating a calculator type keyboard and the ability of reading the print size of a calculator type display. The separate battery pack causes problems of reliability (cable/connector failure) and mounting. This device is a useful communication aid for individuals with severe motor disabilities who require printed output.

Liberator 912. This device is a useful communication aid for individuals with severe motor disabilities who require printed output. Editing of printed text is difficult. The print delay may be utilized to alter codes which have been entered incorrectly. The Liberator 912 is suitable for severely motorically involved clients who can spell and read. It has the advantage of hard copy output facilitating client independence.

Handivoice 110 and 120. These devices are intended to provide to non-oral individuals the capability for synthetic speech. Cognitive abilities required of the user are to make selections from an array and encode (Model 120). The vocal output is artificial and some adaptation is required. The voice output does have several distinct advantages over other methods. Both models require memorization of about one thousand elements. The model 110 requires the user to be able to read information in the small squares.

Optical Headpointing Strip Printer. The most unique aspect of this device is the interface. The head mounted detector is (in current models) a lightweight unit. The power of this approach for severely motorically disabled persons is in the ability to access a full ASCII keyboard using direct selection with the head. Unfortunately, many users have difficulty in making selections in the absence of any feedback as to where the head is aimed until a choice is made. Side mounting of the head detector causes problems in alignment.

Communimate. By basing this unit on a standard personal computer, the manufacturer has allowed the user to access a relatively large vocabulary with only single switch activation. Unfortunately, many other advantages

Table 1

Characterization of Speech Prostheses Evaluated

Characteristic	Zygo Model 16C	Zygo Model 100	Canon	Liberator Model 912	HandiVoice Model 110	HandiVoice Model 120	DUFCO MC3MS	Optical Head-pointing Strip Printer (OHSP)	EMS Communimate
General									
Size (cms)	47x38x9	47x38x9	1.31x8.5x0.30	32x17x17	41x19x6	7x11.5x7	43x33x5	33x6.4x20	Computer: 48x9x31
Weight (kg)	4.55	6	.280 Main Unit .160 Battery	8.2	2.53	2.67	3.74	1.7	Computer: 6
Power Source	Pb Acid	Pb Acid	NiCd Battery Pack	Pb Acid	NiCd	NiCd	4 NiCd Cells	19 NiCd Cells	A.C. Line Voltage
Case Material	Plastic	Plastic	Plastic/Metal	Metal	Plastic	Plastic	Aluminum	Plastic	Plastic & Aluminum
Interface									
Force (gms)	Variable Range: 50-120	Variable Range: 50-120	180 360 (on/off)	N.A.	10-70	70	Same as Zygo	NA	Same as Zygo
Resolution	N.A.	N.A.	1.5	7	1.9	2		2° of Head Movement	Plus Keyboard
Range (cm)	N.A.	N.A.	8x8	N.A.	30x5x15.25	10x10		39° Head-Mounted Detector	
Type (Standard)	Several	Several	25 Keys	Bioelectric (contact)	128 Keys	16 Keys			
Output									
Type	Visual Transient	Visual Transient (also memory)	Visual Hard Copy	Visual Hard Copy	Auditory Transient (also memory)	Auditory Transient (also memory)	Visual Transient	Visual Transient Hard Copy	Visual TV Hard Copy
Additional User Feedback	None	Tone	Sound of Printer	Sound of Printer	LED, Tone	LCD, Tone	None	Tone, Sound of Printer	None
Alarm	Audible in 4 locations	Audible	None	Audible	None	None	Audible	Audible	Audible (Requires Printer)
Magnitude	50(mm)	50(mm)	4(mm)	4(mm)	0-70(dbA)	0-72(dbA)	32(mm)	4(mm)	TV: 1.05(cm)
Controller									
Type	Digital	Digital	Digital	Digital	MC 6800	Mc 6800	Digital	Digital	Sorcerer Microcomputer
User Mode of Selection	1) Scanning 2) Matrix Single	1) Scanning 2) Matrix Single	Direct	1) Encoding 2) Scroll	Direct	1) Encoding 2) Scroll	1) Scanning 2) Matrix	Direct	Scanning (Switched) Direct (Keyboard)
Vocabulary	16 Elements	100 Elements	Full Alpha-numeric and Punctuation	Full Alpha-numeric and Punctuation	Same as Canon and Words, Phrases, and Phonemes	Same as 110	100 Elements	Same as Canon Plus Control Characters	Same as Canon Plus Stored Phrases (420 Total Choices)
Memory	None	16 Entries	None	None	80 Entries	40 Entries	8 Entries	None	224 Characters on TV
Message Correction	None	Time Delay	Backspace	Time Delay	Time Delay	Time Delay	None	Backspace	Delete, Backspace/ Erase

of using a personal computer have not been exploited. For example, the user cannot use Sorcerer BASIC or word processing programs with the EMS single switch system. The modifications of hardware to use the device for communication are minimal. The unit is not designed to be portable.

Matrix communicator. By providing a large array of interfaces, DUFCO has made the matrix available to a wide range of motor abilities. The 100 element display may be used in the same manner as the Zygo 100. The presence of a memory is good, but a maximum capacity of only 8 entries is a limitation.

MICROPROCESSORS AND COMMUNICATION FOR THE HANDICAPPED

Ann Colquhoun, Shirley McNaughton, Brian Wilson and Maurice Izzard

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Ontario Crippled Children's Centre

A pilot research study was undertaken at the Ontario Crippled Children's Centre, funded by the Conn Smythe Research Foundation for Crippled Children to discover the relative strengths and weaknesses of three classes of microcomputer controlled communication aids using Blissymbols: the Blissymbol printer, a portable communication aid; the Blissymbol terminal, a communication station; and the Apple, personal computer with software for Blissymbols. Three case studies have been selected to demonstrate the impact of each of the aids upon the user and those with whom he interacts. These provide examples of Blissymbol messages, style of communication interaction and experiences initiated through use of the aids. The Instruction Guide which makes use of data collected in the study, includes information relating to the selection, instructional support and evaluation of microprocessor technology applied to Blissymbol communication.

In the past five years three or more distinct classes of microcomputer controlled aids have been developed to augment the communicative capabilities of the non-speaking cerebral palsied person. One class is the portable communication aid, designed to be mobile with the user and usually attached to a wheelchair or carried by hand. Such devices are solely communication aids, dedicated to this one function. The second class of devices could be described as communication stations. Although they are not portable, they are usually designed to meet a broader range of communication needs of a user such as message storage, editing and transmission. The lines between these two classes have recently become less distinct as electronics have progressed to allow more and more of the "word processing" functions to be available in truly portable units, but the distinction is still useful when considering the situations where they are used. The third class of device is the general purpose microprocessor as exemplified by the personal computers currently on the market. These devices can be programmed for a wide range of applications and in most cases can also emulate the single function aid or the communication station.

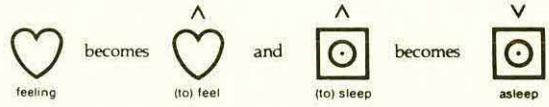
The question of when any particular class of device is the most appropriate for the Blissymbol user has been the focus of a two year study at the Ontario Crippled Children's Centre. Funded by the Conn Smythe Research Foundation for Crippled Children, a pilot research project to discover the relative strengths and weaknesses of the three classes of aids has been initiated. In addition to providing information on the hardware, environmental and user characteristics were also examined in order to help identify and clarify the myriad of interacting variables and the relative importance of each. An instructional guide to assist Blissymbol communicators in selecting and learning to effectively use microprocessor technology makes use of the information gathered from this study.

Blissymbolics is a visual, meaning-based symbol system which has been used as a means of expressive communication by physically handicapped children and adults since 1971. Some of the symbols are *pictographs:*

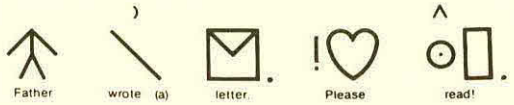
Some symbols are *ideographs:*

Still other symbols are *arbitrary:*

Through the addition or substitution of *indicators* a symbol may be changed from one part of speech to another.



Blissymbolics provides the user with the capability to communicate in *sentences.*



A word equivalent appears under each symbol.

Usually, the symbol user points to the symbols on a flat display positioned on a wheelchair tray. If the user does not have the muscular control to accurately point to a small target area, a more sophisticated communication aid is required. Many varieties of pointers and scanning boards have been developed throughout the 70's to meet this need. In each case the number of symbols which can be displayed is restricted, the time required to access each symbol limits the length and quality of the message, and the symbols are presented sequentially to the receiver making comprehension of the statement difficult.

The three aids evaluated through this study represent each of the 3 classes of microcomputer controlled communication aids developed to enhance the communicative capabilities of Blissymbol users. The target populations for these aids are persons who require this level of technology to serve as their prime communication aid and persons who will use one of these aids to enrich their total communication experience and augment their manual Blissymbol communication. The aids evaluated are: the Blissymbol printer, an accessory to the autocom, developed by the Trace Center of Madison, Wisconsin; the Blissymbol terminal, developed by the National Research Council, Ottawa, Canada and Norpak Ltd.; and the Apple personal computer using software for Blissymbols, developed by the Trace Center.

THE BLISSYMBOL PRINTER

The Blissymbol printer contains over 800 Blissymbols displayed on the flat surface of the autocom. The user operates the printer by moving a magnet over the surface of the aid and holding the magnet over the square containing the desired symbol. There are nine "levels"; each square having the potential for nine symbols. For all levels but level one, the user first indicates the level number of the symbol and then square containing the symbol. If no level is specified, level one is inferred. The magnet activates a reed switch which causes the chosen symbol to be printed out on a paper tape.

The user has the following controls over the functioning of the Blissymbol printer:

- the speed at which the switches are activated can be changed;
- the last symbol in the message can be erased;
- the aid can be turned on and off by the user;
- the aid can be operated continuously in one level containing the letters and numbers.

The Blissymbol printer is being evaluated as it is used in the classroom, home, summer cottage and institutional setting.

THE BLISSYMBOL TERMINAL

The Blissymbol terminal contains 512 Blissymbols, arranged on pages, in meaning-based groups of up to 24 symbols. The alphabet and numbers are also included. The symbols are displayed on a CRT. The user selects a symbol by moving a cursor across and down, first the index page and then on the vocabulary pages. Individually designed interfaces (usually touch-sensitive switches or a joystick) are used. The chosen symbol is entered into the message buffer by pressing a separate "select" switch. The message buffer holds up to 30 symbols or letters. The user has the following controls over the functioning of the Blissymbol terminal:

- the word accompanying each Blissymbol can be removed;
- the last symbol in the message can be erased;
- the entire message can be erased;
- the complete message can be displayed on the screen.

(With a page of vocabulary on the screen, only the last twelve symbols of the message are displayed.) The Blissymbol terminal is being evaluated as it is used in the classroom, home, summer camp, group home and institutional settings.

THE APPLE

The Apple is a general purpose microcomputer which has the capability of high resolution graphics which are necessary if Blissymbols are to be properly displayed. The Apple is being used as a communication station displaying up to 10 of the 1400 available Blissymbols on the screen at a time with the following user-controlled functions:

- the last symbol in the message can be erased;
- the screen can be cleared;
- the message can be printed on a screen printer.

Because these programs are modifiable, experiments with user control of selection and organization of the symbol vocabulary and a wide variety of input devices are possible in an attempt to optimize communication speed and accuracy. The Apple is also used to gather and record vocabulary information for future linguistic analysis.

All of these aids free the receiver of a message from being present while it is being composed. The user can construct and revise a message independently and without the time constraints usually associated with communication between Blissymbol users and speaking persons. The dynamics involved in this type of communication, the communication capabilities provided by the aids and the effect of each of the aids upon the user and those with whom he interacts are examined through the study.

Three case studies have been selected to demonstrate the impact of each of the aids upon the user and those with whom he interacts. These provide examples of Blissymbol messages, style of communication interaction and experiences initiated through use of the aids. The Instructional Guide includes information relating to the selection, instructional support and evaluation of microprocessor technology applied to Blissymbol communication.

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A CLINICAL EVALUATION PROCEDURE FOR COMMUNICATION EQUIPMENT FOR THE SPEECH IMPAIRED - A CASE STUDY, WITH RECOMMENDATIONS, ON THE BLISSTERM AND M.C.C.S. -

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ABSTRACT: The paper describes, in summary form, a clinical evaluation study carried out during 1980 on two assistive communication systems for the speech impaired. The methodological procedures required for this kind of clinical evaluation are described. While only a brief summary of the results of the study are provided here, the complete report is available. The necessity for this kind of procedure in the rehabilitation field is emphasized and general recommendations are given relating to the design of assistive systems for the speech impaired.

INTRODUCTION

A clinical evaluation was carried out during the year 1980 on two assistive communication systems, the Blissterm and the Multi-User Classroom Communication System (M.C.C.S.). Readers are referred to previous publications for descriptions of these devices (1,2). Essentially, the devices are similar in that they both provide Blissymbol and alphanumeric communication, but they differ in the way the user's message is displayed. The Blissterm uses a television display while the M.C.C.S. uses a matrix board, with or without synthetic speech reinforcement.

Both of these systems were designed specifically for individuals who are communicatively impaired due to severe neuromuscular disorder which precludes the development or recovery of functional speech. These individuals also experience socialized handicaps such as lack of independence, occupation, social integration, economic self-sufficiency and others. These external manifestations are so profoundly handicapping that the proper evaluation of assistive devices designed for this population must be carried out to assure suitable matching of device to user, overall value of device to the user, as well as safety and reliability of device in daily use.

Since it is impossible to identify an "average" user in terms of the disorders which circumscribe the speech impaired; and as they manifest such a wide range of motor, sensory, social, emotional and cognitive abilities and disabilities to say nothing of the wide variety of human and physical environments in which the communication takes place, a simple laboratory evaluation would be erroneous and inappropriate. Similarly a purely technical evaluation would be too restrictive to warrant consideration.

In the medical field, new treatments are always subjected to clinical trials to assess whether or not the approach compares favourably with established treatments or non-treatment of the condition (3). Documented results, recorded through this kind of process leads to improvement of treatment techniques and generally advances the field. It is inconceivable that technical aids (such as communication aids) which constitute a means of achieving habilitative/rehabilitative advances for a disabled individual should not undergo similar kinds of clinical trials. This equipment may not fall within the category of implants (e.g. pacemakers) and other "medical" devices; nevertheless the impact of technical aids on the individual is of a global nature.

What is of utmost concern is to ascertain what the impact of the device would be on the user: its function and integration into the lifescope of the individual (how it improves the independence of the disabled user, for example). We must also ascertain the degree of acceptance of the device by secondary users (teachers, therapists, etc.) and how it affects the teaching and/or rehabilitation programme of the user. In addition, we want to know how it affects the non-professional people (parents, family, and friends) interacting with the disabled person. Finally, we want to measure how the device performs in relation to the technical goals specified by the developer. A clinical evaluation is one way of establishing the merits of a particular device in comprehensive operational and technical terms.

METHODOLOGY

The evaluation was commissioned by the National Research Council at a time when both devices were in a pre-production prototype state. The mandate was to provide information on the effectiveness of the equipment in"normal" settings (clinical and/or residential) before proceeding with further design and development or commercial manufacture.

Within this context of pre-production prototype evaluation, in which only a small number of prototypes were available, a clinical evaluation can only reasonably be directed towards a subjective assessment rather than an objective quantitative analysis. Another reason which mitigates against quantitative analysis is the heterogeneity of the users of such communication aids. Statistical manipulations would be difficult to justify as being significant. In addition the

major objective of an evaluation of this kind is to assess the operational aspects of the devices and these characteristics can only reasonably be obtained through subjective observations by the primary and the secondary users.

The scope of this particular evaluation was designed to encompass the user-need evaluation and operational, technical and comparative evaluations.

The Evaluation Protocol

The evaluation protocol was divided into a number of sections.

Section A: Description of primary user. This description provided the base-line data on the primary user and also gave an indication of the changes that occurred in the user over the entire evaluation period. This section was subdivided as follows: general (i.e. diagnosis, etiology, etc); family constellation; level of intellectual functioning; sensory-motor abilities; speech and language abilities; communication abilities (4); distribution of school time (subjects); previous experience with technical aids and interfaces; attendance at school (during the evaluation period).

The therapist or instructor most conversant with each of the above sections was responsible for responding to the questions. Although some of the information requested was available in the primary user's medical field, specific observations were required in order to complete the section.

Sections B and C: Blissterm and M.C.C.S. Evaluation. Part I: Installation and layout of equipment - provided information on the initial installation of the device(s) (and subsequent changes that occurred) and on the configuration of the devices, their layout in the classroom/ laboratory and the individual workstation layout of each primary user.

Part II: Operational evaluation - dealt with the operational performance of the device(s) during use by the primary and/or the secondary user(s). Questions were developed in terms of the following: powering-up; the interface; device functions; environmental impact on physical resources and human resources; safety; functional communication performance; rate of learning; general impact of device on primary user (supplementary to Section A).

Part III: Technical evaluation - assessed the technical specifications of the device and its component parts. Questions were developed in terms of the following: mechanical components; electrical components; reliability of the whole system and its component parts; finishes and textures; visual information; auditory information; documentation.

Part IV: Evaluation of repair procedure - provided a means of documenting the breakdowns that occurred in the equipment and the procedures and time taken to carry out the repairs.

Section D: Comparative Evaluation. This assessment provided a comparison between the Blissterm and the M.C.C.S. Due to the nature of each device and the heterogeneity of the users, this evaluation could only be very general. The section was divided as follows: general considerations; operational concerns; technical concerns.

SUMMARY OF RESULTS

Owing to the non-portable nature of the devices, the clinical evaluation was targetted on cerebral-palsied school children in their classroom environment. The evaluation encompassed two school semesters. During the intervening summer vacation period, some of the children had the Blissterm at home or at summer camp. The total time period for the evaluation, therefore, varied between 8 and 10 months.

Description of Primary Users

At the beginning of the evaluation there was a total of 20 primary users (11 males, 9 females) from 5 evaluation centres. Nineteen had a diagnosis of congenital cerebral palsy and one had a diagnosis of head injury. The children ranged in age from 8 to 16 years (mean of 12.5). The following general descriptive information was gathered from the protocol. Information such as level of intellectual functioning or sensory-motor abilities was used only in the assessment of the individual in relation to his/her use of the device. It was not used for comparative analysis among users. Individual user characteristics of a personal nature are not discussed here.

Level of intellectual functioning. The majority of the group tended towards being 1-2 years below age level.

Sensory-motor abilities. The majority of the group were moderate/severely physically disabled.

Speech and language. The majority tended towards being grossly below age level.

Communication. Eighteen out of the 20 children used Blissymbols for communication. Nearly all were able to "hand" point to the symbols on their communication board in one way or another, although most were described as unable to engage in fine motor skills.

Clinical evaluations are full of "real world" problems and ours was no exception. Initially there were 16 candidates using the Blissterm and 9 using the M.C.C.S. (5 students worked on both devices). These figures were reduced because one evaluation centre dropped out of the study and also because of illness and reassignment of some students to only one device. The final numbers were 10 on Blissterm and 5 on M.C.C.S. (3 working on both). Of the remaining 10 protocols on the Blissterm, even 3 of these were incomplete due to repeated malfunction of the equipment and other factors.

Technical Results

The field study highlighted a number of very real problems with respect to the use of complex technical aids in a classroom environment. Very briefly the major problems were: the frustrations that both primary and secondary users experienced with unreliable and unpredictable prototype equipment; the vital nature of the user's interface and the effect this component had on the overall

functionality of the technical aid; the inflexibility of a fixed vocabulary of symbols, as well as the grouping of the symbols; for the Blissterm: the poor choice of symbols on the control page; for the M.C.C.S.: the poor figure/ground aspect of a large matrix of (more than 500) symbols; for both devices: the "clutter" of inter-connected units and the associated difficulties this caused in terms of physical placement in the classroom, safety of personnel and possible damage to equipment due to accidents and broken wires; and, finally, the lack of informative documentation and/or user training.

While both devices provided for message sending and receiving between units, this feature was only used to any extent with the Blissterm. A screen printer, which was provided for use with some of the Blissterms, was found to be a very effective addition.

OVERALL CONCLUSIONS

Evaluation Protocol

The evaluators generally concluded that the overall methodology and format of the protocol was clear, precise and detailed. This made the process of evaluating the devices easier in that the evaluators were made to think about each device from more than one point of view. The evaluation method did not try to achieve any scientific rigor (i.e. no statistical analysis was attempted). Nonetheless it is felt that this form of clinical evaluation in the field of technical aids in rehabilitation is appropriate, and instructive results may be obtained through a systematic process of structuring subjective observations of user/machine behaviour.

Technical Aspects

Despite the technical unreliability and other problems encountered, the Blissterm in particular was viewed in very positive terms by the evaluators. It was seen as having a great impact on the primary users and their general development, providing them with a new level of independence within the classroom. The visual impact of the television display probably accounted for much of this preference and could explain the greater use of message sending and receiving with the Blissterm than with the M.C.C.S. The "paging" of the vocabulary on the Blissterm was not considered to be a problem, per se; but the need to select the vocabulary and group the symbols into appropriate pages to suit each individual user was emphasized many times. The synthetic voice was the most attractive feature of the M.C.C.S. Hence, it was postulated that if voice synthesis could be added to the Blissterm, the result would be a very effective device.

RECOMMENDATIONS

The authors wish to recommend this type of clinical evaluation to other developers of rehabilitative technical aids. It is a valuable learning experience. Based on what we have learned, the following is a prioritized list of design aspects which must be given careful consideration when developing devices of this type: reliability, interface systems, vocabulary structure and user programmability, physical configuration, documentation and training. In addition, where they can be considered cost-effective, the following features should be considered: hard copy printed output, games for recreation and training in the use of the device, and synthetic voice output.

Overall, it was observed that the interface is still the weakest link (even the "missing link" in some cases). Much more effort is required on the part of rehabilitation engineers in this area. One final recommendation is that schools and institutions seriously consider the hiring of a technician to be on hand to maintain equipment of this type, to provide adjustments to interfaces, and to provide instruction in the operation of the equipment.

ACKNOWLEDGEMENT

This study was conducted under contract to Norpak Ltd., Pakenham, Ont., Canada and the National Research Council of Canada (D.S.S. File No. 09SX.31155-7-4715). Copies of the complete evaluation report are available from: National Research Council of Canada, Publications Sales and Distribution, Ottawa, Ont., Canada, K1A 0R6. (Price $7.50, including postage and handling).

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FACTORS AFFECTING COMMUNICATION RATE IN NON-VOCAL COMMUNICATION SYSTEMS

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ABSTRACT

Features of direct selection and encoding non-vocal communication systems which influence the user's rate of communication are analyzed. This analysis allows unified treatment of diverse systems, establishes a vocabulary by which systems may be compared and simplifies the design of experiments. A simple equation specifying the average time per word is presented. The effects of varying system parameters on the terms of this equation are discussed and the need for experimental data and further analysis to support predictions is noted. A specific numerical example based on the measured performance of one subject is presented and the apparent improvement to be gained by encoded communication demonstrated.

INTRODUCTION

The field of technology for non-vocal communication is characterized at present by an energetic pursuit of device development. Increasingly sophisticated application of large scale integrated electronics, in particular the microprocessor, has resulted in prototype and commercial systems which exhibit features only dreamed of a decade ago. Message memory, prediction capability, multi-level character inventories, flexibility of selection strategy, user-programmability and synthesized speech output are to be found in more than one presently available system.

In contrast, far less attention has been paid to development of principles and techniques for optimizing non-vocal communication system features in design and prescription. The engineering of particular non-vocal communication systems and selection among (or adaptation of) these devices for the needs of a specific person involve choices which will have a major influence on the rate of communication which the user will ultimately achieve. Presently, these choices must be made by designers and practitioners without the support of analytically- or empirically-based guidelines. No common framework of concepts, vocabulary and assessment exists for treating diverse systems and clients in a unified way. A generalizable science of non-vocal communication would not only provide practical guidance to designers and clinicians but would also allow formulation of better defined, more broadly applicable research questions. It would further permit the application to these questions of well-established disciplines such as man-machine systems, information theory and linguistics.

Motivated by this long-range goal, this paper presents a straightforward analysis which embraces direct selection and encoded non-vocal communication systems. The discussion is largely qualitative with numerical data presented for illustration. A simple equation which relates system features to communication rate is developed, its validity clear without reference to mathematical theory. By "features", we are referring not to the details of electronic implementation, packaging or display technology. Rather, we will be concerned with a few generic descriptors which serve to characterize superficially diverse systems in a unified and functionally important way. Omission of scanning mode devices represents a limit to the generality of our analysis rather than a comment on the importance of such systems.

ANALYSIS

Other things being equal, faster communication is better communication. It is clear that the cognitive demands made by a system, its cosmetic appeal, its compatibility with therapeutic goals, and a variety of other less tangible factors will all influence its "optimality". It is equally clear that if one of two otherwise identical devices allows communication at 20 words per minute while the other limits it to 2 words per minute, the former is superior. What needs to be examined, then, are the system features which determine communication rate. The three variables which completely define a device with respect to rate may be defined as follows.

$C \equiv$ linguistic cost, measured in average number of units per word.

This term characterizes the menu or inventory of language units offered to the user by the system. Units may be letters, phonemes, syllables or whole words, for example. These are

the elements from which words will be formed and the particular choice of a unit menu may be shown to have a very strong influence on the value of C. For example, an inventory composed of the 26 letters and "space" will require, on average, 5 units (letters) per word, i.e., C = 5. SPEEC (1), a syllable-based system developed by Goodenough-Trepagnier, provides phonetically correct communication at a much lower cost (e.g., 1.5 units per word for a 400-unit system). It should be noted that C is an inverse measure of efficiency; the lower its value, the more linguistically efficient the unit inventory. Note too that the minimum value for this term is 1, which would be attained by the absurd case of a menu containing a user's entire vocabulary of whole words. (It is theoretically possible that lower values of C might occur in highly predictive, context-dependent, computer-based systems which anticipate whole phrases or even sentences.)

L ≡ average number of acts per unit.

This term specifies the length of a sequence of motor acts required for selecting a unit. In the general case of an encoded system, the number of distinct switches, or joy-stick positions or eye-gaze directions (for example) recognized by the system is considerably less than the number of units in the language inventory. The encoded Handivoice, for example, provides an interface of 10 buttons for selecting from an array of 1000 units. Clearly, then, the selection code requires performance of a sequence of acts to indicate a single unit. While the system may be set up to require more acts for some units than others, the average length of a sequence (during actual language production) is defined as L. This analysis includes direct selection systems as the limiting case of L = 1, i.e., the case for which each unit is selected (directly) by one act.

T ≡ average time per act.

While C is a purely linguistic descriptor and L defines the code which relates the "switch" array to the unit list, T is a function of motor factors (as well as relative frequency of use of the switches during language production). It is the amount of time required (on average over all acts during actual use) to perform a single motor act. In the case of a Canon Communicator keyboard, it is the average time to reach and activate a switch, approaching it from each other switch relatively more or less often as determined by occurence of particular letter sequences in the language. Obviously, this quantity will be strongly influenced by the detailed layout of the key pad or lap board or, most generally, the "signalling space" in which motor output will be sensed as a discrete set of meaningful acts. To the extent that intuition for the neurologically normal may be applied to movement-disordered people, one might expect more widely spaced or smaller buttons to require more time to access, i.e., greater T, with the same accuracy.

From examination of these variables, in particular their units, it may be seen that by multiplying them together, one can determine the average time required to form a word. In mathematical terms:

$$T = C \cdot L \cdot T$$

where T ≡ average time per word. Since our goal is to maximize rate of communication, any system change which serves to reduce T represents an improvement. The form of this equation is so simple that rather than requiring an appreciation for abstraction, it suggests a very real subdivision of system features which can be applied quite generally, promoting an awareness of the essential similarities among physically different devices. This awareness should facilitate comparison of systems with less of a sensation of comparing apples and oranges.

Each of the three descriptive variables, C, L and T, can be shown to depend in turn on a number of independent variables. In a narrow sense, it is the designer's (or practitioner's) task to select the values for these parameters which produce the lowest possible product of C, L and T, i.e., the fastest communication, for a particular client. The two readily definable independent variables on which the system variables depend are:

N ≡ the number of units in the system inventory;
and B ≡ the number of distinct acts recognized by the system, i.e., the number of buttons in the interface.

If linguistic theory had been fully applied to classes of unit inventories for efficient non-vocal communication; and if motor control physiology and psychology of movement had been fully applied to interface design for particular classes of motor disability; then mathematical expressions for C as a function of N and for T as a function of B would be available. Given complete quantitative assessment information for a particular individual, these expressions would allow an analytical prediction of the best inventory size and the optimal number of acts to minimize T and optimize communication rate. The theoretical and experimental work necessary to permit such accurately predictive modelling has not been done. In the foreseeable future, then, some element of trial-and-error must remain in the procedures followed for individualized system design. An iterative approach to the design and prescription task is presented in the companion to this paper (2).

Even without further mathematical precision, it is easy to appreciate the range and qualitative unpredictability of the effects on communication rate of altering N or B. At first glance, for example, it would seem that a simple way to reduce C (units per word) is to increase the size of the inventory, N, by adding a lot of whole words to the list. This would make available more words which need not be built up from smaller units. Other things being equal, bigger N means smaller C. Countering the reduction in C, however, is the effect of N on L. If the number of acts in the interface is kept the same, longer sequences of

acts per unit will be needed to encode a larger inventory. In other words, bigger N means bigger L. Since what really matters is C·L, the net effect of increasing N cannot readily be predicted.

A similar pair of opposite effects results from decreasing B, the number of acts. In practical terms, if the number of buttons is reduced, the interface can be made more compact or the individual buttons larger, or both. Either of these changes might be expected to reduce T, the average time to access and strike a key. So smaller B means smaller T. The effect on L, however, is the opposite; smaller B increases L since the reduced number of available acts will result in longer sequences of acts to encode a particular number of units. Once again, the overall result of changing a system parameter is hard to predict. Research in motor control necessary to establish approximate rules relating switch arrangements, sizes and spacings to required access time--in other words, a Fitts' Law (3) for neurologically impaired movements--is an exciting and largely unexplored area of rehabilitation engineering.

ILLUSTRATIVE EXPERIMENTAL EXAMPLE

In order to emphasize the practical reality of the concepts and variables discussed above, data is presented here which was collected in timed communication trials. The subject, LG, is an experienced user of the Canon Communicator, a direct selection system. Measured values of T and T were obtained during use of this device and during communication with a 400-item direct selection SPEEC board.

Canon	SPEEC
B = N = 26 (letters)	B = N = 400 (syllables including single phonemes)
L = 1 act/unit (direct selection)	L = 1 act/unit (direct selection)
T = LT = 2.4 seconds/unit (measured)	T = LT = 4.8 seconds/unit (measured)
C = 4.0 units/word with no spaces	C = 1.52 units/word with no spaces
T = 9.7 seconds/word (measured)	T = 7.3 seconds/word (measured)

It may be seen that the larger SPEEC inventory, and the larger number of acts it implies, results in the expected increase in average time per act and the expected decrease in linguistic cost. The net result, in this example, was a substantial decrease in the average time per word, i.e., faster communication.

An even more interesting case would be the SPEEC inventory with its low C, encoded on the relatively fast 26 key interface of the Canon. It can be shown that the best way to use 26 keys for coding 400 units is to use 6 of the keys for one-act selection of the 6 most frequent units, while using the remaining 20 to initiate two-act sequences to code the remaining 294 units. Such a code yields a value of L of approximately 1.87. It may be seen then that:

N = 400;
T = 2.4 seconds/act (as for the Canon);
L = 1.87 acts/unit;
C = 1.52 units/word (characteristic of SPEEC);
and T = 6.8 seconds/word (predicted).

While experimental verification is yet to be obtained, a small improvement is predicted. Further comparative experiments of this type in which variation of communication rate with system variables is observed, repeated on enough subjects, could lead to valuable empirical generalizations.

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ACKNOWLEDGEMENT

This work has been supported in part by Grants No. 23-P-55854/1 and 16-P-57856/1-05 from the National Institute of Handicapped Research, United States Department of Education.

MODEL FOR A COMPUTER-BASED PROCEDURE TO PRESCRIBE AN OPTIMAL "KEYBOARD"

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ABSTRACT

A model is proposed for a computer-based procedure to select a "best key-set" for an individual, once a thorough motor evaluation has been conducted, and a language inventory selected on the basis of cognitive and language evaluation. This model is based on the analysis of factors affecting rate in non-vocal communication summarized in the preceding paper (Rosen and Goodenough-Trepagnier). Once the inventory size has been set, this procedure determines the optimal number, location, size and type of motor acts (e.g. switch closures or isometric force levels) with which to encode the language units in order to make communication as rapid as possible. An optimal assignment of act sequences to units is generated.

INTRODUCTION

Communication rate for a non-speaking individual using a non-vocal communication system is almost always so slow as to pose a formidable barrier to social interaction. Enhancement of non-vocal communication rate, typically in the range of 5 to 10 words per minute, in order to begin to approach conversational speeds of 100 to 200 words per minute (Perkins,'71) is a highly desirable goal.

If devices which provide an explicit and readily understood output are assumed, communication rate can be seen to depend on the following factors:

C - the average cost per word in units of the language system (e.g. the alphabet has a C of about 4; that is, 4 letters are required to spell each word on the average in a large sample of transcribed spoken text).

L - the average number of acts, or length of a key sequence needed to encode each language unit. (e.g. an alphabet encoded on 10 keys would require an average of between 1 and 2 key presses per letter)

T - the average time per act (e.g. the time to press each key on the average).

C and L are each determined by independent system parameters. C is a function of N, the size of the inventory of language units. Possible values of N could include 26 (letters), 40 (phonemes), 200 (174 words plus 26 letters), 200 (160 syllables plus 40 phonemes). For any system which can represent language exhaustively (i.e. in which no words are unproducible) a value of C and a frequency distribution for the units can be obtained, using a large representative language sample.

L is also a function of N, and of B, the number of keys. A small B means longer sequences of keys (larger L) to encode each of the N units. The relationship of these factors is detailed further in another paper in these proceedings (Rosen & Goodenough-Trepagnier,'81).

Following is a model for a computer-aided procedure which would allow selection of a "best key-set" for a given user, once type and size of language system had been selected, on other grounds, and given a prior survey of the individual's motor capabilities (Goldenberg & Gaddis, in progress). The purpose of the procedure is to divide the "signalling space" (the range of motor activity the subject can produce by such means as manual, head or foot pointing, eye gaze selections, isometric force, breath pressure, etc.) into discrete acts such that the average access time (LT) of sequences of these acts which encode the language units, will be as low as possible.

SUMMARY OF PROCEDURE

1.-4. Selection of language system, N, signalling space and training criteria, based on evaluations prior to this procedure, as well as therapeutic considerations.

5.-6. Determination of an array of "keys" which subject can access with desired performance level after training.

7.-end. Assignment of language units to act sequences so that greater frequency of occurrence of units is associated with shorter access time. Adjustment according to results of further training.

DETAILED ALGORITHM

1. SELECT RANGE OF N AND TYPE OF LANGUAGE SYSTEM
   Selection of a value for N and of the type of language system would be carried out on the basis of psycholinguistic grounds beyond the scope of this paper (such as developmental considerations, cognitive and language evaluation, memory requirements).

2. DETERMINE FREQUENCY DISTRIBUTION OF THE N UNITS OF SYSTEM BASED ON THEIR USE IN WRITING A LARGE SAMPLE OF LANGUAGE
   The frequency distribution of the language units is found by spelling a large text, large enough to be considered representative of English usage, in those units (Goodenough-Trepagnier, et al., in press).

3. SELECT "SIGNALLING SPACE"
   Global evaluation of the individual's full range of motor capabilities is a complex problem that cannot be dealt with here. Studies currently underway (Goldenberg and Gaddis, in progress) are approaching the problem of surveying the response possibilities of motorically disabled individuals. Therapeutic considerations, such as which movements to encourage and which to suppress, are also important here.

4. SELECT DESIRED PERFORMANCE LEVEL
   A level of performance lower than the final performance level desired is selected, to allow for improvement during training. Performance is defined by an index which increases with speed and accuracy. Training procedures will be refined through preliminary studies (e.g. investigation of the effect of reinforcement for accuracy and/or speed on performance).

5. DIVIDE SIGNALLING SPACE INTO LOCATIONS WHICH SUBJECT IS EXPECTED TO ACCESS AT SELECTED PERFORMANCE LEVEL
   The range of signals is divided into areas ("keys") such that each key is predicted to be accessible by the subject at the selected performance level, using data from the motor evaluation to make this first approximation.

6. TRAIN UNTIL ASYMPTOTIC ACCURACY REACHED. FLAT FREQUENCY DISTRIBUTION, RANDOM ORDER OF LOCATIONS. LOCATIONS LIGHT UP TO ELICIT RESPONSE. SCATTER, TIME RECORDED
   IF LOCATIONS ARE NOT EQUIVALENT IN PERFORMANCE, OR IF AVERAGE PERFORMANCE IS SIGNIFICANTLY BETTER OR WORSE THAN SELECTED TRAINING LEVEL, THEN GO TO 5. ELSE, GO TO 7.
   Each key lights up to elicit the user's attempt to activate it. Keys light up in random order, with equal probability. The following measurements are made: time for each hit (and miss) and "location" (or degree of force, etc.) of scatter. The subject is encouraged to aim for accuracy. To control the outer limit of response time, the subject is asked to complete the response before each light goes out.
   This training continues until asymptotic performance is reached, indicating that little more improvement is to be expected.
   If the performance level for this key-set is much worse or much better than the training level (of if keys differ markedly in performance), go to 5.
   If performance is at the level desired for training, go to 7.

7. ASSIGN UNIT FREQUENCIES IN DESCENDING ORDER TO SEQUENCES OF LOCATIONS IN ORDER OF INCREASING ACCESS TIME
   The frequency distribution of the language units of the system has been determined in 2. Each unit is thus associated with a relative frequency. These frequencies in descending order can be associated with key sequences arranged in ascending order of time. For example, the key requiring the least access time is assigned the relative frequency of the top unit on the list, and the frequency of the lowest unit on the list is assigned to the slowest key or key sequence.

8. TRAIN UNTIL ASYMPTOTIC PERFORMANCE IS REACHED. WEIGHTED FREQUENCY DISTRIBUTION, RANDOM ORDER OF LOCATION SEQUENCES. LOCATIONS LIGHT UP TO ELICIT RESPONSE. SCATTER, TIME RECORDED
   As in 6, the subject's responses are elicited by having keys light up. At this stage of the procedure, in contrast to 6, the frequencies with which various keys are illuminated are no longer equal; they reflect how often the keys would be used in transmitting language. The order is now a random ordering of sequences of keys (sequences may consist of one to several keys). Again, the scatter and time are noted, and training continues until asymptotic performance is reached.

9. COMPARE ORDER OF LOCATION SEQUENCES (ACCORDING TO ACCESS TIME) TO PREVIOUS ORDER OF LOCATION SEQUENCES.
   IF DIFFERENT, GO TO 7.
   ELSE, IF FINAL PERFORMANCE LEVEL USED AND IF AVERAGE PERFORMANCE NOT SIGNIFICANTLY BETTER OR WORSE THAN SELECTED LEVEL, THEN GO TO 11.
   ELSE, GO TO 10.
   Each key sequence (of one or more keys) now has an average time associated with it from 8. The order of these key sequences (by time) can be compared with their previous order (from 6). The first time 9 is reached the order will necessarily be different. In that case, 7 is repeated, i.e., the unit frequencies are re-assigned to the key sequences ordered by time. On subsequent passes the order may still be different, as certain keys are getting relatively more practice, and frequent sequences are becoming automatized. Until the order is stable, the cycle (7,8,9) is repeated. When the order is unchanged, if the performance level being used is not yet the desired one, go to 10. If the final accuracy level is now in effect, go to 11.

10. ADJUST LOCATION SIZE FOR DESIRED FINAL PERFORMANCE LEVEL. GO TO 7.

This step adjusts key size such that the subject's projected performance (based on analysis of the scatter with the more demanding key division of the training performance level) is now as good as is desired for satisfactory functioning of the communication device. In other words, keys may now be enlarged and/or eliminated to raise the performance index to the desired level. Since projected performance can be expected to differ from observed performance on a more difficult key-set from Fitts' Law (Fitts,'54), it is necessary to repeat the training and comparing cycle until performance with this new division into key locations stabilizes (7,8,9).

11. ENCODE UNITS AS KEY SEQUENCES ACCORDING TO THE FINAL MAPPING ESTABLISHED IN 7.
Once the order of key sequences, using final performance level, remains unchanged (9), step 11 maps the units in descending order of frequency onto the keys in ascending order of time.

DISCUSSION

It should be emphasized that the model outlined above is neither the only nor necessarily the best approach to optimizing communication rate. The problem can also be treated, for example, by selecting a keyboard and then deriving a set of language units on the basis of their time efficiency. Such an approach seems particularly suited for a scanning mode, and work on it is in progress (Goodenough-Trepagnier, Tarry). Ideally, of course, the goal is to define an iterative procedure which interactively determines both B and N, without arbitrarily fixing either.

While many practical aspects remain to be worked out, the model described here seems closest to a realizable, general technique for determining, in a theoretically grounded way, the best use of an individual's motor capacities for enhancement of communication rate.

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ACKNOWLEDGEMENT

This work has been supported in part by Grants No. 16-P-57856/1-05 and 23-P-55854/1 from the National Institute of Handicapped Research, United States Department of Education.

HYPOTHETICAL DIAGNOSTIC CLASSIFICATION OF TREMOR ACCORDING TO VARIATION WITH MECHANICAL LOADS

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ABSTRACT

Data from the authors' investigation of alteration of abnormal tremor by mechanical loading is briefly reviewed. It is noted that the results support the concept of compliant restraint systems and loaded device interfaces as means for improving control in movement-disorder patients. Published results of other investigators on tremor modification are also summarized along with analytically-based models for tremorogenic mechanism. Some predictions from these models of variation of tremor properties with applied loads are noted. Emphasis is given to the implication that mechanical loading could be used as a diagnostic test for establishing which of several therapeutically predictive categories a patient's tremor belongs to. A prototype tremor-processing and tremor-scoring instrument for clinical use is described.

INTRODUCTION

In experiments conducted over the past five years at the Harvard-M.I.T. Rehabilitation Engineering Center, a statistically significant reduction in abnormal intention tremor has been achieved in all subjects by application of viscous damping. Neurological patients with pathological movement secondary to multiple sclerosis, cerebral palsy, Freidriech's Ataxia, closed head injury, mid-brain stroke, familial tremor and a sclerotic degenerative disease were tested in visually-mediated wrist extension/flexion tracking trials (1). In many cases, a viscous load (restraining torque proportional to instantaneous angular velocity) improved the accuracy of performance to a clinically significant degree. The implication is that compliant orthoses and interfaces to communication, environmental control and mobility systems may be designed to incorporate mechanical properties which tend to suppress tremor while permitting voluntary intent to be expressed. While a larger number of subjects and a broader range of loading functions remain to be tested (pending approval of submitted proposals), our present data justifies sufficient optimism that a practical viscously-damped joystick is being built. This unit is based on results obtained from a prototype presented at a past ICRE (2). Data from tracking tests conducted with an early group of subjects has been published (3) and more up-to-date coverage may be found in the H.-M.I.T. R.E.C. Proposal/Progress Report for fiscal year 1981. Three manuscripts for publication covering the loading experiments in detail as well as implications for tremor models and design of force-sensing interfaces are in preparation (4,5,6).

The purpose of this article is to define and discuss an application of mechanical loading to differential diagnosis of patients with abnormal involuntary movements. The concept will be justified on the basis of data from our work and from the literature, and on the basis of the tremor models which that data supports. A simple clinical tremor-assessment instrument developed in preparation for testing the proposed approach will also be described. Funding has been sought to test the concept experimentally with a major involvement of the Movement Disorder Clinic of the Veterans' Administration Medical Center at Brockton.

LOAD RESPONSE AS AN INDICATOR OF TREMOR MECHANISM

There is a substantial body of literature which reports variation in the properties of tremor under the influence of peripheral changes, in particular, applied loads. Lippold reported changes in tremor amplitude and frequency when muscles were cooled or rendered briefly ischemic by the application of an inflated cuff (7). More recently, a variety of animal and human preparations tested by Stiles and co-workers (8,9), Joyce and Rack (10), and others demonstrate variation of the spectrum of physiological tremor with applied masses and springs. A consistent increase of amplitude and reduction of frequency of the dominant peak hand tremor, for example, are reported as inertia is increased. While far less experimental work has been done with pathological tremor subjects, Chase et al (11) report a reduction of finger tremor in patients with cerebellar lesions when gravitational forces were applied requiring greater flexor activity than extensor. Our own results from pathological subjects show a consistent reduction in both cummulative-power and peak-frequency measures of low-frequency intention tremor with applied damping loads, as reported above. We have observed that tremor torque in the pathological frequency range is unaffected by isometric restraint, while a torque peak present

in the 8 to 10 Hz (normal) range is severely attenuated. This finding suggests different mechanisms for these two oscillations; it will be interpreted in more detail below.

Results such as these take on particular significance when analyzed in the context of models of tremorogenic mechanism. Published data and application of theory presently support three classes of mechanism for normal and abnormal tremor. While these hypotheses are distinct in systems terms, they may not be mutually exclusive, and, in fact, data obtained by Stiles (9) supports involvement of two mechanisms in mass-altered physiological tremor. The hypothetical mechanisms may be summarized as follows. Central oscillator: According to this theory, tremor is driven by an autonomous site in the brain which generates oscillatory motor-control activity. This locus of tremor drive is autonomous in the sense that it sits outside the major closed loop neuro-muscular systems governing movement (although on the small scale, neuro-anatomical level, the oscillation may be generated by local neural feedback). Biomechanical Resonance: This hypothesis is based on the commonplace observations that the torque produced by muscle systems during attempted postural maintenance has a random noise component and that the unsupported distal limb segment is an underdamped second (or higher) order system. Since such a system will tend to oscillate at its resonant frequency, the broad band forcing produced by unsteady torque will produce a more narrowly tuned vibration of the limb. This theory, then, suggests a biomechanical origin of tremor which requires no central nervous system drive. Considerable support for resonant mechanism for small-amplitude, normal tremor may be found in the work of Stiles and coworkers (8,9). Loop Instability: It is well established in control theory that closed loop systems, particularly those which include time delay and non-linear elements, are capable of generating sustained oscillatory output in the absence of an oscillatory input signal. Since spinal and long loop reflexes have both these characteristics, the hypothesis that loop instability generates or contributes to tremor is justified. In the case of clonus in spastic paraplegia in particular, the oscillation is easily modelled as a limit cycle resulting from abnormally high loop gain, i.e., heightened reflex sensitivity.

While work remains to be done on determining the analytical form and the parameter value estimation required to fit specific models to particular data, even the broad classifications defined above predict certain observations. These predictions can be used to identify the theoretical category to which a measured tremor belongs. Of particular note in the context of our interest in mechanical loading is the tremor load response implied by each model. Some examples of the modulation of observable tremor properties to be expected for various types of load and classifications of tremor are as follows:

1. A resonant mechanism for tremor predicts a peak frequency strongly dependent on mechanical parameters and, as noted above, this dependence is often observed in physiological tremor. More specifically, to the extent that an underdamped second-order model for the muscle and distal limb system is adequate, one expects a change of frequency inversely proportional to the square root of the moment of inertia, and directly proportional to the root of an applied spring constant. Evidence that a tremor responds to masses and springs in this manner offers strong support for the resonance hypothesis.

2. It is well established that the central nervous system can adjust the sensitivity of reflexes while propagation delay, at least for spinal loops, is a relatively fixed parameter in the absence of peripheral disease. It appears, then, that exaggerated loop gain is implicated as the likely basis of instability, when it is present. Since the literature (12) reports that incremental spindle gain is greater for small stretches than for large, isometric restraint should increase tremor torque with respect to the unrestrained case, if the tremor is caused by loop oscillation.

3. A particularly strong-inference result would be the finding that radical alterations in applied loads have no effect on tremor frequency. If a tremor is driven by an autonomous central oscillator, changes in peripheral system parameters can effect the amplitude of that part of the movement which is correlated with the drive signal, but cannot affect its frequency. A finding of frequency invariance with load, coupled with frequency modulation by altered time delay, e.g., by cooling (7), would be strong evidence that tremor is caused by central drive and not by loop oscillation.

IMPLICATIONS FOR CLINICAL PRACTICE

The hypothesis being proposed in this article is that measurement of the variation of abnormal tremor caused by application of mechanical loads constitutes a diagnostic test. This is implied directly by the relation between load response and tremor mechanism if the classifications of mechanism defined above represent therapeutically predictive categories. If it is know, for example, that a particular drug has its effect by reduction of spindle sensitivity, then that drug can be ruled out for a patient whose tremor shows frequency invariance under load--indicating a central mechanism. What is needed is research to establish correlations experimentally between the response to therapies of interest and the response to mechanical loads of the tremors measured in a group of subjects. A study intended in part to determine whether such a correlation exists--as predicted by theory--has been proposed. Should this approach to predictive classification of movement disorders prove valuable, one can imagine a Cybex-like machine capable of applying precisely controlled, simulated loads in various movement modes with computer-based, on-line analysis of the effects on involuntary movement.

Implied in this imagined approach to tremor diagnosis is the capability of making quantitative measurements of abnormal movement. Even outside

the context of mechanical loading, there is clearly a need for more precise techniques for monitoring changes in tremor produced by the progression of disease or the application of therapy. Whereas the common availability of instrumentation tape recorders and computers with provision for analog signal acquisition in the laboratory makes special-purpose instrumentation unnecessary, the clinical environment usually lacks these luxuries. What is needed is a stand-alone processor which will accept movement-related signals from goniometers or accelerometers and generate a tremor score. Further, for those patients whose tremor is induced by voluntary movement, the device should display a tracking task simulating, in an abstract sense, the motions of activities of daily living. An instrument which meets those requirements has been designed and built. Its features are outlined briefly below.

The device accepts a single analog signal obtained from a movement transducer. On its face are two parallel 40-segment "bar graph" displays, one driven by the subject's joint angle and the other by an internal pseudo-random signal generator. A tracking error signal is derived and processed in somewhat the same manner that myoelectric activity is commonly treated, i.e., by filtering, rectification and integration. A high pass operational amplifier filter with its corner frequency at 2 Hz is used to eliminate tracking-frequency components, leaving only the higher frequency tremor activity. Integration is accomplished by a voltage-controlled oscillator whose output increments a digital counter at a rate proportional to the instantaneous, rectified, filtered error. The counter circuit used provides re-coding and direct drive of a four digit LED display. A single reset control is provided which blanks the numerical display until completion of the test, initiates presentation of the target, and times 100 seconds of tracking. The score displayed represents a cumulative movement error in the frequency range of interest during a fixed measurement period. Linearity and frequency independence in the range of interest are within a few percent of ideal. Expanded versions of this instrument might include independent processing in three frequency bands, perhaps 2 to 4, 4 to 8, and 8 to 16 Hz, thereby providing rudimentary spectral analysis of a patient's tremor and detection of frequency shifts, as well as amplitude changes.

SUMMARY

Our experimental results to date provide strong support for the concept of compliant restraint systems which suppress tremor selectively by means of an optimally chosen loading function. Detailed examination of the modulation of tremor parameters with mechanical loads also serves a research function by allowing distinctions to be made among hypothetical mechanisms of tremor. The concept outlined in this paper is a clinical extension of that approach, i.e., diagnostic application of strategically chosen loads to allow classification of movement disorders into categories which suggest appropriate therapy. Research intended to test this idea experimentally has been planned and a clinical tremor-assessment instrument built as a prerequisite to that work.

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ACKNOWLEDGMENT

This work has been supported in part by Grant No. 23-P-55854/1 from the National Institute of Handicapped Research, United States Department of Education.

A STUDY OF NEUROMOTOR CONTROL IN ATHETOID CHILDREN

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We have designed and built a system that gives severely disabled athetoid children control of computer based activities in innovative ways, and allows us to study their movements as they engage in these activities. We are beginning to develop models of the neuromotor mechanisms involved in athetosis based on theory and observation and expect to test aspects of these models over the next months. This paper describes some of the issues of instrumentation and experimental design for the study and use of these mechanisms.

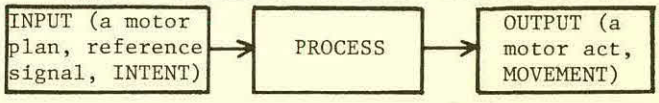
INTRODUCTION

While exploring the electronic enhancements to motor performance that can be used in communication and control aids (4, 5), we have become increasingly interested in the considerable presence of control shown even by individuals most noted and treated for their profound lacks of control. Within the movements of our severely athetoid children, we see a correct signal, generally distorted, and sometimes swamped, with noise. If they can not point accurately to items on their communication board, they can, at least, get near it with their hand. To satisfy both our theoretical and practical interests, we have begun studies to clarify the nature of neuromotor control in athetosis. Such understanding will lay the foundation for the development of "smart" aids that are capable of distinguishing intentional from unintentional components of noisy movements and that, therefore, need not totally ignore those movements as nonfunctional.

We face some staggering difficulties: models of normal adult neuromotor control are far from complete; precise and unambiguous data on movement are hard to obtain; little quantification of athetotic movements has been done; and theoretical assumptions about the nature of athetosis vary widely. While an understanding of the myriad mechanisms underlying voluntary movement is far from complete, it has been possible to devise experimental tasks that isolate particular features of human motor behavior. Furthermore, we take heart at the signal processing successes at filtering out interference in deliberately "jammed" radio broadcasts. Athetoid noise, as it is described clinically, is much more well behaved than the intentional and diabolical noise generated by a clever spy, trained for the task.

We regard human movement control as a heirarchical series of feedback control operations, ranging from spinal level, reflexive adjustment mechanisms to high level feedback required for learning and the acquisition of new skills. Motor plans appear not to consist of minutely detailed strings of commands to individual motor units, but rather to be abstract representations of the desired motor outcome in a high-level language that gets compiled and assembled differently depending on the specific muscles to be addressed, and depending on other internal and external conditions. Thus, with little or no practice, we can sign our name in the air with our nose by moving our head, neck and torso, and produce very much the same signature as if we had signed normally with our dominant hand.

Figure 1 represents the model schematically.



This paper focuses on some of the issues in determining the input, measuring the output and inferring the process. Preliminary results will be shared during the conference presentation.

DETERMINING INPUT

The interaction of motivation with performance is profound with all children and is compounded in disabled children who often learn to be passive and dependent. We have found (5) that computer based video games provide challenge, variety and intrinsic interest for many handicapped children and are played at great length without coaxing, praise, or bribes. Their flexibility both in the cognitive and motoric task required of the child also assures that we can design a game that even a severely disabled child can control well enough to enjoy.

With young children, the problems don't end when an experimentally useful task is presented in a motivating form. If a child attends to an aspect of the task unnoticed by the experimenter, the results may give a false picture of the child's abilities. Thus, close clinical observation throughout experimental sessions, and full videotape records for review and analysis are essential in interpreting the child's intention during the tasks. Instrumented data are examined in the light of the clinical observations to help recognize subtle shifts in attention.

MEASURING THE OUTPUT

One must control a video game in real time. Since we wanted to use 3 dimensional movements for control, we were forced to solve the problems of realtime transduction, processing and recording of 3-D movements, and returning the processed version of these movements to control the game.

Three transducers do most of our work (see laboratory configuration in Figure 2, below), though we also use others. Most important at present is an ultrasonic three-dimensional position monitor adapted for our laboratory by the manufacturer. Members of our staff (1) studied the performance extensively and modified the configuration of the tracking sensors to increase its accuracy. The device, an uncommon variant of the familiar Graf/Pen, passes its data to an 8080 based preprocessor developed at our lab, and from there to a PDP11/34 for further processing and storage. The PDP11 generates coordinates in Cartesian space, a global frame of reference within which the child's position is well established. Sometimes, local frames of reference for the movement of selected body segments are computed as well. Our modified Graf/Pen is capable of tracking three points in space simultaneously. Thus we can monitor the positions of "independent" body segments (e.g., the movements of the dominant hand and ancillary spillover movements of the other hand or of the head) or both the orientation and position of a single body segment (3).

The PDP11 stores data for further analysis and sends a processed form of the data to a stuffed APPLE II PLUS, to which it is slaved. The APPLE main line programs (video games with audio accompaniments) and calls to peripherals including the PDP11 are developed in APPLE PASCAL and 6502 Assembly Language. In addition to requesting input from the Graf/Pen (via the PDP11), the APPLE may select the Graphics Tablet or an isometric joystick. The tablet electromagnetically senses the position of a special

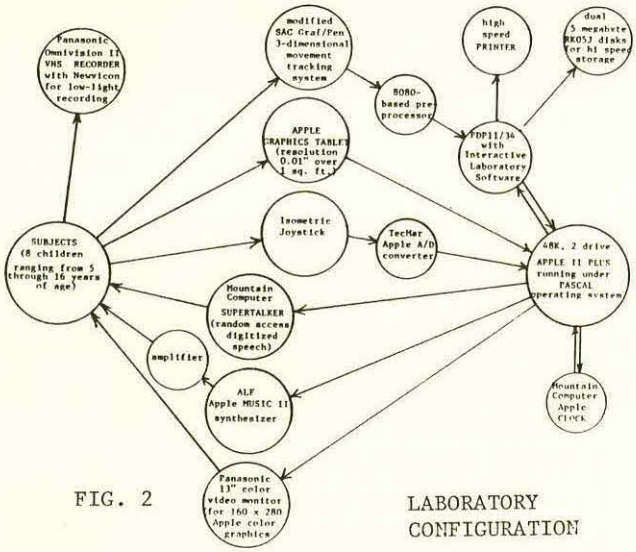


FIG. 2 LABORATORY CONFIGURATION

stylus to better than 0.01" over its roughly 1 sq. ft. surface. The isometric joystick is a rigidly mounted stick which generates a pair of voltages directly proportional to the magnitude and direction of lateral forces applied to it.

AN EXAMPLE TASK FOR ANALYSIS AND AID BY COMPUTER

Pointing is an important part of non-vocal communication, yet there are some subtle problems in interpreting it. Consider a classroom situation in which a child is to spell a word by pointing to her communication board. Her hand writhes around on the board, occasionally pausing for a moment. If she stalls while pointing at none of the items, her teacher waits encouragingly for her to get her hand back in motion. If her hand should pause on the correct next letter, her teacher immediately acknowledges it before an involuntary motion drags her hand away again. If however, her hand should pause momentarily on an incorrect choice, it is sometimes unclear whether she is choosing that item or if, instead, her stall is involuntary. If the teacher hesitates, he influences the child's choice, for his response to a correct choice is always immediate.

Spatial resolution in pointing is another concern. A child's involuntary movements may make it impossible to point differentially to items separated by less than some known distance. Yet the centers of the child's oscillations may resolve smaller distances.

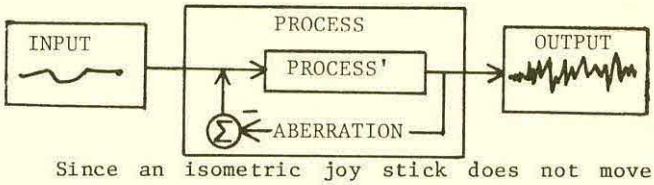
Our computer analyses of the temporal and spatial parameters of pointing -- e.g., duration, suddenness, stillness, and stability of pause, "fuzziness" (imprecision) of position, behavior of other body segments, etc. -- may yield a function mapping "fuzzy" pointing onto precise targets. This offers potential for the development and commercial manufacture of "smart" communication devices that recognize faster, finer distinctions. Of course, it may turn out that athetoid persons find it easier to control force against an immovable object, than to control position of an unrestrained hand. Therefore, we are examining this type of control as well.

INFERRING THE PROCESS

At this writing, we are still very far from deciding, even tentatively, among theories of athetosis. We cannot even be certain we are exploring all of the reasonable ones. Still, we wish to share the questions we are asking and the observations we have made. The risk of exposing our own ignorance seems slight when weighed against the hope that others with the inclination and instrumentation may join in the research.

For the most part, we are looking at three expansions of the simplistic model shown in Figure 1, and attempting to determine which most closely explains the phenomena we observe.

Expansion I: Athetoid oscillation results from faulty feedback in the control system.



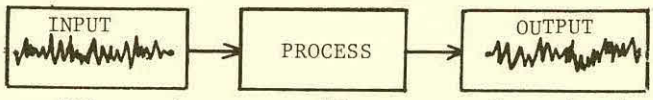
Since an isometric joy stick does not move noticeably when pressed, it gives reduced feedback from joint receptors and muscle spindles. Signal/noise ratio can then be measured under conditions of primarily visual feedback.

When normal adults were asked to maintain a fixed magnitude of force against such a stick and were presented with augmented visual feedback, analysis of the noise (the error) isolated two significant components, one peaking at 10 Hz. and the other between 0.5 and 3.0 Hz. (6).

By delaying visual feedback it was possible to separate these components, demonstrating that one (the 10 Hz. peak, corresponding to normal physiological tremor) was not responsive to the feedback, and that the other was contributed by "the subject's attempts to correct for both his own minute errors and the inevitable drift in produced force that results from trying to sustain an output force level" (6, pg. 4).

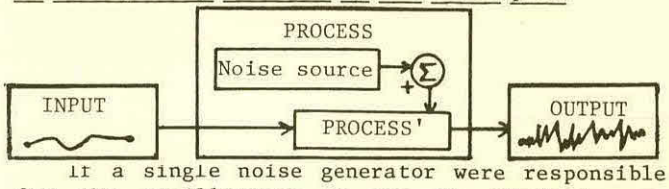
Visual feedback is a higher level feedback system, and not the one most likely implicated in athetoid noise. We are currently developing ways of investigating the interaction between lower level feedback and performance with the purpose of determining more about where in the control loop the athetotic abnormalities may originate.

Expansion II: Athetotic movements represent constantly changing motor plans.



This conjecture would suggest that the low level feedback system is working fine (that is, it is delivering what it is being ordered to deliver) but that the orders keep changing. If the heirarchical view of motor performance is correct, this result could come about if the raw motor plan (e.g., to throw a fast punch) were not adequately expanded (e.g., with commands to maintain postural support and balance against recoil and change in center of gravity) during delivery to the muscles. If this expansion is lacking, the resulting lack of stability will require other compensatory movements (new motor plans) or else the individual will fall over. Though not generally referring to movement aberrations as "compensatory," much of clinical practice explicitly assumes that postural instability is a major contributor to the pathologic movements. These continually changing plans are, of course, feedback induced, but unlike the garbling of motor plans by incorrect feedback as in Expansion I, these are produced in response to correct feedback on partially successful motoric acts. If athetoid noise somehow derives from postural compensation for reactive forces on the body, then we should expect to see a temporal relationship between the noise produced in force control against the isometric joy stick and the forces applied to the stick.

Expansion III: Noise is being introduced into the input by an oscillator either independent of or inadequately modified by the motor plan.



If a single noise generator were responsible for the oscillations we see in athetosis, we might expect to detect it by comparing the power spectra of the noise in different body segments with mechanical characteristics of those segments. A question raised by this possible model is whether athetosis is the result of the abnormal presence of a noise source or, alternatively the abnormal absence of control over a normally present and adaptive frequency generator.

SUMMARY

By studying a small number of subjects intensively, examining control of force as well as control of position, velocity and acceleration, and by analyzing the observations with respect to local as well as global frames of reference, we expect to refine the controllability of aids and prostheses and increase general understanding of the nature of athetotic interference.

ACKNOWLEDGEMENT

This work is supported by NIHR grant #16-P-57856/1-05, U.S. Dept. of Education.

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DIGITAL CLOSED-LOOP CONTROL SYSTEMS FOR FUNCTIONAL NEUROMUSCULAR STIMULATION

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ABSTRACT

Orthoses employing electrically stimulated muscles could be improved by the incorporation of closed-loop control systems to regulate the output of the muscle. The electrically stimulated muscle is modeled as a sampled data system and a digital controller is designed to satisfy stability, repeatability, linearity, and step response criteria over a wide range of recruitment gains. The digital controller can be implemented with a microprocessor and is amenable to adaptive control techniques.

INTRODUCTION

Functional Neuromuscular Stimulation (FNS) has been shown to be a feasible method of providing function in paralyzed extremities. For example, systems have been constructed for restoration of hand function in C5 and C6 quadriplegic patients (4, 5) and for correction of gait abnormalities in hemiplegic patients (6). For almost all orthoses employing electrically stimulated muscles, it is necessary to have accurate, regulated and proportional control of the muscle contractions. The development of closed-loop feedback systems will bring orthoses closer to meeting these goals.

At present, all clinically deployed FNS orthoses are open-loop systems. As a result, they suffer from significant limitations inherent to electrically stimulated muscles. With either surface or intramuscular electrodes, the force produced by the muscle is a non-linear function of the stimulus parameters and muscle length (2). In addition, there is a dependence on the past history of activation (potentiation and fatigue). The overall system input-output properties are therefore non-linear and time varying, making it difficult for the patient to learn how to use the system and to achieve fine control.

In previous attempts to develop closed-loop feedback systems for the regulation of force (1) or position (7, 8) the electrically stimulated muscle was treated as a continuous system. Although adequate system response characteristics were achieved with proportional or proportional plus integral controllers, repeatable performance could not be ensured over a long time period because daily variations in muscle input-output properties required frequent adjustments of system parameters.

In the present study the stimulated muscle is analyzed as a sampled data control system and a digital controller is designed to meet specified time domain constraints. This approach offers the advantages that it can be implemented easily in a microprocessor based system, and is amenable to adaptive control techniques that can automatically compensate for system parameter changes.

SAMPLED DATA SYSTEM MODEL OF STIMULATED MUSCLE

In FNS, muscle is stimulated by a series of pulses, each of which is defined by its amplitude and duration. Each pulse elicits a twitch and overlapping twitches produce a smoothed output. The stimulation frequency is kept at a value no higher than that required to produce an adequately fused contraction (less than 10% ripple in the isometric force). The contraction force is modulated by two mechanisms - recruitment and temporal summation. At low and intermediate forces, is controlled by varying the pulse area which changes the size of individual twitches (recruitment). At high forces, force control is achieved by varying the interpulse interval (IPI), which changes the amount of overlap of successive twitches (temporal summation).

This system is best modeled as a variable rate sampled data system, with the sampling period equal to the stimulus interpulse interval (Figure 1). The output of the sampler is a train of pulses, and the area of each pulse is proportional to the magnitude of the sampler input at the sampling time. The muscle is modeled as a two pole low pass filter with a small pure delay. The non-linear relationship between stimulus area and the proportion of muscle activated by each pulse (2) is described by the recruitment characteristic. The closed-loop system is completed by the controller which operates on the difference between the desired output (Command) and the actual output.

EXPERIMENTAL AND THEORETICAL ASSESSMENT OF PROPORTIONAL CONTROLLERS

Systems of the configuration shown in Figure 1 have been studied both experimentally and theoretically for proportional controllers and recruitment modulation at a fixed IPI. Stability, linearity, steady state error, and response time were measured as a function of proportional loop gain (the product of controller and muscle recruitment modulation gains). The experimental

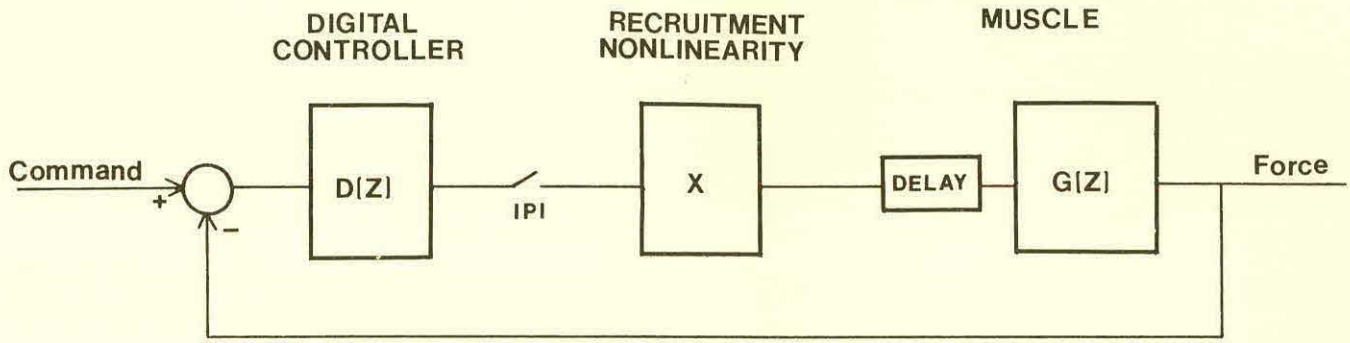

Figure 1. Block diagram of closed-loop control system for electrically stimulated muscle.

tests were carried out in cat soleus and human finger or thumb flexor muscles with force feedback under isometric conditions (1).

Proportional controllers were not found to be adequate for these control systems. Experimentally, the systems became unstable and demonstrated limit cycle oscillations if the loop gain was greater than approximately one. Theoretically, the loop gain could be as high as six, but this difference could be attributed to the presence of local regions of high gain in the recruitment characteristics for the in-vivo tests. A unity loop gain proportional system can only correct for changes in muscle gain (such as fatigue) by 50% and thus is not adequate for clinical use. The theoretical analysis showed that the maximal allowable gain could be increased by decreasing the stimulus IPI (increasing the frequency) but this would cause much more rapid fatigue of the muscle.

DIGITIAL CONTROLLER DESIGN

The design of a digital controller for the closed-loop control of force by recruitment modulation was carried out using z-transform techniques. The controller was designed to meet criteria based on the desired system response properties in the time domain. The system performance has been analyzed by simulation on a digital computer and is presently being tested experimentally.

Performance Criteria

The following characteristics are desirable for FNS orthoses. a) Stability - There should not be sustained oscillations with a peak to peak amplitude greater than 10% of the mean amplitude. b) Repeatability - The steady-state input-output relationship should be repeatable so that commands appropriate for a given task on one day are also usable on other days. Ten percent deviations would probably be acceptable. c) Linearity - The steady state input-output relationship should be linear to ensure that changes in the command are reflected by proportional changes in the output. d) Step response - The response to a step input is a convenient method of chracterizing control system response properties. For ease of control, the step response should have a fast rise time (time to peak response of about 0.5 seconds and limited overshoot (10-20%).

Form of Controller

The overall transfer function for the closed-loop system shown in Figure 1 is:

$$\frac{F(z)}{C(z)} = \frac{X\,D(z)\,G(z)}{1 + X\,D(z)\,G(z)}$$

The pure delay is small and is neglected in this analysis. By breaking the controller into two parts,

$$D(z) = H(z) / G(z)$$

the transfer function reduces to

$$\frac{F(z)}{C(z)} = \frac{x\,H(z)}{1 + x\,H(z)}$$

For a closed-loop second order sampled data control system with specified time to peak and overshoot for a step input, the locations of the zero and the two poles can be specified (3). From these values, and for different values of recruitment gain (X), the locations of the zero and two poles of H(z) can be calculated. In order to ensure that the linearity and repeatability criteria are satisfied, one of the poles is placed at z=1. This leaves the parameters a_o, a_1 and b_o in the following equation to be specified for the controller.

$$H(z) = \frac{a_1 z - a_o}{(z-1)\,(z-b_o)}$$

Effect of Recruitment Non-Linearities

For fixed controller and muscle dynamic properties the effect of varying recruitment gain

is to vary the locations of the closed-loop system's poles, and thus vary the dynamic response of the closed-loop system. Since recruitment gain varies as a function of recruitment level and muscle length (2) the closed-loop overshoot and time to peak will also vary with the same parameters. The values for the controller are chosen so that the overshoot and time to peak are less than the maximal allowable values over a ten to one range of recruitment gains.

Advantages of Digital Controller

There are several advantages to a digital controller. Since stimulated muscle is more appropriately modeled as a sampled data system, the design of the controller is accomplished more easily using discrete time (digital) techniques such as z transforms. A digital controller can be implemented using a microprocessor. The controller parameters can be altered easily for different types of muscles and for daily changes in muscle properties. Finally, a microprocessor could adaptively adjust the controller parameters to compensate for time varying muscle properties. The incorporation of this final feature would alleviate one of the significant problems encountered in the clinical implementation of closed-loop FNS orthoses.

ACKNOWLEDGEMENTS

This research was supported by Contract Number NO1-NS-0-2330 from the Neural Prosthesis Program of NINCDS. We thank Dr. J. T. Mortimer for use of laboratory facilities.

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FUNCTIONAL NEUROMUSCULAR STIMULATION SYSTEMS FOR CONTROL OF THE HAND IN THE QUADRIPLEGIC

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ABSTRACT:

Functional neuromuscular stimulation systems have been developed to supply functional control of grasp and release in C5 and C6 quadriplegic subjects. The type of grasp provided was either lateral pinch (key grip) (1) or palmar prehension (three jaw chuck grip) (2). The patient obtained proportional control of grasp/release via one of several available sources, including shoulder position, head position, a myoelectric signal, or switch commands. Eight of nine subjects who have been fit with this system continue to utilize it on an outpatient basis.

INTRODUCTION

Spinal cord injury at the C5 or C6 level results in severe paralysis to the extremities. While the loss of hand function may sometimes be corrected by tendon transfers and orthotic aids, these techniques are not always indicated or accepted. We are developing the technique of functional neuromuscular stimulation of the paralyzed muscles to provide control of hand-arm movement in the spinal cord injury patient. This report deals with the clinical aspects of the development of systems to provide this function.

METHODS

The systems that we are developing for control of hand function utilize a single proportional command signal, generated by the patient, to grade the coordinated movement of four electrically stimulated muscles. In our systems, we have developed a special purpose controller-stimulator which receives external inputs from one of a variety of sources and delegates appropriate strength stimuli to the muscles at the appropriate time. The controller-stimulator is configured modularly to provide for versatile use of the basic system with minimal hardware variations to tailor it specifically to individual subjects.

The command source is the means by which the subject exerts control over the stimuli. Four command sources are available presently; shoulder position, head position, myoelectric signals (MES), and switch signals. The former two sources generate commands which are proportional to the magnitude of the movement; the latter two sources are used to generate commands which are proportional to the length of time the switch or MES level is held. In the case in which either the head or shoulder position command source is used, logic commands must also be supplied by the subject to activate control logic. The control logic enables the subject to choose new zero command positions and to maintain a stimulus level, thus overriding the proportional command. Logic commands may be supplied by switches, a MES, or in the case of the shoulder position transducer by a movement in a direction orthogonal to the proportional control axis. The control signal which results is used to regulate the stimuli applied to each of the four muscles.

Three muscles are sequentially activated for grasp; one for release. The strength of each muscle is controlled by both recruitment and rate modulation (3). Coordinated movement is achieved by delaying the onset of stimulation between muscles. Stimulation is applied to the muscles through percutaneous coiled wire electrodes. The skin interface is covered with a connector for protection of and connection to the electrodes. Over seventy percent of those electrodes which have been implanted for at least 18 months are still intact.

RESULTS

Six C5 and three C6 quadriplegic patients have been supplied with this system. Table 1 gives details of each of the systems supplied. Only three systems are similar in control figuration, demonstrating the individuality that must be provided, based on the subject's performance and/or preference. To produce the same general type of grasp in different subjects, different muscles frequently were used. These differences enabled us to correct for problems such as unstable joints and denervation.

C5 subjects were required to wear an external orthosis. For lateral prehension, this orthosis stabilized the wrist only. For palmar prehension, the splint was used for wrist stabilization only in one subject, with finger and thumb coordination supplied by the stimulated muscle; in two different subjects the splint stabilized the thumb and finger interphalangeal joints as well. C6 subjects required no orthosis. This enabled them to use the grasp generated by muscle stimulation as an adjunct to their tenodesis grasp, which generally is weak.

Our subjects have been involved in evaluation of the systems, primarily on an outpatient basis, for up to 2-1/2 years. We have a total of

146 patient-months experience with the systems. Of the nine subjects fit with the system,eight are still in the evaluation program. Three use their system regularly; three use it irregularly, primarily for special functions; two are less than four months with the system; one was discontinued. Generally the most active subjects utilized their systems most frequently.

Donning of the systems requires less than two minutes if put on while dressing; otherwise lead wires must be threaded beneath the clothing. The patient must have assistance in putting on the system.

The primary problems that we have encountered generally have not been technical in origin. In response to patient suggestions, we have modified or generated new command sources to solve specific problems. An example was a patient who utilized surface MES electrodes, but whose perspiration caused them to come off after less than two hours. A head switch was constructed to replace the surface recording electrodes. Occasionally we have experienced skin irritation around the connector site due to tape which holds the connector in place (contact dermatitis). This irritation clears in days with removal of the irritant. Connector maintenance (cleaning and changing) is performed by the patients attendant. Generally the electrodes produce sufficiently reproduceable response that modification of stimulation parameters is rarely required. Thus, no adjustments of any kind are available externally on the patient stimulator. Battery lifetime (approximately two months), is generally sufficient, but they are not user changeable.

CONCLUSION

The state of the art of functional neuromuscular stimulation techniques is sufficient to supply controlled grasp and release in the quadriplegic patient. We believe that further enhancement of these systems will come by supplying more versatile two grasp systems and by utilizing implantable stimulators to replace the use of percutaneous electrodes.

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ACKNOWLEDGEMENTS

Supported in part by National Institute of Handicapped Research Grant No. G001005815 and by the Veterans Administration Rehabilitative Engineering R & D Program. These studies were performed at Highland View Hospital and the VA Medical Center, Cleveland, Ohio.

Subject	Patient's Functional Level	Time with Functional System (months)	System Implemented	Command Source		Muscles Activated		Percutaneous Electrode Site	Results
				Proportional	Logic (on/off)	Grasp	Release		
J H L	C5	31 Mo.	Palmar Prehension/ Release	Shoulder Position	Biceps MES (contra-lateral arm)	FDS	EDC	Mid forearm volar & dorsal	Irregular Use
			Lateral Prehension/ Release	same	same	AdP FdP	EDC		
M V R	C5	30 Mo.	Palmar Prehension/ Release	Head Position	Biceps MES (contra-lateral arm)	FDS/P	EDC	Mid forearm volar distal dorsal	Irregular Use
TVHH	C6	25 Mo.	Lateral Pinch/ Release	SCM-EMG (Proportional in time- 3 state control)	--- ---	OP, FDS	EPL	Distal forearm volar & dorsal	Irregular Use
J H J	C6	17 Mo.	Lateral Pinch/ Release	SCM-EMG (Proportional in time)	--- ---	OP, FDS	EPL	Distal forearm dorsal	Regular Use
			Same	Head contact switch (3 state control)	--- ---	Same			
C H G	C6	19 Mo.	Lateral Pinch/ Release	SCM-EMG (proportional in time)		OP,	EPL	Distal forearm volar	Regular Use
M H H	C5	16 Mo.	Lateral Pinch/ Release	SCM-EMG (proportional in time)		AdP, FDP	EPL EDC	Distal forearm volar & dorsal	Irregular Use
B H B	C5	4 Mo.	Lateral Prehension/ Release	Shoulder position	Shoulder velocity	AdP, FDP, FDS	EPL EDC	Distal forearm volar	Regular Use
B H K	C5	4 Wk.	Lateral Prehension/ Release	Head contact switch (3 state control)	--- ---	FDP, AdP, FPB	EPL EDC	Distal volar & dorsal forearm	New system

Table 1. Details on Functional Stimulation Systems Implemented (SCM-Sternocliodomastoid; FDS/P-Flexor digitorum superficialis/profundus; OP-Opponens pollicis; AdP-Adductor pollicis; EDC-Extensor digitorum communis; EPL-Extensor pollicis longus; FPB-Flexor pollicis brevis.) Ninth patient discontinued from program.

THE CONTRIBUTION OF THE REHABILITATION ENGINEER IN TENDON TRANSFER SURGERY

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ABSTRACT

Muscles undergoing surgical tendon transfer were studied in the operating room. Passive lengthening and active shortening from electrical stimulation gave a total functional excursion of muscle tendon units. Length-tension curves were helpful in doing tendon transfers. Electrical stimulation of the transferred muscle gave useful information. The rehabilitation engineer was very important in performing tendon transfers.

INTRODUCTION

Tendon transfers done in the paralyzed upper limb generally have been very successful in improving function.[1,3] This is especially true in the severely handicapped patients with spinal cord injury. Much experience has been gained in our center with tendon transfers. Application of the expertise of the rehabilitation engineer has helped.

When a tendon transfer is done a tendon is transected and reinserted into bone or another tendon with the innervation and blood supply preserved. The purpose is to replace a lost function by another muscle whose function can be spared.

The principles of electrical stimulation have been applied to the patient undergoing tendon repair and transfer in the past.[6] The presence of the rehabilitation engineer in the operating room at the time of tendon transfer has been routine in our institution for the past five years.[4] Not only are discussions, evaluations and testing conducted prior to surgery they are continued during and after the operation. The purpose of this communication is to describe the interaction of the rehabilitation engineer and his expertise with the patient and operating surgeon.

MATERIALS AND METHODS

Studies were performed on adult human subjects undergoing tendon transfer of the hand or arm. All patients were seen prior to surgery by the surgeon and engineer. General or regional block anesthesia were given, but no long term neuromuscular blocking agents were used. Tendon transfer was carried out in the usual fashion with the addition of the experimental testing which added 30 to 45 minutes to the procedures. A skeletal reference point was established by drilling a Kirschner wire into the skeleton near the tendon of insertion. The arm was placed in a standard position of arm at side, elbow at 90 degrees and wrist neutral. The tendon was severed at the reference point.

The tests performed were: 1. measurement of the excursion of the muscle-tendon unit, 2. length-tension curve of the muscle to be transferred, and 3. testing the transferred tendon at completion.

For excursion the muscle tendon unit was passively lengthened and then shortened by electric current. The sum of the passive lengthening and the shortening from electrical stimulation was the inherent capacity of the muscle to shorten and lengthen or its excursion.

Length-tension characteristics were determined by connecting the muscle to a strain gauge and the amount of tension generated with the electrical stimulation in isometric contraction was measured at various lengths.

After the tendon transfer was completed the muscle was stimulated. A satisfactory transfer meant that the lost function was restored when the transferred muscle was stimulated.

A coiled wire electrode was inserted into the muscle. The stimulus applied to the muscle was a biphasic current regulated stimulus. Submaximal contractions were produced. The pulse frequency was 20 HZ.[7]

These tests were performed on 61 muscles in 41 subjects. The majority of patients (38 of 41) were patients with spinal cord injury.

RESULTS

The excursions are listed below:

Muscle	Available excursion (mm)	
	Minimum Resection	Maximum Resection
Brachioradialis	34	76
Pronator teres	26	36
Extensor carpi radialis longus	59	
Palmaris longus	36	
Flexor carpi radialis	41	65
Flexor digitorum superficialis	43	
Extensor digiti minimi	35	
Deltoid		74
Flexor pollicis longus	43	
Extensor carpi ulnaris	35	35

The data obtained can be compared with that of Bunnell, Kaplan, and Steindler,[2,5,8] who derived their date from cadavers. Soft tissue dissection around the muscle generally increased the excursion.

The length-tension studies gave useful information as to the tension at various lengths. In general long thin muscles showed a peaked tension curve with maximim force at the resting length. The deltoid and the brachioradialis consistently showed great force at many different lengths.

Testing the transfers at the conclusion gave a sense of confidence if the transferred muscle did what was expected of it. If not, changes were made.

DISCUSSION

There has never been much objective or scientific data to aid the surgeon in determining the tension needed at the time of a tendon transfer. Experience and judgment have usually determined the tension required. We have developed three useful tests that help to determine proper length. The excursion measurements gave the abilities of various muscles to lengthen and shorten. Every effort was made to match these figures with those of the muscle to be replaced.

The length-tension curves showed where maximum force was exerted in regard to its length. Some muscles had sustained force elevations at different lengths. Others had greatest tension only at physiologic length. This helped in determining tension at time of transfer.

Electrical stimulation of the transferred muscle-tendon unit was a predictable test. If the transfer was good, it replaced lost function when it was stimulated electrically. If desired results were absent the transfer was altered.

The surgeon traditionally has used other tests which have been helpful. One is to put the joints through a range of motion to see what the transfer would do. The surgeon also develops a sense or judgment as to what tension is proper. The surgeon and rehabilitation engineer can use all of these tests in planning and performing tendon transfers of the upper limb.

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TRANSCUTANEOUS ELECTRICAL MUSCLE STIMULATION FOR THE TREATMENT OF PROGRESSIVE SCOLIOSIS

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ABSTRACT

In the treatment of progressive, mild-to-moderate scoliosis, transcutaneous electrical neuromuscular stimulation has been demonstrated to be a feasible alternative to bracing. During hours of sleep, stimulation is applied by a portable pulse generator through surface electrodes to the trunk musculature on the convex side of the spinal curvature. The evoked muscle contraction results in biomechanical correction of the curve. Treatment follow-up from 98 patients show the following rates of success in halting or reversing the progression of their spinal deformities: 90% for idiopathic scoliosis; and 83% for neuromuscular scoliosis. Short term post-treatment observation of skeletally mature curves does not indicate any worsening of the deformities over time.

INTRODUCTION

School screening to detect scoliosis and other spinal deformities in their early stages was the most significant advancement in scoliosis treatment in the 1970's. Early detection of small curves allows early treatment with a brace, thus generally avoiding surgery. As a result, there has been a dramatic increase in the number of patients being fitted with either Milwaukee or low profile underarm braces. In addition to that, if the patients detected as having an abnormal spinal curvature are preadolescent, 2-6 years of brace wear could be required.

Unfortunately, the brace treatment often generates both emotional and physical side effects and restricts daily activities, so it was decided that an alternative non-operative treatment method to bracing had to be developed. This method should fulfill the following criteria: (1) require no surgery; (2) produce no significant side effects; (3) require no additional exercise or othosis; (4) be highly acceptable to the patient; and (5) provide immediate evaluation of likely effectiveness [3].

From previous work at Rancho Los Amigos Hospital it was learned that in straight cat spines, acute curvatures of up to 50 degrees could be induced using electrical surface stimulation with electrode pads placed at an optimum position over the lateral trunk musculature [1]. In a clinical study of 40 scoliosis patients it was found that electrical surface stimulation could be used to reduce existing curvature. Due to the biomechanics of the spine a lateral electrode placement (axillary line) with the advantage of the long lever arms of the ribs and ilium, was three times as efficient as a medial placement (paraspinal muscles) in reducing spinal curvature during stimulation [2].

MATERIALS AND METHODS

For the treatment of scoliosis the technique of Lateral Electrical Surface Stimulation (L.E.S.S.) has been developed. Two stimulation electrodes (discs, 5 cm in diameter), are placed around the apex of the major curve with a nominal distance of 10 cm between electrode centers. As a guideline for adolescent patients the

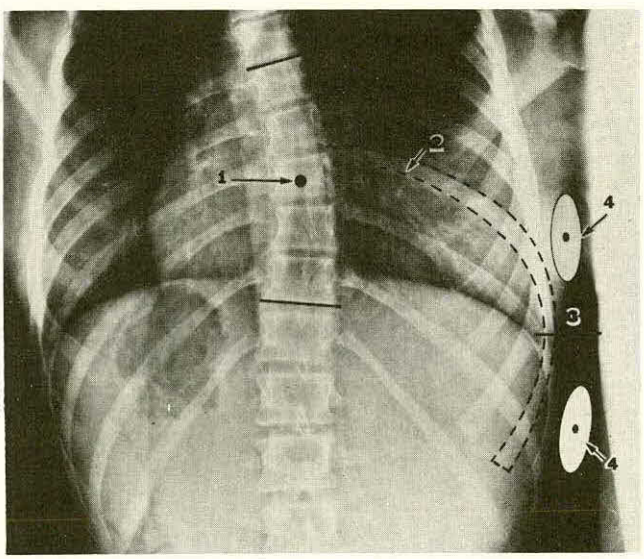

Figure 1 - Surface electrode placement technique for thoracic curves.

electrode distance is 7-9 cm when the curve is short (< 5 segments) and 11-16 cm when the curve is long (> 7 segments).

For juvenile patients with short trunks the electrodes are placed 1 to 2 cm closer together for all curve lengths. The distance between the outer rims of the electrodes is never longer than the distance between the neutral vertebrae of the stimulated curve to prevent stimulation carry-over into the concavity of the adjoining curves. In the thoracic area, (See Figure 1), the electrodes are placed symmetrically around the apical rib at its most lateral aspect, between the anterior and posterior axillary lines. In the lumbar area the reference center for the electrodes is the apical vertebra itself. For thoracolumbar curves the two position rules are combined and carefully crosschecked by palpation of the contracting musculature and the moving spinal column.

The stimulation therapy is applied only at night during the hours of sleep. To prevent muscle fatigue the stimulator turns on and off in a cyclical fashion such that the muscles smoothly build up contraction over a period of 2 seconds, remain fully contracted for 4 seconds and relax for 6 seconds. The muscle stimulation is provided by a portable battery-operated stimulator which

Figure 2 - Application of the L.E.S.S surface stimulation method for scoliosis treatment.

generates trains of balanced, asymmetrical, biphasic constant current pulses of 0.2 milliseconds duration at a rate of 25 pulses per second. The stimulator is connected to carbon-rubber electrodes which are interfaced to the skin via an electrically conductive, adhesive coupling medium (Figure 2).

In order for a scoliosis patient to be admitted to the L.E.S.S. program as a PROTOCOL patient, the following selection criteria must have been fulfilled: (1) idiopathic scoliosis; (2) 20 to 45 degrees of curvature;(3) radiographic documentation of curve progression; and (4) at least one year of growth remaining. Patients with single curves use the ScoliTron (tm) stimulator which is manufactured by Neuromedics, Inc. to our specifications, while patients with double major curves make use of the NME-201 dual-channel stimulator by Rancho Los Amigos Rehabilitation Engineering Center.

All patients are given an equal choice between brace wear and electrical muscle stimulation. Only a small percentage prefer the brace (Milwaukee or low profile) over L.E.S.S. treatment. When the L.E.S.S. treatment is initiated, the patients are given a full scoliosis-related physical examination, the placements of the electrodes are determined, stimulation is started, and the patients are familiarized with the equipment and its use at home.

After a 2-week adaptation phase, the scoliosis patients return for a check of the stimulation efficiency. Two prone X-rays are taken. The first is made without stimulation, to verify curve flexibility (change in degrees from standing to prone position) and location of the electrodes. If necessary, the electrode placement is adjusted. Another X-ray is taken with a stimulation level of 70 milliamperes. Correction of the major curve(s) and no worsening of the compensatory curve(s) must be seen, indicating that the proper muscles are being stimulated. The patients return to the clinic every three to six months for follow-up until bone maturity is reached, at which time stimulation is discontinued and further visits become annual.

RESULTS

Follow-up results of the L.E.S.S. treatment for idiopathic scoliosis are displayed in Figure 3. The average change in degrees is plotted for 77 compliant idiopathic scoliotic curves with a follow-up of three months, 34 curves with one year of follow-up, and eight curves with two years of follow-up. As shown, the pre-treatment progression rate of 2.5 degrees per month is arrested upon treatment initiation and the curves actually reverse .a few degrees during the course of treatment. Not shown in the figure is the horizontal continuation of the graph to 3 years of follow-up of 2 patients. A more detailed analysis of the depicted graph reveals improvement (more than 5 degree decrease) in 12% of the curves, stabilization (between +5 degrees and -5 degrees change) in 84% , and progression (more than 5 degree increase)

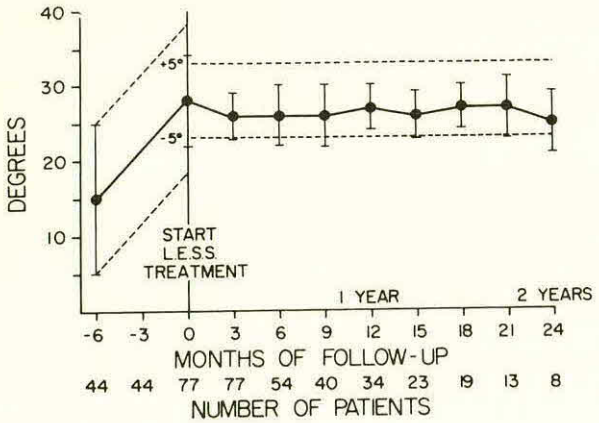

Figure 3 - L.E.S.S treatment results. The graph shows the average degree of 77 idiopathic curves for up to two years of treatment.

in 4%. In other words, the L.E.S.S. treatment method has stopped curvature progression in 96% of the cases in the idiopathic population. However, the overall L.E.S.S. program success is 90% since 6% of the patients for various reasons have not complied with the treatment requirement of using stimulation every night at sufficient strength. The visual deformity, the rib hump, which is measured annually , shows an average reduction of 2 mm after two years of treatment.

In a supplementary treatment program, 11 patients with scoliosis secondary to spinal cord injury, and one with scoliosis secondary to poliomyelitis, are being treated with electrical surface stimulation during nighttime and body jackets for trunk stabilization during daytime. This population also shows a trend of arrest or reversal of progression of their spinal curvature.

Of the 86 idiopathic scoliotics (single curve:76; double curve: 10) and 12 neuromuscular scoliotics who have entered the electrical stimulation treatment program, 17 patients have been discontinued prior to bone maturity due to the reasons listed in Table I.

Table I.
Discontinued Patients

Progression		
1. Non-compliance	:	4 (4%)
2. Electrode problems	:	2 (2%)
3. Treatment ineffective	:	4 (4%)
No Progression		
1. Non-compliance	:	3 (3%)
2. Skin rash	:	2 (2%)
3. Non-related	:	2 (2%)

DISCUSSION

As opposed to the many psychological and physical problems with brace wearing, the only real problem encountered has been skin rash; however, using 4 different alternatives for skin-electrode coupling media no patient has had to be discontinued due to persistent skin rash for the last two years. No other side-effects have been seen. Further research needs to be done to optimize the muscle stimulation parameters for generation of stronger muscle contractions for increased curvature reductions. Today, the limiting factor for the strength of muscle stimulation is the comfort of the patient. High stimulation amplitudes excite the pain receptors in the skin to such a degree that the stimulation becomes uncomfortable. Final data analysis of the treatment results will have to await a five year follow-up of at least 10 patients after they have finished the treatment at skeletal maturity.

This project has been expanded into an International Study on Lateral Electrical Stimulation for Scoliosis (ISO-LESS). The data presented in this paper has now been confirmed by three major European scoliosis treatment centers: Sahlgren Hospital, Goteborg, Sweden, with 23 patients of up to two years follow-up; Orthopaedischen Universitaetsklinik, Muenster, Germany, with 20 patients of up to one year; Centro De Recupero Funzinale per Scoliosi, Florence, Italy, with 16 patients of up to six months follow-up. In total, the ISO-LESS program now includes about 50 centers in the United States and 20 centers abroad. In conclusion, Lateral Electrical Surface Stimulation has proven to be an excellent alternative to brace treatment for progressive scoliosis of mild to moderate degree.

ACKNOWLEDGEMENT

This research was supported by RSA-NIHR Grant No. 23P-55442 and NIHR Grant No. G008003002.

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ENHANCEMENT OF SWING PHASE CLEARANCE THROUGH SENSORY STIMULATION

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ABSTRACT

The purpose of this study was to examine the utility of sensory nerve stimulation to enhance movement patterns. The behavior selected was swing phase clearance of the involved lower limb of a hemiplegic sample. Walking performance was compared prior to and during electrical stimulation to the terminal distribution of the sural nerve. Results suggest that this system or a hybrid system combining afferent and efferent stimulation can enhance the dynamic limb synergy.

INTRODUCTION

A common gait problem in patients with hemiplegia is inadequate limb clearance in the involved lower limb. Despite techniques which enhance ankle dorsiflexion such as orthoses (conventional metal or molded plastic) and peroneal nerve stimulation during swing phase (1,2), some patients continue to have clearance problems suggesting that inadequate limb clearance is the result of an impaired pattern of limb shortening rather than a single joint deviation. Among the factors which contribute to this inability to clear the limb during the swing phase are inadequate elevation of the pelvis and diminished hip, knee, and ankle motion (3,4). The purpose of this study was to improve the pattern of limb shortening during walking through afferent (sensory) nerve stimulation of the hemiplegic patient. This approach differs from the more commonly used electrical stimulation techniques which directly stimulate motor nerve and muscle. Rather than working at the periphery with multiple stimulation sites, a single sensory stimulation site can assist the central nervous system in producing a total limb pattern (5,6).

METHODS

Two carbonized rubber disk electrodes were placed in the area of the sural nerve near the lateral malleolus of the involved leg over two sites which produced a "tingling" sensation in the lateral foot border. Stimulation parameters were controlled by a Grass Stimulator (Model S-8C) and a constant current unit (Model CCU1A). Although parameters were varied, all subjects received stimulation with the following characteristics: 1 ms pulse duration, 250 hz, 100 ms train duration, and a stimulus intensity of four times the patient's perceived threshold.

Bilateral sagittal hip, knee, and ankle motion were measured with high resolution film-type potentiometers mounted on light-weight adjustable linkage assemblies. Footswitches taped to the bottom of each shoe detected heel and toe contact and release and a tachometer monitored walking velocity. Data were sampled at 100 hz by a PDP 11/50 minicomputer.

Using a link model of the lower extremity, relative hip-toe distance was calculated from the output of the goniometers (7). This model assumed that the trunk always maintains a vertical attitude. Thus, hip-toe distance is $\underline{1}$ when the subject is standing straight and less than $\underline{1}$ when the lower extremity is shortened during the swing phase of the walking cycle. "Imaginary toe clearance" was calculated as the difference between hip height in the static upright position and the maximum value of hip-toe distance during the swing phase. This maximum value of hip-toe distance can be greater than $\underline{1}$, for example, when the ankle is plantar flexed.

Steady state walking performance was compared with and without electrical stimulation using a student t-test. Each subject served as his/her own control in a one group pretest-post test design.

RESULTS

Experiment 1

Seven patients, four with right and three with left hemiplegia participated in the first investigation. All patients were independent in ambulation with a cane and an ankle-foot orthosis. The cutaneous electrical stimulation was provided at the time of involved limb heel-off during a minimum of seven steady state steps. Performance for each patient was compared during steady state walking with and without afferent electrical stimulation. Examination of the following parameters revealed a difference in performance at the involved hip or knee for each patient: flexion excursion, average angular velocity and time to peak flexion. The average difference in flexion excursion between the stimulus and control conditions for the hip and knee in each subject is depicted in Figure 1. All patients showed a significant difference in hip or knee motion after stimulation ($p \leq 0.05$). However, four patients demonstrated an increase and three patients demonstrated a

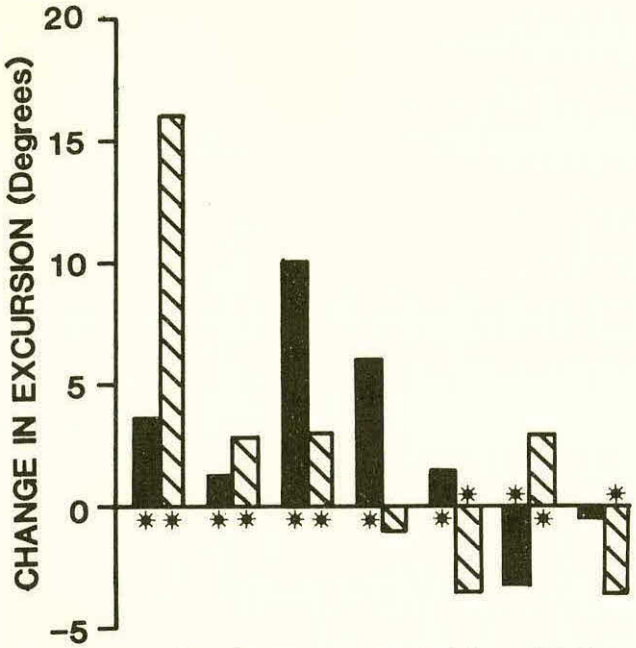

Figure 1. The datum represented here is the difference in joint excursion achieved with as compared to without electrical stimulation. The dark bars represent the hip and cross-hatched bars represent the knee (see text).

decrease in motion excursion. Results were consistent when the experiment was repeated over different days. It is noteworthy that these changes in joint excursion occurred without concomitant changes in average walking velocity suggesting that the primary effect of the stimulus was on the limb pattern rather than whole body movement.

Experiment 2

To date, five subjects have participated in this stage of the investigation in which the time of stimulus delivery was selected for each patient rather than using the standard delivery time of involved limb heel-off as was done previously. For these patients, the stimulus was delivered prior to peak hip extension of the involved limb. A comparison of walking behavior with and without electrical stimulation reveals a difference in the excursion of the hip or knee for each patient in Figure 2. In this case each patient demonstrated a significant increase in excursion ($p \leq 0.05$) suggesting that the stimulus delivery was more appropriately timed to enhance joint motion.

The parameters referred to thus far cannot describe functional improvement in limb shortening since limb clearance is determined by a dynamic synergy pattern of combined hip, knee, and ankle movement as well as inclination of the trunk. One of the parameters developed to describe functional improvement is imaginary toe clearance (ITC) (see Methods). Although there are several limitations to this model, it allows the investigator to examine the utility of improved performance at each joint on the function of the limb as a whole. For example, a significant increase in joint excursion occurred for the first and fifth subjects in Figure 2. However, calculation of the ITC revealed that the effect of the stimulus caused an increased clearance of 1.9 cm ($p \leq 0.05$) in the first subject while the fifth subject demonstrated a decreased clearance of 0.6 cm.

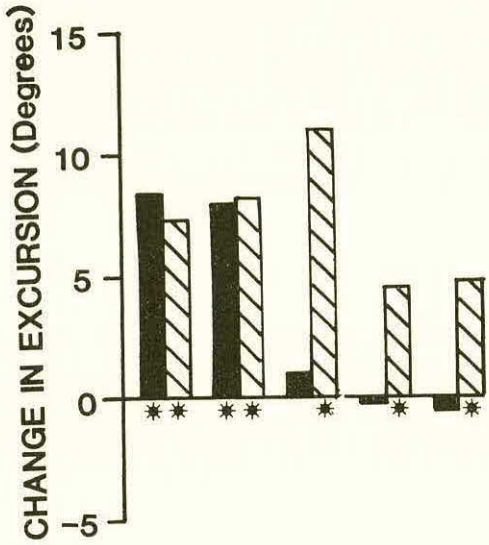

Figure 2. The datum represented here is the difference in joint excursion achieved with as compared to without electrical stimulation. The dark bars represent the hip and cross-hatched bars represent the knee (see text).

DISCUSSION

Since the long term goal of this project is to develop a non-invasive technique for the neurologically handicapped person to maximize residual locomotion movements, much additional work is necessary. However, the results of this study indicate that appropriate electrical stimulation of a sensory afferent may be useful as an adjunct to current treatment techniques. The findings that all subjects show a statistically significant change in many biomechanical parameters during stimulation and that such change is consistent among different stimulus conditions and over different experimental days suggests that electrical stimulation alters the swing phase movement pattern in patients with hemiplegia. Current research efforts include expanding the patient sample to identify the major determining factor(s) of success and failure to produce improved limb clearance and to examine response reliability (habituation). Future studies will include examining the utility of a hybrid system which combines motor and sensory stimulation to enhance limb control by the patient.

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A COMPUTER CONTROLLED MULTICHANNEL STIMULATOR FOR LABORATORY USE IN FUNCTIONAL NEUROMUSCULAR STIMULATION

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ABSTRACT

New systems employing functional neuromuscular simulation (FNS) require that the instrumentation have a great deal of flexibility in both the command control and stimulation algorithms. For our research in development of new FNS systems for hand control we have developed a computer controlled multichannel stimulation system. This system is capable of processing patient generated input commands from a number of sources and regulating the output stimuli to provide the desired coordinated movement in the electrically stimulated muscle. This system is in routine usage in our FNS laboratory.

INTRODUCTION

The ability to create versatile schemes of stimulation for gradation of muscle contraction in a repeatable manner is essential in realizing a functional stimulation system. Since the input-output relationship between the stimulus and force for each muscle vary from person to person and are subject to length and position changes of the particular muscle with respect to the source of stimulation (1), a stimulation system must have a high level of versatility in establishing stimulus parameters which can accommodate these variances. In our FNS system we utilize pulse width modulation for control of recruitment of nerve fibers and interpulse interval modulation for control of temporal summation (2). The characterization of a muscle's recruitment and temporal summation patterns is critical in an open loop stimulation system. Once the profile of the muscle's contraction is established the scheme of flexion and extension of the hand can be created by coordinating each muscle's contraction pattern with respect to one another to provide a functional hand grasp. This coordinated control algorithm can then be regulated by the processed command signal(s). Typically one command signal is used to govern an entire grasping mode.

INSTRUMENTATION

A DEC PDP-11/23 microcomputer is used as the central processor in this system. The A/D, D/A and digital ports allow the computer to communicate with the control input devices and the stimulator hardware. The remaining peripheral and supportive devices are a storage oscilloscope for displaying command input versus interpulse interval and pulse width ranges, a dual floppy disk as a permanent storage device to store stimulus parameters and general patient information, a line printer for hard copy of test results and data, and a terminal to allow a user to interact with the computer.

Nine channels of stimulation are available. Each stimulator channel is pulse width modulated and externally triggered by the computer. Pulse amplitude is adjustable but cannot be externally modulated. The interpulse interval (reciprocal of frequency) is controlled by delivering a trigger pulse to the pulse width modulator. These signals are used to deliver a regulated ("constant") current biphasic capacitatively coupled stimulus to the muscle.

COMPUTER CONTROLLED INTERPULSE INTERVAL MODULATION

Each of the nine stimulator channels may be partitioned into a stimulation "group" which consists of any number of channels. A "group" is defined as a collection of channels, each of which has an associated interpulse interval modulation (3). Channels within the same "group" are activated in sequence and the interpulse interval of any given channel is equal to the interpulse interval assigned to the "group" times the number of channels in the "group".

The computer creates the triggering of each pulse by utilizing one real time clock as its timing source. An internal counter is created in software for each "group" based upon a 1 millisecond interrupt rate at which the clock is running. When the counter times out for a particular channel within a "group" the channel is digitally triggered.

COMPUTER CONTROLLED PULSE WIDTH MODULATION

The pulse width of each channel of stimulation is modulated by the computer. The pulse width can range from 0 to 500 microseconds. The computer translates the processed input command signal into a 12 bit word which corresponds to a particular pulse width value. It then sends this information to the pulse width modulation stage of the channel that is actively being regulated. The program is set up to continually update a channels pulse width to coincide with the command control inputs, thus enabling the computer to modulate each of the nine channels independently.

SOFTWARE GENERATED CONTROL ALGORITHMS

There are various command control techniques which enable a patient to regulate the movements of their hand or the position of their forearm. In our research we evaluate a patients use of several types of command control signal sources such as shoulder position, head position, wrist position, myoelectric signals and switch signals (4). Flexibility in implementing these controller techniques is essential to allow rapid interface of the stimulation hardware to each of these command sources.

An example of a software generated control algorithm is a switch enabled duration controller. By means of an external switch source, the computer modulates the control command at a predetermined rate. The rate at which the hand operates is variable. The input command source can be a digital input or analog input converted to a digital signal and then processed by the computer. The ability to turn the stimulator on or off and to hold a constant stimulation or resume control can also be a function of the computer.

Another example is one in which the position of the shoulder or the head is used as a proportional command source (5). The computer can set up the proper range of functional motion over which the patient can normally operate. It then can further process the input command signal for gain, offset and set a comfortable zeroing point for control of flexion and extension of the hand.

Flexibility in investigating the control algorithms employed allows us to tailor the control algorithm precisely to the individual subject.

THE COMPUTER PROGRAM- INTERFACE BETWEEN INPUT COMMANDS AND OUTPUT RESPONSE

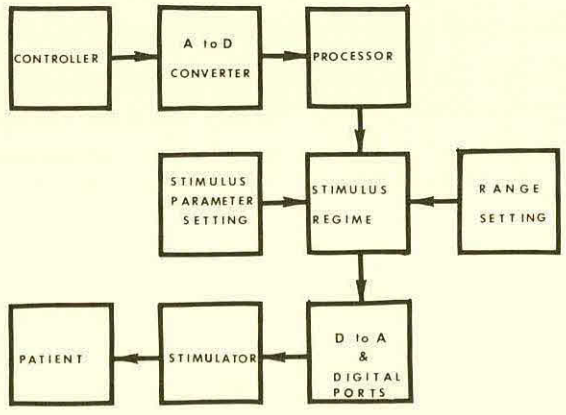

Figure 1. The input / output relation between controller input, computer processing of these signals and the output stimuli to the patient.

Main features of program

The computer program that processes the input control commands and controls the channels of stimulation was written so that a user may have a wide range of flexibilty in its application to FNS research. The main features of the program are:

1) one to nine channels of simultaneous stimulation, sequential stimulation, or a combination of the two can be used.

2) pulse width modulation and interpulse interval modulation can be controlled by any combination of analog to digital inputs.

3) interpulse interval and pulse width modulation profiles which represent temporal summation and recruitment patterns, respectively, can be plotted versus the input command on the storage monitor (Fig. 2). The ability to display these ranges gives the user a visual feedback in determining stimulation parameters as well as the relationship between these stimulus parameters and their range of modulation with respect to the given input command.

4) the individual range of all the channels of stimulation are plotted against the input command and displayed at the terminal along with basic patient information pertinent to each channel (Fig. 2). This display allows the user to see the relation of range of modulation of all channels with respect to one another. Thus, the extent of coactivation of many channels can easily be discerned.

5) the range in which a particular channel will modulate its pulse width and interpulse interval with respect to the input control signal can be set by inputting values at the terminal.

6) the minimum and maximum values of pulse width and interpulse interval can be set manually by inputting the values into the computer via the terminal's keyboard or by accepting values during a stimulation scheme for setting up stimulus parameters.

7) all control input information, stimulus parameters and patient information including the name of the patient, date of the test, muscles being stimulated, electrode information and general comments can be recorded and stored on a floppy disk to be used at a future time in order to facilitate the set up procedure.

8) a hard copy of the stimulus parameters and patient information can be obtained at the line printer.

9)the computers input command source can be run manually by means of external potentiometers controlling the input command signals or by any of the software generated controllers that have been implemented. The program is created in a modular fashion thus allowing new controller modules to be installed as well as old controller algorithms to be updated without modification of the the main program. Therefore, various types of filters and signal processing can be created and used in a compatible manner.

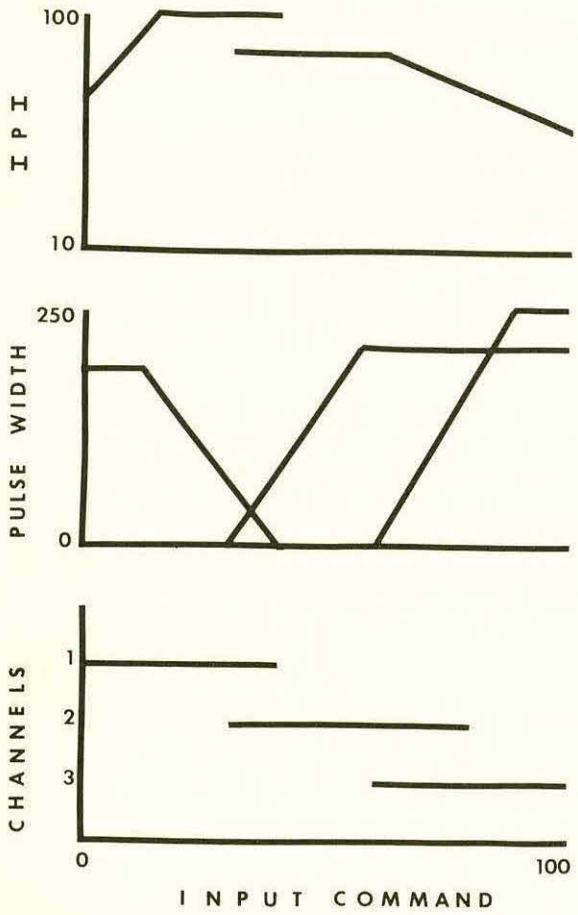

Figure 2. Example of a stimulus regime. Channels: 1=Finger extensor, 2=Finger flexor, 3=Thumb flexor. Channel 1 is in a separate "group" from channels 2 and 3. Note the breakpoints at where pulse width and interpulse interval begin and end and the overlapping of finger extension and flexion.

Characterization of recruitment and temporal summation of a muscle

The ability to characterize the recruitment and temporal summation pattern of a particular muscle in order to grade muscle force in a smooth and predictable manner is essential in creating stimulus regimes.

By allowing the computer to modulate the muscle's force over a wide range one can assign stimulus parameters appropriate for the recruitment and temporal summation characteristics of that muscle. When the particular stimulus parameter is ascertained the user instructs the computer to accept this value. The computer automatically sets this stimulus parameter into the modulation regime. In this manner, the gradation of a muscle's force can be incorporated into a particular hand grasping or elbow extension pattern.

Regulation of varying muscle contractions to achieve versatile hand grasping patterns

Once the profile of a muscle's response is determined it must be incorporated into an overall coordination scheme with other muscles in order to achieve the appropriate hand grasping response. The computer can process the input control commands to accommodate whatever range of modulation a user assigns to a particular channel. Contraction of specific flexor and extensor muscles at varying forces can be regulated by the computer thus producing a hand grasping response which may accommodate a functional task.

CONCLUSION

The ability to control fine hand movements, elbow extension, suppination and pronation of the forearm or lower extremity functions by use of FNS is critically dependent upon the flexibility of the instrumentation. It is evident that a computer is a powerful tool and provides the necessary versatility. The laboratory studies of application of FNS to the paralyzed forearm muscles of quadriplegic patients has allowed us to implement a portable stimulator that enables patients to control prehension and release (4,5). Ongoing studies of these techniques employing the computer to furnish the laboratory with greater flexibility will allow us to design, model and specify the criteria of future stimulation units.

ACKNOWLEDGEMENTS

Supported in part by the National Institute of Handicapped Research Grant No. G001005815 and the Veterans Administration Rehabilitative Engineering RD Program: NIH/NINCDS NO-NS-2-2314. These studies were performed at Highland View Hospital and the Veterans Administration Medical Center, Cleveland, Ohio.

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A FUNCTIONAL NEUROMUSCULAR STIMULATION SYSTEM FOR CONTROL OF GRASP AND RELEASE

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ABSTRACT

A system employing Functional Neuromuscular Stimulaton to provide control of hand grasp and release has been developed for individuals with a high level spinal cord injury. These systems are small, light weight and easy to don and doff. The system's control scheme provides the user with a simple means of controlling grasp-release with one proportional command and two switch commands. While simple to use, this control scheme provides a means for conveniently maintaining a desired grasp during tonic activities. A number of different proportional and switch command sources have been utilized and several systems are currently in field usage.

INTRODUCTION

Functional Neuromuscular Stimulation (FNS) has been demonstrated to provide functional control of grasp and release for people with a high level spinal cord injury (1,2). To aid these individuals in their daily activities, we have developed and are evaluating and refining a user based stimulation system. As a FNS system uses the subject's own hand/arm musculature as the prime mover, the process is intrinsically silent and can be cosmetically most acceptable. To maximize user acceptance, these FNS systems have been designed with the additional constraints of being small, light weight, easy to operate, and easy to don and doff.

Our efforts to date have concentrated on providing or augmenting two hand grasping patterns, palmar prehension-release (three jaw chuck) and lateral prehension-release (key grip), in quadriplegic subjects with a lesion at the C5 or C6 level. Electrical stimulus pulses are delivered to paralyzed muscle tissue via chronically indwelling percutaneous intramuscular electrodes. The site where the electrode passes through the skin is protected by a surface connector which also serves as a point for connection to the external cabling.

The force developed by an electrically stimulated muscle can be graded by recruiting additional muscle fibers into activity (varying stimulus pulse width and/or amplitude) and by temporal summation (by varying the time between stimulus pulses; i.e. the interpulse interval) (3). The biphasic stimulus waveform is a pulse of constant current flow (driving the intramuscular electrode cathodic) followed by a much longer reverse current flow of correspondingly lower amplitude. A typical stimulus waveform has a fixed cathodic current of 10 to 20 ma., a pulse width of 5 to 200 usec and a interpulse interval (IPI) of 20 to 100 milliseconds. Both grasping patterns utilize three separate electrodes firing in an evenly spaced sequence to achieve grasp, and a single electrode for release. The user modulates the stimulus applied to these four electrodes according to a control scheme implemented in the system hardware.

CONTROL SCHEME

An appropriate control scheme should allow the user to control his grasp-release function in a quick and convenient manner. The control scheme utilzed in our system allows the user to position and grasp an object and then to maintain this grasp despite subsequent changes at the control site. This HOLD state has proven to be most effective in tonic activities such as holding an eating utensile or a pen.

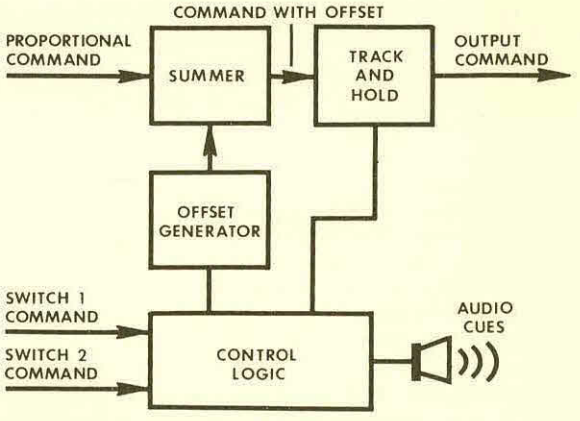

Figure 1. Block Diagram of Control Hardware

The user controls the FNS system through one proportional command and two switch commands (see Figure 1). The proportional command is used to govern the strength of grasp/release. The switch 1 command is used to turn the system ON and OFF, and the switch 2 command is used to enter or return from a HOLD state. The hardware represented in Figure 1 implements the control algorithm shown in Figure 2. Whenever the unit is first turned ON, the command with offset signal is nulled. This process compensates for any initial bias in the proportional command. The state diagram, Figure 2, shows two different methods for leaving the HOLD state and returning to the TRACK state. The FNS system is configured by the investigator to operate in either MODE I or MODE II. Both modes insure continuity of the contractile force when leaving the HOLD state. The user is informed of key changes in the state of the system by audio cues of varying pitch and duration. The output command produced by the control hardware is then decoded and processed to provide four separate stimulator output channels.

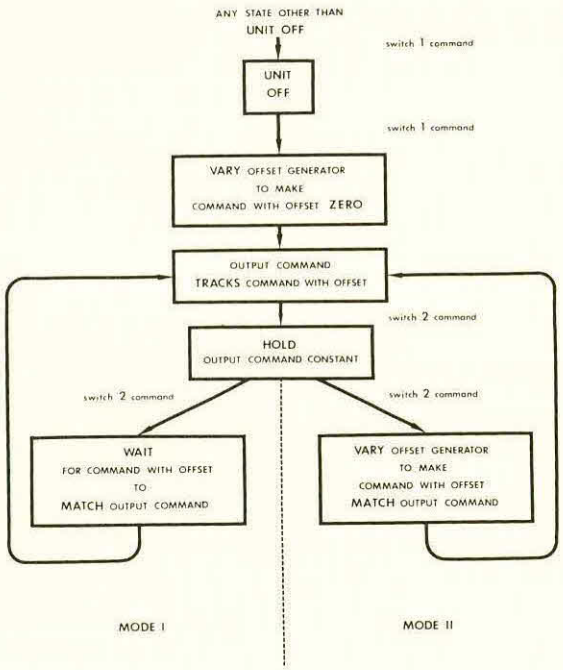

Figure 2. State Diagram of Control Algorithm

The output command from the control hardware is decoded to provide both interpulse interval information and pulse width information. This decoding process is graphically represented in Figure 3. This particular paradigm offers the full dynamic range of contractile force; i.e., from minimum pulse width at maximum IPI to maximum pulse width at minimum IPI. This decoding process also attempts to linearize the relationship between output command and the contractual force developed by the muscle. Since the three channels associated with the grasping function are stimulated in a sequential fashion, they all follow the same IPI versus output command relationship. The pulse width to output command relationship, however, generally is different for each channel, as suggested by Figure 3. The relationship depicted in this figure allows compensation for differences in stimulus thresholds and to stage the onset of muscle contraction among electrodes (1).

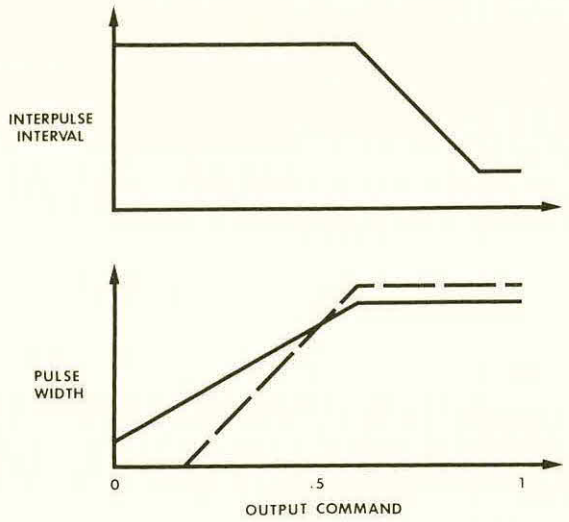

Figure 3. Graphic Representation of IPI and PW Decoding (The dashed and solid lines represent the pulse width decoding for two flexor electrodes.)

HARDWARE, MAN-MACHINE INTERFACE

To date nine FNS systems have been fabricated and are currently in field usage. These FNS devices, shown in Figure 4, are housed in a plastic enclosure of about 15 x 8 x 5 cm and weigh about 450 grams. The connections of the percutaneous electrode surface connectors and various user transducers to the FNS device are made through a cable harness which is typically worn beneath the clothing. This harness terminates in a single, multipin connector which, in turn, mates to the FNS device. A typical cable harness has the proportional command transducer, an audio tone transducer, the switch 1 and switch 2 information source, one or two electrode connectors, and the surface common electrode. Each cable harness is individually configured and sized for the user to minimize the number of interconnections and maintain the ease of application. The FNS device itself is usually worn clipped to the user's belt or resting next to him on the seat of the wheelchair.

Examples of proportional command sources in use are shoulder-to-sternum position and head position relative to vertical. Examples of switch information sources in use are two seperate mechanical switches, one progressive mechanical switch, and a two-level processed (amplified, rectified and averaged) myoelectric signal (MES) obtained from a muscle with some remaining

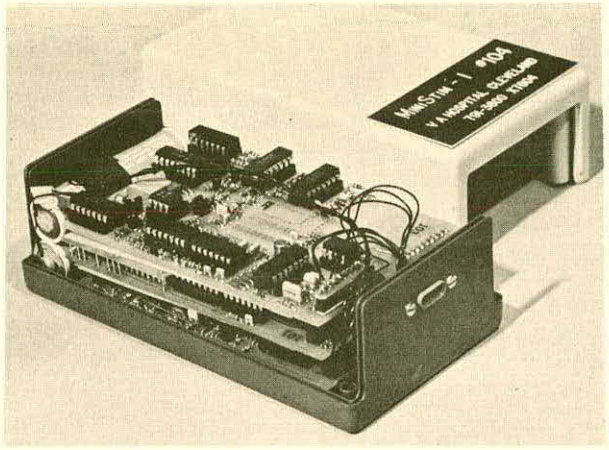

Figure 4. FNS Device with Cover Removed

voluntary activity. In the case of the progressive mechanical switch and the two-level MES switch, the two switch commands are not completely independent. This paticular sequence of switch commands (switch command 2 followed by switch command 1), however, is compatible with the control scheme shown in the state diagram, Figure 2.

HARDWARE, FNS DEVICE

The FNS device electronics is fabricated on three stacking printed circuit board assemblies. This board stack occupies the bulk of the volume of the plastic enclosure. The remaining space is consumed by two mercury batteries and the internal wiring to the multipin connector. The three printed circuit board assemblies are fabricated using miniature components to conserve board real estate. Typical components include 1/8 watt carbon composition resistors, microminiature tantalum capacitors and micro packaged transistors. Circuit density is further enhanced by eliminating internal switches and trimming potentiometers.

The FNS device is programmed for an individual user via hardwire jumpers and removable resistors. For example, the selection of control MODE I or MODE II is made by moving two jumper wires. Eight resistors contained on a removable 16 pin component carrier determine the minimum and maximum pulse width for each of the four stimulus channels. The minimum IPI, maximum IPI, transducer gains, and magnitude of the cathodic current pulses are determined by individually removable resistors. Additionally, by moving jumper wires it is possible to implement minor changes in the control scheme or the stimulus sequencing. The printed circuit board associated with the interfacing of the proportional command and the switch commands is used either fully populated with the MES processor ciruitry, or with a smaller set of circuitry to support mechanical switches.

The FNS device is powered by two 5.6 volt mercury batteries (type 134). These batteries have a functional life of about 8 weeks of essentially continuous use with correspondingly longer life for less frequent use. This period is sufficiently long that battery replacement is not a significant problem and the somewhat less desirable alternative of rechargeable batteries is not needed. To achieve this battery performance, however, major design efforts were made to keep power consumption of the FNS circuitry as low as possible. In general, the analog and digital processing circuitry was implemented with micropower operational amplifiers, low collector current transistor circuits and CMOS digital logic elements. Two other design features specifically aimed at reducing the net power consumption were: 1)the segmentation of circuitry into an always powered section, and a section which is powered only when the FNS device is functionally ON; and, 2) the time multiplexing of the pulse width decoding and modualtion circuitry.

To date the nine FNS systems, with the described control scheme or a variation of it, have received about 146 device-months of field usage (4). The overall user acceptance of these systems has been good. Concerns regarding the FNS device itself largely relate to the great time investment necessary to implement substantially different control schemes or to expand the number of output stages. As the system is proving to be a viable aid, we are presently developing a next generation of FNS systems. These new systems will incorporate the salient attributes of the current system while providing the greatly enhanced flexibility afforded by a programmable control scheme and a larger number of more generalized stimulator output stages.

ACKNOWLEDGEMENTS

This study was supported in part by Research Grant G001005815 from the National Institute of Handicapped Research, and by the Veterans Administration Rehabilitative Engineering R & D Program.

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ELECTRICAL STIMULATION OF INCOMPLETE PARAPLEGIC PATIENTS

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ABSTRACT: This paper describes the results obtained in rehabilitation of incomplete paraplegic (paraparetic) patients by means of functional electrical stimulation (FES). We have selected only severely involved incomplete paraplegic patients who were up to now considered as wheel-chair patients. The therapeutic use of FES for these patients was investigated and the results and rehabilitation possibilities by using FES studied. The preliminary results on two patients while walking with FES are described and the results of FES controlled flexion response synergistic movements of the lower extremity are presented.

In our experiments we have selected only severely involved incomplete paraplegic patients. Most of them were not able to stand without assistance because of disturbed posture, weak extensors or severe extension spasms which are in general combined with strong adduction. Practically all of these patients were wheel-chair users. Because the number of incomplete patients is rising and hence the population of severely involved paraparetic patients, we have introduced the therapeutic multichannel FES program. The goal of this research was oriented towards the answering of the questions how FES can improve locomotion rehabilitation in severe incomplete paraplegic patients. Owing to some preserved supraspinal control (minor sensation and/or minimal voluntary control of some muscles) we believe that multichannel stimulation can provide patterned sensory information inflow for learning and facilitation, provoke the generation of proprioceptive information thus triggering reflex mechanisms, cause inhibition of spasticity, and trigger direct muscle contraction. Only FES can provide all these and it represents a very efficient way to exploit the available neurological mechanisms and plegic muscles. We have incorporated these means for establishing the best possible locomotion pattern and to facilitate the recovery and learning process. The learning process is efficient if the repetition is correct, precisely made and repeated few hundred thousands times. The atmost importance must be paid to ensuring correct and precise repetition of movements and hence of FES. The later can be acomplished only with very careful triggering of the stimulator. Our work is therefore focused mainly in the search for different control means of the stimulator. Very important is also the clinical methodology and the most appropriate FES application.

FES CONTROLLED WALKING

So far we treated only two severely involved incomplete patients. Here we are going to report in brief the results obtained. According to the patients main gait anomalies the required number of stimulation channels is selected and the stimulation sequence in accordance to the stimulation sites and required function determined (1). By the help of a moving supporting frame (Fig. 1) the patient is safe from falling. The patient is asked to walk and the physical therapist is controlling the FES. Once the gait is cyclic enough shoe insole

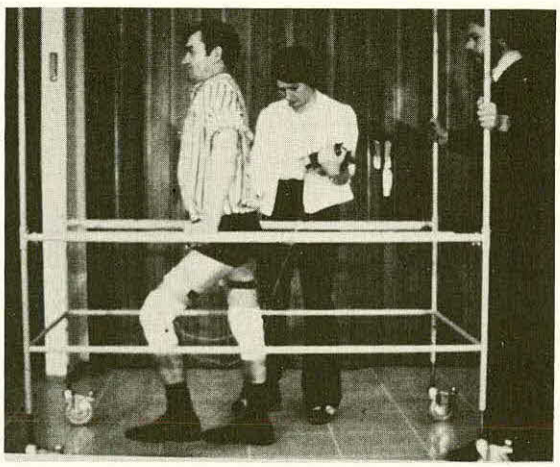

Fig. 1.

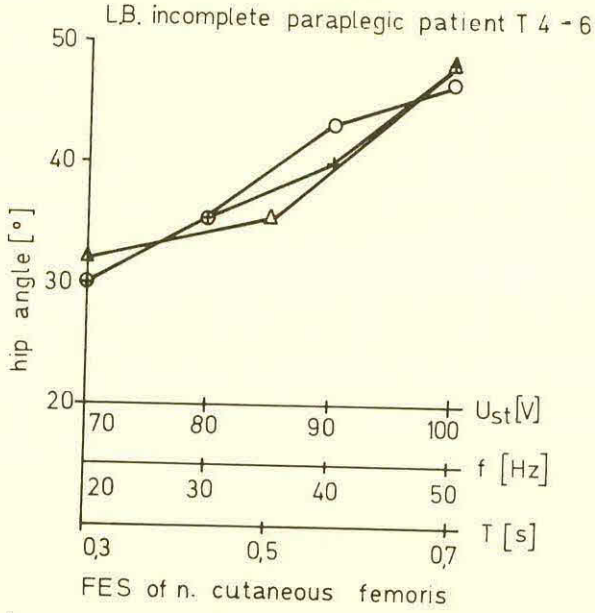

Fig. 2.

triggering is provided and the patient starts using the crutches.

The first patient Z.A., was 41 years old suffering from cystis arochneidalis regionis cervicalis (C-2,4) which after the surgery resulted in spastic paraparesis. The patient completed the standard rehabilitation program and was qualified for using the wheel-chair. At the addmission to our program 6 months after the surgery he was able to stand by the help of hand support, but unable to take steps because of lack of hip and knee extension. The strength of the hip and knee extensors was graded less than fair. FES of the m. quadriceps, m.tibialis anterior and the hip extensors on both sides resulted in an increase of muscle strength. After 8 weeks of treatment the patient left the hospital walking on crutches by using one-channel stimulator for flexor sinergy response triggering providing the swing phase assistance. Without this induced swing phase the patient was not able to walk.

The second patient L.B., was 20 years old, suffering from a spinal cord injury at the T-5,6 level what had resulted in paraparesis. He was treated and discharged in a wheel-chair from the Rehabilitation Institute in spring of 1979. In May 1980 he was admitted as an outpatient to the FES program having lower extremity sensation and strong extensors spasticity combined with adduction which prevented him to stand safely or to walk. Our FES program consisted of reduction of spasticity, facilitating the required muscles. FES exercising was performed for m.quadriceps, hip extensors and abductors (m.gluteus maximus, m.gluteus medius, and tensor fasciae latae). After 10 weeks of training he started with FES assisted gait. With the aid of the crutches and one-channel stimulation for the flexor sinergy activation he was able to walk unassisted after three months of FES program (2).

FLEXION RESPONSE

When stimulating incomplete paraplegic patients above the peroneal nerve in order to achieve dorsiflexion of the foot, several times flexion in all three joints of the paralyzed limb was obtained. It was therefore decided to study the phenomenon more closely. The hypothesis was made that the flexion response is elicited by the stimulation of afferent nerves rather than by the excitation of skin receptors. Very precise positioning of the stimulation electrodes and almost no fatigue of the response have later proven the adequacy of the hypothesis. Small round surface (2 cm diameter) electrodes were positioned over the following sensory or mixed nerves: n.peroneus superficialis (1), n.suralis(2) n.saphenous (3), n.peroneus (4), and n.cutaneous femoris posterior (5). Approximate positions of the five electrodes positions is shown in Fig. 2. The study was performed with seven patients: two hemiplegic patients, two complete paraplegic patients (T-4,5 and T-3,4), two incomplete paraplegic patients (T-7 and T-4,6), and one multiple sclerosis patient. With all of them flexion response was obtained with all stimulation sites. It was also observed that the polarity of the electrodes affects the response

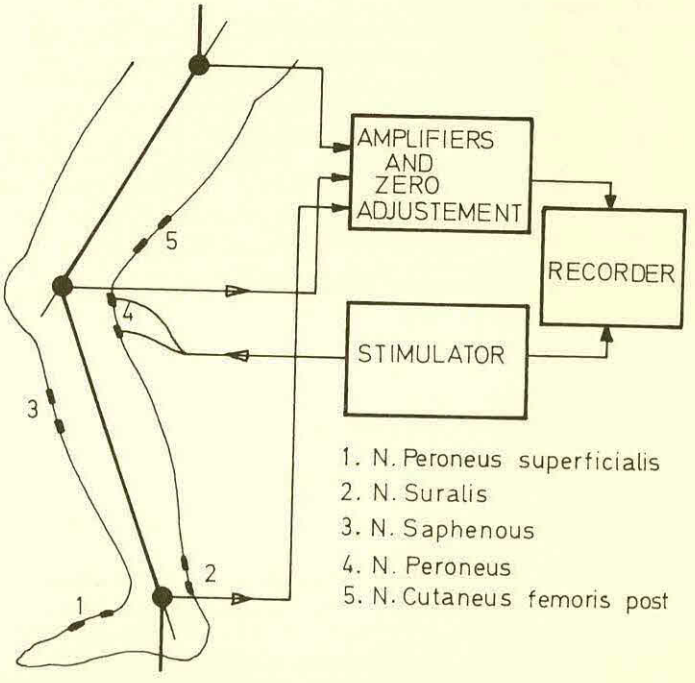

Fig. 3.

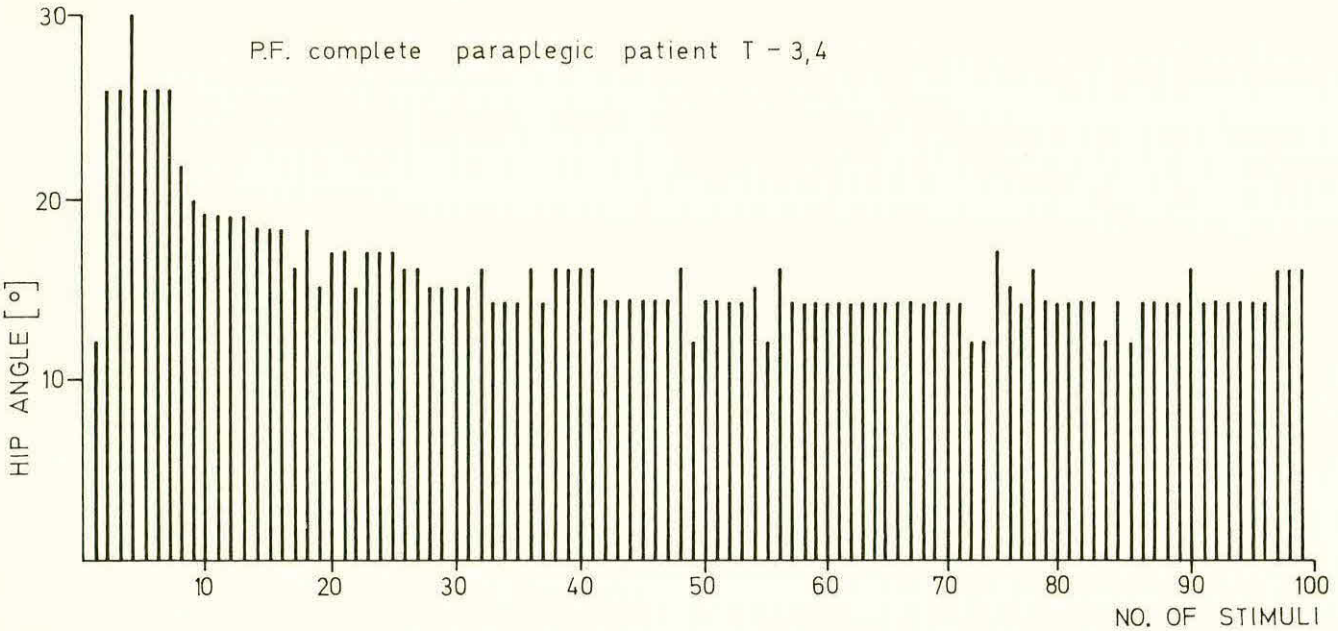

Fig. 4.

significantly. Patient under the test was placed upright on the tilt-table. Electrogoniometer (3) system was mounted to all three joints of one extremity. Hip, knee and ankle angle together with stimulation voltage were recorded.

The influence of stimulation amplitude U_{st}, frequency f and the duration of train of pulses T on the maximal joint angle was observed (Fig. 3). During all experiments the duration of each stimulation pulse was 0.3 ms. In Fig. 3 the dependence of hip angle on stimulation amplitude, frequency and duration of the train of stimuli is shown. The answer is increased when increasing each of the three parameters. The measurement presented was performed with an incomplete paraplegic patient when stimulating n.cutaneous femoris. Similar diagrams were obtained also in knee and ankle with all patients measured. As the hip flexion during normal walking ranges from 30^{o} to 36^{o} it can be seen from the Fig. 3 that such hip angles can be easily obtained with the afferent stimulation. When changing one of the three parameters from Fig. 3 the other two were kept on the following values: U_{st} = 80 V, f = 30 Hz, and T = 0.5 s.

Another important property of the flexion response is it's habituation. The trains of electrical stimuli were repeated hundred times each 2 s, what corresponds to very slow walking. Fig. 4 belongs to the measurement performed on a complete paraplegic patient. The following stimulation parameters were used: stimulation amplitude 70 V, frequency 30 Hz, train of stimuli duration 0.5 s, and single pulse duration 0.3 ms. With almost all of the patients tested the response was stronger at the very beginning and it diminished after first five to ten trains of stimuli. The amount of the flexion remained then about the same up to the end of the experiment.

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While it is known that the precise location of the electrode in the muscle has a substantial effect upon muscle recruitment properties with percutaneous implantation (2) we were not able to precisely establish the internal orientation of the electrode. Generally, the electrode was in the middle one-third of the muscle and oblique to muscle fiber orientation. The sites chosen for implantation were:

1. FDS/FDP from mid to upper one-third site on volar aspect;
2. EDC/EI from mid to upper one-third site on dorsal aspect;
3. FDS/FDP from distal forearm site on volar aspect;
4. AdP/OP from distal forearm site on volar aspect;
5. AdP/OP from distal forearm site on dorsal aspect;
6. EPL from distal forearm site on dorsal aspect.

Following implantation, a surface connector was taped over the implant site. This connector provided protection to the percutaneous electrodes where they penetrated the skin, and provided ease of electrical connection to the electrodes by acting as a junction box. The connector was taped to the skin over the electrodes with double sided tape, electrical connections were made between the electrodes and pins in the connector, a top was taped in place, and hypo-allergetic tape was placed around the connector and dacron tabs. Following implantation, generally no active or passive motion of the wrist or hand was allowed for three days.

Muscles of these subjects were stimulated electrically both for "exercise", in order to increase muscle strength and endurance, and for function. The stimulus applied to the muscle was a monophasic or biphasic, capacitatively coupled constant current stimulus with the following stimulus parameters; stimulus amplitude 0-20 ma, pulse width 0-100 μsec, frequency 0-50 Hz. The IM electrode was always the cathode (or cathodic first with biphasic stimuli), and a saline saturated surface reference electrode placed remotely was the indifferent electrode (anode). No stimulation was applied to the muscle until one week post-implantation.

Subjects were either in-patients involved in a complete rehabilitation program or out-patients. Because of the varied patient status, we could not always ascertain percisely the amount of stimulation or the type of activity the implant was subject to. No activities were restricted, and based on examination at followup, the site clearly was subjected to substantial stress. The connector assembly generally was changed at approximately two week intervals by hospital staff or the patient's family.

Electrode Evaluation. The status of the electrodes was checked regularly (generally at least twice a week for in-patients and at regular followup for out-patients). We monitored the stimulus threshold at which visual contraction was first elicited, the electrode impedance, and the stimulus input-force output (recruitment) characteristics. At least 24 hours without stimulation was allowed before these tests were performed. Threshold was measured as the pulse width required to elicit a contraction during application of a monophasic pulse amplitude of 20 ma applied at 1 Hz. Impedance was measured in two ways: as the peak of the voltage transient across the stimulating to indifferent (anode) divided by the current during application of a 20ma, 100 μsec, 1 Hz stimulus pulse or as the instantaneous voltage transient between the IM electrode and a Ag-AgCl surface indifferent (non-current carrying) electrode divided by the current during application of the same stimulus (i.e. the access resistance).

Recruitment characteristics were recorded isometrically by placing a force transducer against either the fingers (for FDS/FDP muscles) or the thumb (for OP/AdP muscles) and applying a 1-second burst of stimuli to the muscle, using the method described by Crago et.al. (2).

We classified electrodes after each evaluation as either functional or non-functional. Non-functional electrodes were either fractured or exhibited a large change in contractile response. Electrode fracture was detected by a large increase in impedance, frequently accompanied by an alteration in the muscle excited. Electrode fractures were confirmed by pulling the portion of electrode remaining through the skin, which uncoiled the electrode and allowed its removal. Other non-functional characteristics were a large change in response, either as a change in the muscle activated, or a change in the recruitment characteristics of the muscle.

RESULTS

Threshold and Impedance

One hundred and three (103) single strand wire electrodes (SSW) and 75 multistrand wire electrodes (MSW) were studied. The cumulative results of all SSW electrodes are shown in Figure 1. Of the inoperative electrodes, 50% (51 electrodes) failed within the first four months and 66% (68 electrodes) within the first six months. The overall failure rate of SSW electrodes was approximately nine percent per month for the first six months.

Multistrand wires were significantly more reliable. Of the 75 MSW electrodes implanted over the past 28 months, seventy two percent are still functional. Only eight electrodes were fractured (three in one subject after less than 100 days). Thirteen were removed intact because of a change in contractile response. Of 24 MSW electrodes implanted for at least eighteen months, 17 (71%) are operational, 3 broken and 4 removed intact.

The reliability of SSW electrodes implanted at the various sites was investigated. The results are shown in Table 1. Electrodes implanted more proximally generally were more reliable than those implanted at the distal site. Electrodes implanted on the dorsal aspect of the arm were more reliable

PERCUTANEOUS INTRAMUSCULAR EXCITATION OF PARALYZED SKELETAL MUSCLE: ELECTRODE RELIABILITY

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ABSTRACT

Chronically indwelling percutaneous electrodes provide a viable means of electrical excitation of paralyzed muscle. Three aspects of performance of two types of coiled wire intramuscular electrode have been evaluated over a period of five years. The threshold and impedance, open loop recruitment characteristics, and failure rate were recorded for 103 single strand wire (SSW) electrodes and 75 multi-strand wire (MSW) electrodes implanted in various paralyzed forearm and thenar muscles. The results demonstrate the viability of the percutaneous electrode technique for chronic use in functional neuromuscular stimulation.

INTRODUCTION

Electrical excitation of paralyzed muscle through chronically indwelling percutaneous electrodes has been demonstrated to be a feasible technique to restore control to paralyzed limbs (4,5). The viability of these systems is dependent upon the reliability of the electrode. The use of the percutaneous electrode technique for recording of myoelectric activity has been described by Caldwell and Reswick (1) but its viability for chronic stimulation has not been reported. In this paper, we report on three aspects of reliability regarding two types of percutaneous coiled wire electrode in chronic implantation. The aspects reported are alterations in threshold and impedance, stability of recruitment properties, and the failure rate.

METHODS

Studies were performed on sixteen spinal cord injury patients. These subjects were participating in a program to develop control of upper extremity function through the application of electrical stimulation to their paralyzed muscles. Subjects were both in-patients and out-patients who had sustained a complete spinal cord injury at either the C5 or C6 level.

Electrodes. Two types of percutaneous electrodes were studied. The first type (denoted as SSW) is fabricated from a single strand of 45 μ type 316 stainless steel wire wound into a helical spring. At the tip of the electrode, 10 mm. of insulation is removed chemically and a barb is formed. The electrode is fit into a 26 gauge hypodermic needle for implantation. Overall electrode diameter is approximately 230μ. The second type of electrode (denoted MSW), is made from a ten filament type 304 teflon insulated stainless steel wire (Cooner Wire Specialities, Inc.) and wound into a helical spring. The deinsulated length at the barbed end is 10 mm. The junction between insulated/deinsulated interface is filled with silastic (MDX-4210) to taper stress concentration. The overall diameter of the electrode is 580μ and the electrode is fit into a 19 gauge hypodermic needle.

Muscles. The muscles stimulated in this study were those judged to be most appropriate in providing hand function in these paralyzed individuals. The muscles studied were the finger flexors, Flexor digitorum superficialis and Flexor digitorum profundus (FDS and FDP), and finger extensors, Extensor digitorum communis and Extensor indicus (EDC and EI), and thumb muscles, Extensor pollicis longus (EPL), Opponens pollicis (OP), and Adductor pollicis (AdP).

Implant Procedure. The procedure for implantation of an electrode was as follows. The muscle to be stimulated was identified by palpation and, if possible, by stimulation with surface electrodes. The skin surface was then cleansed with alcohol. The needle, containing the electrode, was then inserted through the skin, and a low frequency stimulus was passed through the needle. When the desired contractile response was identified, the stimulus was turned off and pressure applied over the muscle belly as the needle was withdrawn. Bleeding usually did not occur, and if present was always easily controlled by external pressure applied to the skin. The stimulus was then applied via the IM electrode to ascertain that the electrode position was proper. A suitable electrode is one that elicits sufficient force within safe stimulus limits, provides a repeatable contraction, selectively activates a restricted portion of the desired muscle, recruits muscle fibers in a linear manner upon increase of the stimulus, and does not elicit an uncomfortable response. Approximately 50% of electrodes are positioned properly and are retained using this method. No anesthetic agents are employed.

The sites of percutaneous implantation were chosen 1) to be on relatively flat surfaces accommodating a surface connector (see below); 2) to be opposite to one another on the arm if two sites for stimulation of antagonistic muscles were used, with a minimum number of sites being used for any individual; and 3) in areas where they would minimally interfere with the patient's activities, thus being subject to the least external stress.

than those implanted on the volar aspect if the proximal-distal distance was the same. These findings are discussed below.

DISCUSSION

The results described above demonstrate that the percutaneous electrode technique is viable for extended periods of chronic implantation. It provides a safe and inexpensive technique with considerable reliability for achieving selective activation of specific muscles. Electrode implantation can be performed under substerile conditions and without local anesthesia. Muscle contraction is elicited with minimal pain or other adverse reactions. At initial implantation, if the desired contraction is not elicited, the electrode can be easily withdrawn and another implanted. After extended periods of implantation, the electrode frequently can be completely removed by pulling on the protruding end. In the case of fracture, the remaining portion has been demonstrated by x-ray to be grossly stable in its fractured position.

The fracture rate of the SSW electrodes (approximately 9% per month) is high for routine use. MSW electrodes have a much longer lifetime. The patient generally is aware of a fracture, both by a change in the muscle response and by sensation. Fractures most frequently occurred subcutaneously, i.e., in the region of substantial flexion of the electrode (3). If a fracture occurred, the patient would generally report a "pinching" or "pain" in the vicinity of the connector site. This was also accompained by an increase in resistance to current flow.

The time to failure for SSW electrodes was noted to be different at various sites. At proximal sites electrodes were more reliable than at distal sites; the dorsal site was more reliable than the volar site. Among the factors which must be considered to be most important in this difference are the external trauma each surface of the area is subjected to, the excursion of the muscles during movement, and the number of muscle planes that the electrode traverses to reach the desired muscle. Separation of these factors was not attempted from these data. The observation is that reliability is greatest for the dorsal, proximal site of a subcutaneous muscle, and least reliable for the deep muscles at the volar, distal site. This has obvious clinical implications in the choice of electrode site.

No instance of infection has been encountered for any of the electrodes implanted. In our experience, maintenance of the surface connector has been the major inconvenience. Recent change in the connector design to enable the patient's family or attendant to change the connector at home has minimized this problem. Occasional skin irritation occurred in some patients but cleared quickly (days) when the tape was removed.

The use of surgically implantable stimulators will ultimately replace the extended use of percutaneous wires for functional neuromuscular stimulation. However, for long term feasibility studies and patient evaluation of functional systems, we believe that percutaneous coiled wire electrodes play a critical role as a safe and effective technique for chronic electrical excitation of paralyzed muscle.

ACKNOWLEDGEMENTS

Supported in part by the National Institute of Handicapped Research Grant No. G001005815, the Veterans Administration Rehabilitative Engineering R&D Program, and NIH/NINCDS N01-NS-2-2314. The authors acknowledge the active contributions of Dr. J. T. Mortimer, Applied Neural Control Laboratory, Case Western Reserve University for development of the electrode. These studies were performed at Highland View Hospital and the Veterans Administration Medical Center, Cleveland, Ohio.

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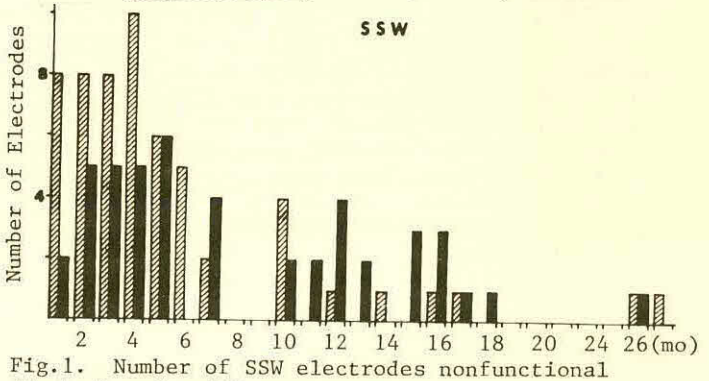

Fig.1. Number of SSW electrodes nonfunctional (dashed) and still operational vs. time (months)

SITE/MUSCLE	MEDIAN TIME TO FAILURE
Volar-proximal/ finger flexors	105 days
Volar-distal/ finger flexors	60
Dorsal-proximal/ finger extensors	195
Volar-distal/ thenar intrinsics	75

Table 1. Reliability of SSW electrodes at four implant sites.

HOW HANDIDNESS, SEX AND FORCE LEVEL AFFECT THE MEDIAN FREQUENCY OF THE MYOELECTRIC SIGNAL

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ABSTRACT

A device has been constructed in our laboratory which monitors the myoelectric (ME) signal during a muscle contraction by tracking its median frequency (MF) on-line and in real-time. During a maintained isometric contraction the MF decreased as a function of time. The initial median frequency (IMF) appears to correlate with the conduction velocity of the muscle at the beginning of the contraction. The IMF of the first dorsal interosseous muscle was recorded for 20%, 40%, 80% and 100% of the maximal voluntary contraction (MVC).

Results indicate that females demonstrate a higher value of the IMF than males at various contraction levels. No relationship was found between the IMF and the contraction level. In right-handed subjects the IMF of the non-dominant side was either equal to or higher than that of the dominant side. This was not found in left-handed subjects.

INTRODUCTION

In the rehabilitation of injured muscles, the normal limb is typically used as a control for gauging the progress of a treatment program of the affected limb. However, the use of the contralateral limb as a reference has not proven to be an appropriate strategy. This is largely due to the lack of objective means for comparing the performance of corresponding contralateral muscles. Currently used techniques, such as muscle testing and clinical electromyography, have not proven reliable for making direct comparisons. In this study the median frequency (MF) of the myoelectric (ME) signal was calculated on-line and in real-time during muscle contractions. This parameter is related to a number of physiological properties of the muscle fibers, e.g., fatiguability and contraction time. Correlations were made between this parameter and the force of muscle contraction of the first dorsal interosseous muscle with specific reference to hand dominance (handidness) and sex (male and female subjects).

METHODS AND PROCEDURES

The Muscle Fatigue Monitor, a device which has been designed, constructed and tested in our laboratory, continuously calculates the median frequency (MF) of the myoelectric (ME) signal on-line and in real-time during sustained muscle contractions (Stulen and De Luca, 1978, 1979). In this device the ME signal is passed through parametric filters to divide the spectrum into two regions. The cutoff frequencies of the filters are set by a control voltage which forces the signal power output of the filters to be equal. Thus, the control voltage uniquely corresponds to the MF.

Eighteen normal adult male and twelve female volunteers (including 3 left-handed subjects) whose ages ranged from 18-35 years were tested using the method of Sabbahi *et al.*(1979). Each subject was asked to abduct the index finger and elicit an isometric contraction while the index finger and hand were immobilized in a specially designed restraining device. This device contained a force gauge which measured the force of abduction of the index finger and displayed the force value on an oscilloscope. The subject was requested to maintain the constant force output for 10 sec. This measurement was repeated three times with adequate resting time in between. The procedure was repeated for contractions at 20%, 40%, 80% and 100% of MVC. The myoelectric signal from the first dorsal interosseous muscle was detected with special surface electrodes and was analyzed with the Muscle Fatigue Monitor. The initial median frequency (IMF), i.e., the median frequency at the beginning of the contraction, was calculated as well as the change in the MF during each sustained muscle contraction.

Each subject was tested twice, once for the right and once for the left hand. The mean value of the IMF of three consecutive contractions of the same level was compared for both hands. The grand mean value of all subjects tested at various contraction levels was compared for the right-handed and left-handed male

and female subjects.

RESULTS

The IMF showed no direct relationship with the force at which the contraction was performed. In some subjects the value of the IMF increased with isometric force, whereas in other subjects it decreased. In most subjects the value of the IMF fluctuated substantially with a different force level. However, with sustained isometric contraction of the muscle the MF consistently decreased monotonically as a function of time irrespective of fluctuations of the amplitude of the ME signals. The rate of the decrease increased with the force at which the contraction was performed.

In the right-handed subjects the IMF of the ME signals at a given contraction level of the first dorsal interosseous of the non-dominant hand was either equal to or higher than the IMF of the corresponding muscle of the dominant hand. This was the case at every contraction level tested. The value of the grand mean of the IMF in all right-handed subjects was substantially higher in the left hand than in the right hand. This was also true for every contraction level tested. However, intersubject variation was large. In the left-handed subjects no relationship was found between the value of the IMF, the muscle force and the hand tested.

A comparison was made between the IMF of the 20% MVC's and the 80% MVC's from the right hand of male and female subjects. The grand mean value of the IMF of the ME signals from the first dorsal interosseous of the female subjects at 20% MVC and at 80% MVC was significantly ($p < 0.05$) higher than the corresponding values for male subjects at the same contraction levels (Table 1). Again, there was a large intersubject variation in both male and female subjects. Six female subjects had a substantially higher value of IMF than all the male subjects, whereas the remaining six female subjects demonstrated no substantial difference from the males.

	FEMALES 20%	MALES 80%
FEMALES 80%	not significant	$p<0.05$
MALES 20%	$p<0.05$	not significant

Table 1. Sex related changes in the initial median frequency of the myoelectric signal.

DISCUSSION

The frequency spectrum of the ME signal is, for the major part, a transformation of the shapes of the motor unit action potentials within the ME signal (LeFever and De Luca, 1976). The motor unit action potential shapes are in turn affected mainly by the size of the muscle fibers and the location of the recording electrodes with respect to the active fibers. The size of the muscle fibers is related to the conduction velocity of the muscle fibers, which in turn is directly related to the MF (Stulen and De Luca, 1981).

In this study no significant difference was noted in the IMF at various levels of contraction. This observation may be explained by the results of Ericson and Hagberg (1979) who noted no substantial changes in the shape of the ME signal frequency spectrum at various force levels. Therefore, it appears that the recruitment of the faster twitch motor units at higher levels of contraction cannot be detected by measuring the IMF of the ME signal.

The IMF of the first dorsal interosseous muscle in right-handed subjects was found to be lower than that of the corresponding muscle in the left hand. This indicates that in these cases the conduction velocity of the muscle fibers in the right first dorsal interosseous is less than that in the left. This difference in conduction velocity might be due to a difference in fiber type composition in the two muscles resulting from the more frequent use of the right hand (Salmons and Henricksson, 1981). Left-handed subjects, however, did not reveal a similar difference. This may possibly be due to the fact that the left-handed subjects involved in the experiment were ambidextrous.

The higher value of the IMF of the ME signal in females with respect to males may be attributed to a difference in the muscle fiber diameter in the two sexes. In fact Vissen and Ryke (1973) have reported sex-related differences in motor unit action potential shapes. Our results

indicate that the first dorsal interosseous muscle of females has a larger percentage of large diameter muscle fibers than that of males. However, such a conclusion should be proven by direct measurements of fiber sizes.

In conclusion, it appears that contralateral first dorsal interosseous muscles may have different performance and anatomical characteristics related to hand dominance and sex. It is conceivable that differences also exist between other corresponding contralateral muscles in limbs. Hence the possible effect of influence of hand dominance and sex should be considered in the design of physical rehabilitation techniques.

ACKNOWLEDGEMENT

The authors are grateful for the technical assistance of Mr. Donald C. Kimball. This project was supported in part by the Liberty Mutual Insurance Company and by Grant No. 23-P-55854 of the National Institute of Handicapped Research.

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Two Specialized Muscle Strength Testing Instruments

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ABSTRACT

Two specialized muscle strength testing instruments are described. The Computerized Isometric Testing System (CITS) is a research tool in which a subject is stabilized in a chair-like structure and isometric torques are measured simultaneously from eight joint axes. The Quantitative Muscle Tester (QMT) is a versatile, portable, clinical instrument that is stabilized by the investigator and used to measure isometric forces from individual joint axes in a single plane. Data from both devices have been found to be linear ($r = 0.99$, $n = 40$, for the CITS, and $r = 0.99$, $n = 90$, for the QMT), and reproducible (average percentage changes between tests were $0.95\% \pm 0.89\%$ (mean $\pm$ S.D.) for the CITS and $1.24\% \pm 0.99\%$ for the QMT). Therefore, the CITS and the QMT promise to be useful measurement tools for research and clinical applications, respectively.

INTRODUCTION

The design criteria for muscle strength testing instruments differ depending upon the application. The primary considerations for instruments used in routine clinical evaluations are simplicity, versatility and efficiency. Secondary considerations are accuracy and resolution. For research applications, the priorities are reversed. In particular, maximum accuracy and resolution are sought, if necessary, at the expense of efficiency.

INSTRUMENTATION

Two specialized instruments have been developed at Washington University for the quantitative measurement of muscle strength. The first device, the Computerized Isometric Testing System (CITS), is a research tool designed to provide maximum accuracy and resolution for the simultaneous measurement of isometric torques in multiple planes from eight joint axes. The second device, the Quantitative Muscle Tester (QMT), is a simple, clinical device designed to provide objective, reasonably reliable measurements of isometric force from individual muscle groups efficiently.

The CITS is a microcomputer based system of instrumentation which includes a mechanical assembly, electronic components, and a microcomputer (Fig. 1). The mechanical assembly consists of a fully adjustable, sturdy, chair-like structure from which multiple sections of telescoping, square, steel tubing project. The telescoping tubes are attached to the chair through interposed adjustable steel joint posts. The tubing framework serves as the interface between the subject and the force transducers. In preparation for testing: 1) the tubing framework is aligned parallel to the limb segments of the test subject, 2) the joint posts are positioned adjacent to the subject's joint axes, and 3) the subject's limb segments are secured to the device via a series of cuffs and straps. The mechanical assembly currently accomodates testing at the shoulder, elbow, hip, and knee joints, bilaterally; the system can be expanded to permit testing at the ankles, wrists, and trunk.

The electronic components include strain gages and instrumentation bridge amplifiers. A set of foil strain gages are afixed appropriately on each joint post to permit measurement of torques in two planes. The bridge amplifier for each strain gage pair is located within 20 cm of its associated strain gage to reduce noise pick-up. The amplifiers include automatic calibration circuitry.

The microcomputer includes an Intel 8080 CPU (Intel Corporation, Santa Clara, California), 48K-bytes of RAM memory, 1K-bytes of PROM memory (for bootstrap), a real-time clock, an 8 inch floppy disk subsystem (250K-byte capacity), a serial interface, a hard copy terminal, a CRT

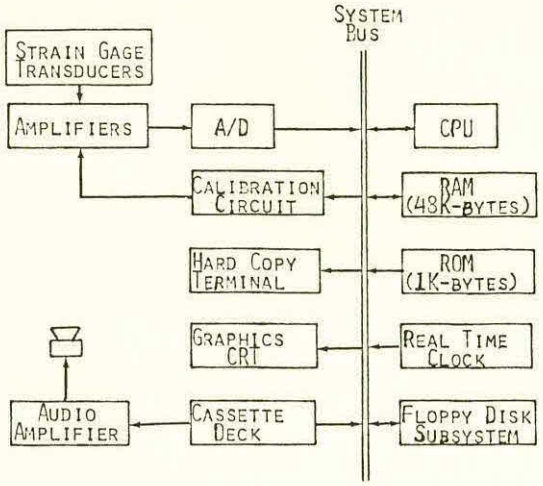

Figure 1: CITS Block Diagram

graphics subsystem, a stereo cassette recorder with interface, and a 12-bit by 16-channel analog-to-digital (A/D) converter. Sixteen channels of force data are sampled by the microcomputer upon operator command at a preselected rate, displayed on the graphics CRT, and stored on floppy disk. Upon termination of each exercise, the peak torque, time to peak torque, and torque-time area are printed on the terminal for the joint of interest. Further processing is performed by a PDP-12 minicomputer (Digital Equipment Corporation, Maynard, Massachusetts). Data stored on floppy disks by the microcomputer are read directly from the disk medium by the PDP-12. Hard-copy graphs of torque verses time can be produced by the PDP-12. The stereo cassette tape deck can be used for instructing the subject throughout the test sequence to reduce inter-investigator variability. Audio instructions are recorded on one of the two stereo channels; digital signals are recorded on the second channel for control of the data acquisition software.

The Quantitative Muscle Tester (QMT) is a versatile, portable, clinical instrument which consists of a centrally located measuring module with a digital meter, a subject attachment, and an examiner attachment. Both the subject attachment and the examiner attachment are easily removed from the measuring module for replacement with a variety of specialized attachments. The attachments enable the examiner to apply resistance to the force generated by the subject's muscle contraction. The subject may attempt to either push against or pull away from the examiner. Since the isometric "break" test is used, optimal accuracy and reliability are achieved only if the examiner's resistance exceeds the subject's force. The maximum force produced by the subject is displayed by the digital meter.

The measuring module consists of an aluminum ring 3" diameter x 0.75" wide x 0.15" wall thickness. The subject attachment and the examiner attachment are secured to the ring in diametrically opposed positions. Pairs of foil strain gages are afixed to the ring in two locations mid-way between the two attachment points. The battery operated electronics are mounted over the ring and consist of three modules (Fig. 2). The first module is a bridge amplifier whose voltage output is proportional to the compression or elongation forces exerted on the measurement ring. The second module is a peak detector whose voltage output is proportional to the peak force exerted by the subject. The third module is a digital display subsystem that displays the numerical value of the maximum force exerted by the sugject. This peak value is retained by the read-out until the "reset" push-button is depressed by the operator. Features also included with the instrument are: 1) an automatic calibration circuit which simulates a known force signal to the bridge amplifier for calibration purposes, and 2) an output jack which enables external time-based recording of the force exerted during a test.

ANALYSIS

Both the Computerized Isometric Testing System (CITS) and the Quantitative Muscle Tester (QMT) were assessed for measurement accuracy and reproducibility. These analyses were performed by applying known forces to the transducers of both instruments and by testing human subjects with the QMT.

The CITS evaluation was performed for the analysis of force in two planes about the shoulder and elbow joint axes. A ten pound weight was suspended from the CITS to load specific joint axes in the appropriate plane four separate times over a two week period. The resultant voltage outputs from each amplifer were compared for each of the four trials. The average percentage change of measured forces between trials was 0.95% $\pm$ 0.89% (mean $\pm$ S.D.). The linearity of the transducer system was evaluated by suspending weights of ten to one hundred pounds from each measuring segment. A regression line was fit to the plot of amplifier voltage outputs verses applied forces for each transducer element. The fit of the regression lines yields a correlation coefficient of 0.99 for all joint axes analyzed.

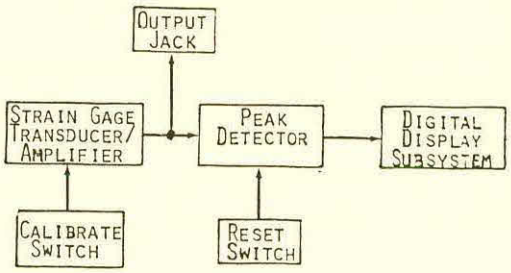

Figure 2: QMT Block Diagram

The QMT was evaluated in three steps. First, weights were suspended from the device in order to determine linearity and induced errors due to applying the QMT at an angle other than perpendicular to the limb segment. Weights in the range of five to forty-five pounds in five pound increments were suspended from the QMT, and a regression line was fit to the plot of QMT determined force verses the actual weight suspended. For a total of 90 determinations made at nine different forces, the fit was very close (r= 0.99, n= 90 determinations). The QMT was then positioned such that the weights were suspended at various angles to the measuring transducer. Over a range of forces from five to forty-five pounds, the average percentage errors of the measured forces were 1.24% ± 0.99% (mean ± S.D.), 1.39% ± 1.03%, 2.41 ± 1.88%, 4.15% ± 2.85%, and 6.86% ± 3.85% for tilt angles of 0, 5, 10, 15, and 20 degrees, respectively.

Second, an investigator held the QMT and applied it against reactive forces. This procedure was performed twenty times each for reactive forces of 10 and 15 pounds and ten times for the reactive force of 20 pounds. The mean percentage error was 1.9% ± 5.3% (mean ± S.D.) for a total of 50 trials.

Finally, the QMT was used to test bilaterally the elbow extensors and the hip abductors in ten normal subjects. The subjects were supine for the elbow extensor test and prone for the hip abductor test. Stabilization was achieved manually for the elbow extensor evaluation and by means of a pelvic strap for the hip abductor evaluations. Subjects were tested for elbow extensor and hip abductor strength on two separate days. the percentage changes in measured torque from the first test to the retest as a mean for the group was 6.37% ± 4.85% (mean ± S.D.) and 7.00% ± 5.27% for elbow extension and hip abduction, respectively.

DISCUSSION

Muscle strength testing is employed routinely by health professionals as part of both neuromuscular and musculoskeletal evaluations. The subjectivity of commonly used manual muscle strength assessments compromises the reliability and the resolution of the measurements. The principle reason for developing two specialized strength testing instruments was to increase measurement objectivity and reliability. The first device, the Computerized Isometric Testing System (CITS), has been shown to be a statistically reliable strength testing device in an engineering sense and is, therefore, a potientially useful measurement tool. However, because: 1) the subject must be rigidly attached to the CITS via a system of cuffs and straps, and 2) the instrument must be adjusted to the subject's size by means of at least twelve controls, the set-up procedure for the CITS is very tedious and time consuming. The CITS is, therefore, not applicable to clinical testing.

The second device, the Quantitative Muscle Tester (QMT), has been shown to be a reliable strength testing instrument. Because of its versatility, mobility, and ease of application, the QMT is capable of gaining widespread acceptance by clinicians. However, since the subject is not rigidly stabilized for QMT testing, the potential for measurement errors is greater than with the CITS.

Formalized testing of patients with the CITS has not yet been initiated. However, data obtained by applying known weights to the device proved to be linear and reproducible. Furthermore, the CITS provides greater subject stabilization than the QMT. Therefore, the CITS is expected to yield more reliable results in patient testing than the QMT. Each of the two specialized instruments described herein show promise as strength testing devices when employed appropriately.

EXPERIENCES WITH MULTICHANNEL ELECTRICAL STIMULATION IN THE CORRECTION OF HEMIPLEGIC GAIT

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ABSTRACT

A control study searching for the orthotic and therapeutic effects of multichannel surface electrical stimulation applied to a group of hemiplegic patients was performed. To compare the effectiveness of electrical stimulation with classical methods of rehabilitation, a similar control group was formed. The methodology of the electrical stimulation applied and the methods used in the evaluation of several important gait parameters are described. New measuring techniques for quantitative evaluation of gait, including ground reaction measuring shoes and crutch, a planar goniometric system, and EMG recording were introduced. The accompanying data acquisition and processing system is also shortly described.

INTRODUCTION

Since the first promising results of the application of surface multichannel electrical stimulation for the correction of paretic gait /1/, further successes obtained with a group of 11 hemiplegic patients were reported /2/. During the stimulation several typical anomalies estimated by kinesiological analysis were lessened or even disappeared. Significant corrections in step time and stance phase time symmetry were achieved , too. In addition, the results spoke in favour of a shorter rehabilitation period and a higher level of rehabilitation, but no control group was established to compare the results with the classical methods of rehabilitation.

Some studies considering short- and long-term effects were performed for one-channel peroneal stimulation /3,4,5,6/. A significant increase of muscle force , improvement of motor coordination, gait pattern, and neurological condition were reported. It was suggested that the complex afferent information flow to the central nervous system during the stimulated gait could change or regenerate structures responsible for gait control.

The goal of our work was to finf stronger indications for the existence or non-existence of long-term therapeutic effects due to multichannel electrical stimulation. Investigations into the existence and the extent of carry-over effects are of utmost importance. Whether electrical stimulation will predominantly take the direction of physical therapy or that of orthosis, depends on such results.

METHODOLOGY

For the purpose of our study , patients were divided into a stimulated and a control group. Each group should contain 10 patients. The main criteria for the selection of patients were similar to those described in /2/, namely: clinical status with emphasis on evaluation of motor functions, functional status, mobility without aid, performance of basic daily activities, and clinical kinesiological analysis of gait. Additionally, the status of the cardiovascular system and the accompanying pathologies were considered after intensive examination, as well as clinical diagnostics, neurological estimation of site and size of the lesion, and examination of field of view. Consideration was also paid to the patient's consent, his motivation, cooperation, and ability to communicate. Due to considerable difficulties in the selection of patients that resulted from this vast spectrum of criteria, the two groups did not emerge as identical. Ethical reasons in themselves directed patients of poorer clinical status into the stimulated group, while the control group consisted of patients with relatively smaller pathologies, and those where electrical stimulation was contraindicated. Also, the groups were not identical with respect to social environment, age, impairment, independence in walking and daily activities.

Similarity in both groups was achieved in status after cerebrovascular insult, adequate motivation, period from insult to the beginning of therapy (approx. 5 months), accompanying pathologies (hypertensia, myocardiopathy, etc.), and the period of therapy. Both groups were treated daily for equal amount of time throughout their treatment. Patients in both groups were involved in a regular therapeu-

tic programme, the difference between them being the exclusion of electrical stimulation in the control group. Stimulation sessions lasted from 10 minutes at the beginning to more than one hour at the end of therapy, five times a week. The therapy in both groups lasted from approximately two to three and a half months.

Electrical stimulation was applied to 4-6 muscle groups (pretibial muscles, plantar flexors of ankle, knee flexors and extensors, hip flexors and extensors, hip abductors) during walking according to the observed disabilities and established methodology /2/. Selection of the stimulated muscle group was based on the anomalies found by the clinical analysis of gait, the aim being to eliminate or diminish these anomalies. The positions of electrodes were chosen so as to achieve the best functional response. Because of the inability to activate deeper muscle structures and excessive pain sensitivity at high excitation amplitudes, it was sometimes impossible to achieve the required functional response.

Two clinical and research oriented 6-channel stimulators were used for the stimulation therapy (Fig. 1). The channels of both stimulators could be programmed by arrays of switches whose position graphically represents the stimulation sequences. Separate channels are triggered by a heel-switch in the shoe of the impaired leg. The determination of stimulation sequences, i.e. when the stimulation of individual muscles is to occur during the gait cycle, is made in a sequential way. First the initial stimulation sequence is chosen and then it is altered by a trial and error procedure to obtain the best gait correction. Each anomaly with hemiplegic patients being either a consequence of absent or uncoordinated muscular activity, those muscles and the timing of stimulation were selected, which best correct these anomalies, not following the timing of normal EMG activity.

Fig. 1

The rehabilitation process of both groups was accompanied by measurements and tests. Gait evaluation without stimulation was acomplished for both groups before the beginning and at the end of therapy, and 6-12 months later at a control examination. During therapy a number of additional evaluations (0-3) were performed. With the stimulated group, measurements and analyses were performed additionally during stimulation, except at the beginning and at the control examination, to evaluate the orthotic effects of stimulation.

The evaluation of gait was based on qualitative and quantitative methods. The clinical analysis of gait adopted at the Ljubljana rehabilitation centre /7/ was used. It depends on the subjective evaluation of the physician or physiotherapist. The anomalies under observation were estimated in all three planes: sagittal, lateral, and transversal.The motion of both legs, together with pelvis and trunk was considered. Observation was divided into three parts: swing phase, loading phase and stance phase. Altogether 55 items were evaluated. The anomalies were rated in three degrees: 1-low, 2-medium, 3-high.

Test of motor functions and walking abilities was performed for each patient at acceptance, on leaving and at the control examination.

Quantitative methods for the assessment of gait were developed in the course of our investigation. Therefore, some of them have not been applied to the earlier members of both groups. Two important biomechanical parameters, namely the average stride length and the velocity of gait, were measured in all patients. Other measuring techniques (ground reaction measuring shoes and crutch, goniometers, EMG recording) were introduced gradually.

Four different pairs of ground reaction measuring shoes /8/ were used for the measurement of the vertical component of the ground reaction force during the stance phase, and its distribution under the foot. With patients using the crutch, assesment of the axial force on it was accomplished by the measuring crutch. An adapted goniometric system /9/ was included in our measuring system. The dual-side system measured flexion-extension movements in the hip, knee and ankle joints.

The data from the measuring equipment were collected by a minicomputer and stored on magnetic media for further processing. An extensive software package was developed, mainly for graphical presentation of the measured data. Two types of presentation were used; each step is presented separately (Figs. 2,3), or several steps (up to 80) are avera-

ged and the mean values together with their standard deviations presented (Figs. 4,5,6,7).

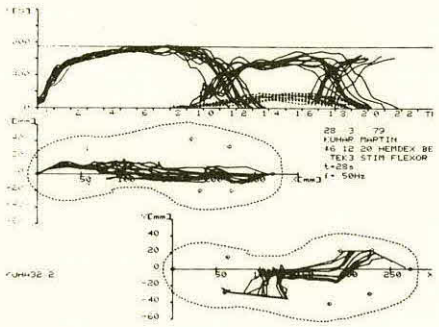

Fig.2

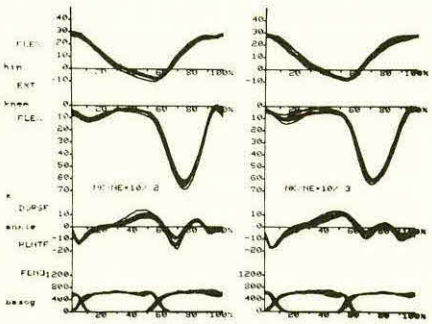

Fig.3

In Fig.2 the time dependence of the vertical component of the ground reactions on both feet and the axial component on the crutch (dashed line) for a right-side hemiplegic are shown. Trajectories drawn inside the shematically outlined shoe soles represent the positions of the centre of pressure during the stance phase. In Fig.4 the same quantities averaged over several steps of a normal person are

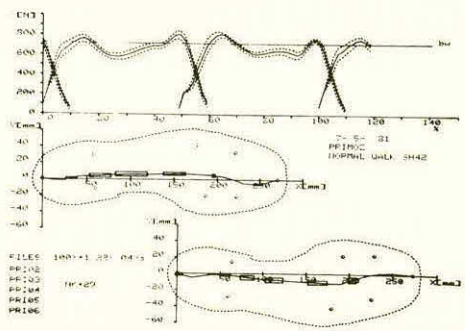

Fig.4

shown. In the force-time diagram standard deviations are indicated by dashed lines. The time axis is given as a percentage of the average stride duration. The numerical value of this time interval, together with its standard deviation, and the number of steps considered in the average are given in the text attached to the figure. Standard deviations of the spatial distribution of the centre of pressure under the feet are plotted at preselected intervals and represented by rectangles giving the standard deviations of both coordinates for the point on the trajectory lying in the centre of the rectangle. Fig.3 shows goniograms of the hip, knee, and ankle, and the ground reaction forces for both legs of a normal person. Similar information averaged over several steps of a right-side hemiplegic patient is presented in Fig.5. With this method of presentation, standard deviations of goniograms (dashed lines), and normal positions of joint angles as given in the literature /7/ (bars) are plotted optionally. Fig.6 is an example of an alternative method of presentation of the ground reaction forces. The time dependence of the averaged coordinates (X,Y) of the centre of pressure for both feet is explicitly shown here. Another optional program plots the time dependence of the averaged output voltages, together with standard deviations for several steps, for the 8 transducers of a selected shoe (Fig. 7), or the voltages for each step separately. The origin of the time axes is defined by the moment a properly selected transducer touches the ground.

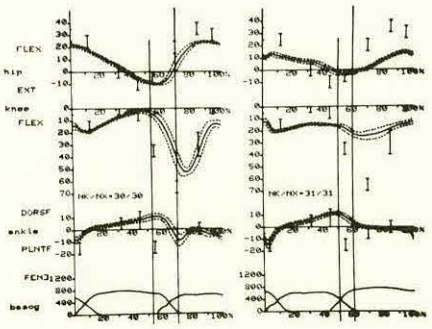

Fig.5

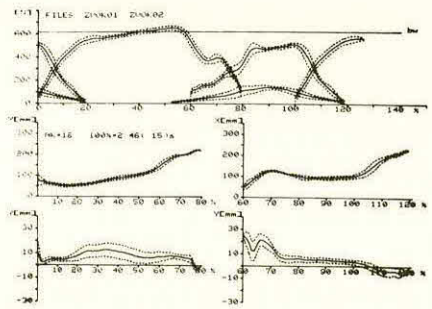

Fig.6

EMG recordings over 6 muscle groups on each side during gait were added in the course of investgation using silver cutaneous electrodes, telemetry, and a polyelectromyograph. EMG activities were recorded over m.tibialis anterior, m.gastrocnemius cap. med., m.quadriceps, m.biceps femoris, m. gluteus maximus, and erector spinae. These muscle

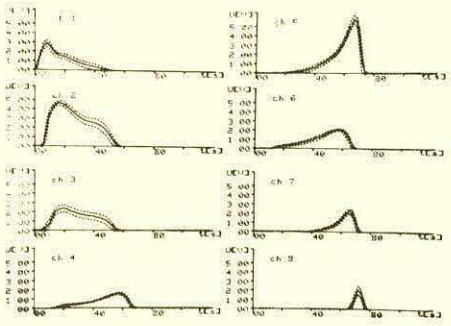

Fig.7

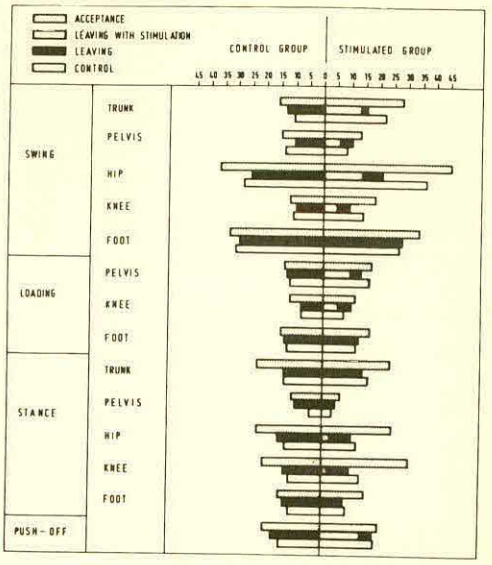

Fig.8

groups, with the exception of the last, were normally selected for the stimulation. The aim of these EMG studies was to get information about the reorganisation of neuromuscular activity and to find possible changes due to the applied therapy.

RESULTS

Our plan was to evaluate the process of rehabilitation according to the established programme for 10 patients in each group. Unfortunately, for various reasons some of the selected patients could not successfully complete the scheduled programme or were not available for the final control examination. Therefore, the results are now available for 9 patients from the stimulated group, and 8 from the control one.

For an overall evaluation of the rehabilitation method by means of clinical kinesiological analysis, an average correction coefficient C was defined as the quotient: $C=(I-R)/I$, where I was the total score of anomalies for all patients in a group before the beginning of therapy, and R the remaining score at the checkpoints of the rehabilitation process. Thus the coefficient represents the relative decrease of anomalies. Similar coefficients were defined for the estimation of the changes in some measured parameters (step length, gait speed). The results are given in Table I. A more detailed presentation of the anomalies of particular body segments at loading, in swing and in stance phases is given in Fig.8. Total scores of anomalies for 8 patients in each group are shown. In contrast to the most expressed improvements in the swing phase, as established by previous investigations /2/, this study showed higher improvements in the stance phase. Again, maximal corrections were achieved in the ankle joint, while corrections in the hip were not so evident because of the inability to activate deep flexor muscles.

Table I

	CONTROL GROUP		STIMULATED GROUP	
	END OF THERAPY	6-12 MONTHS AFTER	END OF THERAPY	6-12 MONTHS AFTER
STEP LENGTH	15%	18%	29% (34%*)	16%
GAIT SPEED	48%	68%	41% (58%*)	43%
KINESIOLOGICAL GAIT ANALYSIS	21%	27%	38% (74%*)	29%

On completion of the programme, the average improvement of step length was considerably higher in the stimulated group, while at the control examination the two groups did not differ significantly. Gait seed continued to increase in both groups after the end of therapy, though nonsignificantly in the stimulated group. When the values of these two parameters are compared to the evaluation of anomalies by kinesiological analysis, a close correlation is found between the dimunition of the anomalies and the improvement of the step length, while this is not the case with gait speed. Evidently, patients with a relatively worse gait pattern can walk faster, at least for short distances. Probably, the greater number of anomalies can be at least partly accounted for by the faster gait itself.

The orthotic effects of the applied electrical stimulation can be seen from the figures given in brackets (Table I). These effects are normally even more expressed in the earlier phases of rehabilitation.

Another qualitative method for the evaluation of rehabilitation was based on a test of motor functions of the lower extremities /10/, and on the assessment of walking abilities graded into several classes. Results are given in Table II. 9 patients from the stimulated group, and 10 from the control one were taken into consideration. The control examination of one patient from the stimulated, and of two from the control group has not yet been performed. Greater improvement of motor functions, as well as of walking abilities, was achieved in the stimulated group. At the control examination , in both groups a drop was observed in the remained motor functions, while walking abilities did not change significantly.

Table II

	acceptance		end of therapy		control examin.	
	S	C	S	C	S	C
remaining motor functions ...	40%	44%	50%	45%	41%	37%
does not walk ...	4	2	0	0	0	0
walks with support of therap...	2	7	0	0	0	0
walks short distances (100m) ..	3	1	1	2	1	0
walks medium distances (500m) ..	0	0	2	6	3	5
walks long distances (over 500m) ..	0	0	6	2	4	3

Legend: S - stimulated group, C - control group

At the end of the programme, indications for permanent use of orthotic devices were approximately equal in both groups, while at the control examination these indications increased in the control group.

The analysis of the EMG recordings also favours stimulation. In the stimulated group, larger activation, stronger contraction, better cyclic activity, reciprocal innervation, and better muscular coordination appeared at the end of therapy. Meanwhile, less significant changes occurred with patients in the control group.

Results obtained by goniometric and force-shoe measurements are in general complementary to those obtained by other methods of gait evaluation. Though the results are incomplete, they confirm the advantages of rehabilitation using multichannel stimulation over the classical methods. Its orthotic and therapeutic effects are clearly displayed by these measurements. Some observations from kinesiological analysis can be compared to the corresponding measurements (e.g. flexion-extension movements of the hip, knee, and ankle, anomalies at foot contact with the ground, at the moment of push-off, etc.).

DISCUSSION

Considering the results of different methods of gait evaluation, no positive answer can be given in favour of the existence of the so-called "long term" therapeutic effects in gait caused by electrical stimulation. After the end of therapy, all methods of gait evaluation showed a certain degree of worsening for the majority of parameters evaluated in the stimulated group, while in the control one, some improvements can still be observed (longer period of rehabilitation), though the exact figures are disputable. Unfortunately, the groups were toosmall, and too heterogenous in several important parameters, to prove at a sufficiently high level of confidence possible significant differences in the evaluated gait parameters between the two groups. The average values of changes merely represent a rough estimation of the effects that a particular method of rehabilitation has on these parameters. Thus an average improvement of a certain parameter normally also includes some examples of worsening, and vice versa.

However, it is evident that therapy including multichannel electrical stimulation is more intensive and efficient; namely, the rehabilitation period is shorter and a higher level of improvement can be achieved. Short term therapeutic and orthotic effects of stimulation are well established. Though the present method of surface multichannel stimulation suffers from several shortcomings that are inherent to the method itself (poor selectivity, rapid fatigue, variability of the evoked muscle responses, inability to activate deeper muscle structures, lack of information about the status of the controlled system, time consuming positioning of electrodes, etc.), it is appropriate especially for severely handicapped patients, where even a relatively "crude" method can establish or significantly improve the gait pattern. When the volitional control remaining is relatively good, the applied method could hardly contribute to significant improvements.

Some improvements in the present method of multichannel stimulation can be achieved by introducing more flexible programable stimulators based upon microprocessor technology. Such stimulators could in principle collect more information about the controlled system, and therefore better adapt to the changing conditions of gait. In this way better timing and gradation of the stimulation sequences would be possible. For this purpose a microprocessor controlled 6-channel stimulator (Fig.9)

Fig.9

has been developed. It can memorize several different stimulation sequences and select them at will. Better prediction of the next step duration, based on the past history of gait, has been implemented in this stimulator. Also, it provides the possibility for statistical analyses of some important gait parameters. It was found in our study that the level of rehabilitation achieved at the end of therapy could be retained only by highly motivated and active patients. When the factors that can promote physical activities (motivation, psychophysical condition, social environment, etc.) are not present, some kind of orthosis will be necessary. The present method of surface multichannel stimulation is appropriate only for clinical use. A lot of shortcomings connected with surface stimulation could be avoided by the application of implant technology, but the later entails new problems, which cannot yet be solved. These include miniaturisation, the source of energy, better control and, probably the greatest problem, our present inadequate knowledge of natural control. We believe that significant improvements can be achieved only by a closed-loop adaptive control, which should take into account the residual volitional control. Therefore, better understanding of the neurophysiology of gait and the development of new methods of obtaining more information about the system controlled are necessary.

ACKNOWLEDGEMENT

This investigation was supported in part by the Slovene Research Council, Ljubljana, Yugoslavia, and by Research Grant 23-P-59231/F from the National Institute of Handicapped Research, Department of Education, Washington, D.C., U.S.A.

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RESOLUTION OF A THREE-DIMENSIONAL GRAF/PEN

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ABSTRACT

A three-dimensional Graf/Pen[1] has been in use at the Tufts Biomedical Engineering Center to track the motion of body segments. This paper summarizes our approach to determining the resolution of the system. The calibration of each microphone was checked extensively over its length, and the results were used to synthesize the three-dimensional resolution of an array of microphones mounted in a plane

INTRODUCTION

The Graf/Pen operates on the principle that the velocity of sound in air is constant under constant ambient conditions. In operation, hypersonic impulses (sparks) are generated at a point as it moves through space. The time it takes to reach a microphone sensor is then proportional to its distance from the microphone. A three-dimensional Graf/Pen utilizes three linear microphone sensors to determine the X, Y, Z coordinates of the sparker.

MICROPHONE CALIBRATION

Before the microphones were permanently mounted, the calibration was checked for each one separately. The sparker was positioned in increments of 3 inches over a range of 6 feet along a line perpendicular to the axis of the microphone. This was repeated for each microphone along lines which were located at mid length, 1/4, 1/8, and 1/16 of the length of the microphone, and also at a distance of 1 inch from the end of the microphone.

The measurement of the time it takes for the impulse to be "heard" by the microphone is obtained by starting a counter at the time the spark is initiated and stopping it when it is "heard" by the microphone. Thus the output of the Graf/Pen is a pulse count which is related to distance.

[1]Manufactured by Science Accessories Corporation (SAC), West Southport, Connecticut.

At each sparker location, 100 sparks were generated and the average and standard deviation of the counts was automatically computed and recorded with a PDP-11 computer. The results of these extensive tests show that the relationship of average pulse counts to distance is quite linear over the range investigated with a slope of about 121 counts per inch. The resolution of each microphone, which is defined by SAC as the smallest distance which will result in the change of one count, is d = 0.0083 inch. The repeatability of the measurement was also quite good over most of the range, having a standard deviation of less than 1 count. Every microphone, however, had considerably poorer resolution in the range of about 30 to 39 inches where the standard deviation was approximately 10 counts (.083 inch). Each microphone was also found to have an offset distance such that the relation between distance and counts is given by,

$$R = K + d(\text{counts}) \qquad (1)$$

where R is the distance from the axis of the microphone, inch
K is the offset (approximately 1 1/2 inch)
d is the resolution (approximately 0.0083 inch/count)

It was also observed that the range of the microphone becomes more limited near its ends. At 5 inches from the end, the range is about 52 inches, whereas at one inch it is only about 18 inches.

GEOMETRY

Consider the arrangement of the three linear microphone sensors shown in Figure 1. If a spark is initiated at a point X_1, Y_1, Z_1, then each microphone will register a count from which 3 perpendicular distances R_1, R_2, R_3 can be calculated. The coordinates Y_1, Z_1 can then be found by noting that in the YZ plane, R_1 and R_2 are the radii of two intersecting circles whose centers are a distance D apart.

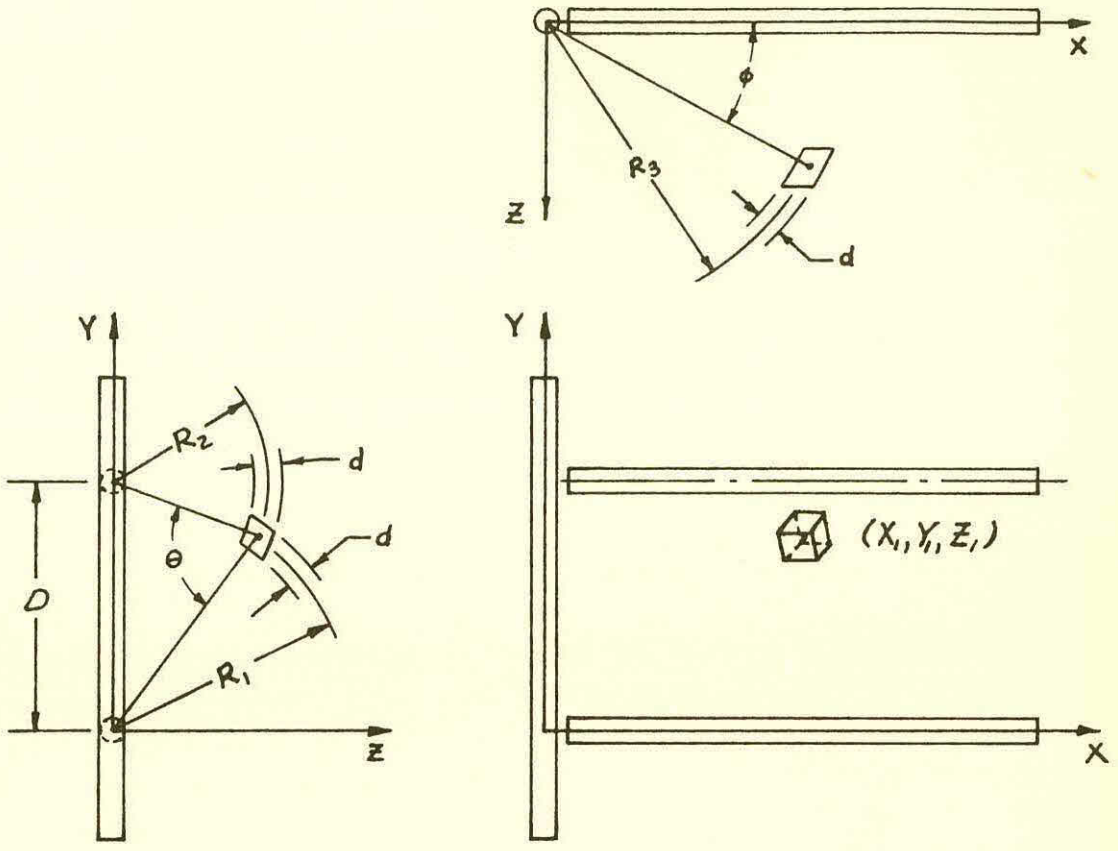

Figure 1 System Geometry

Then

$$Y_1 = \frac{R_1^2 - R_2^2}{2D} + \frac{D}{2} \quad (2)$$

$$Z_1 = (R_1^2 - Y_1^2)^{1/2} \quad (3)$$

Coordinate X_1 can then be found from the right triangle in the XZ plane.

$$X_1 = (R_3^2 - Z_1^2)^{1/2} \quad (4)$$

Since the linear microphones have a resolution, d, however, the sparker could actually be located anywhere within a three-dimensional volume as shown in Figure 1. We will now determine the size and shape of this volume of uncertainty.

First of all, let us consider the area of uncertainty in the YZ plane. Note that for small d, the arc lengths can be approximated as straight lines and the area as a rhombus. The resolutions in the radial and tangential directions are then defined to be,

$$d_r = \frac{d}{\text{Cos}\,\Theta/2} \quad (5)$$

$$d_t = \frac{d}{\text{Sin}\,\Theta/2} \quad (6)$$

where Θ is the angle between R_1 and R_2

By geometry it can be shown that the locus of points for which Θ is a constant is a circle with center located at,

$$Y_C = D/2 \quad (7)$$

$$Z_C = \frac{D}{2\tan\Theta} \quad (8)$$

and a maximum range

$$Z_m = \frac{D(1 + \cos\Theta)}{2\sin\Theta} \quad (9)$$

Along the circumference of such a circle, the radial and tangential resolutions remain constant as listed in Table 1 and shown in Figure 2. Note that the tangential resolution becomes large as Θ approaches zero, and that the radial resolution becomes large as Θ approaches 180°.

The resolution in the YZ plane will be bounded in the X direction by d and by d_r or d_t whichever is larger.

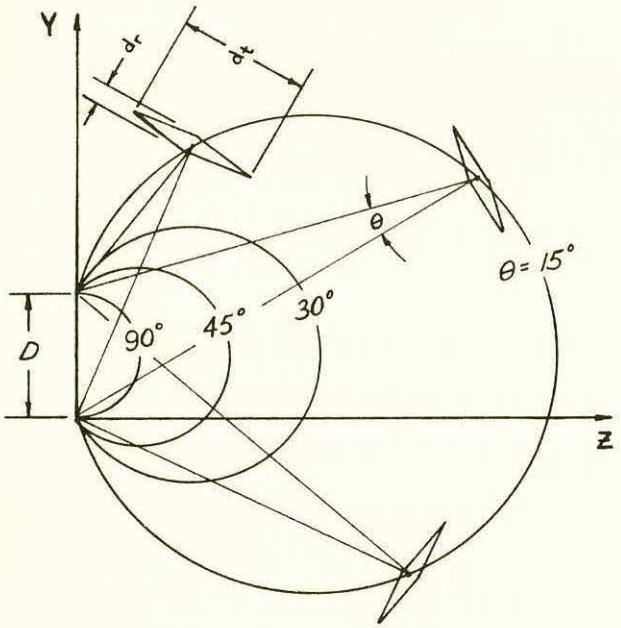

Figure 2 Loci of Constant Resolution

	Z_C	Z_m	d_r	d_t
0	∞	∞	d	∞
15	1.866 D	3.798 D	1.009 d	7.661 d
30	0.866 D	1.866 D	1.035 d	3.864 d
45	0.500 D	1.207 D	1.082 d	2.613 d
60	0.289 D	0.866 D	1.155 d	2.000 d
90	0	0.500 D	1.414 d	1.414 d
120	-0.289 D	0.289 D	2d	1.155 d
180	- ∞	∞	∞	d

Table 1. Radial and Tangential Resolution

$$d_X = \frac{d_m \sin\phi + d}{\cos\phi} \qquad (10)$$

where d_m is the larger of d_r or d_t, and

ϕ is the angle which R_3 makes with the XY plane

Note that when $\theta = 90^\circ$, and $\phi = 0^\circ$, the volume of uncertainty is a cube with edge equal to d. At all other points, the volume is larger.

CONCLUSION

Our analysis indicates that the resolution of a three-dimensional Graf/Pen system varies throughout its spatial range. An understanding of the effects of microphone placement on system resolution, however, allows the experimenter to design the microphone array to obtain an optimum level of resolution in the volume of interest.

ACKNOWLEDGEMENT

Work supported by Grant #16-P-57856/1-05 from National Institute on Handicapped Research of United States Department of Education.

COMPUTER ASSISTED ISOKINETIC DYNAMOMETRY
A CALIBRATION STUDY

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ABSTRACT

A calibration study was performed on the torque measurement channel of a Cybex II isokinetic dynamometer. A total of 2880 trials spanning different days, test speeds and directions were digitized on-line. Correlation, regression and analysis of variance applied to the data determine the dynamometer to be highly linear and reliable to within $\pm$ 4.4 Nm in the range of 0 to 75 Nm if calibration and testing are performed on the same day at the same preset speed. The direction of calibration does not effect test results at the = .05 level. It is shown that a significant unpredictable error is incurred by testing at a different speed or on a different day from that of the calibration.

INTRODUCTION

The Cybex II isokinetic dynamometer (Lumex Inc.) is a device that tranduces the instantaneous moment of force (torque) acting on an electrogoniometric arm. This arm is permitted to rotate in either direction in one plane up to a preset angular velocity. Two channels of output are produced: the instantaneous moment of force and the relative angular displacement of the electrogoniometric arm. Moffroid and Whipple (1) have described protocols for suitable attachment of the Cybex II to various limb segments of human subjects. Moffroid et al (2) performed a study in which specific weights were applied to the lever arm at known distances to produce criterion moments of force. The known mechanical inputs were correlated to the strip chart pen displacements as indices of reliability and validity. Correlation statistics of .995 and .999 were generated for reliability and validity of torque measures, respectively. It was concluded that the Cybex II is an optimal device for monitoring the net moment of force across human joints.

Many papers have been published in the last decade in which Cybex II strip chart data has been used to monitor dynamic and static strength (i.e. peak torque). Results have been analysed qualitatively and quantitatively. Few of the published papers mention calibration procedures (3) and there are no publications to date that deal directly with proper selection of Cybex II calibration protocols.

From an information processing point of view, it is absolutely essential to establish the physical characteristics of the proposed system so that information flowing through it can be reliably and validly detected, and statistically analysed and described. A calibration protocol must then be established to preserve the system specifications for subsequent usage of the machine. Inconsistent calibration between tests can destroy the reliability of test results and unsuitable calibration protocols can render tests results totally invalid.

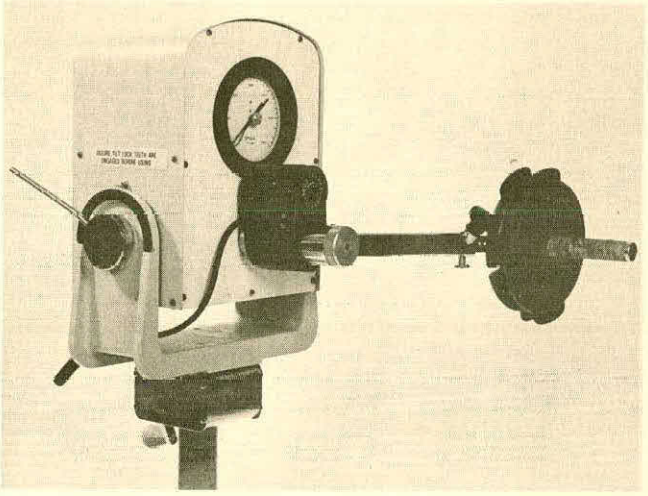

Figure I: Cybex II Isokinetic Dynamometer

Isokinetic dynamometers have the potential to directly measure functional mechanical capabilities (i.e.work, power and energy parameters) of human limb segments (4). The subjective component of clinical assessment will thus be reduced to an optimal form: the reaction of the seasoned practitioner to an objective, quantified, high precision data base. The clinical practitioner will be able to provide far better or at least more efficient patient rehabilitation with precise knowledge of the level of patient function, and small changes or lack of change in this level as a result of treatment.

Isokinetic dynamometers can be used additionally to assess the value of specific treatments, modalities and alternate testing devices and protocols.

In rehabilitation research laboratories it is reasonable to assume that isokinetic dynamometer outputs will not be interpreted from strip charts

but digitized with 8 to 12 bit full scale precision. The results will be used to contribute in some way to life and limb oriented decisions. For such applications it is necessary to re-evaluate the characteristics of the Cybex II utilizing maximum digitizing precision and to analyse and describe these characterics statistically rather than by simple correlation.

The purpose of this study is to analyse and describe the response (i.e.digitized voltage output) of the Cybex II torque transduction system to known mechanical inputs for all possible modes of operation and to specify a precise protocol for calibration.

METHODS

A trial consisted of permitting the lever arm to rotate through a range under each criterion load in the test direction at the preset speed (see Fig.I). When the loaded dynamometer arm passed through the horizontal plane the computer detected and recorded the instantaneous torque channel voltage output. Ten repetitions were performed for each of eight criterion weights at nine different angular velocities. The weights were selected to provide known moments of force that ranged from 6 to 75 Nm. The nine criterion isokinetic speeds consisted of 0, 15, 30, 45, 60, 75, 90, 105 and 120 deg/sec. The speed was determined by differentiation of the lever arm displacement signal and was preset within 1% of the criterion values. The entire procedure was repeated both in the clockwise and counterclockwise rotational directions and on two separate days. The total number of trials was 2880.

The unconditioned analog voltage outputs from the dynamometer were low pass filtered (f_c = 30H_z), time multiplexed at 83 samples per second and digitized with a 12 bit A/D convertor (see Fig.II). Data acquisition was accomplished with the aid of a small desk top computer.

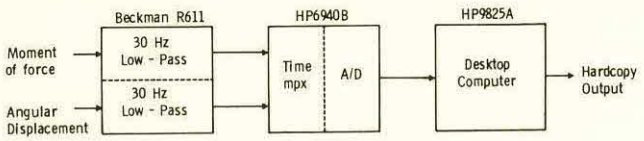

Figure II: Information processing schematic

The statistical analysis was performed on a macrocomputer system utilizing the 1979 S.A.S. software package. Pearson correlation co-efficients were generated within and between speeds. Regression curves were fitted to the data with the eight weights representing the independent variables and the digitized voltage output readings corresponding to the dependent variable (see Fig.III). Three hundred and sixty curves were fitted this way corresponding to the number of trials over 2 days, 2 directions, 9 speeds, and 10 repetitions per speed plotted against the eight separate weights. Two analyses of variance were performed on the slopes of the regression speeds, days and directions as separate factors.

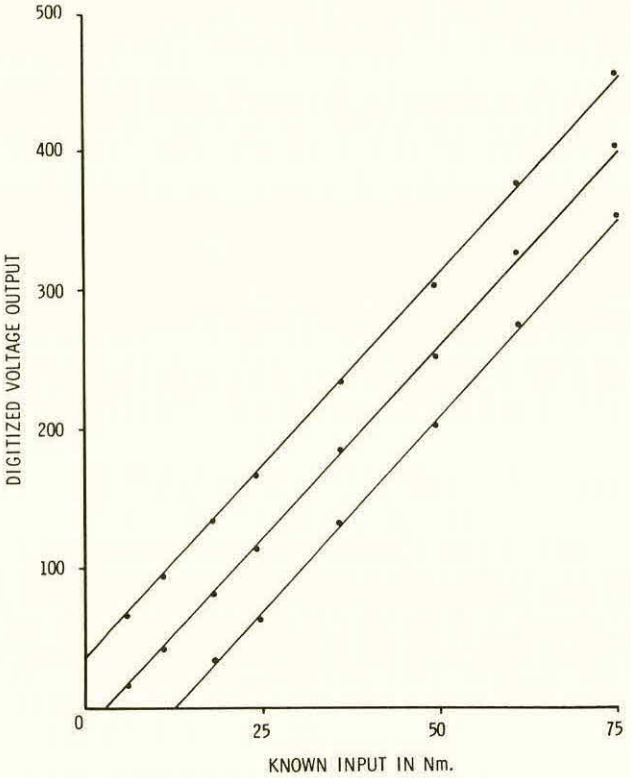

Figure III: Sample regression curve

RESULTS

The digitized voltage output was correlated to the known torque input within speeds. The 9 Pearson correlation coefficients ranged from .994 to .999. The digitized voltage output was also correlated between speeds. These 36 Pearson correlation coefficients ranged .990 to .999.

Table I shows the slopes and standard deviation of the regression curves generated for the 36 test modes (9 speeds, 2 directions, 2 days). The mean standard deviation for the regression curves in Table I is 4.4 Nm.

Table II demonstrates the results of an ANOVA performed on the slopes of all 360 regression curves. Table III presents the results of an ANOVA performed on the slopes of the 320 regression curves generated from dynamic calibration (i.e. all static test mode data was removed). The ANOVA structure of Tables II and III are otherwise identical. The results of Table II and III indicate no significant differences in regression curve slopes due to direction but significant differences due to speed, day and interactions (α = .05).

DISCUSSION

The 9 Pearson correlation coefficients generated within speeds demonstrate a high linear relationship between the torque input and the voltage output for the test range (0 to 75Nm). These correlation coefficients can be thought of as an index of validity within test speeds. The 36 Pearson coefficients correlating voltage outputs between speeds can be thought of as an index of reliability between speeds.

TABLE I

Speed (deg/sec)	Day	Dir	Slope (V/Nm)	SD (V)	SD (Nm)
0	1	1	5.38	11.74	2.2
	1	2	5.53	14.80	2.7
	2	1	3.32	14.03	4.2
	2	2	5.37	15.51	2.9
15	1	1	5.46	28.43	5.2
	1	2	6.60	17.84	2.7
	2	1	5.25	41.55	7.9
	2	2	5.63	17.21	3.1
30	1	1	5.91	33.85	5.7
	1	2	6.04	26.22	4.3
	2	1	5.09	23.87	4.7
	2	2	5.70	19.77	3.5
45	1	1	6.56	21.13	3.2
	1	2	5.71	23.79	4.2
	2	1	5.24	20.94	4.0
	2	2	6.02	22.46	3.7
60	1	1	6.54	19.13	2.9
	1	2	5.94	25.40	4.3
	2	1	6.08	23.08	3.8
	2	2	5.97	20.80	3.5
75	1	1	6.79	28.63	4.2
	1	2	6.22	29.48	4.7
	2	1	6.66	27.52	4.1
	2	2	5.74	30.72	5.4
90	1	1	6.14	37.81	6.2
	1	2	6.27	24.87	4.0
	2	1	6.24	31.49	5.0
	2	2	5.94	30.82	5.2
105	1	1	7.01	50.02	7.1
	1	2	6.10	28.92	4.7
	2	1	6.09	31.77	5.2
	2	2	6.33	33.60	5.3
120	1	1	6.37	35.17	5.5
	1	2	6.02	36.85	6.1
	2	1	6.34	28.85	4.6
	2	2	6.32	25.29	4.0

TABLE II

ANOVA for Slopes based on all test modes

Source	DF	SS	MS	F
Speed	8	2186.819	273.352	38.35
Day	1	458.008	458.008	64.26
Dir	1	7.986	7.986	1.12
Speed*Day	8	315.187	39.398	5.53
Speed*Dir	8	859.765	107.471	15.08
Day*Dir	1	170.906	170.906	23.98
Speed*Day*Dir	8	537.846	67.231	9.43
Error	324	2309.127	7.127	
Total	359	6845.645		

TABLE III

ANOVA for Slopes on dynamic mode trials only:

Source	DF	SS	MS	F
Speed	7	652.981	93.283	11.70
Day	1	247.627	247.627	31.06
Dir	1	15.210	15.210	1.91
Speed*Day	7	138.394	19.771	2.48
Speed*Dir	7	472.407	67.487	8.47
Day*Dir	1	63.060	63.060	7.91
Speed*Day*Dir	7	363.023	51.860	6.50
Error	288	2296.052	7.972	
Total	319	4248.754		

While correlation is a useful statistic for determining predictability and linearity it is a poor predictor of reliability within speeds. A statistical description of the data is presented in Table I. The standard deviation of the regression lines provides a useful quantification of the reliability of torque measures. It can be concluded from Table I that any data collected at a test speed identical to the calibration speed will have an error component with a mean S.D. of 4.4 Nm. This means that for most applications it will be reasonable to assume that any test result will be accurate to within $\pm$ 4.4 Nm.

The slope of each regression curve (see Table I) represents the calibration factor for that test mode. The results show that the calibration factor changes significantly from speed to speed and day to day. Table III verifies that this is not an artifact due to the difference between static and dynamic calibration.

The differences in slope indicate that the error expected by calibrating in one mode and testing in another will vary not only with the discrepancy in slopes, but also with the magnitude of the signal. Therefore the error induced by testing in a different mode from the calibration mode varies not only from day to day and speed to speed but also from trial to trial. This means that a general estimate of the additional error incurred by testing at different speeds or on different days from that of calibration cannot be made.

The only test mode change that does not require a recalibration is a rotational direction change.

It can be concluded from the results of this study that it is necessary to calibrate the Cybex II isokinetic dynamometer every testing day and at every test speed. It is not necessary to calibrate in both directions. If the above protocol is followed in conjunction with the standard calibration and testing techniques (provided by the manufacturer) the reliability and validity of test results obtained will be preserved to within $\pm$ 4.4 Nm for a linear range up to at least 75 Nm. The authors are confident that further testing will show the linear range of this dynamometer to extend far beyond 75 Nm.

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A GENERALIZED APPROACH TO FORMULATE MECHANICAL ANALOGS OF JOINT-MOTION

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ABSTRACT

This paper presents a generalized method to formulate the mechanical analogs of joint-motion based upon the concept of ruled surface approximation of continuous space motion. The true axode of motion is approximated by an appropriate second degree surface of revolution. Synthesis procedures are presented to arrive at the kinematic parameters defining the generator and the axis of the surface of revolution. The method is demonstrated by formulating mechanical analogs of vertebral motion. Such mechanical analogs are useful in formulating motion simulation models of any one or more joints of the musculoskeletal system.

INTRODUCTION

The joints in the human musculoskeletal system are characterized by two or more articulating surfaces moving relative to each other and kept in positive contact due to elastic restraints of the connective tissue. The components of motion permitted at a given joint and the coupling relationships between these motion components are functions of the applied loads, the elastic properties and configuration of the connective tissues, and the surface contours (geometric properties) of the articulating surfaces. Because of the complex nature of these contacting surfaces it is sometimes difficult to understand their exact role in governing the kinematics of joint-motion. This difficulty can however be surmounted by studying the mechanical analogs that are capable of reproducing the joint motion over a finite range of motion. This indirect approach to study the kinematics of joint motion using its equivalent mechanical analog has been employed in the past in the formulation of motion-simulation models of individual joints (1 - 3).

This paper presents a generalized method to formulate the mechanical analogs of joint-motion based upon the concept of ruled surface approximation of continuous space motion. The method is demonstrated by formulating the mechanical analog of an intervertebral joint.

RATIONALE

The continuous space motion of a body can be characterized by a set of instantaneous screw axes (ISA) of motion. These axes are defined by lines and associated pitch values. The locus of the ISA due to relative motion of a joint over a finite range is a mathematical ruled surface and is called the axode of motion. There is a one-to-one correspondence between a given pattern of joint-motion and its corresponding axode of motion. Hence, the properties of joint-motion can be studied indirectly by studying the properties of the ruled surface (axode).

A second degree ruled surface may be selected to approximate the axode surface due to continuous space motion at a joint. The choice of a second degree surface will allow one to study the acceleration properties of joint-motion. The most general form of a second degree ruled surface is the hyperboloid of one sheet which is generated by rotating a hyperbola about the perpendicular bisector of the line joining the foci as shown in Fig. 1. This ruled surface is uniquely defined by three skew lines not parallel to the same plane.

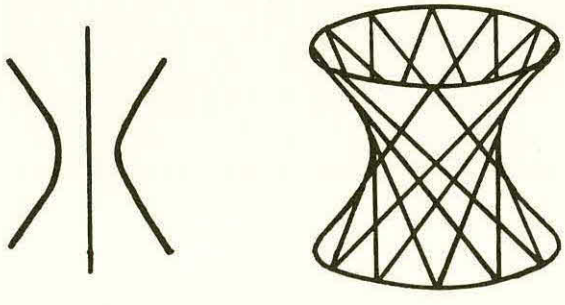

Fig. 1. Hyperboloid of one sheet.

The second degree ruled surfaces are also called the surfaces of revolution since they can be generated by rotating a line (generator) about another line (axis). Depending upon whether the generator and the axis intersect at a point, or are skew with respect to each other, the resultant ruled surface is a cone (circular or noncircular), or a hyperboloid of revolution respectively. If the generator of the surface of

revolution is taken to be the instantaneous screw axis of motion, then the approximation of the true axode of motion by a cone would allow one to study only the rotational components of motion at a joint. On the other hand, the axode approximation by a hyperboloid of one sheet would allow for the rotational as well as the translational components of motion at the joint.

The method of formulating the mechanical analogs of joint motion is based upon the concept of approximating the true axode of motion by an appropriate second degree surface of revolution. In the following, synthesis procedures are presented to arrive at the kinematic parameters defining the generator and the axis of the surfaces of revolutions. These procedures require a set of instantaneous screw axis of motion describing a joint-motion pattern for which an equivalent mechanical analog is to be synthesized. The formulation of mechanical analogs is divided into two categories.

Spherical Motion

The rotational components of motion of a joint may be reproduced by a spherical kinematic pair e.g. ball and socket joint. Let $(\ell_i, m_i, n_i, \alpha_i, \beta_i, \gamma_i)$ be a set of screw axes $S_i, i = 1,3$; corresponding to a mode of joint motion. The coordinates of the apex C (x_o, y_o, z_o) of the cone approximating this set of screw axes are obtained by minimizing the sum (E) of the squares of the shortest distances from the apex C to the screw axes. The sum E is given by:

$$E = \sum_{1}^{n} (\alpha_i + \ell_i r_i - x_0)^2 + (\beta i + m_i r_i - y_0)^2 + (\gamma_i + n_i r_i - z_0)^2$$

where,

$$r = \ell_i (x_0 - \alpha_i) + m_i (y_0 - \beta_i) + n_i (z_0 - \gamma_i)$$

Hence, the sum E is a function of the coordinates (x_o, y_o, z_o) of the apex C.

The minimization of the squared error E will yield

The coordinates (x_o, y_o, z_o) of the apex C are obtained by solving the above three linear equations (1) simultaneously. This method is applied to the experimental data on vertebral motion presented in table 1.

Using this methodology the coordinates of the apex of the cone are obtained as:

$$x_o = -0.685645,\ y_o = 1.816414,\ z_o = 2.692477$$

The shortest distances from the apex to the three screw axes are:

$d_1 = 0.084070$, $d_2 = 0.094435$, $d_3 = 0.109887$, least squared error = 0.028061

General Space Motion

When both the rotational and the translational components of joint motion are significant, it is observed that the least squared error (E) is significant implying that the approximation of joint motion by a spherical joint is inadequate. This leads to the second type of mechanical analog which corresponds to the hyperboloid of one sheet generated by revolution of a generator about a skew axis. This yields the modular analog (R-C) shown schematically in Fig. 2.

The axis of revolution $(\ell_o, m_o, n_o, x_o, y_o, z_o,)$ corresponding to a set of three screw axes $(\ell_i, m_i, n_i, \alpha_i, \beta_i, \gamma_i, i=1,3)$ is synthesized using the following methodology:

1. The direction cosines (ℓ_o, m_o, n_o) of the axis of revolution are obtained using the following three equations:

$$\ell_o (\ell_1 - \ell_2) + m_o (m_1 - m_2) + n_o (n_1 - n_2) = 0$$

$$\ell_o (\ell_1 - \ell_3) + m_o (m_1 - m_3) + n_o (n_1 - n_3) = 0$$

$$\ell_o^2 + m_o^2 + n_o^2 = 1$$

2. A plane ¶ perpendicular to the axis (ℓ_o, m_o, n_o) is defined so that it contains the origin of the reference system XYZ. The coordinates $(x_i, y_i, z_i, i=1,3)$ of the points of intersections of the three screw axes with ¶ are obtained by solving the following three linear equations simultaneously:

$$\ell_o x_i + m_o y_i + n_o z_i = 0$$

$$(x_i - \alpha_i)/\ell_i = (y_i - \beta_i)/m_i = (z_i - \gamma_i)/n_i$$

3. The coordinates (x_o, y_o, z_o) of the point of intersection of the axis of revolution with ¶ are

TABLE 1 Data for Formulation of Mechanical Analogs

0.477333	-0.6779525	-0.5671032	-0.1825692	0.9851212	1.9507478
0.4304682	-0.6984427	-0.5717298	-0.0830322	0.9929570	1.9243803
0.3758692	-0.7384927	-0.5597750	-0.2616016	0.9472326	2.1703959

obtained by satisfying the following three constraints:

$$(x_2-x_o)^2 + (y_2-y_o)^2 + (z_2-z_o)^2 = (x_1-x_o)^2 + (y_1-y_o)^2 + (z_1-z_o)^2$$

$$(x_3-x_o)^2 + (y_3-y_o)^2 + (z_3-z_o)^2 = (x_1-x_o)^2 + (y_1-y_o)^2 + (z_1-z_o)^2$$

$$\ell_o x_o + m_o y_o + n_o z_o = 0$$

These constraints will yield three simultaneous linear equations in x_o, y_o, z_o. The above methodology when applied to the set of screw axes specified in Table 1 yields the axis of revolution of the second degree ruled surface approximating the vertebral motion:

$\ell_o = -0.477429$, $m_o = 0.774652$, $n_o = 0.414699$

$x_o = 0.814346$, $y_o = -0.262446$, $z_o = 1.427775$

It should be noted that the apex of the cone approximating the same set of screw axes of motion may not, in general, lie on the axis of revolution obtained above.

DISCUSSION

The choice of a second degree ruled surface leads to a piecewise approximation of the continuous space motion. The total domain consisting of a set of screw axes corresponding to a given mode of joint motion is divided into a series of subsets each consisting of three successive screw axes. In order to maintain continuity at the boundaries of two consecutive subsets, the screw axis at the boundary is included in both the subsets simultaneously. Each subset consisting of three screw axes yields its characteristic primary ruled surface which is defined by its axis of revolution. Hence, three consecutive primary ruled surfaces will generate a secondary ruled surface. Thus, depending upon the number of discretized positions, the total domain corresponding to a given mode of joint motion can be characterized by the parameters of the primary, the secondary, and the tertiary ruled surfaces and their mechanical analogs. This concept is illustrated in Table 2 using the example of an intervertebral joint.

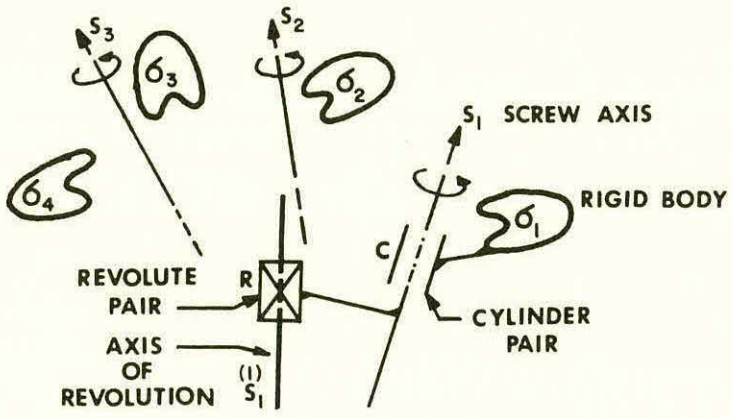

Fig. 2 A modular analog of general space motion

TABLE 2 Primary, Secondary, and Tertiary Ruled Surfaces

Vertebral Positions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Screw axes	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	
Primary		(1)		(1)		(1)		(1)		(1)		(1)		(1)		
Axis of Rev.		S_1		S_2		S_3		S_4		S_5		S_6		S_7		
Mechanical Analog		R-C		R-C		R-C		R-C		R-C		R-C		R-C		
Secondary Axis of Rev. Mechanical Analog				(2) S_1 R-R-C				(2) S_2 R-R-C				(2) S_3 R-R-C				
Tertiary Axis of Rev. Mechanical Analog								(3) S_1 R-R-R-C								

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SHOE LAST REPLICATION BY MOIRE CONTOUROGRAPHY

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ABSTRACT

A shape processing system has been developed to deal with the problem of shape storage and retrieval. In a preliminary run, replicated shoe lasts were identical to their originals within 0.045±.006 inches from a longitudinal axis. The sensing technique used could not obtain information at the ends of the last.

OBJECTIVES

Currently, the United States Veteran's Administration has in its possession approximately 15,000 shoe lasts. These foot shapes are stored in a warehouse in downtown New York. The aim of this project was to develop a means by which these shoe last shapes could be a) stored in a computer and b) retrieved by means of carving the stored data. The USVA specified that the process should be able to replicate a shoe last to within 0.05 inches of the longitudinal axis.

In order to meet these requirements it was necessary to develop a shape sensing system which could be interfaced with a machine capable of replicating the desired shape. The entire replication process involves three main steps: a) sensing the shape to obtain three-dimensional information, b) storing and organizing that data so that the shape can be carved and c) machining the properly organized data.

RESULTS

Sensing The Shape

A camera was built which enabled a moving film to be synchronized with the rotation of a turntable (see section on Method). The camera was then mounted in an apparatus which used a technique of Moire contourography (1) to obtain contour information on the shape. The ability of the sensing equipment to define different elevations exceeded the necessary requirements.

The shape information was recorded on a strip of photographic film, as shown in Figure 1. The result looks very similar to a geographical contour map. Experimentation resulted in a photograph with both high contrast and high accuracy.

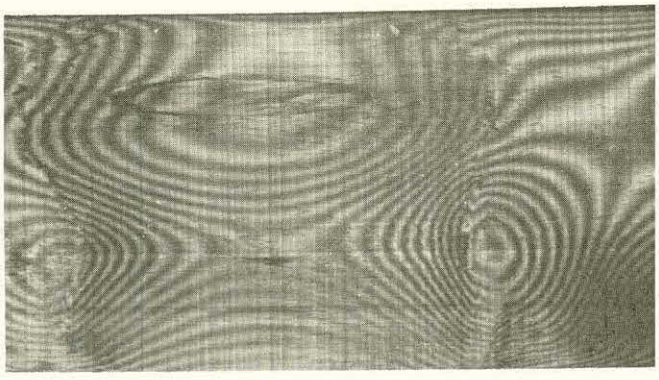


Fig.1 Partial contourograph of SACH foot.

Storing And Organizing Data

In order to put the Moire information from the photograph into the computer a manual digitization process was implemented. A link was estabished between a digitizing table and a PDP 11/34 computer (Mechanical Engineering, U.B.C.). This allowed digitized data to be stored on a disk in the PDP computer. The shape was then accessible through software.

A programming package was developed which enabled an operator to interactively specify parameters related to the photograph, to the machining process, or to a plotting routine. Film parameters included length and width and center of perspective; machining values involved feed rates, tool diameter, etc. This information was then used to organize the shape in the form of a spiral. Prior to actually carving the shape, the resultant spiral path could be plotted on a viewing screen.

Machining The Spiral

In order to send the spiral path data to be carved, a hardware link was established between the PDP 11/34 and a numerically controlled (NC) machine.

The NC machine was configured as shown in Figure 2. A machining process was developed which ensured that the cutting tool did not interfere with the surface of the shape.

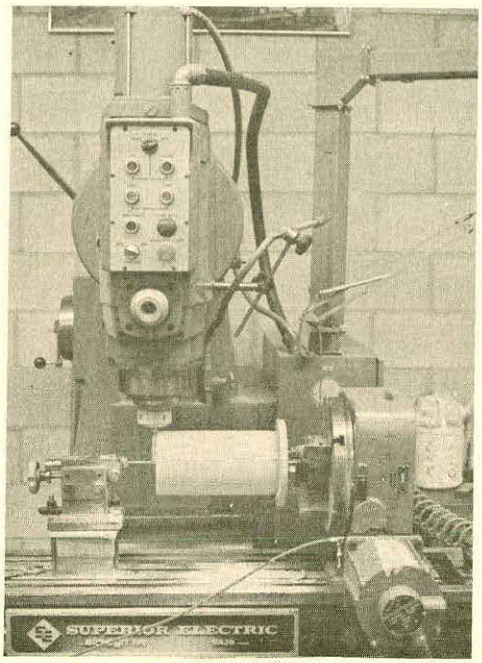


Fig.2 Configuration of NC machine with blank mounted.

A total of 13 shapes were replicated. The best surfaces were those that were in the middle of the foot and those that did not exhibit sharp curvature. The difficulty in regions which slope away quickly is that the Moire fringe lines crowd together and cannot be discerned by eye.

Once our skills and the alignment of the sensing apparatus were improved, the desired 0.05 inch tolerance specification was obtained. With our current level of expertise an accuracy of 0.025 inches from the longitudinal axis is possible.

EXAMPLES

Standard Shape

In order to assess the capabilities of the process, a standard shape in the form of a rectangular block was sensed and replicated. Since both the sensing and the replication are best suited to cylindrical type shapes, the block represented a severe test of the system.

108 measurements were made on both the original and the copy. The resultant absolute off-axis error was 0.045±.006 inches. The measurements at the upper end of the block were less accurate than those at the lower end. This has been attributed to a 0.5 degree deviation from vertical of the rotational axis of the sensing apparatus.

Representative Shape

The next step was to replicate a shoe last shape. A typical shape and its replica are shown in Figure 3. It can be seen that data is lost at both the heel and the toes. The surface texture appears as pits and ridges, however this can be improved by passing a tool of larger diameter over the surface or simply hand-sanding the ridges off.

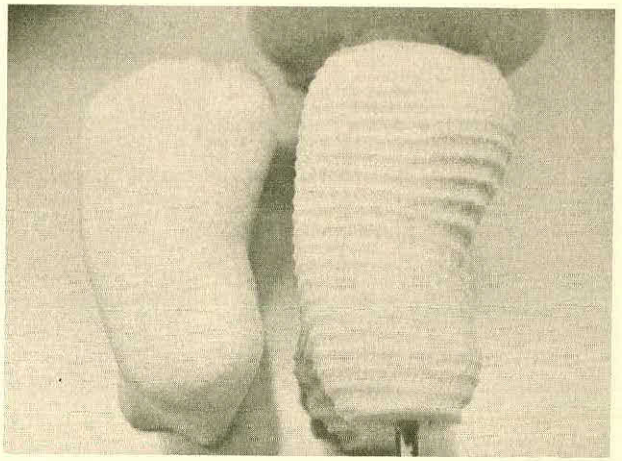


Fig. 3 Typical last shape and its replica.

METHOD

Peri-contourography (1,2) is a technique which provides a single continuous photograph of the entire surface of the sensed object.

The shoe last to be sensed is mounted on its longitudinal axis and is rotated about that axis. A conventional grid and linear light source are used to produce the Moire patterns on the last. As the last rotates, the patterns change since they follow the varying surface contours. To record this information on film, a camera which has an adjustable slit in its focal plane, moves the film past the slit. By adjusting the slit width (of the order 0.2-0.7 millimeters), a very narrow strip of the object is exposed. The film is translated as the object is rotated; a subsequent strip of the shape is recorded on the next strip of film, and so on, until the last has completed one full rotation.

In practice, both the film and the last move in a continuous fashion rather than in discrete steps. The effect is one of 'unwrapping' the topography of the shoe last; an analogy is the method of developing a globe as a planar world map.

In order to digitize the photograph the fringes have to be identified beforehand. With the last mounted in the sensing apparatus, the distance between a reference mark on the last and the grid screen is measured while the last was in the sensing apparatus. A simple calculation gives the fringe number at that reference mark. If the surface recedes from the reference mark then the fringe numbers increase, and if the surface raises above the reference mark then the fringe numbers decrease.

DISCUSSION

It is now possible to store the three-dimensional data of a shoe last in approximately one ten-thousandth of the physical volume of the last itself. This data can be retrieved at any time and with present technology the last can be replicated in 5 to 10 minutes.

Shapes which do not have severe curvatures or discontinuities are well suited to the described technique. An example would be the shapes required to restore prostheses cosmetically, ie. the ends are not significant.

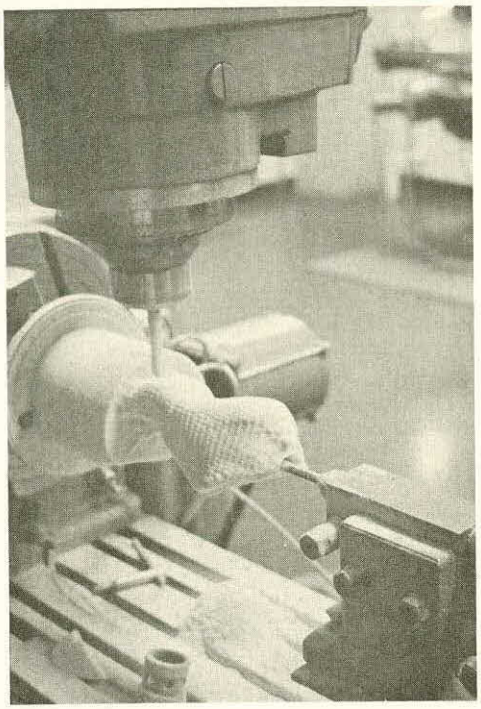
The element of the process which is the most painstaking is the manual digitizing. Typically, 1500 points were needed per shape at a cost of between 1.5 and 2 hours of digitizing time. Obtaining satisfactory results also required a high level of expertise from the operator.

This shape storage and retrieval system is appropriate for dealing with inanimate objects. There are two basic requirements to make the process clinically viable: a sensing apparatus which is capable of going around the patient and an automated digitizing system. Such improvements would allow a technician to carry out the entire operation.

From our experience to date, it is clear that the shape processing system we have developed represents the skeleton of a "dedicated" shape processing plant.

ACKNOWLEDGEMENT

The authors wish to thank the Medical Research Council, the Workmen's Compensation Board, and the United States Veteran's Administration for their financial support ranging from 1972 to the present. Supporting personnel included Mr. A. Steeves, Mr. J. Hoar, Mr. D. Camp and Mr. F. Knowles.



The final step of the process - machining the last.

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A TRACTION PLINTH FOR CONTINUOUS APPLICATION IN THORACO-LUMBAR FRACTURES

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ABSTRACT:

A portable traction plinth with adjustable torsion spring tension was designed and tested to apply halofemoral traction in thoraco-lumbar spinal fractures. Using a capstan design on each end of a board, the instrument can maintain adjustable distraction force across the fractured spine during patient transport, in-bed and through radiologic examination until the time of surgery.

INTRODUCTION:

The treatment of thoraco-lumbar fractures with skeletal traction is an accepted procedure. One of the successful methods is to use halo-femoral traction to achieve closed reduction and to stabilize the injured spine (1). Halofemoral traction is particularly useful in treating acute and subacute fractures during the early investigative state of the disease.

Commonly the distraction force in halofemoral traction is generated by hanging weights acting under gravity through pulleys and ropes attached to the skeleton proximal and distal to the fracture site. The proximal force at the head is applied to the halo ring, attached to the skull while the distal force is applied to transverse femoral pins driven through the bones just above the knee.

The free swinging weights are usually external to the bed and suspended from pulleys attached to the bed frame. The bedside swing of the weights requires extra space and produces painful oscillating pressure changes on the traction pins set in the bones.

Thus the externally weighted traction is cumbersome for the staff and is most uncomfortable for the patient. More importantly the hanging weights interfere with patient transport and prevent access to radiographic diagnosis such as myelogram and the computerized axial tomogram.

The current work was initiated to design and test a new method of traction (plinth) which would maintain adjustable distraction forces on the fractured spine during patient transport, in-bed positioning and through radiologic examinations.

DESCRIPTION:

A wood transfer board (1" x 11" x 79" pine) was used for the structural base of the plinth. This board, covered with 4" thick "egg crate" foam served as the base for the tensioning devices on both ends and as the patient transfer stretcher. Two capstan type tensioning devices were built and each fastened to the ends of the board. A vertical revolving cylinder was used to wind in the

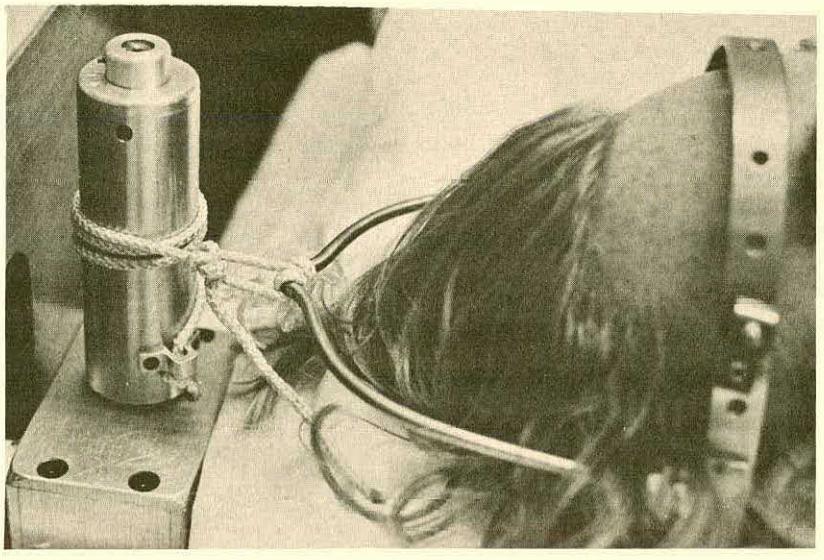

Figure 1. Halo component of the plinth near the head of the patient.

traction cable that was attached to the patient. Tension in the cable was adjusted by winding a coil spring that is driven by a 20:1 reduction worm gear. Up to 90 lbs. of traction could be developed through the reduction gear by one hand turning a small knob at the base of the cylinder.

The tension cord is tied to the halo (Figure 1) on the patient's head or to a crossbar. The crossbar delivers force to the femurs through traction bows and transverse pins. Vertical components of the traction force can be adjusted by elevation of the tension cord on the vertical capstan cylinder, to control the cervical spine or the femoral angulation (Figure 2).

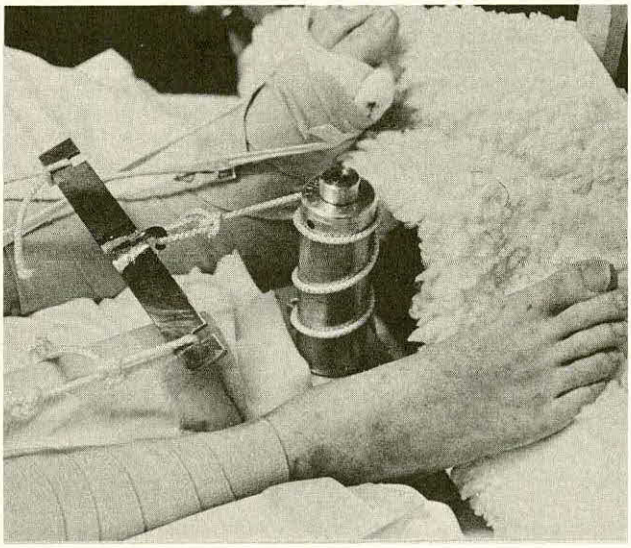

Figure 2

Crossbar and capstan at the femoral end of the plinth between the patients feet.

RESULTS:

The capstan design was used on a 28 years old paraplegic with incomplete fracture of the second lumbar vertebrae. The patient was transferred from the hanging weight traction, onto the plinth in his bed and transported to the radiology exams under 80 lbs. of traction, divided between the two femurs and 40 lbs. applied to the halo. The radiologic exams showed that the traction worked effectively and the tensions could be reduced to 70 and 35 lbs. at the legs and head respectively. The patient's reaction was very favorable, he reported immediately increased comfort and security with the traction plinth far above the previously used hanging weight traction. He remained on the plinth until surgery four days later.

CONCLUSIONS:

The self-contained portable traction plinth with adjustable torsion spring functioned well in the spinal injury unit and during radiologic examination. The plinth allowed the physician to treat spinal injury in traction continuously without interruption for radiologic examination. Furthermore, the plinth could be used for patient transport during CT scan for direct confirmation of effect of distraction in reducing and stabilizing the fractured spine.

ACKNOWLEDGEMENT:

This project was supported in part by National Institute for Handicapped Research Grant PGN-23-P-577995/3.

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DESIGN OF A SYSTEM FOR TRANSPORT OF SPINAL INJURY PATIENTS IN TRACTION

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ABSTRACT

An improved sectional backboard and cervical traction system has been developed incorporating radiolucent traction tongs, constant-tension-spring motive force and measures to minimize pressure sores. The system is compatible with inter- and intra-hospital transport, CT scanning and hyperbaric oxygen therapy of patients in traction. Laboratory and clinical tests of prototypes have been successfully completed.

INTRODUCTION

Cervical traction is a long-established mode of management of spinal trauma [1]. Commonly used traction apparatus may, however, conflict with simultaneous diagnosis and treatment methodology, such as computerized tomography (CT) [2] and hyperbaric oxygen therapy [3]. Existing methods of transporting patients in traction from emergency hospitals to specialized treatment centers, and within the treatment center, are cumbersome and not without risk to the patient [4]. Accordingly, at the request of staff of the Santa Clara Valley and R.K. Davies Medical Centers, we have undertaken development of an improved spinal injury patient transport (SIPT) system.

The SIPT system when complete (Figure 1) will consist of: (1) radiolucent traction tongs, (2) an array of constant-force springs yielding a known traction vector, (3) a backboard with head, shoulder and torso restraints and detachable leg support, (4) pads designed to conform to body contours, thereby reducing probability of pressure sores and further immobilizing the patient, (5) a cart or ambulance cot modified to retain the backboard, and (6) adaptors to connect components of the system to existing Stryker frames and Stoke-Mandeville beds.

BACKGROUND

Traction Tongs. Cranial calipers or tongs are the most common apparatus for transmitting force to the axial skeleton [5]. Halter [5,6] and halo [7] traction are occasionally used during acute treatment. Types that do not require skin incision or pre-drilling of the skull are preferred. Only the halter is commonly made of rediolucent materials; X-ray opaque metals create artifacts in CT scans above the level of tong insertion.

Traction Device. In stationary situations [7] as well as some intra-hospital transport designs [8], traction force is commonly provided by hanging weights. A spring force gauge was used in one type of mobile cervical traction brace [6]. Some designs [6,9] have given consideration to compatibility with radiology procedures. One common method of inter-hospital transport traction is the Collins apparatus [10], which consists of a Stryker frame with a cable passing over two pulleys to a rubber "bungee" cord fixed to the foot of the frame. A study by NASA-Ames Research Center [11] investigated the force inaccuracy and motion sensitivity of both weight and Collins traction during ambulance and helicopter transport, and recommended development of methods based on constant-force springs.

Patient Support. Spinal injury patients are often moved between hospitals on extrication backboards lacking traction capability [4]. Patients must then be transferred to special beds for long-term nursing to minimize pressure sores, and must be re-transferred to the platforms of CT scanners and other instruments, each time requiring readjustment of traction. A single traction system compatible with all the above functions is clearly desireable. If the patient is to be placed on such a device for more than two hours, extreme attention to prevention of pressure sores is necessary [12]. During ambulance and helicopter transport, lateral and axial support (head, shoulder and torso restraint) must be provided; axial tilting may also be needed to prevent aspiration of fluid or vomitus.

S.I.P.T. SYSTEM DESIGN

Traction Tongs. Design criteria included X-ray transparency of components intersecting CT scans, compact size, geometric stability, installation without incision or drilling, minimal possibility or pull-out or over-penetration of the skull, and integration with the traction device plus capability of independent use. The current design (Figure 2) is similar to Vinke's tonge [5] in that two cantilever bars bearing conical pins at their free ends extend from a cross-member. The cantilevers ultimately will be made of graphite-fiber-reinforced plastic U-channel, but in the prototype are of aluminum extrusion. Spacing of the cantilevers is coarsely set by fixing at one of four locations on the cross-member with a ball-lock pin. Fine adjectment and skull penetration force is provided by a threaded rod and tube connecting the cantilevers.

Penetration depth is limited by a calibrated spring at one end of the adjustment rod, similar to the method of Gardner [13]. Geometric rigidity is assured by a thumbscrew at the other end of the rod.

Traction Device. Criteria were minimal weight, size and motion sensitivity, precise and fail-safe force magnitude, ease of attachment to tongs, variable angle in the A-P plane, non-interference with CT scanning and adaptability to existing equipment. Traction force is generated by nine "Negator"[1] constant-tension springs coiled on a common shaft above the head. The shaft is clamped into brackets at one of four positions anterior to the body axis. Selected springs are attached using "clothespin" hooks to a bar linked to the tongs, yielding force increments of 2.6 lbs. The attachment bar can be made integral with the cross-member of the tongs described above. The shaft can be removed from the brackets and attached to a bed or Stryker frame without altering the traction vector; spring extension is limited to about 24 inches. The springs are susceptible to crimping, which is minimized by an enclosure surrounding the shaft.

Patient Support. Criteria were oxygen compatibility (non-flammable, non-sparking), X-ray transparency, conformity to body contour with minimum depth of padding, geometric compatibility with CT and hyperbaric chamber platforms, mechanical strength and rigidity, and ease of fabrication and maintenance. The backboard is a 3/8 inch thick, 18 inch wide section of 30-inch-radius cylindrical shell, with the torso section 42 inches and the leg section 37 inches long (Figure 1). All attachments are by means of clamps sliding on the edges of the board, interlocking with grooves parallel to the edge and with detents molded into the board. The leg section has pegs fitting into holes in the torso section in addition to edge clamps. Final material selection is upper and lower skins of graphite-fiber/epoxy over a syntactic foam core; the initial prototypes are laminated mahogany plywood.

The first prototype has head restraints consisting of U-shaped silicone-coated urethane foam, mounted on aluminum L-brackets with 3-axis positioning (Figures 1, 3); these must be moved out of the CT scan field. Two later prototypes have head and shoulder restraints of the same material as the backboard, hinged to fold alongside the head and locked by clamps on the traction shaft bracket and on the board at the shoulder. Neoprene foam pads are attached by "Velcro" strips to fit between the patient's head and the hinged side board, allowing for free movement of the traction tongs.

The curvature of the backboard provides only partial conformity with body contour; exact adjustment to an individual, as well as increased lateral stability, is passively produced by a pad of "Flo-lite"[2] material, a low-density high-viscosity gel. Pads at the shoulders and behind the head, plus an overall cover of synthetic sheepskin may be added as needed.

[1] AMETEK-Hunter Spring Div., Hatfield, PA.

[2] Courtesy of Hansen Industries, Boulder, C O.

TESTING AND RESULTS

Materials. Samples of backboard materials were examined by CT scanning for artifact production; X-ray density of graphite laminate was intermediate between fiberglass and plywood:

wood (lauan)	-223	
Flo-lite pad	-161	Scale:
graphite skin	- 96	air = -500
fiberglass skin	- 50	opaque=+500
solid acrylic	+ 73	
solid fiberglass	+165	

These results show that materials used in the prototype SIPT system will not produce discernable artifacts. Specimens are being cut from these samples for mechanical testing in three-point bending [14]. Pressure on the patient's skin at various points on the Flo-lite pad are also being measured [12].

Laboratory Trials. The first prototype torso section was tested in various orientations carrying a student volunteer with 7.8 lbs. halter traction. The SIPT board was tilted 45° to either side and raised anteriorly to near vertical. Accuracy of the direction of applied traction and ease of transfer of the traction spring assembly to an AOA-Chick frame were excellent. The trials showed that leg restraints will be useful in reducing sliding of the lower body during 45° axial tilt. The board could be raised to nearly a sitting position without affecting traction direction, but increased force would be required to support the head.

Clinical Trial. Portable traction was needed for a patient in halo traction for an incomplete C6-7 lesion during intra-hospital transport and CT scanning (Figure 4). The first prototype board was placed on the patient's back while prone on a Stryker frame; 7.8 lbs. traction was transferred from weights to the SIPT after returning to the supine position. The SIPT system performed as designed. The head restraints used at the time were ineffective in preventing head motion due to muscle spasms. Smooth change-over from SIPT to weight traction was difficult but not ordinarily required.

CONCLUSIONS

After further clinical and field ues of the three prototype SIPT systems, the design and materials will be modified as required and additional units manufactured. The SIPT tongs and traction spring assembly may offer advantages in accuracy of force vector and compatibility with diagnostic radiology compared to existing devices. The complete system provides the capability for movement of patients with minimal possibility of aggravation of the injury and maximal compatibility with new diagnostic and treatment instrumentation.

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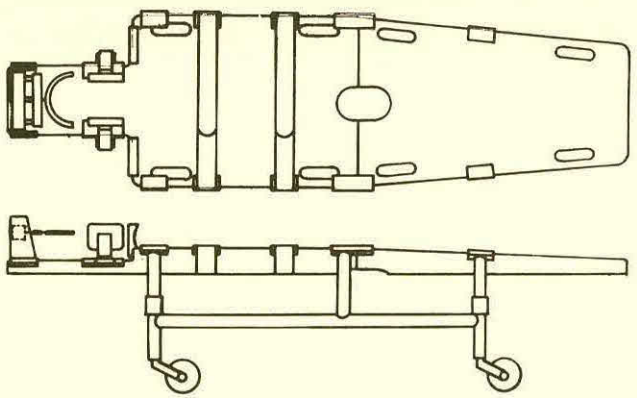

Figure 1: Complete SIPT system including cart

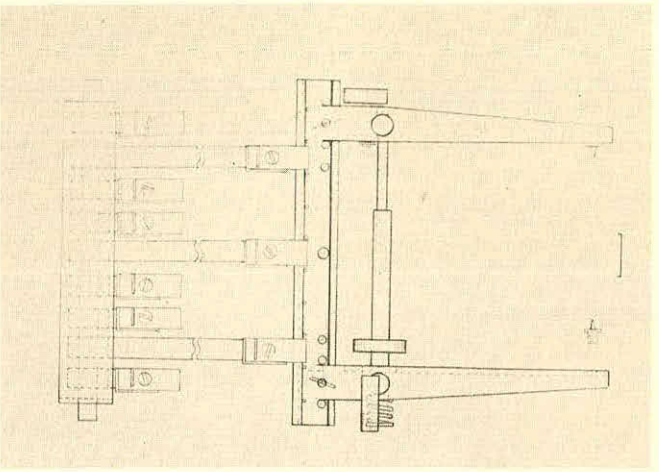

Figure 2: Traction tongs (scale bar = 1 inch)

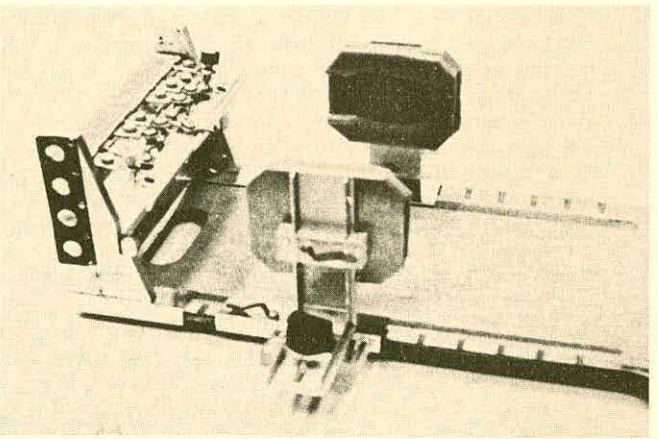

Figure 3: Prototype board showing head restraint and traction device

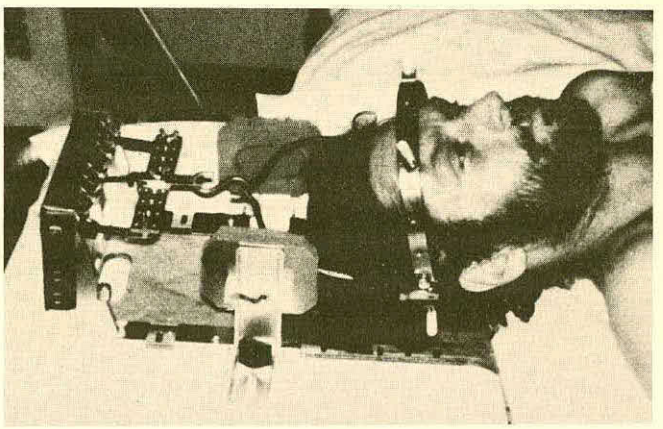

Figure 4: Patient with 7.8 lbs. SIPT traction

THE CONTROL OF AN ELECTRICALLY POWERED ORTHOSIS MICROCOMPUTERS AND MULTI-COMMANDS

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ABSTRACT

To effect the control of an electrically powered orthosis by means of microcomputers and multi-commands, it is necessary to establish an appropriate control program and compile the data which provide the required information concerning the rotation of each motor. To obtain this data, we have analyzed the mechanism of an electrically powered orthosis and measured its movements using potentiometer.

In this paper, we shall describe a new control method for such an orthosis using microcomputers and multi-commands.

INTRODUCTION

The number of handicapped persons such as quadriplegics or near quadriplegics who have been severely crippled by traffic, industrial or sports accidents, cerebral palsy, cerebral vascular lesions, etc. is tending to increase throughout the world. In order to enable these handicapped persons to live independently in ordinary society, they must be properly trained and reeducated in the use of their muscular functions, and it is often necessary to supply them with prosthetic or orthotic devices to supplement their impaired functions. There has been a great deal of research on and development of such devices throughout the world, however, up until the present time, there have appeared no practical prosthetic or orthotic devices which can be said to possess high precision and truly excellent capabilities. In particular, as regards powered orthotic devices possessing many degrees of freedom, there are numerous problems such as the construction of the device itself, methods of command and control, attachment to the arm, operation, reliability of the command units, the safety of the system, etc.

The control of the usual type of powered orthoses is effected by analogic control methods which utilize the special characteristics of the command signals(such as myoelectric commands, mechanical commands, etc.).

As regards the control of powered orthoses with many degrees of freedom, individual control by means of the above-mentioned type of command signals, demmands a great of training of the part of the handicapped person, and consequently entails considerable fatigue.

In order to solve these problems, coordinated control of all the various actuators, rather than mere individual control, is necessary. The use of microcomputers provides an effective method for the realization of such a system. In the research to be dealt with in this paper, we have constructed and studied an electrically powered orthotic device having five degrees of freedom, and developed a coordinated control system for this device using microcomputers. In the design of the command units, we have attempted to incorporate voice commands in addition to myoelectrical and mechanical commands. In the present report, we shall describe the control of this electrically powered orthosis using microcomputers and multi-commands.

SUMMARY DESCRIPTION OF THE ENTIRE SYSTEM

A block diagram of the entire system is shown in Figure 1. The system consists of a command apparatus, a control apparatus, a power amplifier and the orthosis itself.

Construction of the Electrically Powered Orthosis

D-C motors are used as the actuators of the orthosis. Describing the device in analogy with the human arm, one could state that the mechanism possessed a total of 5 degrees of freedom, that is 3 degrees of freedom in the shoulder, 1 degree of freedom in the elbow, and 1 degree of freedom in the forearm. Figure 2 illustrates the mechanism of the orthosis. The maximum ranges of the various degrees of freedom are as follows; for the upper arm, 90° of adduction-abduction in a horizontal plane, 90° of elevation, and 90° of pronation-supination; for the forearm, 90° of flexion, and 90° of pronation-supination. These ranges are determined by the setting of the limit switch in each motor. Except for the motors, the mechanism is of aluminum construcion. The motors are equipped with reduction gear boxes and shaft-encoders.

Command Apparatus

Three types of apparatus can be used for the issuance of commands to the orthosis, i.e., a voice command apparatus, a mechanical command apparatus, and a myoelectric command apparatus. This portable voice input apparatus, which distinguishes the tune and ryhthm of humming, sounds produced by the handicapped person, has been developed to the level where various patterns of humming correspond to various specific instructions. The apparatus is unique in that music can be utilized as a voice input; the unit measures the vaiations of pitch(frequency) and the duration of humming sound, which is detected by a condenser-microphone, and "recognizes" the humming instruction by its pattern matching with one of the templates stored in memory. A typical humming pattern is shown in Table 1.
The mechanical command apparatus consists of a potentiometer and a mass loaded on its axis, forming a kind of electro-mechanical clinometer. Two such apparatus are fixed on the head of the handicapped person at right angles to one other. When a handicapped person directs his sight toward some visual object, he rotates his head in the direction of the object. The components of this rotation are detected by means of these mechanical clinometers, thus, the angles subtended at the object point are measured and thus the direction of movement of the arm is determined. The myoelectric command apparatus detects a muscular electric potential by means of electrodes which are fixed on the face or the base of an ear, and thus determines the pronation-supination of the arm.

Control Apparatus

The control unit is centered about a 8085 microprocessor and contains, as read only memory two EP-ROM 2716(4K bits), as random access memory two RAM 2114(2K bits), as input/output device one PPI 8225, a decoder unit, an address latch unit, and a bus buffer.
Analogic signal from each command apparatus are transformed into digital signals via interface units and are fed into a microcomputer unit. Voice commands, mechanical commands, and myoelectric commands all employ 8 bit codes.
The output signals(movement commands) from the microcomputer are transmitted to each motor through a multiplexer and amplifiers. The output signals(feedback) of the shaft-encoders attached to the motors, which indicate the current position and velocity, are transmitted through counters to a microcomputer.

CONTROL METHOD

We fixed a rectangular coordinate system in the space in front of the handicapped person (as shown in Figure 3), established a three dimensional grid of equally spaced lattice points in this coordinate system, and measured, by experiment, the number of revolutions of each motor which are necessary in order to effect the movement of the tip of the hand to each lattice point. We compared these data with the relations between the target(desired) position of the tip of the hand and the total angle of rotation of each motor $\begin{bmatrix}\theta_1 \\ \vdots \\ \theta_4\end{bmatrix} = k \begin{bmatrix}x_t \\ y_t \\ z_t\end{bmatrix}$, as calculated by successive numerical approximations to a formula derived by a theoretical analysis of the mechanism of the orthosis; thus, by checking the realistic accuracy of the numerical calculations, we decided upon the number of approximation terms which must be used in computing the data. We carried out this analysis in order to compile the data required for the control of the orthosis. We used the corrected data to prepare the tape shown in Table 2.
In utilizing this data base, we first select one of the three planes through the origin which are perpendicular to one axis of the lattice and call it the X-Y plane and consider a family of planes parallel to and at integral distances from the X-Y plane(see Figure 4); next, in each of these planes, we select a set of lattice points which demarcate the periphery of the maximum range of possible movement of the orthosis. These maximum ranges are obtained by analysis of the mechanism of the orthosis and by experiment. One example of such a set of lattice positions is given by the points, 0.0, 0.1, ...0.9, shown in Figure 4.
Next, we assign to each such point Pn the four angles θ_1^n, ...θ_4^n, which give the total rotation of each motor required for the orthosis to move from a fixed position Po to this point Pn.
Next, we select a reference point Q in each plane in such a manner that all these point Q lie on a perpendicular to these planes. Each lattice position Pn (e.g., the points 0.0, 0.1, ...0.9 in Figure 4) determines an angle of elevation ($\phi n = \tan^{-1} An$) at the reference point Q (see Table 2). Conversely, if a direction from the reference point Q is given, then a corresponding lattice point Pn is determined, which in turn determines a set of four angles θ_1^n, ...θ_4^n.
Table 3 shows the functions of each command apparatus. The handicapped person can specify the plane of a desired(target) position and effect vertical movement by means of the voice command apparatus, and can specify the direction of movement of the orthosis on each plane as well as the initial velocity of the movement by means of the mechanical command apparatus. Even after the execution of the command has begun, the user can alter the velocity by means of just one component of the mechanical command apparatus (i.e., the Y component).
The reference point Q corresponds to the neutral point of the potentiometer in the mechanical command apparatus. The handicapped person can also effect pronation-supination of the forearm by independent use of the myoelectric command apparatus. The flow chart for the various stages of the control process of this system are shown in Figure 5.

CONCLUSION

In the present report, we describe the results of our attempts to establish new and effective methods for the control of orthotic devices by means of microcomputers and multi-commands.

We have, in fact, been able to basically establish the effectiveness of these methods. Through the application of these methods to the requirements of various handicapped persons and the continued improvement of both the hardware and software features of our system, we hope to implement the development of practical powered orthoses.

Number of Mora	Accent 0	Accent 1	Accent 1
1	stop		
2A	start		
2B	restart		
3A	central plane	under plane	upper plane

Table 1.Humming Patterns

tañ' An	Pn	Data
ϕn	0.0	$(\theta_1, \theta_2, \theta_3, \theta_4,)^{0.0}$
ϕn	0.1	$(\theta_1, \theta_2, \theta_3, \theta_4,)^{0.1}$
.		
.		
.		
ϕn	0.9	$(\theta_1, \theta_2, \theta_3, \theta_4,)^{0.9}$

Table 2. Data Base

Voice Controller	Start,Stop,Restart, Select planes
Mechanical Controller	Movement of right and left Movement of near and far
Myoelectric Controller	Pronation-supination of forearm

Table 3. Functions of Each Command Apparatus

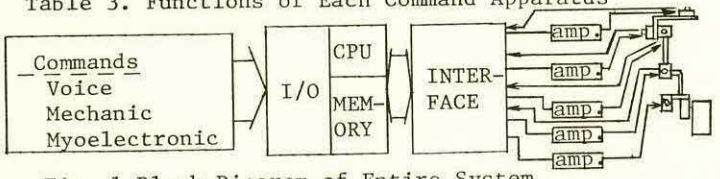

Fig. 1 Block Diagram of Entire System

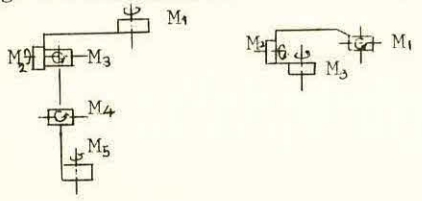

Fig. 2 Construction of Orthosis

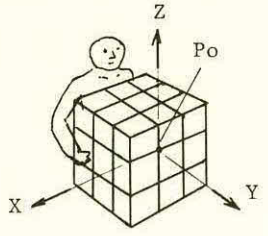

Fig. 3 Rectangular Coordinate System (Lattice Point Method)

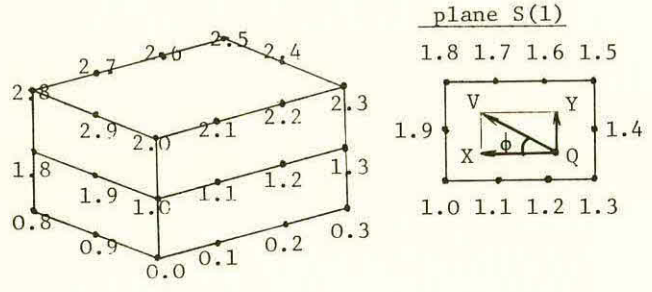

Fig. 4 Lattice Point Method

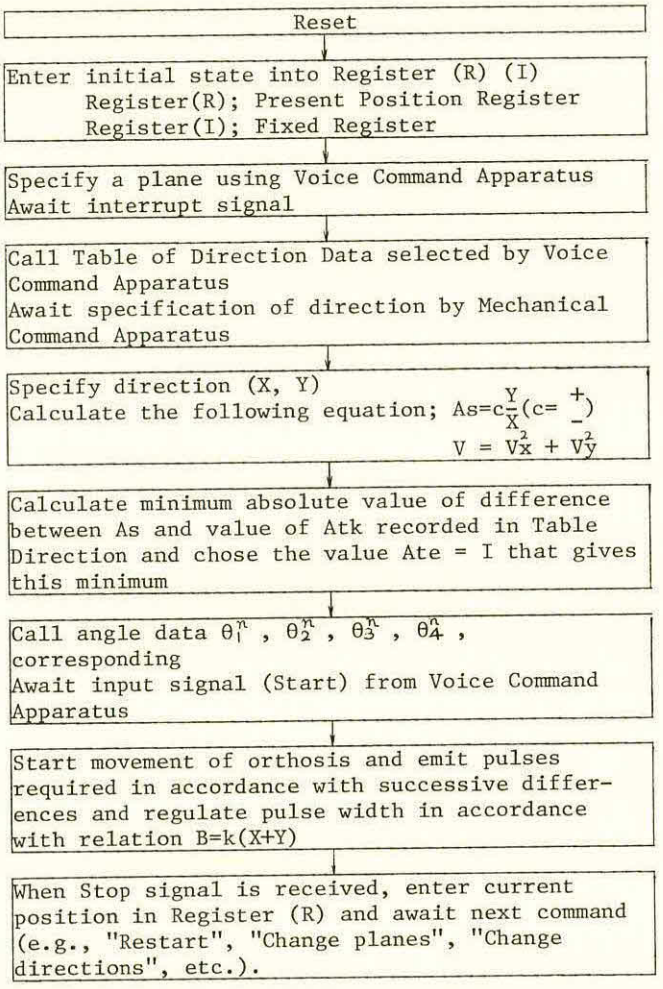

Fig. 5 The Control Process of This System

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Mr. N. QUESNEL, to Mr. O. JEANTET, and to Mr. P. MARTIN, students of Ecole Supérieure L'ingenieur en Electronique et Electrotechnique in Paris for their contribution.

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A HIGH-RESOLUTION TACTILE SENSORY AID FOR THE PROFOUNDLY DEAF

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A high-resolution tactile sensory aid has been developed for the profoundly deaf. The aid presents acoustic information as touch patterns, by means of a belt worn around the abdomen. The patterns associated with specific sounds must be learned, like a language. The aid significantly enhances lipreading accuracy, and enables deaf persons to monitor their own speech.

PROBLEM STATEMENT

Eight percent of our population has a measurable impairment in hearing. Three percent of these, or 410,000 persons, have impairments so severe that they cannot understand speech, even with high-powered hearing aids. These are the profoundly deaf. Approximately 92,000 of them are children. The origins of their handicap include genetic anomalies, diseases of pregnancy such as rubella, and major infections such as meningitis.[1]

Children who have been profoundly deaf since birth have a double handicap. They cannot hear the sounds of the environment or the speech of others; they also receive no feedback from their own voice, and are unable to compare their utterances with the speech of parents, teachers, and peers. Without arduous training, speech does not develop in these children. Often, even with the best of training, their speech is only marginally intelligible. They therefore have both a receptive and an expressive handicap, which has lifelong implications in terms of social isolation, employment, and quality of life.

THE TELETACTOR: A TACTILE SENSORY AID

The teletactor is a high-resolution tactile aid for the profoundly deaf, a system which translates sound into touch patterns on the skin. The acoustic spectrum is transformed according to frequency into a linear multi-channel tactile presentation, via a belt of electrotactile stimulators across the abdomen. Each speech sound generates a characteristic tactile pattern which observers can learn to identify.

A classroom-oriented, non-portable version of the teletactor is shown in Figure 1. The desktop enclosure contains an internal microphone, pre-amplification circuits, bandpass filters for frequency analysis, circuits to generate tactile stimuli, and rechargeable batteries. A row of 32 light-emitting diodes indicates the outputs of the 32 bandpass filters, which are sent to the tactile belt.

The audio signal is pre-emphasized (boosted) to preserve the high-frequency components of speech. A limited automatic gain control, with a 6 dB time constant of 1/4 sec, adapts the average signal level to the 30 dB of intensity available at the tactile display. Thirty two bandpass channels, each approximately 1/4 octave wide, display the audio spectrum from 80 to 8000 Hz. The sensation intensity at each point, over a 30 dB range, represents the signal intensity within each band.

The tactile display surface may be seen in Figure 1. Individual stimulating electrodes, spaced 1/2" o.c., are mounted on a one-inch wide elastic belt, worn against the skin of the abdomen. The electrodes are constructed from silver-plated printed circuit board and from sterling silver rivets; a 4 mm diameter (12 mm^2) active center is surrounded by a 1 mm ring of rigid epoxy insulation, then by a 12 mm x 25 mm ground plane. The active center is slightly convex, protruding by 2 mm to maintain constant contact with the skin. A flexible multi-conductor cable connects the display belt to the sensory aid. Prior to application of the tactile belt, the skin is moistened with warm water; no further attention is required.

The individual quantal stimulus consists of a biphasic constant current pulse at $\pm$ 10 mA, at a voltage sufficient to drive a skin impedance of 5K ohms. The overall current amplitude is controlled by a single user-operated potentiometer; this control regulates the amount of charge per pulse, and therefore the overall sensation intensity of the display. The number of quantal pulses per unit time modulates the perceived intensity at a given stimulator, which in turn varies according to the energy present in a given bandwidth.

Our present classroom model of the teletactor is housed in an impact-resistant case, 12" wide x 5" high x 9" deep; its weight, including batteries, is approximately seven pounds.

EVALUATION OF THE TELETACTOR

Subjects

Subjects for our experiments are drawn from participants in a special program for the hearing impaired, in the Marin County, California public school system. Children are selected who range in age from 5 to 9 years, exhibit profound bilateral sensorineural deafness (in excess of 90 dB above 250 Hz), and have no other concomitant neurological, educational, or psychomotor handicaps.

Acceptability of the aid

Early studies in the school setting showed that young deaf children found the tactile sensation acceptable, and enjoyed vocalizing to create sensations on the belt. An hour's training was sufficient to familiarize the child with the operating controls and the association between sensations and sounds.

Speech recognition and auditory awareness

In individual training tasks, the children learned to discriminate and to imitate the number and duration of utterances, the direction of fundamental pitch changes, and simple syllabic rhythmic patterns. The children were taught a vocabulary of ten spondaic (two-syllable, equally stressed) words, along with the ten decimal digits and other common words; as the discriminability of individual words reached acceptable levels, the words were combined into short connected phrases and simple sentences: "Touch the glass, John"; "Give me a yo-yo." The rate of vocabulary acquisition, the confusions resulting from phrase-length material, and the difficulties in parsing connected discourse seemed analogous to the processes of secondary language acquisition; i.e., that the children were learning to recognize these tactile patterns in much the same way that normal children learn a second language.

Improvement in speech production

After obtaining videotaped baseline measures of the children's running speech, and after spectrographically analyzing the children's responses to a standardized test of syllable production, specific goals for speech improvement were identified for each child, and appropriate training tasks were devised. The training encouraged the child to compare the tactile pattern resulting from his own speech with the pattern produced by the trainer, rather than emphasizing the articulatory means by which the sound was produced.

Periodic videotapes and spectrographic analyses were taken during the course of training. In the opinion of unaffiliated consultants, a greater amount of improvement was found at the completion of training than would have been expected from a similar amount of conventional training, without the added tactile information provided by the sensory aid.

THE PROMISE OF A FULLY WEARABLE AID

The experience which our deaf children have received to date is limited to two half-hour training sessions per week, in that the device is presently non-portable, and the children's experience is restricted to the classroom.

Continuous wearability is a highly desirable characteristic for any sensory aid. A portable, simple-to-operate system, suitable for continuous use by a deaf child, would permit the child to receive day-long experience from his own voice and the voices of teachers, parents, and peers. With a wearable device, both structured and incidental learning should be possible, enhancing the development of speech, language, and auditory awareness.

Design strategy to achieve a wearable aid

Short-term (two year) plans. The ultimate technology of choice, for implementing a wearable, power-conserving, economical sensory aid, is large-scale-integration. The high initial costs of LSI fabrication, however, did not seem justified until certain basic questions of long-term acceptability and potential benefits had been answered. The decision was therefore made to utilize hybrid technology in the construction of four prototype wearable sensory aids, for exhaustive field evaluation both of the design and of the concept of a wearable tactile sensory aid.

In Figure 2, a hybrid circuit is shown alongside the stimulating belt. Utilizing hybrid techniques, the electronics required to filter the signal and to generate the electrotactile stimuli, for each of the 32 channels, could be mounted directly on the belt, adjacent to the stimulating surface. In this form, the electronic circuitry could be portable and concealed under clothing, requiring only a microphone and a battery pack.

Commercial availability. We anticipate that high-resolution, continuously wearable tactile aids could be made available to the profoundly deaf within a five-year period. The effects of this new technology, upon the lifestyle of the handicapped, may be as profound as their present level of impairment.

References

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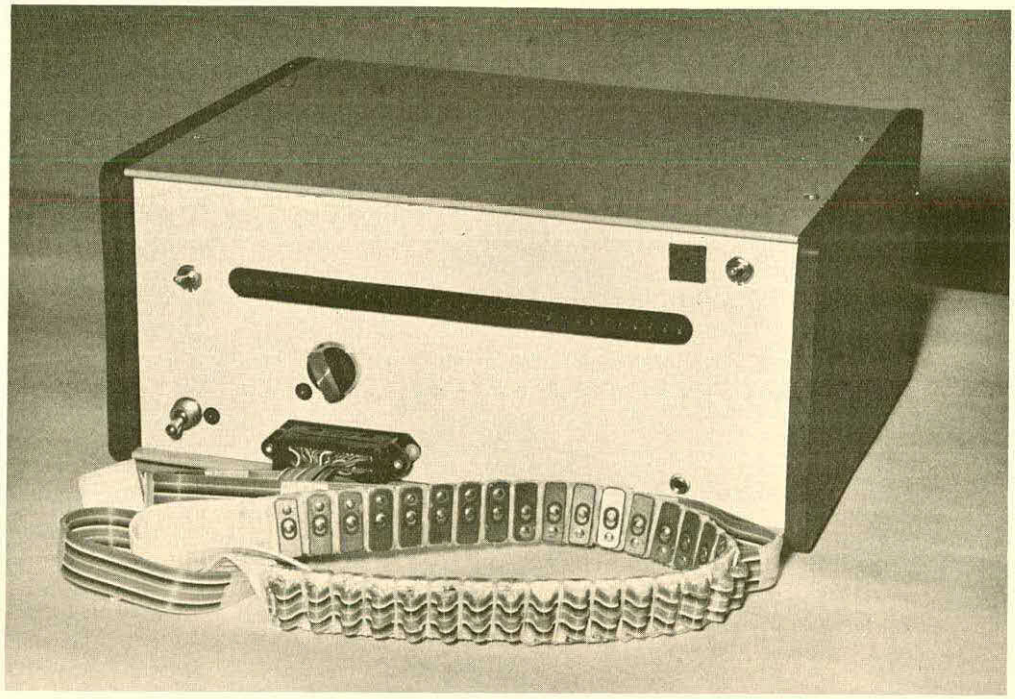

Figure 1. A classroom model of a tactile sensory aid for profoundly deaf children. Sounds are displayed as touch patterns on a belt, worn around the abdomen.

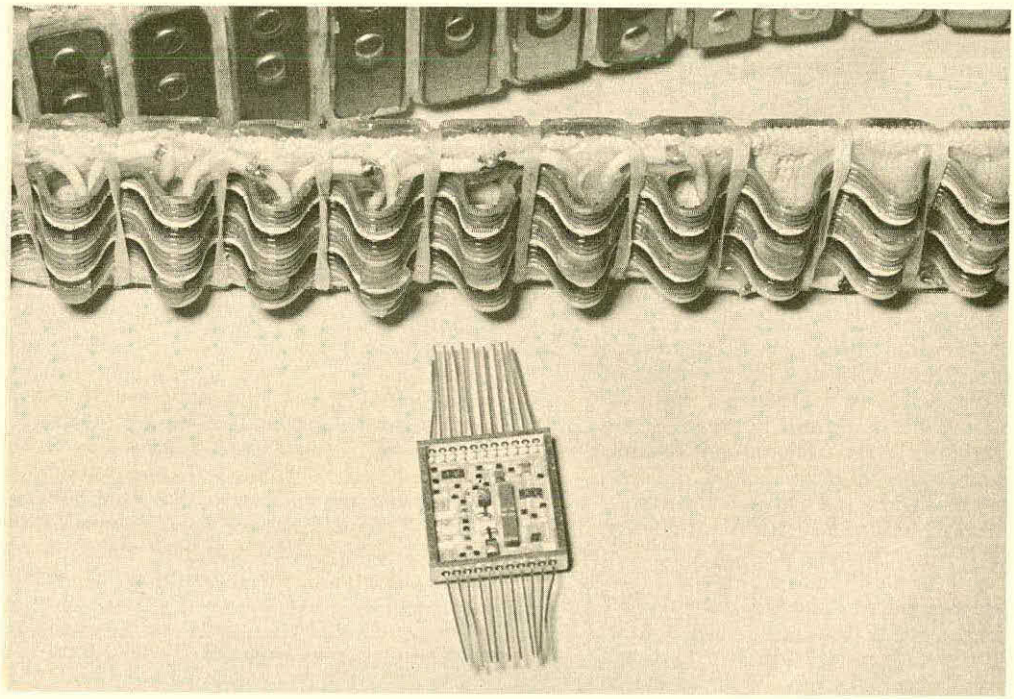

Figure 2. Hybrid technology enables the sound-analyzing, stimulus-generating circuitry to be mounted directly behind each stimulator, yielding a lightweight, continuously wearable sensory aid.

The research described above was supported by the National Institute of Neurological and Communicative Diseases and Stroke NS09714, the National Institute of Handicapped Research, the Rehabilitation Services Administration, the Smith-Kettlewell Eye Research Foundation, and the USPHS Biomedical Research Support Grant of the Institutes of Medical Sciences.

STUDENT PAPER

A GUIDANCE SYSTEM FOR THE BLIND

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Helen Keller aptly summarized the problem with the blind where "The curse of the blind is not blindness but idleness." Crucial to any individual's psychological and physiological development is the promotion of physical activities, both recreational as well as an equivalent competitive environment. This facet of development is even more critical for the visually impaired individual. On a daily basis 87% of all information processed by a sighted individual is visual. Considering the visually handicapped one readily recognized the magnitude of the problem of integrating these people into a visually based environment. Recreational and sports activities are highly based on visual feedback which to date has essentially eliminated the visually handicapped from participating. An area which has yet to be addressed seriously is that of free running for the blind, both in a competitive and recreational context.

Without the utilization of appropriate teaching aids to promote independent physical activity the blind are more prone to: (1) arthritis, (2) bursitis, (3) abnormal postures, (4) lateral disparity problems, (5) stiff leg gaits, (6) and blindisms such as rocking, twitching, probing at the face, shaking the head, and sticking fingers in the eyes.

The visually impaired individual must rely upon his four remaining sensory modalities to cope with the environment. In the context of promoting physical activities any system designed must effectively relate to one or more of the remaining four senses. Due to the fact that 67% of all visually handicapped individuals also suffer from some type of hearing impairment a design cannot be proposed based on auditory feedback as it would be ineffectual for three quarters of the blind population. Of the remaining three senses, tactility, olfaction, and speech, a tactile guidance system approach seems most appropriate.

The visually handicapped individual represents a very small group, 0.001% of the total U.S. population. For a design to be accessible to such a small sector it must be extremely cost effective; financially feasible for an independent or large rehabilitation program.

Important is to develop a guidance system which will apply not only to the promotion of recreational activities but also to educational programs. In the context of educational applications, such a system must accommodate for variations in the anticipated user population such as age, body types, and the various levels of psychomotor development.

These above concepts and criteria are the basis of an effective guidance system for the visually impaired. The promotion of an independent motokinesthetic development cannot be overemphasized, it is essential for a visually handicapped individual's total development.

To optimize the performance of a guidance system for the blind six primary objectives must be embodied in the final product. It must: (1) adapt to all ages, (2) minimize the threat to injury, (3) be suitable for indoor and outdoor use, (4) be highly portable, easily maintained and storable, (5) foster a correct independent motokinesthetic development, (6) and be financially feasible for an independent or large rehabilitation program.

In review of the state of the art in guidance systems none offer the user a free independent involvement. Three methods are currently employed. The first requires that a coach direct the runner with the use of a bull horn, usually running along with the runner. Secondly, a coach will run hand in hand, or alongside of the runner. Lastly a connective shock pole attached at waist height between the runner and his coach. All of these methods are dependent upon the coaches athletic capabilities, so in many instances they directly affect the blind athlete. Other guidance systems are available but all fall short of the optimum for similar reasons.

Various alternatives were studied. Auditory feedback systems were investigated but later ruled out due to the fact that 67% of all users would have some type of hearing impairment. Possibilities of various ground textures and contours were studied but their applications are limited due to high capital costs and long implementation times. Teather systems were ruled out as they inhibit the runners movement.

Research indicated that a guidance system should relate to the user tacitly. An analysis of walking and running defined a contact area which would provide optimal tactile feedback to the individual without inhibiting his locomotion. This contact band is between the shoulder and elbow

The anticipated variety of users, both in age and body types require that this contact band adjust from a 30" minimum to a 54" maximum. See figure 2.

Figure 1: Guidance System in place at a running track.

The proposed design is composed of a series of standards placed intermittently, supporting a continuous contact band located at a height midway between the elbow and shoulder; refer to Figure 1. In operation the blind runner merely brushes his upper arm against the contact band. The entire system is based on four parts; see Figure 3. The standard is a ¼" cold rolled steel wire form, 54" tall, and has an integrally formed triangular base. The stand off is a 1/8" medium high carbon steel wire form. At one end a clip is formed which holds the contact band and at the other a coil is formed which allows for vertical height adjustment. The contact band is a 1/8" x 1" x 12' –0" birch strip. Bands attach together via velcro located at the ends of each strip. The sandbag is constructed of 8 oz. rip stop nylon and holds 25 lbs. of sand.

Unique to this design is that no tools or equipment are required to set it up. Fill the sandbag, clip on the contact band and it's ready for use. Because of the flexible nature of the wooden contact bands curves can also be formed, such as the curves of a track. It will interface with all track facilities, indoor and outdoor without damage to the surface. The design is highly portable and economical to transport due to its minimal size and lightness.

It poses no threat to injury. The weight of the sandbag is such that if the runner bumps into the contact band more than usual it will not fall over but if he falls into it, it will collapse and the contact band will break.

The design is cost effective, well within the reach of an independent or large rehabilitation program. It is envisioned to be manufactured by a cottage industry. The cost of one standard and a twelve foot section of contact band based on prices available February 1980 was $3.17 per unit.

In application it can be utilized on indoor or outdoor track facilities. It will allow the blind individuals to compete against one another or even sighted individuals in a fully competitive environment. One example of an educational application would be for mobility training. The system would be used to set up a schematic of the outdoor route. The blind individual could then walk this schematic, learn his path while under supervision at the same time. Many other applications are envisioned but it is beyond the scope of this paper to discuss them.

To date the design has been prototyped and field tested by blind individuals on two separate occasions. The results from these two sessions were most encouraging. Available upon request is a film documenting these trials.

In closing I feel confident when I say it is a successful design. It interfaces well with its anticipated users and environments, is highly portable, fosters a correct moto-kinesthetic development, allows for a totally uninhibited interaction and most importantly is economical to purchase.

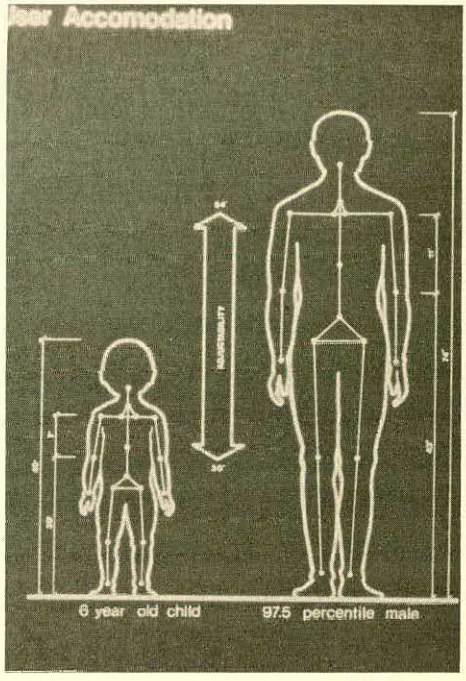

Figure 2:

Orthographics

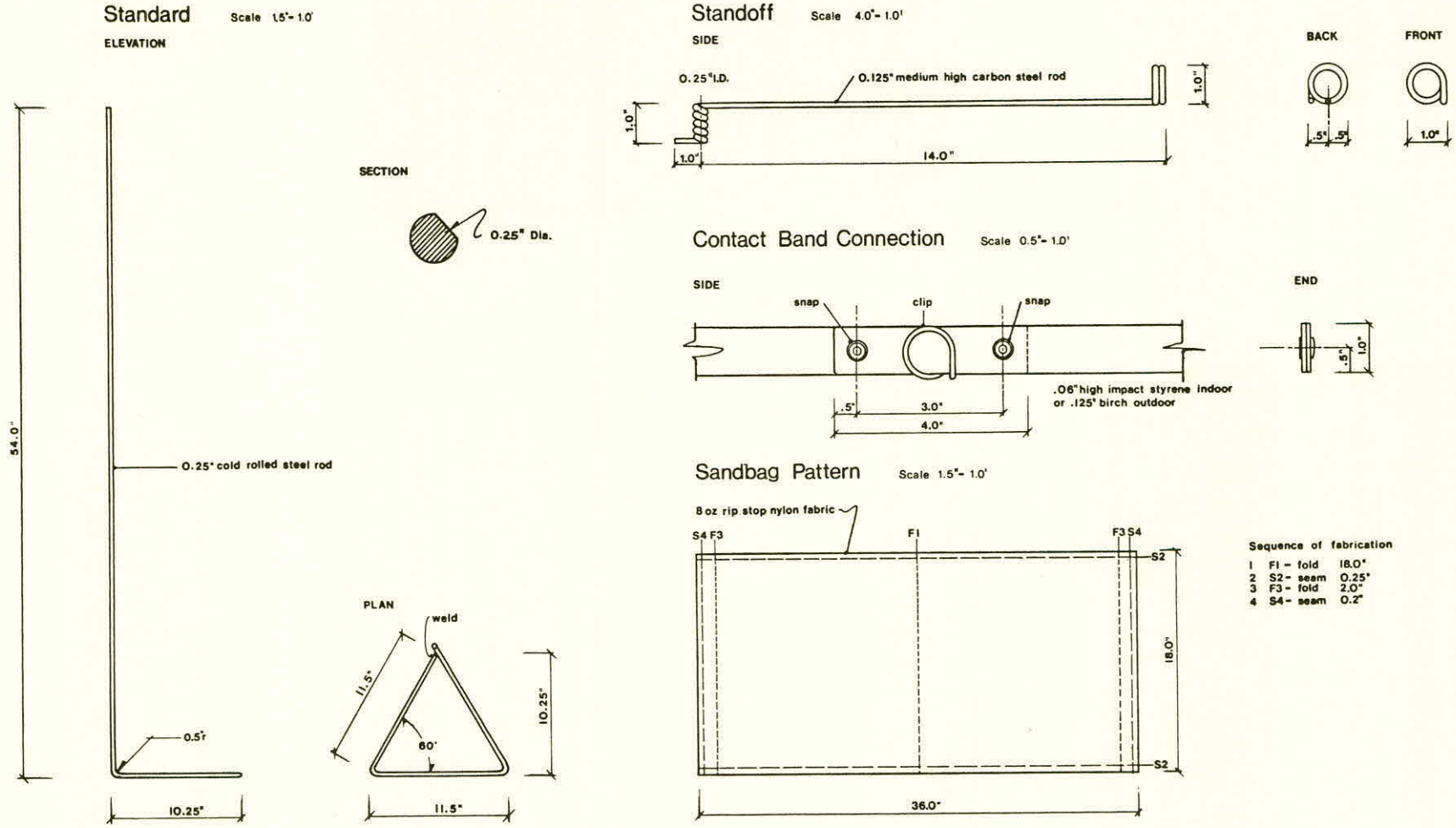

FIGURE 3

COMMUNICATION MEDIA FOR THE BLIND
WHY ISN'T THERE ONE BEST WAY?

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This article is written from the point of view of a consumer, teacher and evaluator of communication aids for the blind. Addressing the questions of rehabilitation researcher and sponsors, it explains why no single communication medium, be it braille, recordings or reading machines, is likely to meet all needs. A multifaceted philosophy of research and development is briefly presented. Its facets are cooperation or co-invention, cost/effective solutions, learning from the past, and willingness to pioneer.

Now that we have tape recorders, why do we need braille? If braille is faster than the Optacon, why doesn't the Optacon produce braille characters? Now that computers can talk, why do we need the Optacon?

Those questions are often asked by the bewildered observers of the new communications technology for the blind. Engineers and researchers are no less perplexed. Only their questions are more sophisticated. This paper addresses the questions of professionals in work for the blind and those doing research in our behalf. Judging from the questions I am asked and the state of confusion of the field, many people need to read it.

1. Should Braille Be Replaced With Recordings? Emotions run high. Braille has been the mainstay of written communications for the blind. Now many people use recordings in addition to or instead of braille. Recordings are cheaper and take less skill to make and use. They are faster for some applications. Why keep braille? There are at least five reasons. (a) Braille leaves the ears free. This facilitates activities like aural reading, lecturing from notes and working in study groups. (b) Braille requires no machines for reading. As with print, it takes only the human body to read it, and writing is done in a variety of ways: by hand with a slate and stylus, by machine called a braille writer, by a special press or computer terminal. (c) Because it is usually written on pages or cards, filing and accessibility are facilitated. Music, math and graphs are better in braille, and would you prefer your address file on a cassette if instead you could use braille? (d) Braille is a written code designed as an exact transcription of the alpha-numeric code which usually appears as printed characters. Just as material intended to be heard loses meaning when written, so it is that written material loses some meaning when transcribed into speech. Have you ever had to extract from a recording precise spelling, foreign words, punctuation and proper format for printing? Why should we settle for second-class citizenship with only one medium or the other? (e) Deaf-blind people cannot use recordings.

2. Why Do We Need Tapes And Talking Computers? Since braille can be read rapidly and efficiently, why not use only braille except for recreational recordings? Braille is fast only for those who have unimpaired tactual perception and have learned it as a child or read a great deal of it. The Gray-Todd study found people reading 200 words per minute but the average to be around 60. A common cause of blindness in older people is diabetes which often results in neuropathy, leaving fingers unable to read braille efficiently. A number of occupations impair tactual perception. Besides the fact that recordings are easy to produce and duplicate, phonographs and tape recorders have become the toys of society. They are therefore, inexpensive and convenient if not as reliable as desired. Speech compression now adds to the efficiency of learning through listening. (See our article on speech compressors published in Technology Review.) With compression, 300 WPM is common; 400 is not unusual.

Recordings used to be bulky and expensive, but new flexible, slow-speed discs are less bulky even than ink print and sometimes cheaper. The new LOC cassette format permits four times the length of time available with commercial formats. Recordings were hard to index, but new tone-indexing features combined with cue-and-review features of newer machines help a lot. With voice-indexing reference books including recorded dictionaries are becoming feasible. Future possible digital storage and laser technology could boost the efficiency and accessibility of recordings by a lot. Skimming is hard to do with recordings, but speech

compression and the other features described help with review and skim potential.

Here are two personal examples. In a study group or when teaching a class, I prefer braille books and notes. For lengthy background material needed for the same group, I prefer recordings. For reference works, I may look up the material with the Optacon and then read passages in it with the Kurzweil Reading Machine. For typing, I prefer a computer terminal which I call my forgiving typewriter. I use a paperless braille terminal while typing, but for reading long passages from computer storage, I prefer the talking terminal which is faster. In the future, talking outputs should be inexpensive add-ons to ordinary video or special braille terminals.

In fact, the increased use of recordings and synthetic speech has given rise to a new skill similar to skill needed in instant language translation. We need sometimes to respeak material in our own voice and inflections. I am debating whether to call this new skill human articulation of synthetic speech (HASP) or people articulating recorded or robot output talk (PARROT). Both acronyms have symbolic significance. The skill is useful in such divergent activities as broadcasting, telling bedtime stories and sharing information with friends. And of course, it saves retranscribing data into braille.

3. Why Paperless Braille (sometimes soft-copy or refreshable braille?) The machines to read and write it are costly and still evolving. The question cannot yet be answered; the concept of paperless braille is more fully described in our article "Communication Aids for the Blind" in Blindness 1980. Four machines are available -- Elinfa, VersaBraille, Braillocord and Brailink. Typically, they display a short line of characters. Pages are stored in "short-term" memories accessible with "scanning" controls. Texts are permanently stored in digital form on cassettes. Rapid, automatic search of stored data is controlled by a micro computer. Soft-copy braille is an attempt to combine the advantages of braille, magnetic recording and small computers for the tasks of reading, composing, filing, note-taking and using a computer terminal. Several full-page displays are being designed and should also be tried.

4. Why Do We Need Reading Machines? Instead, why not have braille or talking versions of books and periodicals produced from the digital-storage media such as compositors' tapes used to drive automatic type setters and printers? First, we need access to things already in print.

Why should be settle for second-class citizenship in academic pursuits? Secondly, most proponents of this worthwhile alternative are ignorant of the formidable formatting tasks involved. Imagine a recorded newspaper strung out on a tape with no effective table of contents. Who would read it? A recent international conference on computer production of braille concluded that largely because of formatting problems, it is not cost effective for most applications. The American Printing House for the Blind uses human intervention to reformat texts for braille which it receives in digital form originally intended for ink print formatting. A less difficult task, however, is enabling access by phone to computer-assisted data bases and information services such as The Source. Facilitating such access is one good reason for implementing braille, talking and large-print computer terminals.

5. Why Not Use The Optacon Reading Machine Instead Of Transcribing Anything For Blind People? After all, the Optacon which has a tactile output is used well by many people, notably typists and programmers. Much skill is required, but experienced users can read a wide variety of print styles and handle formats no computer has been programmed to track. (Details on all the reading machines and the needs for them will be found in our article "Personal Reading Machines for the Blind" published in The Braille Forum, Jan. 1980.) The problems are that using the Optacon is slower than other methods, and many people are unable to learn the skill. We expect that it will continue to be needed for what are called small-quantity reading tasks.

5.A. Since braille is easier to read than the vibrating letter shapes of the Optacon, why not have the Optacon present braille characters? The Optacon does not identify characters; it identifies or recognizes dark areas on the page and turns that information directly over to the user in the form of vibrating patterns. That's why we call it a direct-translation reading aid. It takes a powerful computer to identify the characters as such, and that brings the price up by at least several thousand dollars.

5.B. Since the Optacon is successful, why do we need a tonal output direct-translation reading machine? Some people cannot use the tactile output, and some do better with the audible output presented as tone patterns. There is some evidence that a bimodal approach including both tactile and audible codes has value. The additional cost of an audible output would be minimal.

6. Why Not Have Talking Reading Machines Replace Others Like The Optacon? They can't do that now and will not be able to do so in the foreseeable future. There is good reason to believe that the most successful machine will have both types of outputs. Users of the Kurzweil Reading Machine (which talks) use their Optacons to preexamine material and read unusual and degraded print. The manufacturer of the Kurzweil machine plans to incorporate a direct-translation output. The maker of the Optacon is building a talking Optacon with essentially the same goal--to incorporate both systems in the same machine. (For details, see the article on reading machines and our report on the evaluation of the Kurzweil

Reading Machine to be published in the forthcoming Bulletin of Prosthetics Research, Spring, 1981.)

Where Lies The Road To Independence and Productivity In This Technically-Oriented Society? Having discussed the technical problems, let us review six approaches to their solution. All these have been tried, more or less in their pure forms. What do you think of them?

(1) Should we rummage through the toys of the affluent society for useful tools in order to overcome the handicaps created in part by technical change? (2) Should we demand nothing but the best and become costly tax burdens or tax write offs for employers--glorified beggars? (3) Should we forge ahead in justifiable desperation and risk ignoring the lessons of the past and ignoring concurrent projects? (4) Should we study our nature and functioning until scientists are sure they know exactly how we tick as blind people and then go ahead and try to invent things? (5) Should we hide our work in a laboratory until we have a fully-developed aid or technique and then have people try to use it? (6) Should we never try or buy anything until someone else has proven its worth?

Let us combine the positive aspects of these six negative approaches. We should stop saying that anything is bound to help unfortunate blind people and stop saying that nothing is too good for blind people. Those are patronizing attitudes. We should start working together with other researchers and blind people. Accept the fact that inventing for blind people is not easy. We should study how we function as we work toward cost/effective solutions as they are needed.

STUDENT PAPER

A MUSICAL LANGUAGE COMPUTER TERMINAL FOR THE VISUALLY IMPAIRED

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BACKGROUND

The purpose of this project was to design an alternative computer terminal for the visually impaired: A computer terminal which would enable them to quickly and efficiently enter and edit data and text. Such a terminal would open up a variety of job opportunities for them in a rapidly expanding field.

There are currently a number of computer terminals for the visually handicapped on the market, but each one has its drawbacks. The Braille terminal is very expensive and awkward to use for text editing. The new "talking" computer terminals either read data/text one letter at a time or use occasionally imperfect rules of word pronunciation. One-letter-at-a-time reading of text is very cumbersome, but, on the other hand, it is straining and irritating to listen to and try to understand text which is being, sometimes imperfectly, and monotonously pronounced.

Another drawback of phonetically pronounced text is that it does not always indicate whether words were properly spelled. This is a serious flaw compounded by the fact that the visually impaired are becoming increasingly illiterate precisely because they rely so much on the spoken word.

The alternative designed by this researcher was partly based on the stereo toner, a device which sold in limited numbers during the 1960's. The stereo toner translated the relative lightness and darkness of printed characters into varying audible tones. The advantages of the stereo toner were its simplicity, lightweight portability, low cost, and its demonstrated use at high reading speeds by veteran users. The main disadvantage of the stereo toner was that a great deal of practice and perseverence was required to enable one to use the device proficiently at any reading speed.

The goal of the present project was the design and construction of a prototype which maintained all the advantages of the stereo toner, yet overcame the main disadvantage. This researcher's solution to the problem with the stereo toner was the creation of definitive character and/or word tone sets which could be easily recognized and quickly learned. The current prototype is an implementation of this solution.

DEVELOPMENT OF A STRUCTURED MUSICAL LANGUAGE

Two elements were considered as essential in the development of the musical language. First, in order to maintain simplicity and to enhance operator literacy, the tone(s) created by each computer character would have to be consistent and unique. Second, if high reading speeds were to be achieved, tones comprising syllables and often-used letter combinations had to fit together as easily recognizable patterns.

A number of references concerning information coding in the English language were consulted in order to determine the most frequently used letter and syllable combinations. These combinations were then organized according to frequency of use. A graduate music student was consulted in order to determine the most common and pleasant-sounding musical phrases and intervals. These were also organized by rank. The two lists were then matched as best as possible under the constraint that each letter was to be assigned a unique tone which would not differ from syllable to syllable. Because the punctuation and number characters do not form word patterns, each was assigned a unique tri-tone in order to make it more easily recognized.

In this manner, then, a musical language was created which could be easily learned because of its simple structure. It also had the capability of being quickly listened to and comprehended because the experienced listener would listen for musical phrases, not the individual tones of each letter sounded.

HARDWARE DESIGN

An APPLE II microcomputer with 48K of memory and a disk drive was chosen to be used as a terminal. Along with the APPLE II, two computer interfaces were also purchased: An RS–232C interface for connecting the APPLE II to a direct computer line, and a D.C. Hayes modem for connecting the APPLE II to a telephone line connection with another computer. Each of these interfaces enabled the APPLE II, under a variety of circumstances, to act as a computer terminal. An ALF products music synthesizer board, which is capable of generating three simultaneous musical tones over a range of five octaves at independent volumes, was chosen to produce the musical tones.

All of the above parts were found readily available in local computer shops and were easily plugged together. The complete system weighed less than thirty pounds and cost $2100.00, or about $1100.00 more than a standard computer terminal.

SOFTWARE DESIGN

The software written, to date, allows the user to operate the APPLE II as a musical language computer terminal, either over a direct computer line or over a telephone line.

This software also allows the APPLE II to be used as a self-contained musical language microcomputer. By operator command, the APPLE II will remember incoming data/text and will play it back repeatedly, if necessary. The operator may also vary the reading rate from five to 35 words per minute at any time. In addition, the tones sound as each character is typed, thus reinforcing letter/word sounds and allowing the operator to hear and correct mistakes immediately.

SYSTEM EVALUATION

To date, there has been time only for a limited evaluation of the system. However, of the three blind students who have used it in connection with a computer training program, all have worked with it enthusiastically, and one was able to attain a reading rate of 120 words per minute after only four weeks of working with the system.

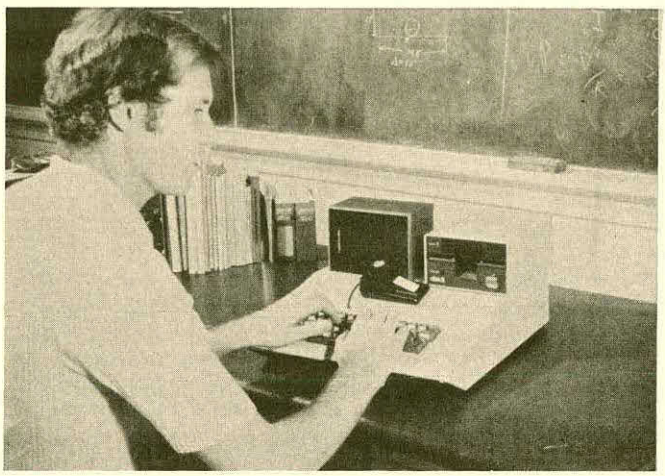

Figure 1: Musical Language Terminal in use.

CONCLUSION

The purpose of this project was to produce an alternative computer terminal for the visually impaired which avoided the problems of other existing terminals. These problems included expense, portability, ease and speed of use, and operator literacy.

The proposed solution was a musical language computer terminal. A prototype was built which displays text in a format of easily learned musical patterns at comfortable, operator-controlled, reading rates. It is expected that reading rates of at least 250 words per minute are possible.

The structure of the musical language promotes operator literacy since the spelling and the sound of words are literally synonymous. The software also constantly reinforces the learned sounds and emphasizes the spelling of words.

The prototype hardware was easily obtained and assembled at a reasonable price. The finished prototype was relatively portable, weighing less than thirty pounds, and was simple and easy to operate.

In other words, the prototype has met all the goals set forth above.

THE APPLE COMPUTER AS A GENERAL PURPOSE VOCATIONAL AID FOR BLIND USERS

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ABSTRACT

Many vocational tasks are difficult for blind users to perform because of their inability to monitor meters, guages, and industrial processes. The building of special purpose devices to deal with these tasks is expensive, and must be repeated each time job requirements change. The authors have developed a system using the widely sold Apple computer and commercially available speech synthesizers and interface hardware to provide an inexpensive, general purpose, user-programmable monitoring device.

1. INTRODUCTION

Many job situations require the employee to check on the status of equipment: to determine temperature, pressure, dial settings, guage readings, etc. At present, if a blind person is to be placed at such a job, typically an engineer is hired to design a special purpose device that will convert the information needed by the employee into tactile or voice form (3). This method is very costly because good engineers command high pay, and because the blind person remains unemployed while the special device is being designed and tested. It is also inflexible, since, if job requirements change, a new specially-engineered device is necessary. The authors have developed software to convert an Apple computer into a general purpose talking monitoring device which can easily be adapted to different tasks. The retail cost of the computer with the necessary accessories is about $2500.

2. HARDWARE

The hardware for the system comprises an Apple II Plus computer with 48K bytes of memory, one disk drive, a Street Electronic Corporation Echo II speech synthesizer, and an appropriate interface card for the particular task. When the system is used, signals are received from the processes being monitored through the interface card and are analysed by the computer; the computer generates an appropriate message to the user and converts this message to speech codes. The codes are sent to the speech synthesizer, which then speaks the message in ordinary English to the user.

A specific example of a possible use would be as a digital voltmeter. The user would measure voltages with probes connected to an analog to digital converter board plugged into the Apple. The computer would then convert the digital signals from the board into spoken numerical values. Another example would be that of monitoring the status of 48 telephone lines. Status signals for the lines would be wired to parallel interface boards in the computer. The computer would scan the lines and report on any changes in status and allow the user to review the status.

The Apple computer was selected because it is cheap, sturdy, and widely distributed and because many types of interface hardware and applications software are available for it. There are a wide variety of interface cards available for the Apple computer, generally priced at between $100 and $300 each. Apple and other manufacturers produce serial and parallel interfaces. D.C. Hayes makes a modem which connects the computer directly to a telephone line. California Computer Systems makes clock, timer, analog to digital, and IEEE 488-1978 General Purpose Instrument Bus boards. Mountain Computer makes controller, digital to analog, and analog to digital boards. The Street Electronics Echo II speech synthesizer (costing $225) is being used for speech output. It is expected that another inexpensive synthesizer using the Votrax single chip synthesizer will be available for the Apple Computer soon.

3. SOFTWARE

Peter Maggs previously developed a program for the Radio Shack TRS-80 Model I computer (2) to translate from ordinary English to synthesizer phoneme codes using the Naval Research Laboratory algorithm (1) and intonation rules developed by Professor Bruce Sherwood of the University of Illinois (4). Dianna Visek has translated and optimized this program for the Apple computer. Application programs may be written and altered easily using the BASIC language interpreter supplied with the computer. For some purposes, commercially sold application programs may be used unchanged or with minor modifications. Blind users may be given the option of having the synthesizer speak output sent to the screen and of replaying individual lines of the screen, thus allowing them to program the computer themselves.

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ACKNOWLEDGEMENT

This research was supported by United States Department of Education Grant No. G008005092.

AN ELECTRONIC INFORMATION SYSTEM USABLE BY THE BLIND

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An electronic information system provides two distinct benefits for a blind user. First, it allows access to a type of system that is becoming common in office settings. Second, the system can have interfaces to accommodate special I/O devices for the blind. At present a dynamic Braille display and a speech synthesizer provide output for our system. These devices will connect to a microcomputer system with several I/O ports, an adequate amount of main memory, and a Winchester-technology disk for mass storage. A PDP-11/70, running the UNIX Time-Sharing System, presently simulates much of the information system while providing powerful software development tools.

The proposed system will help perform many daily home and office tasks. Examples are document preparation and printing, calculating, financial record-keeping, and general information storage and retrieval.

Using present technology, such an information system cannot be made portable. With rapid advances in bubble memory and CMOS circuit development, we believe portability can be achieved within the next three or four years.

INTRODUCTION

Many electronic information systems are providing efficient information storage and retrieval for sighted individuals. The advantages of such a system can be made available to blind users with the addition of specialized software interface modules allowing the connection of suitable input/output devices. Improvements in integrated circuit technology and mass storage devices over the past decade have made the information system a cost-effective idea.

Such advances in technology have already been applied to specialized aids for the blind. Most of these aids have been designed to perform a specific task(1,2). More recently, portable information systems for the blind user have been introduced(3,4). To gain portability, however, flexibility and processing potential had to be sacrificed, since current technology still has limitations. One such example is the cassette tape used in the portable systems. It is not practical to have random access files on cassette tape.

Although these specialized aids provide assistance in performing some tasks, they do not provide an integrated approach to the problem of information handling. Rapid growth in the amount of information processing an individual must do is taking place in both the home and the office(5,6). Offices are becoming more computerized and dependent on rapid access to computerized databases every day. Many projects are currently under way to provide an individual access to everything from newspapers to the Yellow Pages through electronic means.

The traditional means of information handling available to a blind individual have been paper Braille and audio cassette recordings. These methods will not compete with the electronic information systems available to sighted colleagues. Our electronic information system attempts to solve this problem. It takes advantage of current technology in microcomputers and mass storage media to provide an individual with a powerful and easy-to-use system. The system is designed to accommodate special devices for output, currently dynamic Braille displays and speech synthesizers. Another attractive feature of the system is its ability to connect to a standard computer terminal and provide access to the same information by both blind and sighted users.

The system also can communicate with other computers or devices using a serial interface: printers to provide a hard-copy output of any information within the system, other computers to provide information look-up capability or processing needs, and any other devices using the standard RS-232C interface.

SYSTEM DESCRIPTION

The hardware used for the information system is currently undergoing a transition from a minicomputer to a microcomputer. Since the project was started a PDP-11 running the UNIX Time-Sharing System(7) has been used to simulate the system.

More recently, a VersaBraille has been added to the system to provide a limited-feature portable system. A microcomputer system is currently being set up. Software developed on the PDP-11 will be executed on the microcomputer system.

The two main components of the microcomputer system are hardware and software. The hardware breaks down into processing hardware and hardware for input/output. The key elements of the processing hardware are central processor, main memory and mass storage. The elements of the input/output hardware are devices used to input information and devices used to "view" information stored by the system.

The central processor in our system is an Intel 8088 microprocessor(8), which we have found will execute C programs three to five times as fast

as other eight-bit microprocessors, and one-third as fast as the PDP-11/70 minicomputer.

The other important advantage of this processor is its ability to address up to a megabyte of main memory. The typical microcomputer system currently available is limited to 64K unless some form of bank switching is implemented. The drawback of bank switching is the requirement that the operating system have knowledge of the memory architecture. The implementation of bank switching often restricts a designer to a particular operating system.

The input/output operations are provided by either a VersaBraille from Telesensory Systems, Inc. or a TOTAL TALK speech terminal produced by Maryland Computer Services. Software modules are also included to allow connection of a standard computer terminal, giving a sighted colleague access to the information system.

The mass storage for the information system is provided by a combination of a Winchester technology hard disk drive and a floppy disk drive. The hard disk can store up to ten million characters. At present we estimate approximately half of this storage capacity will be occupied by the system.

The flexible diskette allows the user to remove infrequently used information from the system. In addition to expanding system capacity, the flexible diskette provides a means of making back-up copies of important information to protect against any system failure.

The other important hardware components of the system are those related to communications. These are the printer and a modem for communications over a standard telephone line. The printer will provide a high-quality hard-copy output of work performed on the information system. The modem allows the system to communicate with computers having similar communications facilities. In the future this capability will become more important with the increasing number of publicly available computer databases.

Possibly the most important element of the system is the software. The software must provide the user with a convenient interface to the system. Information on operating the system should be supplied by the system itself upon request. This "help" feature allows a novice user to sit down and, with a brief explanation, begin using the system.

The software must go as far as possible in anticipating errors the user might make. This anticipation might include the option of "undoing" the last action. In the area of system reliability the software must attempt to give early warning of any possible problems with the system. If a failure occurs it is important that the software be designed to continue to support a limited system that is guaranteed to be good, or to suspend system operation to avoid further damage. If some form of damage occurs to the information stored in the system, it is important that the software make all possible efforts to recover the information.

Currently, we are developing software based on the above goals. The programming is being done in a high-level language, C, to allow for efficient movement of the programs to the microcomputer from the PDP-11.

SYSTEM OPERATION

The system provides a wide variety of functions useful to an individual in both personal and office transactions. These functions include text entry and editing, filing of information under a number of headings, performing calculations, communicating with other computers, and acting as a controller for printers.

These functions are some of our initial ideas for applications. Our joint study with the Western Blind Rehabilitation Center at the Palo Alto Veterans Hospital will provide valuable feedback on the usefulness of these features, which are commonly found in computerized systems for the office of today. The following brief description of the preparation of a letter using the information system illustrates the efficiency gains it can provide.

Suppose a letter is to be written to Bob Smith. To do this one gives the command "start letter." The machine knows the general format of a letter, so much of the formatting can be done automatically. It will ask for the name of the addressee and the user responds, "Bob Smith." At this point the machine searches an address book stored on the system. If Bob Smith's address is located, the machine will fill it in. Otherwise it will ask for his address. Since the machine knows the address of the sender, the heading of the letter is now complete. The machine might also insert a salutation, "Dear Mr. Smith." It is important to note that the user may deviate from the standard format of the letter as established by the machine. It is possible to change parameters to make adjustments in the machine's idea of a letter format.

Once the user has typed in the body of the letter, the machine can automatically add the closing. Another command produces a printed copy of the letter.

Many other tasks can be performed by the machine with a similar increase in efficiency(9). Any task that has a repeated format can be handled easily and effectively by the system.

CONCLUSION

Although the technological advances of the past few years have included many gains in the capabilities of integrated circuits, there is a great deal of work to be done in the area of making information systems portable and also in making them useful to a non-technical person.

The near future will bring increased use of magnetic bubble memory and CMOS technology. Magnetic bubble memories will provide reasonably priced mass storage for portable systems.

The CMOS technology requires very little power consumption. When combined with large amounts of bubble memory, this technology can be used to implement nearly all the functions described in this paper in a portable system.

With the continued growth of the number of computers being used by non-technical consumers, manufacturers will work harder to make their systems easy to use.

In order to keep pace with these advances in hardware, we must concentrate on producing truly user-oriented software.

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TOYS, TEACHING AND TECHNOLOGY: A COMPUTERIZED EDUCATIONAL TOY FOR BLIND CHILDREN

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ABSTRACT

The Auditory Arcade is a computerized educational toy designed to help visually impaired children develop particular skills and concepts while enjoying playing a game. Auditory feedback in the form of tones enables the player to monitor his own performance. Because it has a modular design, new games may be added to the Auditory Arcade through interchangeable playing boards, or Problem Panels. This flexibility extends its potential as an educational or therapeutic tool to children with non-visual handicaps.

INTRODUCTION

In the wondrous world of childhood, the words "toy" and "game" are magical. They conjure up thoughts of fascination, intrigue and challenge which are so powerful that they can entice a misbehaving child into complete obedience. And in today's world of technology, some toys and games have an even more magnetic quality than those from the past. Their attractiveness is reflected in the brisk sales of hand-held electronic toys, and in the tenacity of young customers who are seen playing with larger units in stores and amusement centers by the hour.

Unfortunately, the joy which technology provides through toys does not extend to all youngsters. In fact, for some it has the opposite effect. For example, since most electronic games have visual displays of major importance to the playing procedure, they cannot be used by visually impaired persons. This adversely affects visually impaired children in two ways: (1) they form a set of devices with unrealizable potential to provide much enjoyment and education for this population, and (2) they add to the already long list of activities which separate visually impaired youngsters from their sighted siblings, friends and classmates.

The Rehabilitation Engineering Center at the Smith-Kettlewell Institute of Visual Sciences has many years of experience in modifying equipment and in fabricating new instruments so that blind adults can access information typically displayed visually. This is done by presenting the information as an auditory output, a tactile output, or a combination of the two.

Given the new need for blind children to also have non-visual displays in order to access devices, the Rehabilitation Engineering Center recently undertook a project to provide electronic games for blind children.

Because congenitally blind children experience developmental lags in particular skills, and because there are a number of skills of special importance to them, the decision was made to develop an electronic toy which would specifically address some of these special areas. The areas selected include fine motor control, familiarization with particular objects, texture matching and sequencing, auditory localization and tracking, spatial concept development (including some aspects of map reading), and auditory memory span.

In order to obtain the flexibility to address such a diverse list of skills and concepts, as well as to provide the children with a device capable of monitoring their performance, a microprocessor was needed. For still additional flexibility, the final plan depicted a game which was modular in design in that it would have interchangeable playing boards or "Problem Panels."

THE AUDITORY ARCADE

Fig. 1 shows the first model of the "Auditory Arcade"--a collection of games which provide auditory feedback in the form of tones and tonal patterns. The particular Problem Panel affixed to the Auditory Arcade in this photograph, the Manipulation Panel, presents 16 different manipulation tasks to the user. The tasks include pressing, snapping, screwing, threading, hooking, etc., with some of the problems requiring the use of only one hand and others demanding the use of both hands simultaneously. If some of the problems are too difficult for a user, they may be selectively eliminated from the Problem Panel. That is, while normally all 16 problems must be completed correctly in order to win a game, these particular tasks may be easily removed from the required set and thus ingnored by the user. This is accomplished through switches inside the apparatus.

Three Games for Each Problem Panel

The user can choose any of three games for each Problem Panel. The nature of these games is explained in terms of the Manipulation Panel for convenience.

Game 1: Familiarization. Game 1 allows the player to become familiar with the "manipulata" (which include both the hardware on the Manipulation Panel itself, and several loose pieces of hardware--"props"--which reside in a small container next to the Auditory Arcade), and the 16 tasks themselves. As is true of all of the games, the Auditory Arcade itself provides the user with the necessary feedback. In Game 1 the player is rewarded with a tone every time one of the 16 tasks is completed correctly. Each task provides a different scale tone. If the player performs the tasks in the sequence of left to right and top to bottom, he will produce two octaves of a major scale. This positive reinforcement gives valuable encouragement and practice to young children in working in the same sequence as required for reading, whether print or braille.

Because Game 1 imposes no time limits upon the player, he can familiarize himself with the manipulata and the tasks in a liesurely manner. Once he has done this, he is ready to attempt the more pressured situations provided by Games 2 and 3.

Game 2: A Race. Game 2 is a race between the player and the microprocessor, each represented by a different speaker within the Auditory Arcade. The speaker under the control of the microprocessor acts as an auditory clock by presenting two octaves of a major scale in a slow, even sequence of tones. (The player may choose one of three rates for the auditory clock prior to starting the Game). The speaker under the control of the player produces the same tonal sequence, but the tones advance only when the player correctly completes a task plus presses an "enter" button. Thus, it is a race to see which speaker completes the two octaves first. For the player, this means completing all 16 tasks within a given time period. If the player is successful he is instantly rewarded with a "win" tune; if the microprocessor completes its two octaves first, however, a "lose" song is heard.

Game 3: A Race Involving Chance. In Game 3 only four tasks need to be completed within a given time period for the player to win, but part of the problem is determining which four. The tasks to be completed are "chosen" randomly by the microprocessor with the restriction that they must be in a single line, that is, in one of the four columns, one of the four rows, or one of the two diagonals on the Problem Panel matrix. The player locates one of the four correct tasks simply by trying various problems until he hears a little tune informing him of a correct choice. He must then learn which of the various other problems in line with that one form the remainder of the correct set of four. Because the actual spatial relationships among the 16 tasks are involved in Game 3, both chance and logic are introduced in this mode.

The auditory clock used in Game 3 is different from that of Game 2. It marks time with a brief intermittant tone. The space between tones is initially quite long, but eventually decreases to zero so that a single long tone is heard. To elicit the "win" song the user must complete the four required tasks before this long tone can be sounded. If he fails to do so, the "lose" song is presented. As with Game 2, the user may set the auditory clock at any of three different rates before starting to play.

Response to the Auditory Arcade

The Auditory Arcade has generated much enthusiasm from a large number of rehabilitation and special education professionals, as well as visually impaired consumers. The flexibility of the device seems to be an especially appealing feature, and many professionals have pointed out the potential for this device to benefit not just children with visual impairments, but also children and adults with a wide variety of different types of handicaps and combinations of handicaps. For example, even as the Auditory Arcade is pictured in Fig. 1 with the Manipulation Panel, its potential as a therapeutic aid for persons with motor problems involving the hands is evident. And since Problem Panels can be custom designed, tasks of particular therapeutic value for particular individuals could be fabricated.

Another possible application for the Auditory Arcade is to help teach youngsters with learning disabilities to sequence information in specific ways. The microprocessor and interchangeable Problem Panels allow the device to address tremendously diverse situations.

Future Plans

New Problem Panels to address a multitude of problems will be designed. Fabrication of the next Problem Panel--the Texture Panel--is already well under way. It will display 16 different textures on the playing surface, and the same 16 will be contained in a box adjacent to the Arcade. In addition to the obvious task of matching textures, this Panel will also require some tasks of a more cognitive nature: (1) texture sequencing according to roughness and (2) learning the names of the textures and then ordering them alphabetically. The player will indicate his sequencing answers by pressing the fabrics, and these responses will be conveyed to the microprocessor via contact switches.

Still other Problem Panels will be fabricated to meet the educational or therapeutic needs of particular handicapped individuals.

SUMMARY

Although technology has served to increase the isolation of blind children by presenting more and more fun-to-use educational electronic devices to their sighted peers, this need not be the case. By fabricating devices with non-visual outputs, visually impaired children can also reap the benefits of modern technology. The Auditory Arcade, a computerized game developed at the Rehabilitation Engineering Center at the Smith-Kettlewell Institute of Visual Sciences, is specifically aimed at helping blind youngsters enjoy themselves while developing skills and concepts of special importance to them. In addition, the flexibility built into this device makes it a potential educational and/or therapeutic tool for children with other types of handicaps.

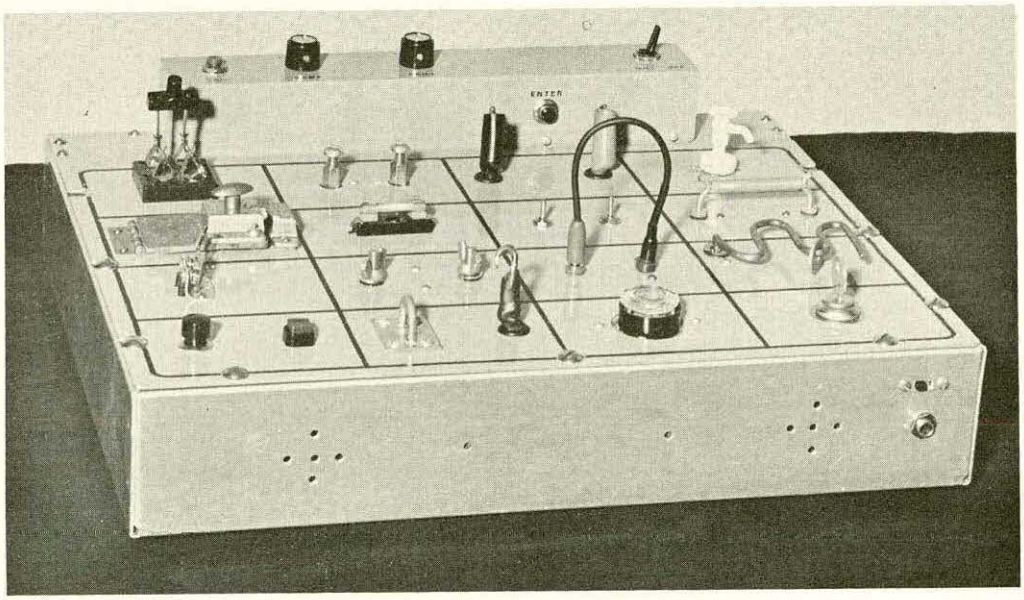

Fig.1 The Auditory Arcade - A Computerized Educational Toy for Blind Children

MEASURING PERFORMANCE BY BLIND TRAVELERS

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ABSTRACT

While training and the use of electronic mobility aids have increased the mobility of blind pedestrians, large-scale improvements in travel performance are dependent upon an understanding of the cognitive and sensory bases of mobility. Such an understanding requires in turn a quantifiable measuring system of that performance to successfully analyze blind mobility. Position and position-derived measures of travel behavior were instrumented and tested. Derivatives of position measures (distance, speed, and acceleration) were found to differentiate between trained and novice cane users, indicating their viability as performance measures.

INTRODUCTION

Improvements in training methods or electronic travel aids require a better understanding of the mobility process of blind travelers. Increased knowledge of this process can be obtained by studying the tasks performed by blind travelers, the information they need to perform them, and the perceptual and cognitive abilities they employ to acquire and use that information. To do this, we must be able to assess the performance of visually handicapped travelers objectively and quantitatively (1,2,3).

Previous attempts to measure performance by blind travelers have concentrated on the safety, efficiency, and stress of the pedestrian (1). Safety measures included number of bodily contacts with obstacles; departures from the travel path; and problems with crossing streets.

Measures of efficiency included: overall travel time; continuity of travel; and variation in pavement position. The pedestrian's average walking speed was calculated from the length of the route and the overall travel time. Continuity of walking was estimated from the ratio of the amount of time spent actually walking to the total time on route. This ratio was called the productive walking index (PWI). If a person walked continuously with no stops then his PWI was 1. As the amount of time he was not walking increased, his PWI would decrease below unity.

Measures of stress in blind pedestrians concentrated on physiological indicators such as heart rate. There was a failure to establish a correlation between instantaneous heart rate changes and any specific environmental events, making this a relatively uninformative measure for the mobility task. This failure is due to the influence on heart rate of factors, such as work load, unrelated to cognitive or emotional processes.

The performance measures of safety and efficiency have proven useful in assessing the pedestrian's performance during training or with certain mobility aids. However, they reflect the person's overall performance and do not reveal responses to particular environmental variables. If the mobility process is to be studied in detail, performance measures should be continuous, allowing correlation with subtle changes in the pedestrian's environment.

The purpose of this project was to develop measures of performance for blind travelers which meet this criterion and also allow estimation of the traveler's safety and efficiency. Measures of position and position derivatives (speed and acceleration) were considered. Determination of the pedestrian's position with respect to objects in the environment and the intended travel route contributed to measures of safety (obstacle contact) and efficiency (departures from intended route). The derivatives of position such as velocity and acceleration provided an index of the smoothness of travel.

THE MEASUREMENT SYSTEM

The position measuring system consists of a matrix of electrically conductive tape placed upon the floor. The strips of conductive tape are placed four inches apart. The pedestrian has a piece of conductive material attached to the sole of one shoe. As that shoe hits the floor, the two axes of the matrix of conductive tape are connected. A special-purpose electronic circuit determines the pedestrian's position from the particular pair of intersecting tapes contacted at each footfall. The circuit provides the

coordinate in both analog and digital formats.

The coordinates of each footfall are recorded along with the time of occurrence relative to the previous footfall. The position measure gives a direct indication of the pedestrian's proximity to objects in the travel space, as well as their deviation from the intended path. The pedestrian's instantaneous velocity is obtained from the first derivative of position. This is estimated from the ratio of the distance traveled in one step to the time required to travel that distance. Instantaneous acceleration is obtained as the first derivative of instantaneous velocity in a similar manner.

PRELIMINARY RESULTS

In order to be useful for future studies of blind mobility, the measures of position and stride length must be sensitive to factors influencing the pedestrian's mobility. A gross measure of this sensitivity was made by comparing the position measures (position, velocity and acceleration) for two groups of blind pedestrians. Both groups used the long-cane travel aid. One group was experienced users of the aid and the other was novice users. Both groups were selected from trainees at the Central Blind Rehabilitation Center.

With the matrix for position measurement system we have a method for reliable and accurate measures of a pedestrian's position, walking speed and rhythm. These measures appear adequate to discern between trained and untrained pedestrians.

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A SYSTEMATIC APPROACH TO EVALUATING PHYSICAL ABILITY FOR CONTROL OF ASSISTIVE DEVICES

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ABSTRACT

When disabled individuals consider using assistive devices for mobility, communication or for controlling their environment, an interface must be identified that will provide the necessary control. A systematic approach and theory to interface assessment have been developed and used at the Assistive Device Center at California State University - Sacramento and the Rehabilitation Engineering Center at Children's Hospital at Stanford. The procedures of an interface evaluation can be described in three steps: the control site selection, the interface selection and the comparative testing of the control site and interface combinations.

INTRODUCTION

Assistive devices for communication or control applications require an interface by which the client can interact with the device. Many types of interfaces (switches, keyboards, joysticks, etc.) are available and this makes the selection difficult. Generally either a totally intuitive (limited only by imagination) approach is taken or the matching of client needs to an interface is determined by those types available in the specific clinic. Although overall assessment strategies are beginning to emerge(1), no general methodology exists for determining which interface to match to which client. The major objective of this paper is to describe an approach to and theory of interface assessment that has been developed over the past several years. There are three major steps of interface assessment: control site selection, interface selection and comparative testing of a set of control site/ interface combinations (Figure 1). We will describe both the theoretical considerations and the application of these with actual clients. The methods describe here have been used with over 150 Clients.

CONTROL SITE SELECTION

The first step in the determination of the interface/control site combination is the determination of appropriate control sites. We define a control site an anatomic site with which the person demonstrates purposeful movement. The degree to which a person can carry out this purposeful movement is termed the controllability of the site. Sites with the greatest controllability are thus preferred over those with less controllability. Therefore the first stage of an interface evaluation is to rank the person's anatomic sites in terms of controllability.

There is an inherent ranking of controllability based on the functions for which various anatomic sites are best suited. Since the interaction between the person and the device involves relatively fine manipulative control, we have determined an hierarchy of control sites. The hand and fingers are favored because they are typically used for manipulation. If the hand is not controllable, then the use of gross head movement (chin movement, tilting of the head, etc.) should be considered. Head movement can also be tapped using attachments such as head pointer or light sources. This can provide finer control by improving resolution. For some persons the foot provides a viable alternative due to this capability for fine control. The arm and leg are less desirable because their primary function is gross motor movement.

In the case of neuromuscular disability, this hierarchy may be significantly altered. The inital step is to ask the person which anatomic sites are the most controllable. For any given anatomic site, the first parameter to be measured is the range over which the perons can exert voluntary control. Involuntary reflex patterns may preclude certain movements. Also, an individual's range may be reduced by an inability to cross the midline. For the limbs this can be accomplished using a simple board with target locations. By asking the person to point to certain locations, an indication of ability to initiate, track and terminate a movement in a controlled manner may be determined. If, the exercise relatively fine movements in a given spatial location can be determined by having them touch the corners of the square successively. The purpose of these techniques is to determine gross range and the person's ability to function in various locations. This results in a functional definition of the person's workspace. There are many other techniques that yield this same result. For the head, range can be measured in both vertical and horizontal directions. There ability to tilt the head to the left and right can also be determined in degrees. This measurement should also take into account any restraints to head movement such as head rests.

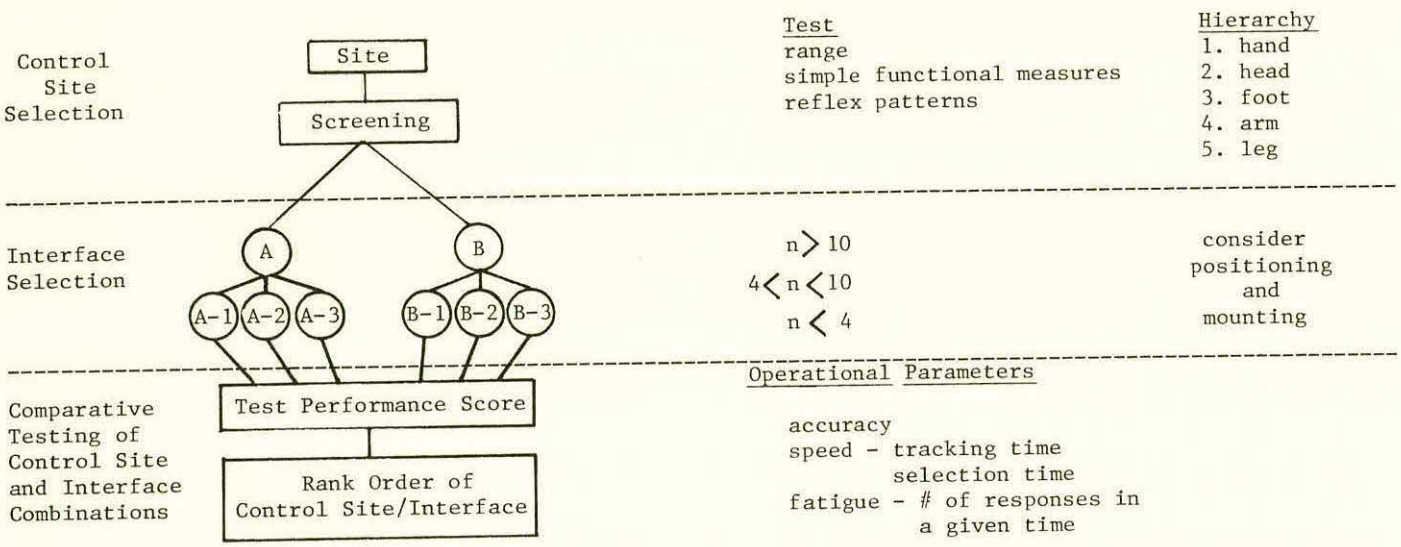

FIGURE 1: INTERFACE ASSESSMENT

A measure of controllability is the degree to which an anatomic site can be used to complete functional tasks. An advantage of these types of tasks is that they are goal-directed. This may make it easier for the person to complete the task in a controlled manner than if a strictly physical measure were used. For example, hand function can be evaluated using functional grasps. The skills required for the grasps are the same as those required for many interfaces. Functional tests of ability to blow or sip through a straw can be related to the use of pneumatic switches. Other functional tests can also be developed for additional parts of the anatomy.

The outcome of this phase of interface assessment is a set of anatomic sites over which the person has control. The controllability of each site relative to the others should also be noted.

INTERFACE SELECTION

Given the set of control sites, we must determine the manner in which they can be used. This is the process for determining a set of interfaces for each control site. A basic consideration is the number of independent outputs that can be generated with one interface/control site combination. For example, a keyboard provides many different outputs all of which are generated by the hand/finger control site. Another basic consideration is the speed of selection possible with a given interface type. For example, a sequential access system utilizing a single switch is inherently slower than the keyboard for the same number of outputs. These considerations and others led us to define the flexibility of an interface in terms of the number of independent outputs that it provides. Based on this flexibility criteria, the three ranges shown in Table 1 can be used to determine the desirability of an interface. Four or fewer outputs from an interface dictate that either only a few commands be generated (such as in wheelchair control with a joystick) or that a sequential access approach be used for larger arrays of commands or vocabulary. Either single switches or switch arrays (including joysticks) fall in this category. Range required is small and the resolution may be relatively gross. For many encoding systems a numeric keyboard may be used. This requires 10 outputs and is slightly faster than a sequential selection system. These interfaces are typically small keyboards requiring small range and fine motor control. The most desirable type of interface is one with more than 10 outputs, preferably a full ASCII keyboard. This requires large (relatively) range and fine motor control.

	Range	Resolution
$n > 10$	large	fine
$4 < n < 10$	small	fine
$n < 4$	small	gross

TABLE 1: NUMBER OF INDEPENDENT OUTPUTS BASED ON PHYSICAL ABILITIES

These considerations apply to all controllable sites. for the head, for example, a headpointer may be used to access a keyboard. Likewise, the foot can be used with a joystick. Single switch control is possible with many anatomic sites.

A crucial aspect of the interface is its proper location in the workspace so as to be easily accessible to the chosen control site. This problem must be addressed during the interface assessment in order to insure that a chosen interface/control site combination will actually be useable. If an interface is merely held by the tester for the person to use, there may be unnoticed compensation for poor client performance. On the other hand, if the interface is fixed in the workspace, then the degree to which the client can control it will be independent of the tester.

Feedback to the user from the interface plays a major role in the success or failure of any interface/control site combination. Two kinds of

feedback may be distinguished: environmental and performance. Environmental feedback is via visual or auditory channels. For interface assessments, lights, tones, alpha-numeric LED's, video monitors and printers all play the role of providing environmental feedback. Performance feedback refers to those properties of the interface that provide tactile, proprioceptive or kinesthetic input. In general, the greater the performance feedback the better. Unfortunately, the amount of force necessary to activate a switch, for example, is higher for a switch with good tactile and proprioceptive feedback. This there are tradeoffs between the degree of feedback provided by the interface and the ease of operation.

All of the tradeoffs must be addressed when selecting a switch or group of switches for further evaluation. The client's preference may be a major factor in helping to make this choice. When this phase of evaluation is completed, there will be a group of candidate interface/control site combinations that can be further evaluated to determine a final recommendation.

COMPARATIVE TESTING OF CONTROL SITE AND INTERFACE

Having determined a set of control sites and corresponding interfaces, it is possible to quantitatively evaluate them against each other to select the "best" interface/control site combination. The quantitative measures that are most useful are those that are derived from functional tasks. One major method of quantifying performance is to measure track and select time using a given interface/control site combination. Tracking time is measured from the person's rest position to the successful activation of the interface. Some physically disabled person may have a great deal of difficulty getting to a switch, but they can easily select between two or three switches located in close proximity. For this reason, we also measure the select time: the time necessary to move between two interfaces located close together. For example, a client may be asked to type a set of characters on the keyboard. If the time to type one letter is not significantly shorter than the time to type three consecutive keys, then the tracking time must be minimized. This can be accomplished through stabilization or through proper location of the interface in the workspace.

A second type of quantitative measure is accuracy. This typically involves a determination of number of errors made in selecting an interface output. With a keyboard, it would be the number of incorrect keys typed. With a joystick,it would be the number of times that incorrect directional response was made. For a single switch accuracy may be related to the ability of a person to maintain the switch closed until told to release it or to avoid closing it until told to do so. Alternatively the ability to hit a switch a set number of times in succession can be used to determine accuracy.

Accuracy and speed can be combined in measures such as corrected rate. In this case the erroneous selections of an interface are subtracted from the total number of selections made in a given amount of time. This gives a lower rate for the corrected version than for the uncorrected one.

The number of responses that can be elicited in a given amount of time can be related to both fatigue and short term learning. If the number goes down then fatigue is a probable factor. If, on the other hand, the number rises then learning may be occurring. Obviously, other factors may also influence these results.

At each stage of this assessment, it is necessary to obtain the client's imput regarding which interface is preferred. Often, the amount of feedback provided, the force required or the amount of movement necessary to activate the interface will make one choice more desirable than another for a client. In other cases, no clear preference will emerge and the quantitative measures will form the basis for a choice. In any case a set of interface/control site combinations should be specified. There should, however, be a priority listing. This is important in case the first choice doesn't actually fit the need when connected to the device or there is a change in seating, etc. Having second and third choices can be extremely helpful when doing a final fitting of client to device. It is also very important to document the mounting used for the interface/control site during the assessment so that it may be repeated.

SUMMARY

The interface assessment is only one portion of a total assessment battery. Following the determination of a ranked ordering of interface/control site combinations,additional information must be collected to insure that that the individual will in fact be able to use the interface to control the device. For example, the cognitive demands of row/column scanning may be too high for a specific person. In this case, he or she would be unable to use a sequential access system even though several single switch interfaces may have been found to be suitable. Other factors of importance are cognitive and language abilities (spelling for example), sensory abilities and environmental considerations.

The interface assessment presented here does provide a logical approach to the determination of a control site/interface combination. This step must necessarily preceed other aspects of the total assessment.

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ACKNOWLEDGEMENT

This work was partially supported by the Office of Special Education, U.S. Department of Education under Grant # G007902261 and National Institute of Handicapped Research, U.S. Department of Education under Grant # G008005817

A VOICE-OPERATED RESPONSE UNIT FOR USE IN PSYCHOLOGICAL ASSESSMENT OF MOTOR IMPAIRED PERSONS

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ABSTRACT

Many patients in rehabilitation settings have insufficient hand function to complete machine scorable mark-sense answer sheets. A number of standardized psychological tests use such sheets, e.g., the Minnesota Multiphasic Personality Inventory (MMPI). Reading personality test items to patients and the examiner recording responses is neither cost-effective nor a valid method of test administration. We are in the process of developing a voice-operated response unit (VORU) which will allow patients without sufficient hand function to take standardized psychological tests originally designed as paper-pencil measures.

INTRODUCTION

There is increasing interest today in the psychological aspects of physical disability. Pre-morbid personality factors often prove to be more limiting than physical deficits in ultimate rehabilitation success. The tools most commonly used by psychologists in personality assessment are the clinical interview and the Minnesota Multiphasic Personality Inventory (MMPI).

The MMPI is a true-false paper-pencil test consisting of 566 items. It is designed to be self-administered, and takes 1-3 hours to complete. While other psychometric instruments are used in the rehabilitation setting (intelligence tests, for example), the MMPI is the test of choice in personality assessment. No other personality assessment tool is better standardized, has had more research about it published, or generates more research data than the MMPI(1).

MMPI data are not, however, obtained at many rehabilitation centers from quadriplegics and/or other patient groups for whom the ability to make small, accurate pencil marks is impossible (Guillain Barre, some CVA, CP, MS). This important source of both clinical and research data is, therefore, not available because reading items to clients invalidates the test and is time prohibitive. A voice-operated response unit for answering the MMPI questionnaire would, as much as possible, mimic standardized MMPI administration procedures. It would also make the gathering of MMPI data time-feasible for the clinician/researcher. In addition, the patient would be participating in a procedure which is admittedly intrusive (personality testing) but which would not be additionally frustrating (e.g., using a mouth stick to operate toggle switches). Patient cooperation would likely be greater, making results more valid. In addition, other psychological tests could be interfaced as well; e.g., the Handicapped Problems Inventory, data from which are not presently being gathered from patients with hand limitations.

METHODS

A voice recognition unit interfaced to a commercially available micro-computer will be used to receive the voice input (Figure 1). Prior to use, the subject will "train" the micro-computer to his/her voice for a specific set of appropriate words, e.g., "True," "False," etc. The micro-computer will then present questions one at a time on a CRT screen and evaluate the subject's voice response to each item. Immediate feedback will be provided to the subject to insure that the computer interprets each response correctly. At the end of the session the stored responses will be subjected to a preliminary analysis by the micro-computer, as well as a more detailed analysis by a larger, remote computer, in this case, Spain Rehabilitation Center's PDP-11/40. Access to the remote computer will be via communication line with the micro-computer acting as an automatic data entry terminal.

PRELIMINARY RESULTS

We are in the process of refining the software and hardware aspects of our system. To date, a number of volunteers have taken the MMPI via the voice-operated mode. Most have had little difficulty and have subjectively reported a pleasant experience. We are considering alternative voice recognition hardware units in an attempt to maximize voice signal recognition accuracy. We anticipate completion of this project by August, 1981 as scheduled, at which time final hardware/software configurations as well as the effect of the voice-operated response mode on MMPI profiles will be available for publication.

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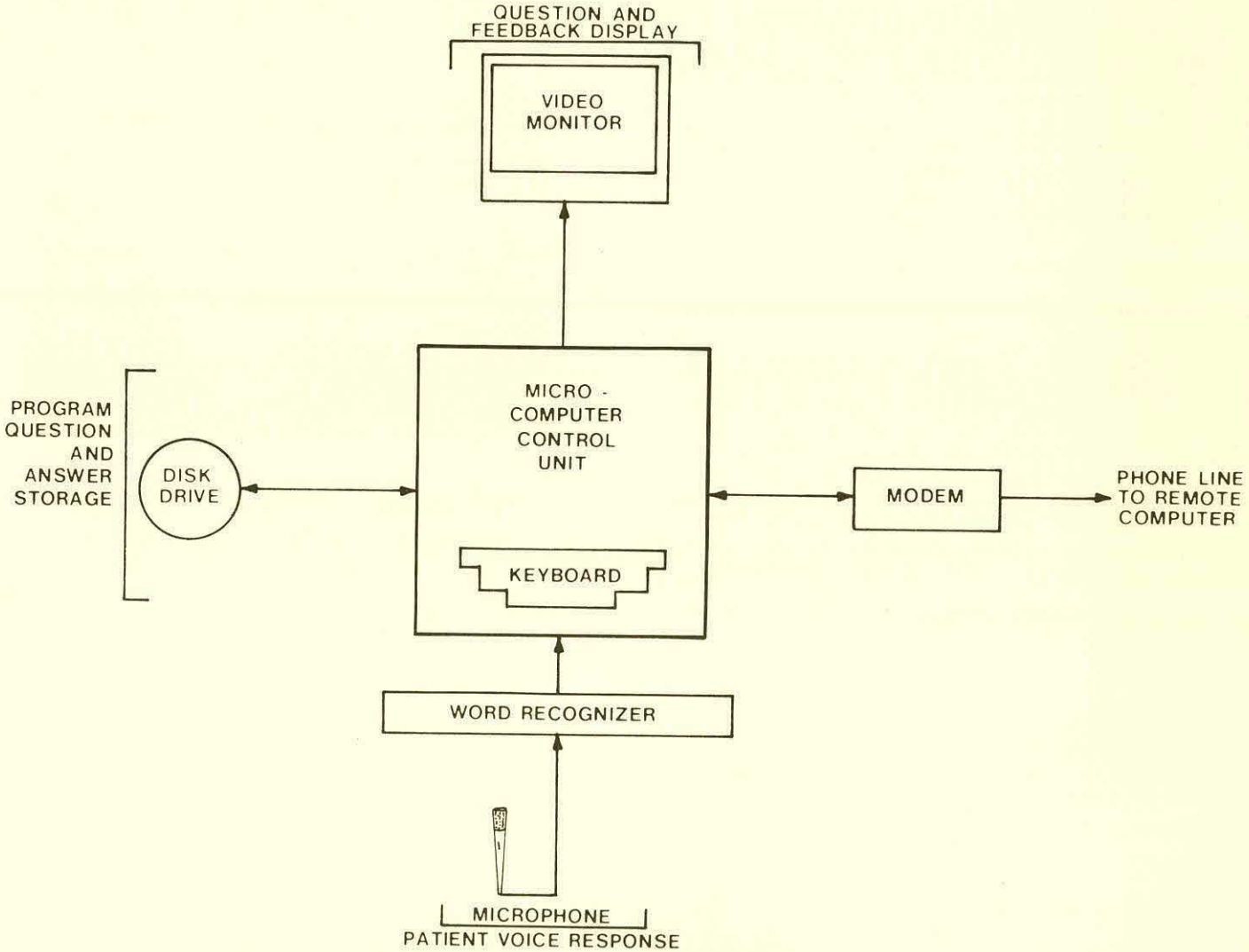

FIGURE 1. VOICE RESPONSE UNIT FOR PSYCHOLOGICAL TESTING.

A MICROPROCESSOR BASED UPPER EXTREMITY PLACEMENT TRAINER

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ABSTRACT

A microprocessor based upper extremity placement trainer has been developed to train spatial orientation and upper extremity limb placement in patients with motor and/or perceptual deficits, and to quantitate range of motion and speed and accuracy of movement. The device uses an array of 49 glass squares in a 7 X 7 matrix on a special adjustable table which can be positioned in front of the patient in either a vertical or horizontal plane. The squares are lit individually under program control and are sensitive to touch. In operation, the device lights a square and the patient is required to reach out and touch that square within a predetermined amount of time. The total correct and incorrect responses, average response times, average number of guesses per square and the patient's range of motion are calculated by the device. Preliminary evaluation of the trainer is encouraging and suggests that many different classes of patients may be able to benefit from treatment with the device.

INTRODUCTION

The rehabilitation of the neruologically impaired patient is a difficult process and requires a tremendous amount of therapist attention. An automated device has now been developed which can both quantitate a patient's upper extremity motor control and train for that control. The device provides treatment of upper extremity placement via a motivating, multi-dimensional motor task that has the additional benefit of reducing the time requirement for therapist supervision.

MATERIALS AND METHODS

The Upper Extrmeity Placement Trainer presents the patient with the task of sequentially placing his upper extremity in different prescribed positions in space. This is achieved by placing the patient in front of a special matrix of squares which light one at a time in random fashion, and which can tell a controlling device which squares have been touched. The patient's ability to reach out and touch the appropriate squares is determined and a simple quantification of his or her motor control is available to the therapist during and at the end of treatment.

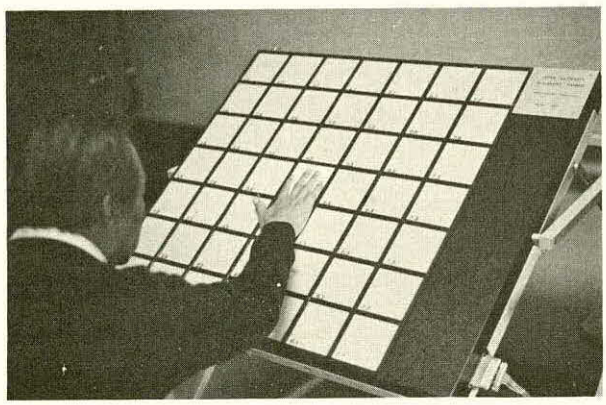

Fig. 1 The Upper Extremity Placement Trainer in the clinical setting.

The trainer is based on the Motorola 6800 microprocessor and consists of two components: a light board which can be positioned in any plane in front of the patient, and a small controller box. The light board is a 7 X 7 matrix of 4 inch by 4 inch glass squares (Fig. 1). These glass squares are coated with a tin oxide coating and thus are electrically conductive but still retain their

transparency. Located behind each square of glass is a light bulb that can be switched on or off by the controller. The glass squares are electrically connected to the control inputs of 49 F.E.T. switches which are activated when the patient, wearing a conductive plastic strap, completes a low current circuit (I < 0.1 uA). In this manner, the controller can determine exactly which square the patient touches. The therapist can additionally require which part of the patient's hand must contact the glass squares by using gloves with, for example, one finger removed. This would require the patient to not only contact the proper square, but also to maintain a particular hand orientation while performing the task. The light board is mounted to an adjustable-height table which can allow patients in wheelchairs easy access to the device.

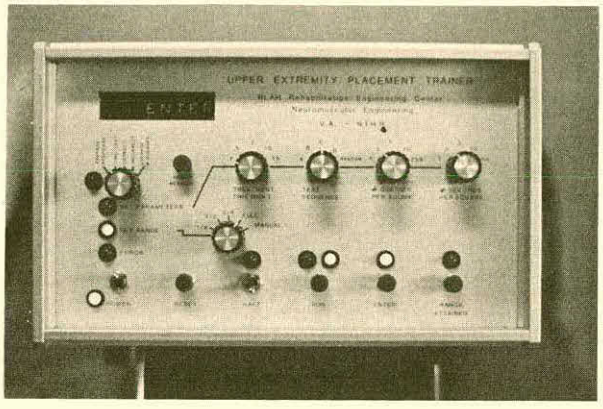

Fig. 2 The front panel of the controller box. A message display is at the upper left corner.

The controller, Fig. 2, has an eight character alphanumeric message display used to indicate scoring information and also to prompt the therapist on exactly how to use the device. The function of the front panel switches could best be explained by a description of a routine treatment session.

Upon power up, an auto-restart circuit starts the control program and the device conducts a diognostic test of its memory and peripheral devices. When this is completed the device informs the therapist via the alphanumeric display that the tests are complete and to press the RUN button to start operation. LEDs (light emitting diodes) next to the switches indicate which functions are operable. When the RUN button has been pressed, the device instructs the therapist to enter the range of squares to be used for the treatment session. Five settings are available for either left or right extremity tests: 1/4, 1/2, 3/4, Full range, or Manual selection of range. In the manual selection of range the therapist can select any of the 49 squares to be active in the test simply by holding the patient supply strap in one hand and touching any squares desired. The squares chosen will flash until the ENTER button is pressed. This is particularly useful if a patient has a unique range of motion not suitably tested by the pre-defined ranges.

After the range has been selected and the ENTER button has been pressed, the device will request that the therapist set the four remaining parameter switches: Treatment Time, Test Sequence, Number of Guesses per Square, and Number of Seconds per Square. The Treatment Time is selectable from 2 minutes to 15 minutes. The Test Sequence selects either one of four known starting locations in a table of 1024 random numbers corresponding to the coordinates of the glass squares, or a random starting location within that table. The known sequences would be used in evaluating patient progress and the random setting would be used in the normal treatment of patients so that there wouldn't be any chance of a patient memorizing a test sequence. In operation, the device chooses a square to light from the random table and checks to see if that square is within the active squares specified by the range switch. If not, it selects the next random number. If the number is valid, it lights the appropriate square and waits for the patient to make a response.

The remaining two parameter switches determine how long it waits before going to another square. The Number of Guesses per Square setting determines how many squares the patient may incorrectly hit before the device selects a new square. Five choices are available: 1, 3, 5, 7, and Don't Care. In like manner, the Number of Seconds per Square setting also determines how long the device will stay at a particular location before selecting a new square. Five settings are available: 1, 3, 5, 7 seconds, and Indefinitely.

If for some reason a switch is not functioning properly, there are built-in diognostics which will inform the therapist of the problem and what assumptions it is making about parameter values so that the machine may still be

used. If there is a malfunction that it cannot accomodate, then the device will tell the therapist whom to call to obtain service or advice. The messages sent to the threapist can be repeated if missed, or deleted entirely for faster setup of the machine.

Once all of the parameter switches have been set and the ENTER button is pressed, the device instructs the therapist to ready the patient and to press the RUN button. When RUN is pressed, the device starts to light up one square at a time and monitors patient responses. During treatment, the display can be set to show either treatment time counting down, the average number of guesses per square, the average response time of the patient, or the total number of correct or incorrect choices made by the patient depending upon the position of a display select rotary switch. When the treatment is over, the active range of the patient is shown by flashing of the squares which the patient was successfully able to touch. These statistics can be recorded by the therapist on a special form to document patient progress.

The control program for the trainer is stored in 5 kbytes of EPROM memory including the table of 1 kbyte of random numbers. All of the front panel functions of the controller box are handled by two 8 bit data ports, and the lights and switches of the light board are handled by an additional four 8 bit ports. All of the control, data and power lines to the light board are made with one cable, so the device is very simple to setup.

SIGNIFICANCE

The quantification of upper extremity movement is very desirable though difficult to achieve. The Upper Extremity Placement Trainer attempts to assess patient control of extremity placement via a simple task. Horizontal and vertical plane extremity placement can be measured and the speed and accuracy of the placement process are additionally measured. The trainer is currently being evaluated on the stroke and head injury services of Rancho Los Amigos Hospital and has been enthusiastically accepted by the therapy staff and patients. The device is simple to operate, monitors its own operation, and even therapists without a formal introduction to the device can operate it properly owing to the prompting messages displayed. It is believed that a number of different classes of patients will benefit through use of the trainer and that more accurate quantification of motor control of the upper extremity will now be possible.

ACKNOWLDGEMENT

This work was sponsored in part by NIHR grant 23P-55442/9-09 and VA grant V600P1064-79.

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MICROPROCESSOR BASED ASSESSMENT OF CONTROLLER INTERFACES FOR DISABLED USERS

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ABSTRACT

A computer-based evaluator of controller interfaces for disabled users is described. The system can be used to assess user/switched interfaces independent of the device to be controlled. This permits the evaluation of interfaces between users and communication aids, environmental or powered-wheelchair controllers. A case study is presented and discussed with an indication of further pertinent steps.

INTRODUCTION

The Mobility Interfaces Programme at the Ontario Crippled Children's Centre (OCCC) is directed towards the achievement of independent powered mobility by those children too severely handicapped to operate conventional control systems with commercially provided electrically powered wheelchairs. Persons with cerebral palsy, muscular dystrophy, spinal muscular atrophy, traumatic spinal injury, arthrogryposis and multiple sclerosis are served by controls which range from simple switches to head-position controllers and special electronic touchplate systems. The determination of an appropriate controller and its positioning in relation to the person is decided upon by a multidisciplinary team. The subjective trial and error approach of the present and usual assessment procedure motivated the development of a user/controller-interface evaluation system.

DESIGN CRITERIA

The objectives were to produce a system wherein:

i) The device user could be assessed using any one of a variety of controllers such as gated joysticks, touch-plates and head-position detectors.

ii) The task would be presented to the user in a visual and readily understandable form.

iii) Performance data could be easily collected and stored for later analysis and display.

iv) There could be flexibility in making adaptions to incorporate new criteria which might result from experience gained with usage of the system.

v) Minimal instruction of the user would be required prior to testing.

iv) There would be no need for a powered wheelchair as part of the system. Assessing the user/controller interface in this way eliminates the influence of sensation relating to wheelchair movements, thus ensuring that there is a focus on evaluation of the ability to effect control.

vii) The visual display should provide positive reinforcement of task performance.

The latter two criteria become more important if the system is to be used as an aid for training potential powered wheelchair users with comprehension difficulties.

SYSTEM COMPONENTS

The need to maintain a flexible and easily adaptable configuration during development of the evaluation system, together with the need to store and conveniently analyse performance data initially ruled out construction of an analogue or dedicated microprocessor system.

A readily available general purpose Tektronix 4052 computer with graphics capability was used. The system ultimately realised is easily transported on a mobile base. It incorporates analogue-to-digital (A/D) convertors, a digital input/output port, floppy disk drive, and 32K of memory.

IMPLEMENTATION

Figure 1 depicts the computer-generated display for the user. A circle represents the driving area. In initiating the program test, an arrow at the centre of the circle can be pointed in a pre-selected direction. This arrow then simulates the user's position in the circle. Directions on the screen are presented such that left and right to an observer facing the screen are maintained on the corresponding sides, while forward and reverse respectively are represented by the top and bottom of the screen. A target for the user and represented by a kink in the circle boundary is preset together with the selected direction. The system ensures that the arrow moves towards the target only if the controller is correctly positioned, thus presenting positive rein-

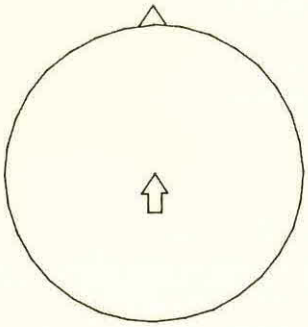

Figure 1: Computer generated simulation presented to the subject during a test.

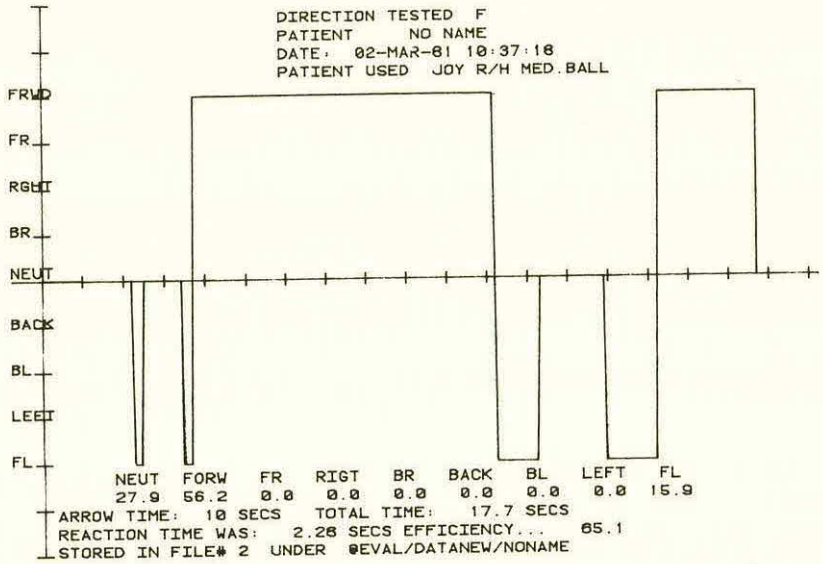

Figure 2: Typical graphical representation of results of a test immediately following test completion.

forcement for the user. A variable in making an assessment is the time scale (arrow activation time) in which the arrow traverses the distance from the origin (centre of the room) to the target. Setting this variable determines the total accumulated time the controller must be positioned in the correct way before the test is completed. This value is nominally set at 10 seconds.

Any switched interface system can be assessed. Typical types with which we have experience are: an eight positional joystick, five capacitive touchplates, and a head-position detector.

A universal plug, incorporated in a junction box situated between the interface and the digital input/output port of the computer enables connections to be made to any one of these interfaces.

DATA RECORDING AND DISPLAY

If the controller signals a position other than that being tested, the direction is recorded and the arrow remains stationary. When the controller is correctly positioned, the direction is recorded and the arrow redrawn so that it appears to the user to be moving towards the target. This procedure is repeated until the target is reached.

Data from each trial run are displayed graphically as shown in Figure 2. Directions are reflected on the vertical axis. The horizontal axis corresponds to the neutral position and also represents time in second increments. The display dynamically accommodates to the time duration of a test within the same horizontal distance on the screen. Numerical values calculated and displayed on the screen are: the percentage of time spent in each direction, (B(i)), total elapsed time, (t_t), reaction time, (t_r), and efficiency, (E), together with pertinent user information as shown in the figure.

Efficiency, E, is defined as:

$$E = \left(\frac{t_a * 100}{t_t - t_r} \right) \left(1 - \frac{\sum_{i=1}^{8} B(i)}{B(j)} \right)_{i \neq j}$$

where:

t_a = arrow activation time
t_t = total elapsed time
t_r = time from start of test to initial activation of the interface (reaction time)
j = tested direction
B(i)= % of time spent in direction i

It should be noted that E incorporates a measure of the user moving in directions away from the target. Thus a negative value of E signifies that the user is further from the target than when he first started moving.

CASE STUDY

A pilot experiment with an 18-year old male, D.B., with severe cerebral palsy with spastic quadriplegia and athetosis was undertaken. D.B. had been provided with a powered wheelchair and a Blissymbol board on his laptray. A joystick had been positioned on his left side such that it protruded 10" above the tray (position 1, Figure 3a). Activation of the joystick was to be achieved by D.B. arcing his left arm thus causing his hand or wrist to collide with the joystick. He then had to slide his hand down towards the tray while grasping the joystick. A single baseline measurement was made in which the forward direction was tested. It took D.B. 144.5 seconds to perform the 10 second test with an efficiency of - 40.38%. Table I summarizes the test results. The 10" joystick was then replaced by a 3" rod with a 1.25" diameter knob at the top. No improvement in performance was noted. Locating the joystick between the subject's knees produced similar results (position 2, Figure 3a).

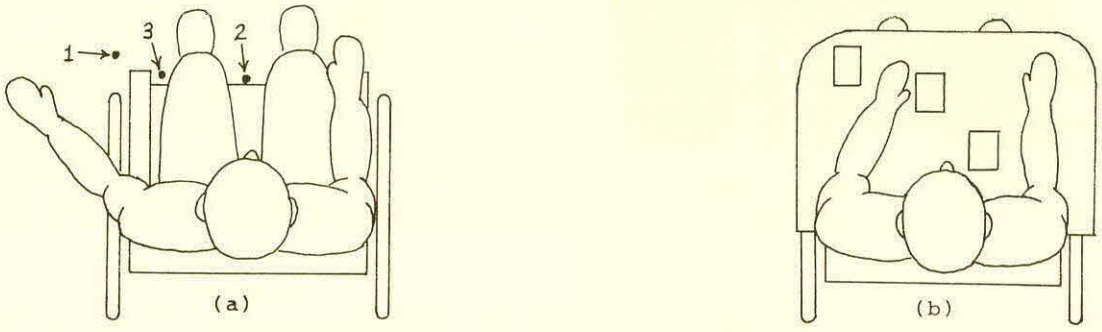

Figure 3: Positioning of interface controllers for subject D.B.

CONTROLLER	TOTAL TIME (SECONDS)	REACTION TIME (SECONDS)	E (%)	$\bar{E}$ (%)	STAND. DEV.
JOYSTICK					
10 IN. ROD	144.5	5.4	-40.38		
3 IN. R.B.B.	109.0	2.2	-60.02	-51.5	10.1
3 IN. R.B.B.	195.5	1.1	-54.10		
JOYSTICK	32.0	2.3	-14.20		
3 IN. R.B.B.	73.4	7.0	-30.87	-11.5	20.9
	20.2	2.2	10.64		
TOUCH PLATES	76.4	15.4	5.93	-2.0	11.3
LEFT HAND	148.2	3.3	-9.99		
TOUCH PLATES	43.3	6.8	25.48		
LEFT HAND	22.5	5.7	55.45	49.8	16.6
4 LB. WEIGHT	36.4	18.2	54.90		
	14.0	0.0	62.23		

TABLE I: Test results of subject D.B. (direction tested is forward in all cases).

Positioning the joystick between D.B.'s left knee and the arm rest of the chair (position 3, figure 3a) resulted in a significant improvement in performance. As seen from Table I, however, D.B.'s final position would still have been further from the target than when he began (E = -11.48%). It was observed that while D.B. had great difficulty in stopping his hand at the joystick, he had the ability to better control hand position by sliding his hand along the top of the tray. It was thus decided to evaluate D.B.'s ability to use a touchplate controller.

Three out of a possible five capacitive touchplates were mounted on D.B.'s tray as shown in Figure 3(b). The positions of the touchplates were within a full radius about his left elbow. During the first two trials, D.B.'s arm moved in a random fashion. A four pound weight was then strapped about his left forearm in an attempt to limit flinging of the hand over the tray. Four trials were performed under these conditions in which his ability to select the forward direction was evaluated. Using the "Student's" t test, improvement in this case over that of using a joystick in position 3 was significant with $p < .01$.

CONCLUSION

The case study presented illustrates the potential of the assessment system to facilitate objective evaluation of user/controller interfaces. While the system was designed to aid in the choice of an appropriate powered wheelchair controller, any switched interface system can be assessed. The potential also exists to employ the system to train first-time users of interface controllers who may have difficulty in comprehending their use. This is by virtue of the positive reinforcement of task performance inherent in the system.

A study is presently being undertaken to evaluate effects of learning on results obtained. o Initial reactions of therapy staff are extremely positive. Future directions include the synthesis of a driver obstacle course in which both immovable and moving objects are represented.

ACKNOWLEDGEMENTS

This work is supported by the generosity of the Toronto Rotary Club in making available to A. Basacchi, a scholarship.

The authors thank E. Snell and A. Mandel of the Rehabilitation Engineering Department and, M. Martin and H. Maxsted of the Cerebral Palsy Unit, for their suggestions during development of the system and their aid during the clinical trials.

MICROPROCESSOR TRACKING TRAINER FOR HEMIPARETIC PATIENTS

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RANCHO LOS AMIGOS REHABILITATION ENGINEERING CENTER

ABSTRACT

A microprocessor based tracking trainer has been developed to train fine reciprocal joint motion of flexion and extension for patients with poor joint control. The device is presently being evaluated in a physical therapy ward at Rancho Los Amigos Rehabilitation Engineering Center to treat hemiparetic patients and to test motor skill progress. The device presents a randomly moving target on a TV screen for a patient to track by means of an electrogoniometer, and scores the patient's responses. Preliminary trials with stroke patients show encouraging results and very good acceptance of the device by both patients and therapists.

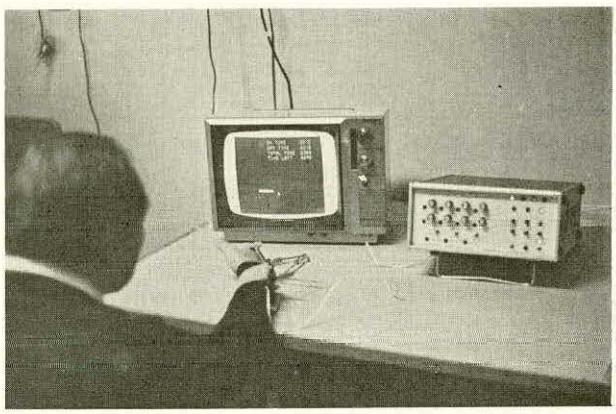

Fig. 1 Tracking trainer in the clinical setting.

INTRODUCTION

A common problem for many patients suffering from stroke, head injury, spinal cord injury or arthritis, is the control of joint motion. Stroke patients in particular can suffer from a number of effects integrating to a loss of function. Proprioception, the position sense, may be diminished and can be compensated for by visual feedback. Cognitive losses may result in spatial perceptual problems, including confusion in direction sense in which case the patient may fail to differentiate between left and right motion of his extremity. In addition, visual-motor perception, putting together sight and movement, may be affected. The effects above combine to form a severe debilitation of the patient which additionally make treatment and measurement of patient recovery very difficult, and often require costly one-on-one patient-therapist attention.

A desirable treatment for the stroke patient would integrate all of the above affected functions into a single task which would provide simple quantification of motor abilities and rehabilitative progress. In keeping with this, a microprocessor based tracking trainer has been developed to train for fine reciprocal joint flexion and extension in patients with poor joint control. The device presents a visual image for a patient to track by means of an electrical goniometer positioned about the affected joint. Programmed control of the instrument provides a standard treatment sequence as well as simple evaluation of patient progress without sacrificing ease of adaption to the varied abilities and difficulties of patients in a treatment program.

BACKGROUND

Tracking tasks have been used sucessfully by several researchers in the past for both studying and treating stroke, Parkinsonian, and other neurologically affected patients. The devices used in these previous studies have generally been either simple, with sinusoid or stepped forcing functions, or relative complex, with pseudo random noise generators as forcing functions and computer assisted analysis. Most of the devices require a laboratory setting, and some require a complete computer facility to analyze data, even for clinical use.

Evidence of tracking tasks being used in routine clinical treatment and evaluation may be found in the work by Potvin, et al(1) wherein they report the inclusion of a tracking task device in a battery of 57 neurological function tests. Potvin's device is used in three modes: pursuit tracking, where the patient is presented with a target and is required to track it; compensatory tracking, where the patient is presented only with the error between system input and output and is required to minimize that error; and ciritical task tracking, where the patient's own instability serves as system input, exciting increasingly unstable tracking dynamics.

Jones(2) used a preview tracking task to quantify neurological recovery. Using a PDP 11 computer to generate the forcing function and a graphics display unit, head-injured and stroke patients were requested to track sine waves and random signals. The most noticable results of this study showed that sensory-motor control patterns could be relearned using the device and that there was an accompanying increase of motivation through immediate performance feedback.

Similar studies utilizing tracking tasks have been reported by Flowers(3), Cassell, et.al.(4), and Bowen, et.al.(5) to study specific problems characteristic of Parkinson's disease. Two groups have reported using tracking tasks in the assessment of disability from stroke. De Souza, et.al.(6) reports using a pursuit tracking task and found a high overall correlation between measurements made on his system and those based upon standard clinical measurements. Lynn, et.al.(7) used sinusoid forcing signals and pseudo random binary sequences and a PDP 11 computer to assess the disability of a patient due to stroke.

A prototype of the tracking trainer discussed in this paper was evaluated at Rancho Los Amigos Hospital by Kataoka and Kikkawa(8). In their study of 20 normals, no significant differences in tracking ability were found to exist due to differences in age, gender, or hand dominance, and target speed was found to be a determinate factor in tracking ability.

MATERIALS AND METHODS

The Rancho Tracking Trainer presents a randomly moving target on a standard television screen for a patient to track by means of an electrical goniometer placed about an affected joint. The trainer can be used for both coordinated motion treatment and for measurement of patient motor control progress. The device is based on the Motorola 6800 microprocessor and has a tremendous amount of control options available to the threapist using the device. These include target shape and motion parameters, treatment times, patient compensation parameters, and a number of special functions to be described below.

Physically, the tracking trainer consists of three devices: the Trainer chassis, a television set, and an electrical goniometer. The trainer operates in three modes: Load, Setup, and Track. In the load mode, all of the operation parameters are entered into memory. This occurs in a logical, stepwise manner, with light emitting diodes lighting up next to entry switches, leading the therapist through the entry of the parameters. Ten parameters are entered: scale, offset, cursor size, velocity, treatment time, test sequence, dwell time, orientation, response type, and dwell type. The functions of the ten parameter switches are:

1. Scale- sets the range of motion for the joint being tested: 20 deg. to 180 deg. This is set to accomodate the range of motion of the patient being treated.
2. Offset- the reference neutral position of the goniometer: 0, + 15, and +30 degrees. This compensates for patients with abnormal resting neutral joint positions.
3. Cursor size- sets the width of the tracking target: 16, 24, 32, 40 and 48 degrees.
4. Velocity- selects the set of speeds to be used for the tracking target to use in its destination seeks. Four settings are available:5,10,15 deg./Sec.; 10,20,30 deg./Sec.; 20,35,50 deg./Sec.; and 40,60,80 deg./Sec.
5. Treatment time- selectable from 15 seconds to 99 minutes and 45 seconds.
6. Test sequence- selects the starting location in a table of random numbers representing the destinations for the target. Five settings are available: four correspond to known locations in the random table, the fifth selects a starting position in that table at random. The four known settings would be used in the testing of patient progress, and the fifth setting would be used in the regular treatment of patients so that there wouldn't be any chance of a patient learning the sequence of a treatment session.
7. Dwell time- selects the time that the target waits at a destination before seeking a new destination: 0,1, and 2 seconds. The dwell time can be used to allow patients with poor motor control time to catch up to the target before it seeks a new destination.
8. Orientation- selects the direction of target travel, either horizontal or vertical, and is changed according to the joint being tested.
9. Response type- a function to be added at a future date. When selected, it will record patient motions throughout a test session, do a spectral density analysis utilizing Fast Fourier Transform techniques, and will print the test parameters chosen, the scores of the patient, and the results of the spectral density analysis along with a record of patient and target locations throughout the session. This is intended to provide a measure of tremor in the affected joint and a more detailed analysis of motor function.
10. Dwell type- selects either Wait or Auto dwells. In the auto dwell mode, when a destination is reached by the target, the target will automatically begin to dwell at that location, as defined above, and then move to its next destination. In the wait dwell mode, when the target arrives at its destination it will wait for the patient to arrive at that location before it begins to seek a new destination.

The parameters above are all set in the Load mode. In the next mode, the Setup mode, the patient is placed in the goniometer at the selected joint, and the device is zeroed. (Zero position is defined as resting neutral joint position on the goniometer and center on the TV screen.) A special display on the television verifies correct zero position and range of motion for the patient. The third mode is the Track mode. When this mode is started, the target and patient cursor are displayed and the target seeks its destinations. The destinations for the target are chosen from a random number table stored in the memory of the microprocessor. A set of 512 locations from 0 to 180 and velocity choices from 1 to 3 are stored in this table in pairs. In using the table, the microprocessor would look up a destination and a velocity number. The destination would be transferred to either the vertical or horizontal operation routine. The velocity number is first converted to an actual speed corresponding to one of the three velocities set with the velocity parameter switch before it is transferred to the vertical or horizontal operation routine.

When the trainer is in the track mode, there is a legend at the top of the television display which is updated regularly. Included in this legend are ON TIME, the time for which the patient is within the bounds of the target cursor, OFF TIME, the time for which the patient is outside the bounds of the target cursor, TOTAL TIME, the total accumulated time of the treatment session (counts up as treatment continues), and TIME LEFT, the time in seconds left in the treatment session. The display may be cleared from the screen during treatment with a switch

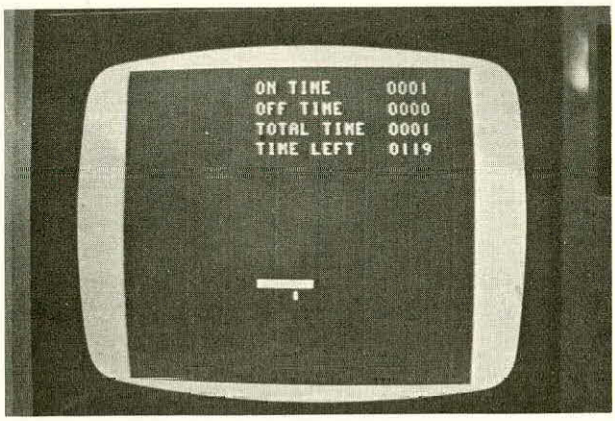

Fig. 2 TV display in the horizontal tracking mode.

on the front panel of the trainer if the patient is being distracted. If at any time during the treatment the patient's cursor is outside the bounds of the target cursor, a tone is turned on and remains on until the patient's cursor is again within the bounds of the target. At the end of the treatment or test session, regardless of the position of the disable switch, the associated times are displayed. The ON TIME indicates the total number of seconds and tenths of seconds on target for that particular session.

As mentioned previously, the trainer is built around the Motorola 6800 microprocessor. Internally, the trainer is seperated into modules: 1) the microprocessor module with 512 bytes of random access memory, four parallel 8-bit ports with handshake lines, and the bootstrap loader program located in a 1024 byte programmable read only memory; 2) the video controller module for the 256 by 192 picture element television display; 3) the goniometer interface module, which interfaces any standard goniometer to the analog to digital converter module and allows automatic zeroing of the patients' joint position; 4) the analog to digital module which converts the analog signal derived from the goniometer and converts that value into an eight bit binary number for the microprocessor, and three programmable timers for creating a time base and tones; 5) and a memory module with program memory of 6 thousand bytes of read only memory.

The electrical goniometer can be any of several types already developed and produced by this lab and in use presently in the physical therapy wards and Pathokinesiology Service of Rancho. Goniometers presently available can be used for measuring joint position in the finger, wrist, elbow, shoulder, knee and ankle. The television used is a standard Sony black and white television equipped with an antenna adaptor identical to those used for TV games. No modification to the television is required. The tracking trainer is tuned to channel 3 on the VHF band and is interfaced to the television with a standard RF cable.

SIGNIFICANCE

At present there is not an acceptable method of training for reciprocating motion in the hemiparetic without requiring a great deal of one-on-one therapist time. We believe that the tracking trainer can significantly provide needed therapy to stroke patients, and would be useful for other patient populations such as head and spinal cord injured patients, and for measuring the progress of motor function recovery in general. Further automation and the development of a home use unit that could run a prescribed series of treatments and record patient responses that could be analyzed and reviewed later by hospital personnel could prove even more useful. We believe the device offers numerous benefits, many to be realized once the device is made a standard part of the clinical environment.

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This project was supported by NIHR grant 23P-5544/9-08.

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BEHAVIOURAL ENGINEERING APPROACHES TO THE PROBLEM OF DROOLING

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ABSTRACT

This paper presents a review of current approaches to drooling and elucidates a technologically-based approach that is presently being evaluated at the Ontario Crippled Children's Centre (OCCC). With the assumption that drooling can be regarded within a behavioural context, steps combining technological aids and behavioural principles (behavioural engineering) can be taken in attempting to modify this socially stigmatizing problem. A recently developed technique to quantify drooled saliva is described along with other technological devices that have been devised at the OCCC, each with implications for the treatment of drooling. Save for some preliminary test trials with various devices and techniques, the results of treatment are not included in this report.

INTRODUCTION

Drooling (defined by the presence of saliva outside of the mouth) is a problem experienced by 10% - 13% of all individuals with cerebral palsy (1,2). The social distress arising from drooling can be severe, and in addition, excoriation of the chin due to constant wetness can cause considerable discomfort. Unfortunately, a paucity of effective treatment modalities other than surgery and pharmacotherapy leaves the person who drools with few alternatives. At the OCCC the Biofeedback Research Project (BRP) has recently embarked on an investigation of drooling with the goal of developing and evaluating alternative treatment modalities which utilize biofeedback and behavioural engineering.

Specifically identified as target areas for intervention are: (a) improving the efficacy of noninvasive treatment techniques; and (b) increasing the reliability of evaluative efforts in assessing treatment outcome. It became apparent from a literature review that there is no consistent and effective method of quantifying drooled saliva. This has led to a situation where there are no known accurate norms for rates of drooling in cerebral palsy. As a further consequence, the evaluation of treatment interventions has been limited to subjective means, and it is therefore difficult to make sound comparisons between intervention techniques. While it is appreciated that subjective impressions can be valuable, at the same time it is recognized that the use of quantitatively-based and reliable measurements represents a significant step towards enhancing scientific knowledge about drooling as well as the techniques that are used to address it.

Treatment approaches presently used in an effort to control drooling are of a varied nature. They include: the use of anticholinergic drugs (3); radiation (3); and surgery varying from salivary duct relocation to chorda tympani neurectomy (4). However, these treatment modalities are invasive and laden with a high probability of undesirable side effects (eg. arising from the effects of hospitalization or from the long-term use of drugs). Conservative treatment approaches include: feeding techniques (5); tongue-thrust therapy (6,7); the use of constant pressure sensory-input modalities (8,9); and the application of operant conditioning principles (10,11). The inclusion of behavioural engineering strategies (12) in the treatment of drooling offers a further alternative that will, at the least, increase the expertise of clinicians regarding the treatments they choose and hopefully improve the efficacy of interventions. The central tenet of this approach is the use of technology in conjunction with psychological principles to teach someone a more desirable or functional behaviour (13). It is suggested that in the case of a person with cerebral palsy who drools, three behaviours are primarily responsible for saliva leaving the mouth: (a) not having effective lip closure, especially during swallowing; (b) poor head control (ie. dropping the head forward or to either side); and (c) not swallowing at appropriate frequencies to clear the mouth of saliva.

QUANTIFICATION OF DROOLED SALIVA

Quantification of drooled saliva is necessary both before and after any treatment intervention if an objective evaluation of treatment efficacy is desired. Two main approaches to quantifying drooling have appeared in the literature. They are: (a) weighing the drooled saliva which has been collected either in a bib (9) or in a plastic bag taped to the subject's chin (14); and (b) simply counting the number of bibs and/or clothing changes required per day (15). These methods, however, do not provide consistent results and have many inherent problems such as ineffective adherence of tape to a damp chin, and evaporation of saliva from bibs prior to measurement.

Initial efforts by the BRP focused on produc-

ing a more accurate and reliable quantification technique. After much experimentation, a trough-like device has been developed that fits comfortably on the chin and catches the drooled saliva, which is then suctioned off to be measured volumetrically (16). Orthotic splint material (Sansplint) is used to form the device. It is held in place with velcro straps which are attached to an orthodontic net head bonnet worn by the client. A 3 m. length of plastic tubing is connected at one end to the bottom of the device and at the other end to a collection chamber, which in turn is connected to a vacuum pump. The suction produced by the pump facilitates the continuous withdrawal of saliva from the device and the saliva is collected in a graduated test tube within the collection chamber. This system has been named the "droolometer"(see Figure 1).

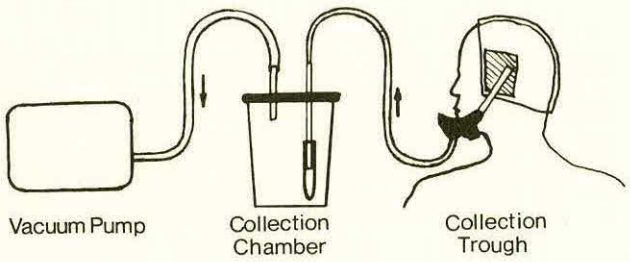

Figure 1: The droolometer system.

Preliminary testing of the collection device with five children who drool has shown that the device is well accepted and that it provides objective and easily quantifiable results. Loss of saliva within the system is minimal and the only real problem encountered to date has been when the child's drooling pattern is such that only frothy saliva appears around the mouth or when the saliva is highly viscous. In this case, the saliva tends not to fall into the device and therefore is not suctioned off and measured.

Figure 2 graphically depicts the drool collected over ten 15-minute sessions in a five-year old child with cerebral palsy. To study variability in drooling rates, the sessions were conducted during both morning and afternoon periods. It can be seen that the droolometer facilitates the objectification of variations in the rate of drooling, thus pointing to its potential as a reliable means of evaluating treatment efficacy. It is felt that this system represents a significant improvement over previously-reported attempts to measure changes in drooling rates.

FACIAL MUSCULATURE EVALUATIONS

As mentioned previously, an inability to seal the lips together and to swallow are significant etiological factors related to the problem of drooling. In persons with cerebral palsy these behavioural deficits stem from motor dysfunction. With this knowledge, it was decided to monitor EMG activity of certain facial and neck muscles (i.e. masseter, orbicularis oris, and infra-hyoid) in order to attempt to identify specific motor dysfunctions and with a view to evaluating the effects of training on the motor functioning of

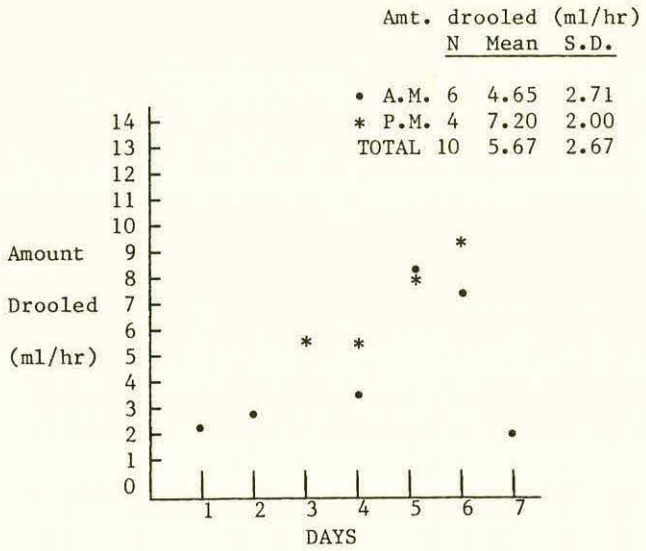

Figure 2: Graphic presentation of drooling rates in a five-year-old child with cerebral palsy as measured by the droolometer system.

these muscles. Also, because there appears to be a hiatus in the literature concerning facial muscle action during swallowing, exploratory work has been undertaken with normal subjects to identify patterns (ie. phasing, duration and amplitude) of EMG activity which occur during the act of liquid ingestion. It is anticipated that these can then be used as a basis for comparison in order to more specifically assess and treat the motor dysfunction in cerebral palsy subjects. One finding that has already emerged is that EMG recordings may be useful in indicating deficits in lip closure ability, and that EMG biofeedback can be used to aid in the teaching of improved lip closure.

TRAINING AIDS

Technology has the potential to play a significant role in the treatment of drooling within a behavioural engineering framework. Through the reliable and accurate provision of some consequence contingent upon a target behaviour, that behaviour can usually be modified. With respect to the problem of training behaviours to influence drooling, a number of technological devices have been developed. A head position trainer (HPT) (17) devised at the OCCC has implications for teaching better head control in order to reduce the incidence of drooling. However, in previous studies using the HPT or similar devices the effects of improved head control upon drooling have unfortunately not been examined.

Recently, a multi-purpose sensor and binary feedback unit utilizing a moisture detecting circuit has been developed to monitor tongue extrusion and other related mouth behaviours. This unit, which is also capable of monitoring lip closure, provides or removes an auditory signal contingent upon a successful response, depending upon whether positive or negative feedback is desired. Additional features of the unit enable it to be

used with more rewarding feedback modalities (18) and to be interfaced with the OCCC Time Event Counter to monitor performance before, during and after training. Testing of this device in teaching lip closure is now in progress.

The task of teaching swallowing is somewhat more difficult. Through our experience and the experience of physical and speech therapists at the OCCC, it has been noted that the children with cerebral palsy who drool are often capable of swallowing, but perform this behaviour at a low frequency. When they are asked to swallow they can do so, but they need to be continually reminded. With this in mind a simple timing device that emits an auditory stimulus at fixed intervals was constructed. A therapist can set the timer at an interval and teach the client to swallow at the sound of the tone which acts as a cue. This device follows from a successful programme developed in England (11), but there is a limitation to the timer as it provides no consequence if a swallow does not occur.

CONCLUSIONS

The incidence of drooling in persons with cerebral palsy is a problem that can cause social and physical distress. To date, surgical and pharmacotherapy interventions have been only partially effective, and these may have negative physical and psychological side effects. Other techniques such as physical therapy show promise, but they too are only partially effective, possibly due to non-comprehensive efforts that do not address all the aspects of drooling. A major problem has been the lack of an objective and reliable method for quantifying drooling rates.

Although a final solution to the problem of drooling in cerebral palsy is not proposed, a behavioural engineering approach is advocated. Inherent advantages in this approach are: (a) the provision of alternative strategies in treating a problem that has clear behavioural components (although taking into account physiological dysfunction); and (b) the possibility of increased acumen on the part of clinicians in evaluating their interventions. Three factors have been identified that may lead to drooling and it is hoped that the appropriate use of technology in conjunction with proven principles of psychology (behaviour modification techniques) will have therapeutic impact. Collecting and quantifying drooled saliva is now possible with a recently developed "droolometer" and oral motor functioning can be assessed using EMG techniques. To aid in the actual training periods a number of devices have been developed. These include a head position trainer, a tongue and lip sensor, and a fixed interval timer. Studies are currently under way to evaluate the efficacy of this approach.

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the generous support of the Atkinson Charitable Foundation, Toronto. The contribution of Ruth Gannon, Director of Speech Pathology, OCCC, is also appreciated.

A REVERSIBLE ROLLER CLUTCH FOR A LEVER-DRIVE WHEELCHAIR

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ABSTRACT:

This paper describes a lever propulsion system for a wheelchair which uses a unique reversible roller clutch. The clutch enables the levers to maneuver a wheelchair in a manner similar to handrims while providing greater biomechanical efficiency and ease of operation. The mechanism of this clutch is fully described, followed by a discussion of the direction future development must take to realize the full potential of the clutch.

BACKGROUND:

Most wheelchairs used today are propelled by a handrim which is attached directly to a large diameter wheel. This system has the advantages of simplicity and reliability, but it also has a few significant drawbacks. Wheelchair users with impaired hand function have difficulty grasping the handrim and are consequently limited in their ability to propel the wheelchair. For those users who have no difficulty with grasping, the handrim is not the most effective or efficient propulsion system (1) (2). A lever propulsion system has the potential to overcome some of the drawbacks of handrims, permitting handle adaptations for impaired hands and allowing more efficient motions to be used to propel the wheelchair.

Previous designs of lever propulsion systems have sought to develop the potential of this approach, but various problems have prevented these designs from receiving wide use. The most common problem is that the levers do not permit the user to maneuver the wheelchair as well as with handrims. This is the problem with lever systems using a crank-rocker linkage, such as the lever-drive model made by Ortopedia. Some designs have employed ratchet mechanisms which had problems with noise and excessive backlash, as well as being difficult to reverse. Other designs have used hand control to lock a clutch, and these designs require good coordination and hand strength. These previous designs have served to illustrate the advantages of lever propulsion, but have not demonstrated the feasibility of lever propulsion for everyday use. Our prototype is one step closer to that goal of widespread use. The specially designed reversible roller clutch enables the levers to maneuver the wheelchair while avoiding the problems of previous lever drive systems mentioned above.

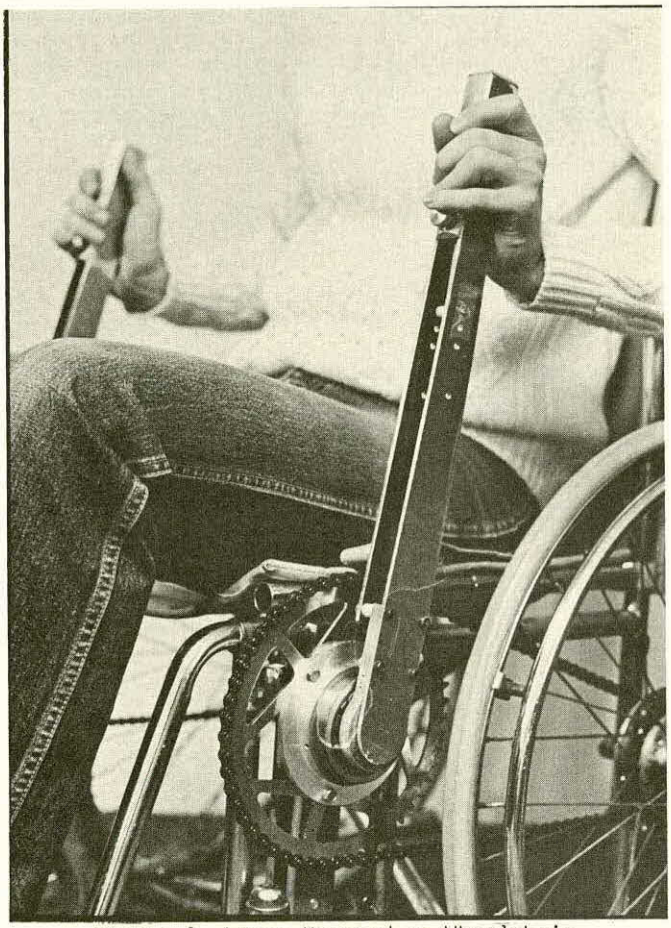

Figure 1 Lever Mounted on Wheelchair

DESIGN GOALS:

The chief design goal was to eliminate the necessity for grasping, while still enabling the user to propel the wheelchair with the same maneuverability afforded by handrims. This must be accomplished in such a way that little energy is required to engage or reverse the propulsion system, or to brake the wheelchair. It must be possible to place the levers in the position which is best for the biomechanical efficiency of the body, regardless of the position of the drive wheels.

Wheelchairs are not often used at high speed, so the lever system was not designed for maximum efficiency at high speed. That would have

required the lever system to deliver power to the drive wheels on both the forward and reverse strokes. Instead this lever system offers the user the option of ratcheting in either the forward or the reverse direction. Pushing propels the chair forward, while pulling moves the chair backward. The user must be able instantly to engage or reverse the system, but the system should normally be disengaged. A brake should be incorporated to complete the functional requirements of the lever system, permitting the user to quickly slow the motion of the wheelchair.

THE MECHANISM DESIGN:

The key to the lever system is a special roller clutch that permits instant engagement in either direction with a freewheeling neutral position. The principle of the roller clutch is not new, but the ability to reverse the direction in which the torque is transmitted or to disengage the clutch altogether does not seem to have been used before. A pair of these clutches have been built and mounted in the hub of a lever, and the clutches couple the levers to a bicycle chain which drives the rear wheels. Figure (1) This is not the best configuration for the system but it confirms that the clutches do work as intended.

At the same time a Sturmey-Archer bicycle hub brake was modified for use on a wheelchair. This, too, works as intended. The next step will be to mount both of these components on the same wheelchair, completing the lever propulsion system.

THE ROLLER CLUTCH MECHANISM:

The mechanism of the clutch will be described in some detail because it is the only new mechanical element employed by the lever system. The clutch itself is an assembly of four components: a cam, twelve rollers, a cage, and an outer race. Figure (2). The cam is in the center of the assembly and is driven by the lever around a central axle. The cage contains the rollers and rotates on the cam. The outer race rotates around the central axle and is driven by the rollers when the cage is positioned with the rollers wedged between the cam and the outer race.

The clutch is generated from the handle by a control lever which protrudes through the handle on the front and rear surfaces. This control lever is held by springs in a central, neutral position. When the hand presses the control lever out of the neutral position at the handle, the cage rotates to engage the rollers with the outer race. Figure (3). Only a small force is required to engage the rollers; once engaged they develop tremendous locking force in one direction while slipping with no noticeable friction in the opposite direction. Reverse action is simply accomplished by pressing the control lever in the opposite direction.

DESIGN PARAMETERS:

The prototype clutches are overdesigned by at least a factor of two. They were designed to handle 200 ft.-lbf. of torque for 50,000 cycles

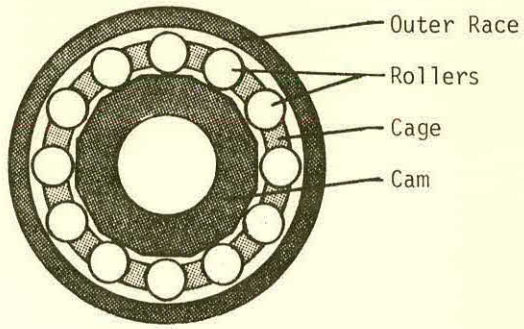

Figure 2 Clutch Elements

with a safety factor of 1.5 (3). For an 18 inch lever this is the equivalent of bench pressing 250 lb. fifty-thousand times, and would obviously require a long time and a very strong person. The mode of failure for this analysis is fatique failure due to hertzian contact stress between the cam and the rollers, based on permissible maximum compressive stress of 500,000 psi. These stresses require that the cam, rollers, and outer race be made of hardened and ground bearing quality steel. Since few users could ever develop torques close to this design value, these clutches can be expected to outlast the wheelchair.

EVALUATION OF THE PROTOTYPE DESIGN:

The prototype clutch operates as planned with no noticeable backlash or noise and is still working despite hard use. Control of the clutch requires a little more force than necessary due to friction between the cage and cam, and this friction could be reduced with ball bearings. Occasionally the clutch will engage itself unexpectedly, but this seems to be due to motion of the cam along the axis of the shaft which permits interference between the cam and the outer race. This problem will be solved with a few simple design changes.

The clutch and lever are a source of additional weight and cost for the wheelchair. Increased biomechanical efficiency may justify increases in both these undesireable characteristics if they are not increased appreciably. The cost of the prototype was minimized by using rollers and outer race from a ten dollar roller bearing. The few problems that are apparent from the prototype are solveable, and the design can be judged a success because of its ability to maneuver a wheelchair in a manner similar to handrims.

DIRECTIONS FOR FUTURE DEVELOPMENT:

More work is needed to develop a control system which is easily operated by users with impaired hand function - such as high level quadriplegics. In addition a wheelchair needs to be developed to take full advantage of the possibilities of the lever system. The best

position for the lever must be determined; experiments are in progress at the University of Virginia, Rehabilitation Engineering Center, and the results of that study will be put to use as they are obtained. A linkage between the clutch and the drive wheel should be developed which permits a variable mechanical advantage for various circumstances and different users. With this development levers could become a feasible propulsion system for wheelchairs.

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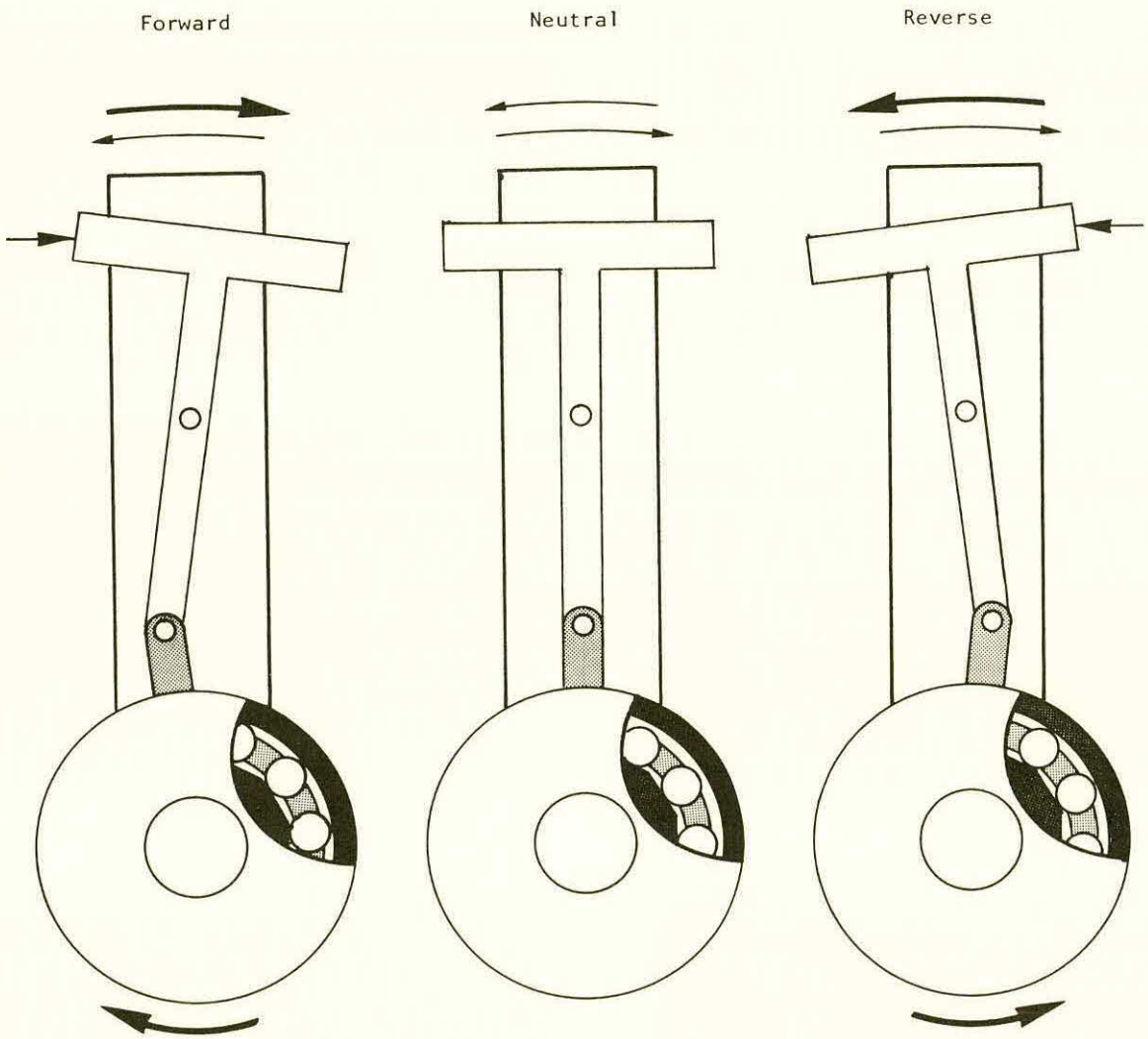
1 Engel, P., and Hildebrandt, G.: Wheelchair Design - Technological and Physiological Aspects, Proc. Boy. Soc. Med. 67:409-413, 1979.

2 Annual Report 1979, University of Virginia, Rehabilitation Engineering Center, Charlottesville, Virginia.

3 One-Way Clutch Design Guide; Types Selection Applications Borg-Warner Corporation, Spring/ Brummer Division C. 1978.

Figure 3



ESTIMATED WORK AS A FUNCTION OF SEAT POSITION IN LEVER PUSHING

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ABSTRACT:

The relationship between lever location relative to a seated subject and the subject's ability to generate torque at discrete 15-degree increments about an axis was investigated for eight paraplegic subjects. The axis of the levers was variably place in 27 different positions relative to the seat according to a randomly determined three-dimensional matrix. Lever position within the sagittal plane was found to be a factor in performance.

SUBJECT:

Eight paraplegic individuals were used in this study with the highest level of injury being T5 and T6 incomplete. The group included one female and the average age was 23 within a range of 15 to 34.

METHOD:

A torque measuring apparatus consisting of a movable seat and two movable, instrumented levers, all mounted on a platform was constructed at this laboratory (Figure 1).

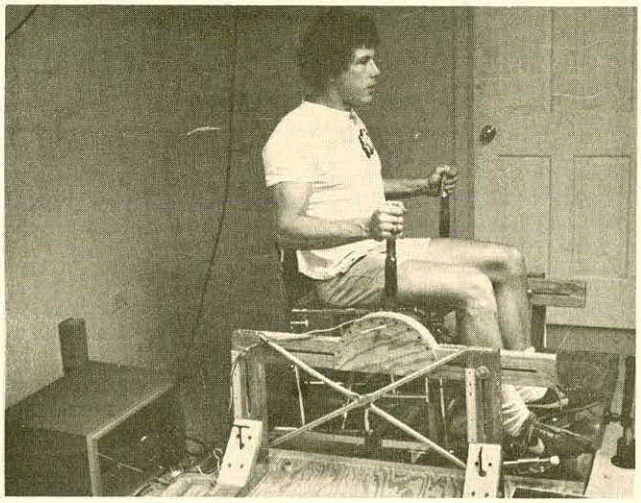

Figure 1

This system provided for variation of the position of the axis of the levers relative to the seated subject in three dimensions. The seat was movable in the sagittal plane and the levers could be moved in both the transverse and frontal planes relative to the subject. The levers were articulated about a common axis and could be fixed at points 15 degrees apart along an arc about the axis of rotation (Figure 2).

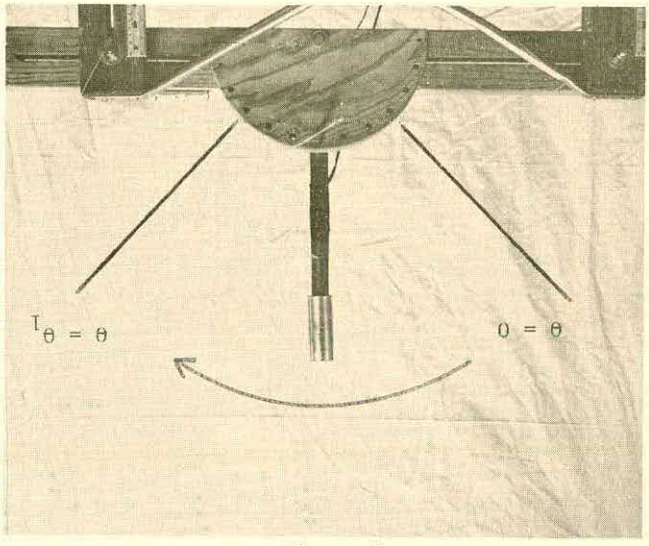

Figure 2

Strain gauges were bonded to the levers on all four sides which permitted calculation of the forces at the handle grip to be measured in two planes.

The subjects were asked to perform a five-second maximum, isometric contraction. The output of the strain gauge network was monitored by a LSI-11 mini-computer which calculated the maximum force generated during the exertion. The lever positions were randomly assigned from a 3 by 3 by 3 Matrix (three position transverse, three positions frontal, and three sagittal). The increment between the transverse positions was 20% of the subjects biacromial diameter, the increment between the frontal locations taken as 10% of the subjects seated height as measure from the lowest extent of the buttocks to the top of the head, and that between the sagittal positions as 10% of the upper extremity length measured from the axis of rotation of the humerus at the shoulder to the tip of the finger with the elbow extended. A basic position was established for each subject with the levers located in the sagittal planes as close to the subject as permitted by the apparatus and at the highest

position. The seat was positioned in a frontal plane so that the subject's elbow was at 90° flexion when the levers were vertical. At each position, the subject was ask to perform maximum contractions at all of the lever angles that could be reached. All subjects could reach four or five angles. The results at each angle were summed and multiplied by the number angles (four or five) the subject could reach at that position. As was suggested in a paper by Asmussen et al (1), the number arrived at in this manner is an estimate of the work that could be done by a dynamic system working through a similar angular displacement. With this estimate of work as the dependent variable and the position as the independent variable, an analysis of variance was performed using the BMDP statistical packages run on the University of Virginia's CDC Cyber 172.

RESULTS AND DISCUSSION:

The statistical analysis revealed no significant difference ($P > 0.05$) between lever positions in the transverse and frontal planes. However, significant difference ($P > 0.01$) were found between the three-positions in the sagittal plane. When the levers were placed in the farthest forward position, away from the subject, the estimate of work was significantly less than in the two closer positions. These results are similar to the positional study done, using a rim propelled chair, by Brubaker, et al. (2)

REFERENCES:

1 Asmussen, E., Hansen, O., and Lammert O.: The Relation Between Isometric and Dynamic Muscle Strength in Man, Communications from the Testing and Observations Institute of the Danish National Association for Infantile Paralysis, No. 20, 1965.

2 Brubaker, C. E., McLaurin, C. A., Gibson, J. D. "Effect of Seat Position on Wheelchair Performance", Proceedings of 1980 Conference on Rehabilitation Engineering, Toronto.

TABLE 1

AVERAGE ESTIMATED WORK

(Units are Arbitrary)

Lever Height	Seat Depth (LEVER WIDTH)	Forward	Middle	Back
Low	C	14600 (4448)	14620 (5010)	9435 (3284)
	M	14360 (5606)	15080 (5396)	10070 (3027)
	W	15250 (4895)	15370 (5277)	9669 (2945)
Middle	C	15900 (5506)	16320 (5745)	11440 (4070)
	M	16520 (5278)	15620 (6054)	10700 (3791)
	W	15530 (5098)	15080 (5654)	10170 (3421)
High	C	16690 (6380)	17140 (5663)	11100 (3923)
	M	16360 (5828)	17020 (6899)	11070 (3712)
	W	16120 (6208)	15580 (5438)	10690 (4295)

N= 8 for all averages
Standard Deviation is in Parenthesis
For Width: C= Close, M= Middle, W= Wide

EFFECT OF HAND POSITION ON LEVER PUSHING PERFORMANCE

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ABSTRACT:

This study investigated the effect of hand position, either pronated or partially supinated, on torque generation in isometric lever pushing. The subjects performed isometric contractions at 15° increments along an arc centered at each of nine different positions, located in a sagittal plane to the subject. This procedure was repeated for each of the two handle configurations. The results for each handle showed no significant difference ($P < 0.05$) in performance between the two handle types.

SUBJECTS:

Three male quadriplegics, patients at the University of Virginia Hospital, volunteered to participate in this study. The subjects were of ages 23, 26, and 53 with lesion levels C-6, and C-8 incomplete, and C5, 6 respectively.

METHODS:

A device consisting of two levers and seat between them, all mounted on a platform, was constructed at this laboratory (Figure 1).

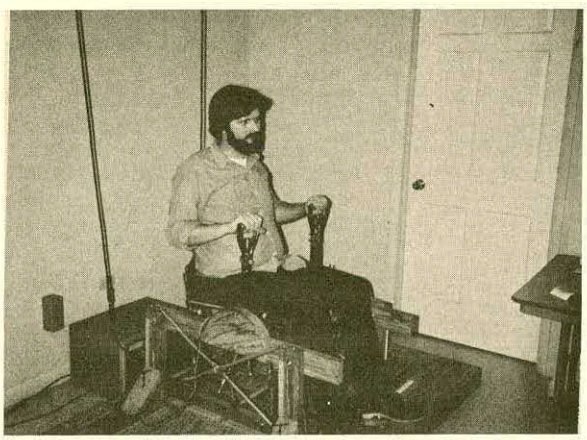

Figure 1

The levers could be fixed at different heights vertically above the platform and the seat could be fixed at different positions horizontally from the front of the platform, which the seat faced, to the back of the platform. The levers could be rotated and fixed at 15° increments along an arc about their center of rotation. Three lever heights, low, middle and high, were used. The high position was 40 cm above the platform in all cases with the two lower positions separated by an increment of 10% of the subject's seat height as measured from the bottom of the buttocks to the top of the head. Similarly, three seat positions, front, middle, and back were used. The middle position was chosen so that, with the levers in the high position, the long axis of subject's humerus was in a frontal plane. The other two positions were located 10% of the subject's arm length from the axis of rotation of the humerus at the shoulder to the tip of the middle finger with the elbow extended, either side of the middle position. All possible pairings of the lever and seat positions gave the nine positions at which the subjects were tested. At each position, the levers were fixed at as many of the points, separated by 15 degrees, along an arc about their common center of rotation, that the subject could reach. At each of these lever angles the subjects were asked to perform a five-second maximal isometric contraction pushing on the levers. The levers were instrumented with electric strain gauges and were calibrated to measure the torque generated in a sagittal plane. The strain gauge network was interfaced with a LSI-11 micro-computer programmed to report the maximum torque reached during the five-second contraction.

The order of the test positions, as well as the order of the lever angles for each test, was random for each subject. All subjects performed the nine tests for the first handle design, which allowed the subject's hands to be pronated (Figure 2). Then they repeated the tests for the second handle design which positioned their hands 90 degrees away from pronation toward supination (Figure 3).

RESULTS AND DISCUSSION:

Due to the linear relationship between isometric torque and dynamic torque generated along the same path (1), if the torques produced at the lever angles comprising a particular test are summed, the resulting number is an estimate of

the work that could be done with a dynamic lever

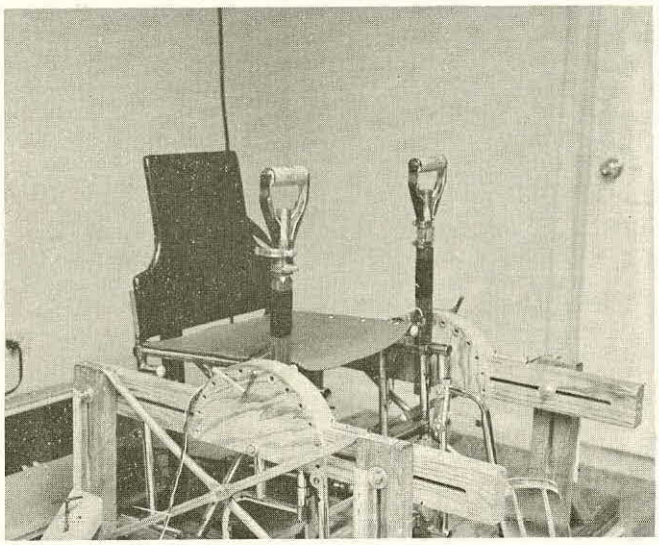

Figure 2

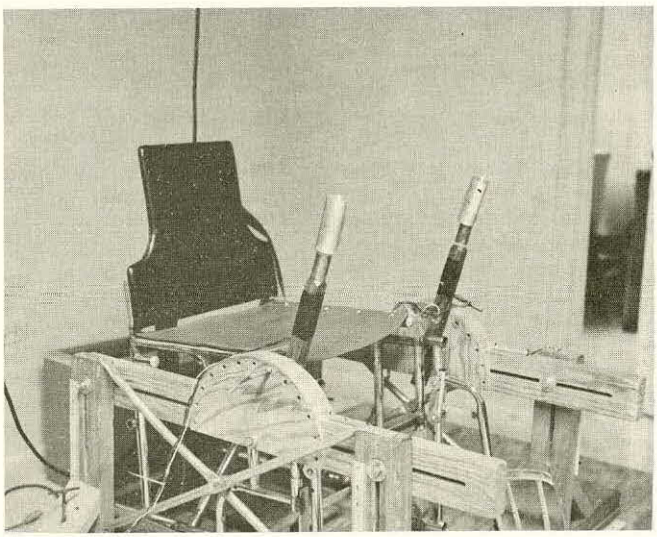

Figure 3

system. This was done for all test performed by the subjects. An average estimated work was found for each handle type. The equality of these two means was tested using the BMDP3D statistical package, which performed a t-test run on the University of Virginia's CDC Cyber 172. This showed no significant difference between the means for estimated work produced by the pronated handle or the semi-supinated handle ($P < 0.05$). What this implies is that the hand may be rotated through 90° with no impairment of the user's ability to perform work. This motion could be used to perform some sort of control function such as, say, engaging reverse gear or steering the front casters. It is worth noting that the subjects preferred the pronated grip.

REFERENCES:

Asmussen, E., O. Hansen, and O. Lammert: The Relation between Isometric and Kynamic Muscle Strength in Man, Communications from the Testing and Observations Institute of the Danish National Association for Infantile Paralysis, No. 20, 1965

TABLE 1

AVERAGE ESTIMATED WORK

(Units are Arbitrary)

HANDLE	TYPES	Front	Middle	Back
Low	P	875 (476)	936 (630)	1089 (640)
	SS	992 (789)	1144 (879)	884 (717)
Middle	P	811 (490)	865 (598)	710 (375)
	SS	1037 (955)	1033 (924)	809 (715)
High	P	666 (324)	792 (183)	545 (247)
	SS	822 (548)	792 (433)	672 (452)

Standard Deviations are in Parenthesis
For Handle Type: P= Pronated, SS= Semi-Supinated
N= 3 for Each Cell

THE POWER REQUIREMENTS OF AN UPPER EXTREMITY CRANKED VEHICLE

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An upper extremity cranked 5-speed tricycle with gearing of 40.6 to 91.4 cm (16 to 36 in) (gear ratio times diameter of driving wheel) and a conventional wheelchair were tested on a treadmill at speeds of 3, 4, 5, 6, and 8 km/h and with grades of 0, 1, 2, and 3%. The 0_2 uptake ($\dot{V}_{02}$), CO_2 production ($\dot{V}_{CO2}$), respiratory exchange ratio (R), and heart rate (HR) were measured at the above conditions with (a) a hand cranked tricycle with unlocked steering, (b) a hand cranked tricycle with locked steering, and (c) a conventional wheelchair. The steering was locked in an attempt to reduce energy costs. The results showed the hand cranked vehicle required from 8.5 to 27% less power expenditure, with the greatest savings at low grades or at higher speeds. Locking the steering required approximately 5% less power. The results also indicated a wider gear range is needed for general use.

INTRODUCTION

Recently, at least two manufacturers have produced multispeed upper extremity crank vehicles for use by paraplegics. Claims have been made of the superior performance of the vehicles. Hildebrandt et al. (1), Brattgard et al. (2), and Glaser et al. (3) have reported that conventional wheelchairs operate with efficiencies of only 6 to 9%. In contrast, upper extremity cranking of a laboratory ergometer has a reported efficiency of up to 18%. Engel and Hildebrandt (4) have reported that the metabolic and cardiovascular stress of the lever operated wheelchair and upper extremity cranked wheelchair were significantly lower compared to a conventional wheelchair. The efficiency of the crank operated wheelchair varied with the two different gear ratios used, but they did not report the value of the gear ratio. A report based on heart rate measurements by Warren (5) suggests that the crank operated wheelchair is less stressful on the cardiovascular system. The purpose of this study is to compare the power requirements and cardiovascular stress of a hand cranked tricycle with a conventional wheelchair under various conditions.

METHODS

The hand cranked tricycle used in this study was a 5-speed Unicycle manufactured by Orthopedic Systems Incorporated. It weighs 10 kg and attaches to the front of a conventional wheelchair lifting up the front wheels. The wheelchair used was an Everest and Jenning's premier model with hard rubber tires which weighs 18.6 kg. In the experiment a 4.5 kg pack was added for equipment to record the ECG and for the gas collection. The gearing defined in terms used in the bicycle industry, was from 41.4 to 92.7 cm (16.3 to 36.6 in) (gear ratio times diameter of the driving wheel). The gearing was controlled by an internally geared 5-speed hub. The gearing on a typical 10-speed bicycle ranges from 96 to 254 cm (38 to 100 in). The crank arm lengths were 12.5 cm.

The hand cranked tricycle and the standard wheelchair were tested on a large treadmill (2 m x 4.5 m) at speeds of 3, 4, 5, 6, and 8 km/h at grades of 0, 1, 2, and 3%. Three able bodied male subjects, with an average weight of 69.5 kg, were studied for at least 5 minutes at each grade and speed combination unless the subjects stopped due to fatigue. The $\dot{V}_{02}$, $\dot{V}_{CO2}$, R and HR were continuously measured using a Beckman metabolic cart. A Medilog tape recorder was used to record the ECG. The average data from the last 3 minutes of each run was used for the analysis. Preliminary testing indicated that the effort required to stabilize the steering during cranking may be significant. Therefore, all of the above conditions were repeated with the steering locked. The gearing was selected to keep the cranking rate in the range of 50 to 60 RPM except at the slowest speed where the crank rate was 38 RPM due to the lack of a lower gear. The same subjects also hand cranked a Godart-Lanooy electrically braked laboratory ergometer at 40 watts at a rate of 30, 40, 50, 60, 70, 80, and 90 RPM to determine

the optimum cranking rate using crank arm lengths of 12.5 cm and 17 cm. The power required to propel the wheelchair and tricycle was calculated from measurements of the force required to hold the vehicle on the treadmill and the velocity.

RESULTS

Table 1 shows the power required to propel the two vehicles as a function of speed and grade. An asterisk shows the level at which the subjects could not continue for at least 5 minutes. Figures 1 and 2 show the power requirements in terms of $\dot{V}_{02}$ and HR respectively. The power requirements measured on the laboratory hand ergometer showed the minimum $\dot{V}_{02}$ to occur at 40 RPM for 17 cm length crank and 60 RPM for the 12.5 length crank.

The power rose rapidly as the grade increased. On the level the tricycle requires 40% less power as shown in Table 1 than the wheelchair due to less rolling resistance but as the grade increases to 3%, the difference is only 4%. This is due in part to the power required to lift the added weight of the tricycle up the grade. On a grade of 1% or more, the majority of the power is required to lift the weight of the vehicle up the hill. This can be seen in Table 1 by comparing the power required on the level (due to rolling resistance) to the value of 1% grade. The human power expenditure as determined by $\dot{V}_{02}$ measurements shows the crank tricycle requires 27% less power at 0 to 1% grades compared to the conventional wheelchair. At 3% grade the average difference is only 8.5%. At 6 km/h at both 0 and 1% grade the tricycle requires 39% less power suggesting at higher speeds the efficiency is greater. Locking of the steering reduced power expenditure approximately 5%.

Although with the 12.5 cm length crank on the laboratory ergometer, the most efficient rate of cranking was 40 RPM, the subjects preferred to crank at 50 to 60 RPM.

DISCUSSION

Even using the lowest gearing on the tricycle, all the subjects became fatigued climbing a 3% grade at 3 km/h (1.9 mph) for 6 minutes which required cranking at 38 RPM. At a comfortable cranking rate of 60 RPM in the highest gear, the speed would be 10.8 km/h (6.7 mph) and at 100 RPM, the fastest practical rate, the speed would be 17.7 km/h (11 mph). A lower gearing would be needed to climb hills. For general use, the design should allow a typical individual to climb a 5% grade hill. A low gear around 25 to 30 cm (10 to 12 in) should allow this. For higher speed level cranking, gearing up to 150 cm (60 in) would be useful. The results of this study indicate that the cranked tricycle required significant less power but that a wider gear ratio would be required for general use.

Table 1

Grade	Speed	Power Required (watts - 70 kg subject) Wheelchair	Tricycle
0%	3 km/h	9.2	5.4
	4	12.3	7.2
	5	15.4	9.1
	6	18.5*	10.8
	8	24.6	14.5
1%	3	18.9	15.9
	4	25.2	21.2
	5	31.5*	26.5
	6	37.8	31.7
	8	50.4	42.3*
2%	3	26.7	24.4
	4	35.6*	32.6
	5	44.5	40.7*
	6	53.4	48.8
	8	72.2	65.2
3%	3	35.0	33.6
	4	46.7*	44.9*
	5	58.4	56.0
	6	70.1	67.3
	8	93.4	89.7

*Last level completed by subjects.

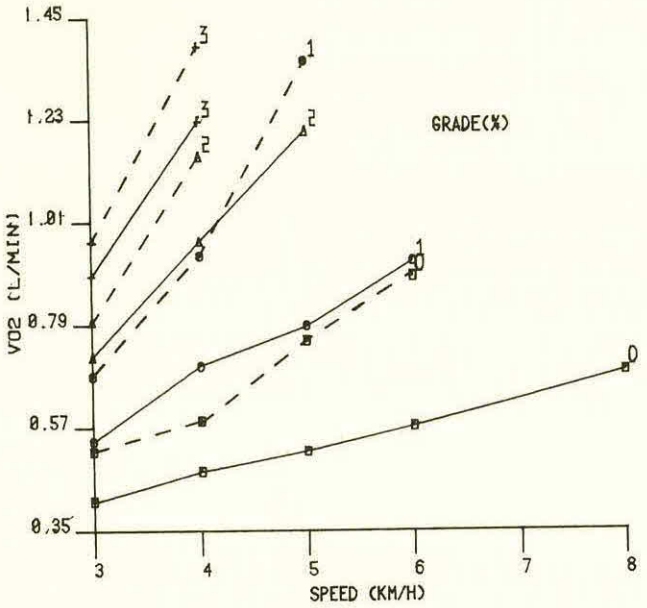

Figure 1

Figure 1: 0_2 uptake vs. speed for grades of 0, 1, 2, and 3%. Dashed line - wheelchair. Solid line - hand cranked tricycle.

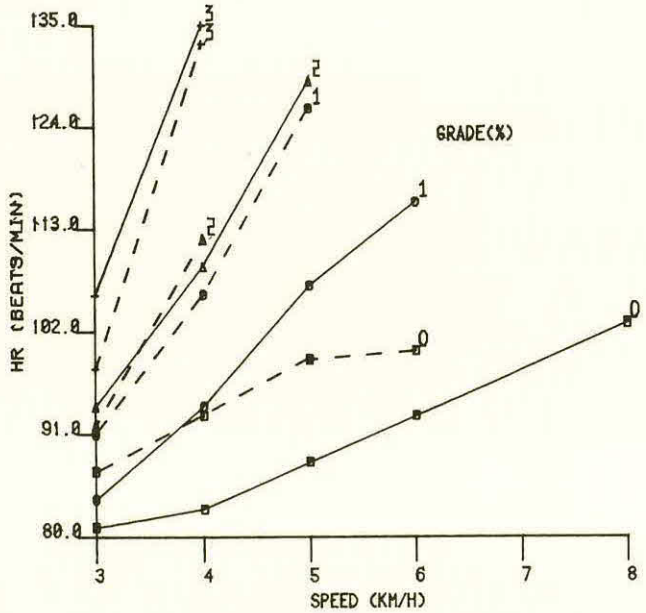

Figure 2

Figure 2: Heart rate vs. speed for grades of 0, 1, 2, and 3%. Dashed line - wheelchair. Solid line - hand cranked tricycle.

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This study was supported in part by Research Grant #G008003033 from the NIHR Dept. of Education, Washington, D.C. 20202

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ERGONOMIC EVALUATION OF A NOVEL CURB-CLIMBING AID FOR MANUAL WHEELCHAIRS

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ABSTRACT

A simple and lightweight aid consisting of portable ramps and telescoping articulating control rods which enabled a wheelchair-bound paraplegic person to quickly and safely surmount curbs was tested using able-bodied and paraplegic subjects. Data collected on each subject included ascent and descent times on 10cm and 20cm curbs, center of gravity changes during curb climbs, and the subject's force generating capabilities in his upper extremities. Force capabilities of the subjects were compared to forces required to operate the curb-climbing aid. Subjects could operate the device successfully on curbs as high as 20cm and in as little as 20 seconds. Key conclusions drawn from this evaluation were that this curb climbing aid was workable, practical, and usable by most of paraplegics and even some quadriplegics. Using this aid on curbs as high as 21cm did not require excessive strength.

INTRODUCTION

Current legislation has mandated the elimination of such barriers in public buildings, but full accessibility for wheelchair-bound persons is far from reality. Buildings often have single or multi-step entrances which limit their accessibility to wheelchair-bound persons. An alternative or interim solution to the elimination of such barriers is to implement devices that can overcome such barriers - - particularly the frequently encountered barrier of curbs(2).

Most devices which have been developed to enable wheelchairs to overcome curb barriers use some type of cranking mechanism or lever mechanism to lift the wheelchair over the curb(6,7). Such devices have proven to be infeasible because of their mechanical complexities, limited capabilities, slow operation and/or excessive strength requirements for their operation. The solution that involves major modification of commonly used wheelchairs are not cost-effective(1,6).

Helping paraplegic persons in wheelchairs to overcome the curb barrier represents an on-going rehabilitation engineering effort at the Department of Biomedical Engineering at Louisiana Tech University. Present efforts have focused on evaluating a prototype curb-climbing aid using both able-bodied and handicapped individuals as subjects. The construction details of this device have been reported elsewhere(8). Only a brief description of the device will be presented there.

DESIGN CONCEPT

The essence of the curb-climbing assistive device is that ramps for overcoming curbs would be carried along with the wheelchair and used by the chair's occupant when needed. Two aluminum ramps 91.4cm long and 10.2cm wide with 2.5cm sidewalls are held in alignment with the wheels by telescopic control rods which attach to and rotate about the wheelchair's main axles. These rods would also be used by the paraplegic to manipulate the ramps into their proper positions prior to ascending or descending a curb (Figure 1).

The curb-climbing task is performed using the aid by lowering the ramps into place, rolling the chair up the ramps and onto the upper walkway, and then rotating the ramps up and over the shoulders and back into their forward positions.

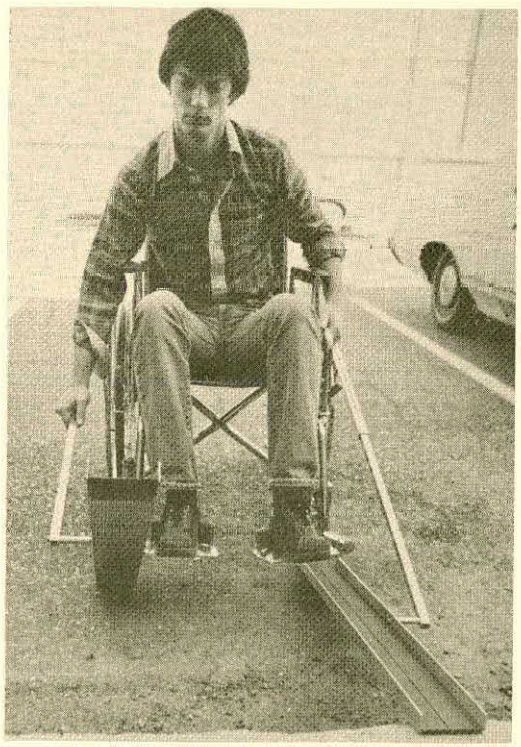

Figure 1- The portable-ramp curb-climbing aid in use.

The curb descending task is performed in a similar manner.

The curb-climbing aid requires some upper body strength and good hand dexterity for its operation. This paper reports an ergonomic evaluation of the aid in order to identify its potential users and functional limitations.

EVALUATION OF THE CURB-CLIMBING AID

For a thorough evaluation of the utility of the aid, the following information was gathered:

1. Force required of the user (measured statically) to operate the aid.
2. The Stability and safe operating range of the device.
3. Times required for ascending and descending curbs of typical heights.

The amount of effort required of a person to use an assistive device determines the acceptability and practicality of that device. In performing tasks of short duration, such as surmounting curbs, the effort required can be adequately estimated by the strength (i.e. static force) requirements(4). Hence the evaluation of the curb-climbing aid necessitated that the static forces necessary for the operation of this aid be obtained.

Stability and safety are two other key determinants of an aid's acceptability and practicality. For the wheelchair and its occupant, stability depends on the proper relationship between the position of the overall center of gravity (CG) and the base of support. In the dynamic situation encountered during wheelchair operation, the CG of the total system must be determined for the changing conditions of slope, speed of travel, and the occupant's body position.

Because curb-climbing may be done in heavy traffic areas, the time required to use the curb-climbing aid must be minimized. Ideally, the aid should allow the wheelchair operator to descend a curb, cross the street, and ascend the curb on the other side within one street light cycle, typically one minute.

Volunteers used for the evaluation of the aid included eighteen able-bodied subjects and four handicapped subjects. Twelve of the able-bodied subjects were male; six were female. The handicapped subjects included one paraplegic female, one partial C4-C6 quadriplegic and two paraplegic males. The ages of the able bodied subjects ranged from 18 to 31 years. The ages of the handicapped subjects ranged from 18 to 28 years.

METHODS AND RESULTS

The amount of effort needed to surmount a curb using the aid was estimated by comparing the maximum voluntary strength that the subject possessed against the required strength to operate the device. The strength required to use the device was calculated using the following equation:

$$F = W(\mu \cos\theta + \sin\theta)$$

where F is the required force, W is the weight of the wheelchair plus occupant, μ is the static coefficient of friction at the wheelchair's rear axles, and θ is the angle of incline of the portable ramps. The amount of strength available from the subject was measured using a strain gauge instrumented handrim.

The effort required for surmounting 10.2 and 20.4cm high curbs was recorded as a percentage of the measured maximum voluntary strength (Table 1). Seventy-five percent of maximum effort was chosen as the practical upper limit of force that can be exerted continuously without operator fatigue during use of the curb-climbing aid. The curb height which required the user to exert 75% of his maximum strength was taken as the tallest curb that could be ordinarily surmounted (Table 2).

Table 1 - Percentage of maximum effort required to climb 10.2cm and 20.4cm curbs.

		10.2cm Curb	20.4cm Curb
Able-bodied	mean:	26.5%	47.3%
Men (N=12)	s.d.:	±5.4%	±9.8%
Able-bodied	mean:	41.0%	73.3%
Women (N=6)	s.d.:	±7.5%	±9.8%
Handicapped	mean:	29.4%	52.6%
Persons (N=4)	s.d.:	±10.8%	±19.4%

Table 2 - Curb heights requiring 75% of maximum effort.

		Curb Height
Able-bodied	mean:	34.9cm
Men	s.d.:	±7.7cm
Able-bodied	mean:	21.4cm
Women	s.d.:	±4.1cm
Handicapped	mean:	33.7cm
Persons	s.d.:	13.4cm

Stability Measurements The horizontal location of the center of gravity of the wheelchair and occupant was determined using a center-of-gravity platform suggested by Peizer et al (1964)(4). The vertical location of the CG was calculated using the angle of tilt at which the subject and wheelchair would be balanced just on the rear drive wheels, and the horizontal location of the CG was obtained from the CG platform.

As the subject pushed forward on the handrims of his wheelchair, he applied an equal but opposite reaction force against the backrest of his seat. The moment thus produced tended to tip the chair backwards. A counter moment which stabilized the wheelchair existed as long as the overall CG remained in front of the rear axles. Thus, wheelchair stability required that the CG moment be greater than the reaction moment.

Based on analysis of the various static forces and moments involved, the wheelchair will not tip over if the angle of incline of the curb-climbing ramps is less than $\tan^{-1}\left(\frac{d_1 - d_2\,\mu}{d_2 + d_3}\right)$

where d_1 is the horizontal distance between the center of gravity and the rear axle when the chair is on level ground, d_2 is the height of the reaction force above the rear axles, d_3 is the height of the CG above the rear axles, and μ is the coefficient of friction of the rear axles. The seat rest reaction force was taken to be parallel to the incline because this would produce the maximum destabilizing moment. Because d_2 varied very little from subject to subject, it was set at its average value of 35.6cm.

The curb heights which would cause rearward tip-over of each subject seated in the wheelchair were calculated based on the above expression and are shown in Table 3.

Table 3 - Curb height causing rearward tip-over with subject's upper torso bent at 70 with respect to his thighs.

		Critical Curb Height
Able-bodied Men (N=12)	mean:	28.4cm
	s.d.:	±2.1cm
Able bodied Women (N=6)	mean:	25.1cm
	s.d.:	±3.0cm
Handicapped Subjects (N=4)	mean:	29.5cm
	s.d.:	±2.4cm

Task Completion Time

For curb-climbing tests, each subject was given a demonstration plus verbal instructions on the operation of the curb-climbing aid after the subject practiced once ascending and descending a 10.2cm high curb, his or her ascent and descent times for this curb height were recorded. The process was then repeated for a 20.4cm high curb. The time needed for the subject to put the ramps in place, go up (or down) the ramps, and then return the ramps to their rest positions was recorded. Data for all 22 subjects are listed in Table 4.

Table 4 - Average time in seconds for ascending and descending 10.2cm and 20.4cm curbs.

		10.2cm Curb		20.4cm Curb	
		Ascent	Descent	Ascent	Descent
Able-bodied Subjects (N-18)	mean:	39.2	39.4	43.3	40.6
	s.d.:	±13.8	±14.8	±14.1	13.3
Handicapped Subjects (N=4)	mean:	49.8	46.9	75.2	68.9
	s.d.:	±18.9	±14.4	±41.4	±26.6

DISCUSSION OF RESULTS

The maximum curb height that an individual could surmount with the curb-climbing aid depended on the user's available strength and the stability of the wheelchair and its occupant during curb ascents or descents. Obviously, the lower of these two parameters will determine the range of each heights on which the device can be used. The able-bodied data for males in Tables 2 and 3 showed that in all cases the maximum curb height surmountable was limted by the stability parameter (i.e. tip-over angle) rather than by their available strength. In contrast, five of the six able-boded female subjects has their maximum curb heights limited by their available upper body strength, rather than by their tip-over angles.

As would be expected from the above findings, the weaker handicapped subjects (i.e. the male quadriplegic and female paraplegic subjects) were limited in their curb-climbing capabilities by their strengths. The quadriplegic subject was predicted to exert 75% of his maximum effort in using the aid to ascend a curb 23.9cm high. The female paraplegic subject would exert 75% of her maximum effort in climbing a curb 20.8cm high. The rearward tip-over angle data of these two subjects indicated that they would remain stable climbing curbs as high as 28cm.

For the two male paraplegic subjects who possessed excellent upper greater body strengths, their rearward tip-over angles limited their curb-climbing capabilities to curbs 27cm in height.

Based on the data in Tables 2 and 3, the effective range of the curb-climbing aid appears to be about 25cm high curbs. Curbs higher than 20cm begin approaching either the stability constraints or strength limitations. The curb-climbing aid, therefore, allows the user to easily surmount often encountered curbs of heights less than 15cm with minimal risk of tipping over.

Although this assistive device was designed for paraplegic persons, it was successfully used by one quadriplegic person on 10.2 and 20.4 cm curbs. This suggests that the utility of the device extends beyond the targeted paraplegic population.

The usefulness of a curb-climbing aid depends in part on how quickly the aid enables the operator to surmount curbs. The task completion time data given in Table 4 represents the time required by the novice user to surmount curbs. Time limitations for the experiment did not permit sufficient practice time for subjects to become experienced users of the aid. Despite his inexperience, one handicapped subject surmounted a 10.2cm high curb in as little as 27 seconds. Thus, it is anticipated that, with practice, a user should be able to perform the curb surmounting task quickly enough to cross a street during one traffic light cycle.

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Acknowledgements:

Project was funded by a grant from the Division of Vocational Rehabilitation, State of Louisiana.

REHABILITATION ENGINEERING FOR SEVERE LIMB DEFICIENT CHILDREN

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Severe limb deficient children offer a great challenge to the field of Rehabilitation Engineering. Mobility, manipulative ability and mealtime activities are the three most important requirements to achieve relative independence. Our Rehabilitation Engineering Department had the opportunity to deal with these problems and will describe the special equipment designed for two limb deficient young girls to optimize their independence. The important improvements resulting from this work indicates the need for further research and development for the rehabilitation of disabled children.

INTRODUCTION

Mr. Meyer was responsible for the design and development of the devices. Mr. Grzymala was in charge of the fabrication and the assembly. The othermembers of the Orthotics, Prosthetics and Bio-Engineering Department headed by George Vitarius,[1] provided valuable advice and assistance.

The development and fabrication of these devices took place in the Rehabilitation Engineering Division of The Burke Rehabilitation Center in White Plains, New York under the direction of Peter H. Stern, M.D.[2] and was partially sponsored by the Variety Club of New York.[3]

Two amelic children, referred to The Burke Rehabilitation Center in 1979 and 1980, necessitated the design of highly specialized equipment.

The equipment designed in our facility and presented in this paper consists of the following devices: two motorized carts, a powered headband manipulator, an ultra-lightweight endoskeletal prosthesis and a modified automatic feeder. The key words determining the development of these items were simplicity of control, lightweight components and adaptability to the child's environment.

MIRTHA

The first system was designed for a six year old girl with congenital total amelia compounded by the existence of severe scoliosis and torticolis. Her needs were to be mobile in her environment at the other children's height. We wanted to enable her to manipulate objects, feed herself and to be able to participate in everyday activities. Miss Nancy Joy Matis,[5] and Mirtha's parents gave us the indispensable feedback concerning these requirements.

Mobility

The picture below shows Mirtha using her battery powered electric cart. Mounted on a triangular shaped aluminum plate are two uprights to which Mirtha's scoliosis brace is attached to hold the child firmly upright. The padded roll on the right counteracts the otherwise severe torticolis. The drive motor and the traction wheel has a 360° steering mechanism allowing omnidirectional mobility. Control problems were solved as follows: acceleration is through an adjustable linkage system activating a carbon pile switch for proportional propulsion. Chin controlled microswitches activate the steerage motor which positions the drive assembly via a chain linkage.

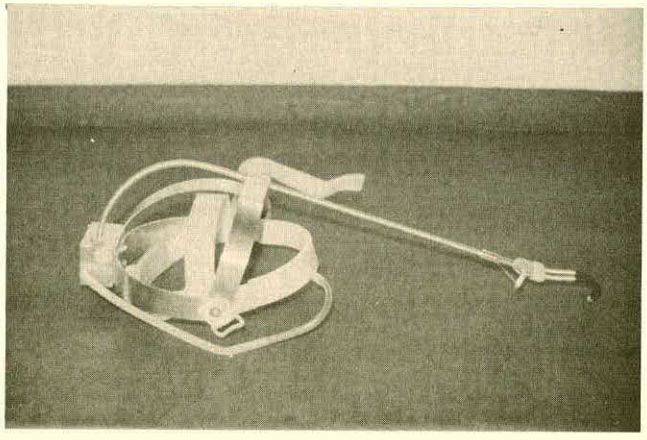
Manipulation

Manipulative ability is achieved by using a lightweight externally powered headband manipulator. It is shown in the following picture and consists of four basic components.

1. An adjustable plastic headband reinforced with a metal frame to support the system.
2. A voluntary opening hook assembly activated by a dacron line through the aluminum tubing.
3. A drive mechanism consisting of a micromotor-pulley assembly and a 9 volt rechargeable battery.

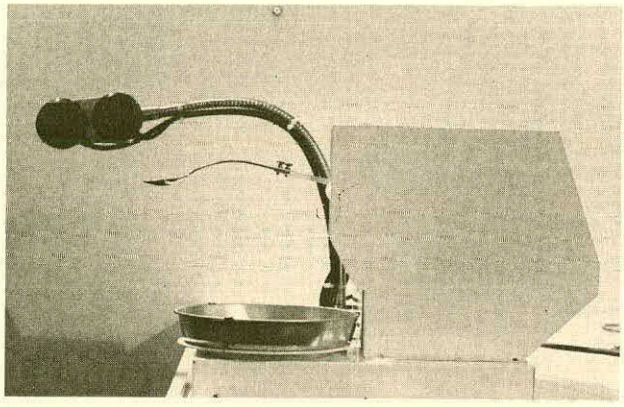
4. A control system including a pressure switch, a microswitch and a few electronic components.

Both drive and control units are located in a lightweight housing positioned posteriorly to the head for better balance.



Feeding

Mealtime activities were accomplished using a modified Maddak automatic feeder[6] shown in the picture below.



The two pressure switches activating the plate and the spoon had to be adjusted to a lower pressure and were mounted at the extremity of a metal gooseneck to be accessible by the head. The control of the spoon has been changed to a cycle movement. It now requires a single pressure on the pad to complete a full action of the spoon, ending at the level of the patient's mouth.

Results

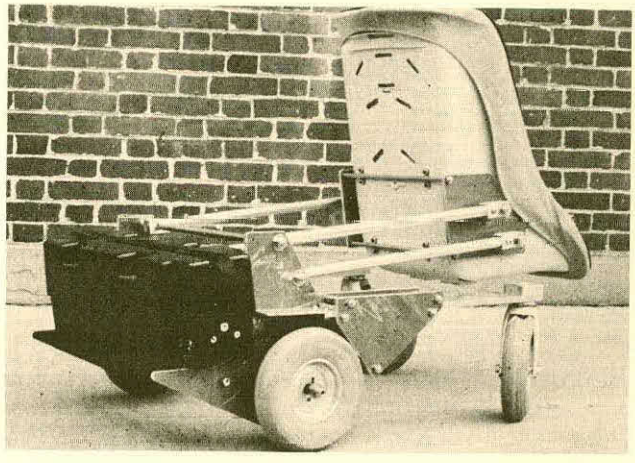
The controls of the equipment described are very simple and were rapidly mastered by Mirtha. After a year she drives around with skill, is able to control the feeder and shows great dexterity with the manipulator. There is still limitation in the effectiveness of this last device since there is no proximal control of the hook. To overcome this problem some improvements are under investigation.

LISA

Lisa is a bright 6 year old girl and was referred to us in the middle of 1980. She has total amelia on the right side and congenital above-knee and above-elbow amputation on the left side. The partial leg allows her to be stable in a sitting position and to propel herself on her bottom. The partial humeral stump is very mobile and is able to control the prosthesis. To fully use her natural mobility and agility, we had to take a different approach than with Mirtha.

Mobility

To extend her independence to a maximum, we wanted her to be able to get in and our of her cart on her own. This has been done by mounting her infant car seat at the extremity of an electrically powered 4-Bar Linakge Assembly. The seat can be positioned between the floor and 25 inches of height. The main frame was constructed around a Proportional Chin Controlled A-BEC kit.[7] It consists of two motorized rear wheels, an electronic control box, a chin-controlled joystick and a rechargeable Gel-Cell battery pack. To allow for flexibility, wheel independence and vibration-free ride, a set of leaf springs is used for the attachment of the front wheels to the main frame. This system is under construction and will be completed during the first quarter of 1981. The picture below shows the principle mechanism.



Manipulation

Available components and standard approach for Lisa's prosthesis produced a heavy, uncomfortable and impracticable system. We decided then to design a very lightweight body powered prosthesis. Using the suggestions of Renee Okoye [8] and Lisa's mother, and analyzing the previous problems encountered with the first fittings, we were inspired to create a totally new system.

Shown in use below, the completed prosthesis weights about 4 ounces and consists of the following components:

1. Voluntary opening hook with friction wrist joint.

2. Voluntary extendable forearm with friction-locking elbow joint.
3. Laminated cuff.
4. 1/4" tubing used for the upper arm and lower arm sections.
5. Rubber bands used for the hook closure and elbow flexion.
6. Harness for suspension and control.

The prosthesis was used in the following manner: The humeral pronation controls the tension on the cable and activates the mechanism. If the elbow is free, the forearm first extends and then the hook opens. The release of the cable closes the hook and then flexes the elbow. The elbow can be locked with the leg or the edge of a table in any position. This allows the hook to be activated independently.

Feeding

The same modified Maddak feeder was experimentally used by this child, but will prove unnecessary when she becomes more skilled with her prosthesis.

Results

Being a bright and skillful child, Lisa easily understood the controls. It was more important and difficult to take full advantage of her natural abilities. To fulfill these requirements, the equipment was designed to be functional instead of cosmetic.

The results are still unknown since the equipment described is undergoing final adjustments, but we expect them to be positive.

CONCLUSION

Equipment design for highly handicapped children is a great challenge for the Rehabilitation Engineering field. It requires the true understanding of their limitations. Size, weight and control of the equipment take a very important place in the design. Adaptation to the environment is critical. Teamwork between Doctor, Occupational Therapist, and parents is indispensable and provides feedback to achieve these goals. Once this has been understood and has been taken into consideration, it becomes a pleasure and is so rewarding to work with and for these children.

FOOTNOTES

1. George Vitarius, C.O., Director of the Orthotics/Prosthetics and Bio-Medical Engineering Department, The Burke Rehabilitation Center, White Plains, NY.

2. Peter H. Stern, M.D., Director of Physical Medicine and Rehabilitation, The Burke Rehabilitation Center, White Plains, NY

3. Variety Club of New York. Tent 35.

4. St. Agnes Hospital Children's Unit, White Plains, New York.

5. Nancy Joy Matis, M.S., CCC. Speech Pathologist St. Agnes Hospital Children's Unit, White Plains, NY

6. Maddak Inc., Pequannock, New Jersey

7. A-BEC, Torrance, California

8. Renee Okoye, M.S., H.S., O.T.R., Wantagh, New York

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SOME DEVICE DEVELOPMENTS FROM A REHABILITATION ENGINEERING SERVICE*

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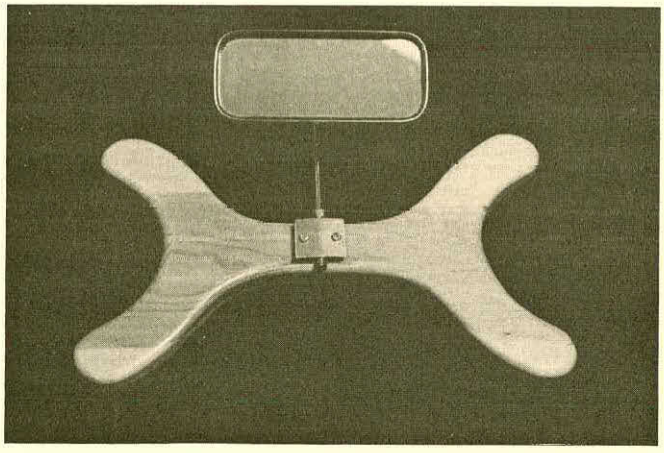
Solutions to rehabilitation engineering problems are sometimes easily effected by the purchase of a commercially available device or by the design and modification of standard items such as a ramp, transfer board, etc. However, for the particular five problems presented in this paper, not only were commercial devices not available, but in addition the resolution did not lend itself to routine design/fabrication. Oftentimes, existing devices serve as starting points in developing a solution, but in any event this calls for some redesign and/or modification of the basic structure. This was the case for two of the devices. For the balance of the cases, the clinical problems have been encountered before, but to our knowledge simple and effective solutions do not exist. Although many devices have been fabricated at the Rehabilitation Engineering Center #2, we feel that the five devices presented here required a novel approach in the design and implementation, resulting in a pragmatic and effective solution.

FEMALE SELF-CATHETERIZATION ASSISTIVE DEVICE

The first case was that of a female client who was mildly spastic with some form of paralysis in the lower extremities, so that she was not able to perform the routine manual method of self-catheterization. To generalize, the client cannot abduct her thighs, or having done so she cannot maintain the abducted thighs in a stable position. The other aspect of the problem is visualization. Some patients cannot sit up, others who can sit up usually encounter some groping in order to orient the catheter and negotiate the insertion.

Although commercial abductor devices are available, they require the services of a nurse. The wooden abductor bar shaped in the form of a dog bone was conceived in order to permit self-catheterization. The bar is placed on the inside of the distal portion of the thighs with the thighs resting in the lateral arms, so that the bar can ride along the inner surfaces of the thighs. The form factor and dimensions of the bar facilitate the abduction, maintain a stable abducted position, and the bar can accommodate a wide variety of thigh configurations.

A small mirror (bicycle rear view mirror) is gimbal mounted on the axis of the abductor bar and permits the client to direct and monitor the insertion of the catheter from a range of positions - either lying almost supine or sitting upright.



Abductor Bar with Mirror

PNEUMATIC FEMALE CATHETERIZATION ASSISTIVE DEVICE

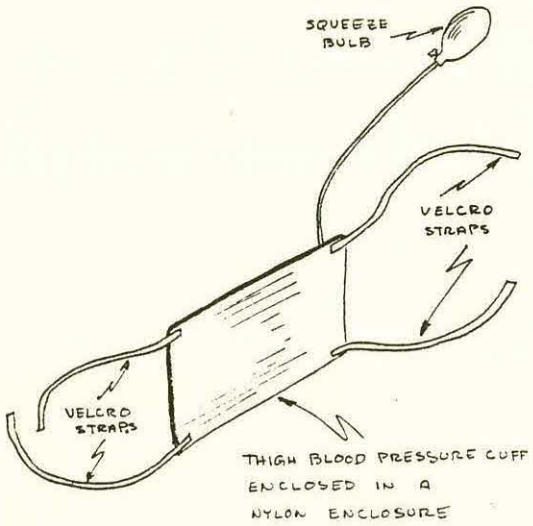
The second case was that of a female client with some form of paralysis and because of the severe spasticity she was unable to use the abductor bar described previously. Therefore, this pneumatic device was conceived to assist an aide in abducting the thighs in order to catheterize the client.

A pneumatic sausage shaped abductor bag 8" long is inflated into the shape of a cylinder of approximately 4" in diameter. The deflated bag is placed between the knees and strapped onto each leg with Velcro straps. Inflation takes place with a squeeze bulb. The soft contours (more surface contact than the abductor bar) and the gradual inflation avoid triggering additional spasms and keep the legs comfortably separated for catheterization.

COMMUNICATION ACCESS AID FOR THE FOOT

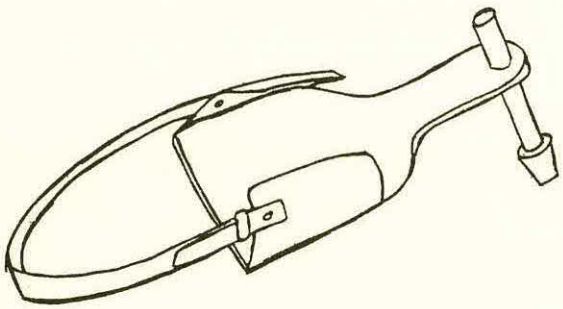
In this case, the client was a spastic quadriplegic with no verbal communication ability, and the only functional control site was his foot. We utilized this characteristic in designing an access aid so that the client would be able to communicate. A slip-on pointer was attached to the shoe, allowing the individual to use a direct selection technique for communication.

A device, fabricated from Plexiglas, slides



Inflatable Abductor

onto the front of the shoe and secures around the back. A 3-inch long torque tongue protrudes from the front of the Plexiglas form and a rubber tipped pointer is inserted through the tongue. The patient rests his or her heel and, using a tapping motion, gains access to a keyboard by direct selection of keys.



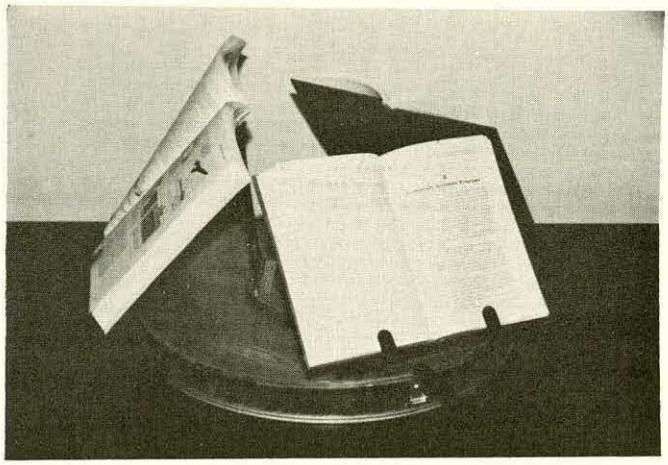
Communication Access Aid for the Foot

ROTATIONAL READING AID

.A student afflicted with phocomelia (with no manual dexterity) wanted several textbooks available to him with the option of going from one to another independently.

Three Miller Deluxe Bookholders (Sammons #BK-4059 #3814) are mounted 120° apart on a rotating platform with a detent mechanism to secure the book selected and lock the rotating device in that position.

Access to the other books on the platform is achieved by unlocking the latch mechanism and rotating the platform with the chin. Thereafter, the pages of the book can be turned with lips or a mouth stick.



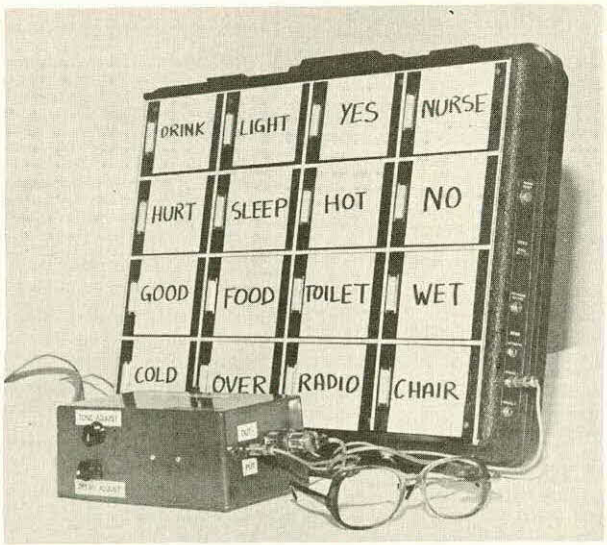
Rotational Reading Aid

EYE BLINK INTERFACE

The only remaining functional control site for a quadriplegic was his eye blink. This was utilized as an access to communication. An eye blink interface system was designed to control a Zygo or Prentke-Romich Communication Board.

The sensory unit is a self-contained emitter and sensor, mounted on an eye glass frame so that it can be positioned from approximately 7 mm to not more than 13 mm from the subject's eyelid.

A dot of reflective material is placed on the eyelid. When the eyelid is in closed position, the sensor detects the dot and triggers a momentary switch closure. The system is designed to ignore normal eye blinks.



Eye Blink Interface

*The work was supported in part by grant #G008003003 from the National Institute of Handicapped Research.

THE RANDOM ACCESS TAPE RECORDER SYSTEM

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The Random Access Tape Recorder System is designed to be a teaching tool for classroom teachers of severely-handicapped children. It consists of a push switch, a fifty-six box scanning communicator (SYMTIC), and a Random Access Tape Recorder. The system is battery-powered and designed to be portable. It allows rapid changing of lessons during a teaching session and can be easily programmed in advance for an upcoming session. It is currently being tested by the Prenke-Romich Company for marketing possibilities

INTRODUCTION

The Biomedical Engineering Center at Tufts-New England Medical Center recognized a need for audible feedback to disabled children using a SYMTIC (Symbolic Tufts Interactive Communicator) for learning and communication. The scanning, fifty-six box SYMTIC allowed different words or symbols to be displayed and selected but required another person to spell or pronounce the selection. Consequently, children received less instruction time than would have been possible with a self-contained unit.

DESIGN CRITERIA

The Random Access Tape Recorder was designed to provide the desired audible output. The design criteria called for a self-contained unit that could reproduce any spoken phrase, was easy to program by non-technical people, and had high-quality speech for low cost. Additionally, the unit needed to be as readily portable and battery-powered as was the SYMTIC used with it.

After some thought, a tape deck was decided upon as the best implementation method, as synthetic speech at the time was of low-quality and difficult to program. An eight-track type of unit was considered and dismissed due to the length of time required to access a selection. A cassette deck provided the required high-quality and low cost, as well as commercial availability. Consequently, the Phi-Deck manufactured by Triple-I, Inc. was selected.

The Phi-Deck is an audio tape deck with control signals available for the user. It has high-speed fast forward and reverse modes and offers a slotted disk and light producing eighteen pulses per revolution of the takeup reel. This allows a location on the tape to be accurately located repeatedly. Finally a beginning-of-tape sensor locates the clear leader of the cassette tape.

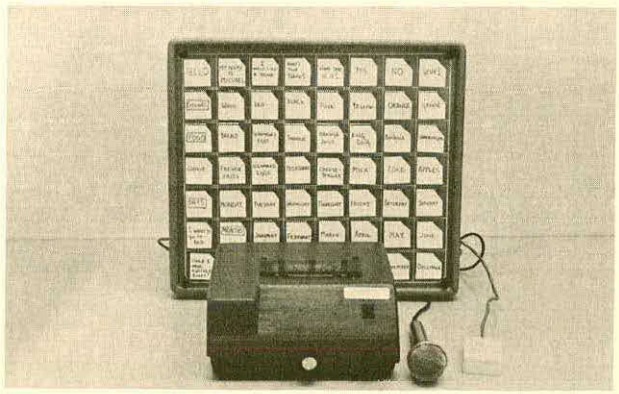
Controlling the tape deck is an RCA 1802 microprocessor. Chosen for its low-power CMOS circuitry, it offers sufficient flexibility to allow different message lengths or device input codes to be used. Support circuitry for the microprocessor provides the signals necessary for control.

Audio connections to the tape deck include a standard, one-quarter inch microphone jack for recording new tapes, an earphone jack to permit use of the deck in locations where silence is necessary, and a three inch round speaker for sound reproduction. The deck also has a volume control for playback, a record/play switch, and an on/off switch. The tape recorder measures nine inches deep by ten inches wide by five inches high and weighs eight pounds.

A battery charging unit external to the deck plugs in to charge the battery while allowing the unit to be used during charging.

METHOD OF OPERATION

The teacher connects the tape deck and the switch to the SYMTIC which is placed in a location visible to the student. A translucent plastic overlay is placed on the face of the SYMTIC and the appropriate cassette tape placed in the deck. After the SYMTIC and tape deck are turned on, the tape deck rewinds to the beginning of the tape.



The user sees a horizontal row of lights behind the plastic overlay moving from top to bottom continuously until the switch is pressed. Whenever the switch is held down, all scanning stops with the light(s) frozen in the state they were in at the time of switch closure. Upon releasing the switch, a single light scans across the selected row until a second switch closure selects a single box. A third closure begins the process anew.

When a box is selected by the second switch closure, the tape deck reads the code output by the SYMTIC and fast forwards to a unique corresponding location on the tape. At that point, a message of fixed length is stored and is played or recorded depending upon the state of the record/play switch. Currently, the message length is approximately six seconds, although this value can be changed in software, and access time to the message ranges from one-half second to eight seconds depending on location. Then, the tape deck rewinds to the beginning of the tape. Messages cannot be strung together by the tape deck although a new selection can be made while the current message is playing.

USAGE

The philosophy of the Biomedical Engineering Center for device development is to design a device, built approximately ten prototypes, place them in the field, and evaluate their effectiveness. The small number of manufacturers in the field are consulted throughout this process to determine their interest in adding the device to their product line.

Ten Random Access Tape Recorders have been built and placed with customers; seven have been used with SYMTICs, one has been modified to work with a ZYGO 100, and two are being used with special twenty-four paddle direct-selection devices designed at B.M.E.C.

Customer reaction has been positive. Most applications have used the recorders as a combination of a communication device and a teaching tool for children. The therapists using the decks have found language feedback to be a strong motivation for learning and communicating. The problems encountered have primarily been related to different teachers learning to use the deck by recharging the battery, connecting everything together, and recording new messages.

CONCLUSION

The Random Access Tape Recorder system is a useful tool for teaching handicapped children. It can also be used as a limited communication device, particularly in situations where deviation from standard responses is unusual. Its programmability allows many imaginative uses for a large number of different students while its portability does not limit it to a strict classroom situation.

ACKNOWLEDGEMENTS

This work has been supported by Grant #16-P-57856/1-05 from the National Institute of Handicapped Research, U.S. Department of Education.

INFLATABLE BATHING SYSTEM FOR THE DISABLED

Robert T. Whalen

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President, Bathing Aids to the Handicapped

ABSTRACT

A new approach to bathing has increased the accessibility and improved the quality of bathing for the severely disabled. With the use of a portable, inflatable bathtub, complete bathing is accomplished without the bather having to leave his/her own bed. Temperature adjusted water is fed into the bathtub and then pumped out through the same hose by utilizing a Venturi device.

INTRODUCTION

Unfortunately, for many people the act of bathing is not a simple task. In fact, persons afflicted with muscular dystrophy, cerebral palsy, spinal cord injuries, arthritis, or simply "old age" all share a common problem -- general inaccessibility to the bathroom. In many cases, the cost of lifts and bathroom conversion remove conventional bathing as a possibility. In other cases, a person's physical condition is such that lifts and/or conventional bathtubs are uncomfortable. In addition, transportation of the person to the bathroom is often too physically taxing on the attendant -- he/she typically being a family member. A common solution has been to replace bathing with sponge baths.

Thus, ample motivation existed to establish an alternate method which would make life easier and more satisfying for all persons involved. The following design is an attempt to remove some of the burden from the attendant, while at the same time making a "real" bath once again a viable choice for the severely disabled. It must be emphasized that the central idea is not to confine someone to bed, but rather to extend to a proportion of the disabled community functions easily performed by the able-bodied population.

DESCRIPTION OF BATHING SYSTEM

The bathing system is basically very simple and best explained using photographs. Figure 1 shows the deflated bathtub positioned under the bather. Installation and removal of the deflated bathtub each takes a "few" minutes. The bathtub ring is inflated with a hand-held blower in approximately one minute. As shown in Figure 2, water has already been partially pumped into the bathtub.

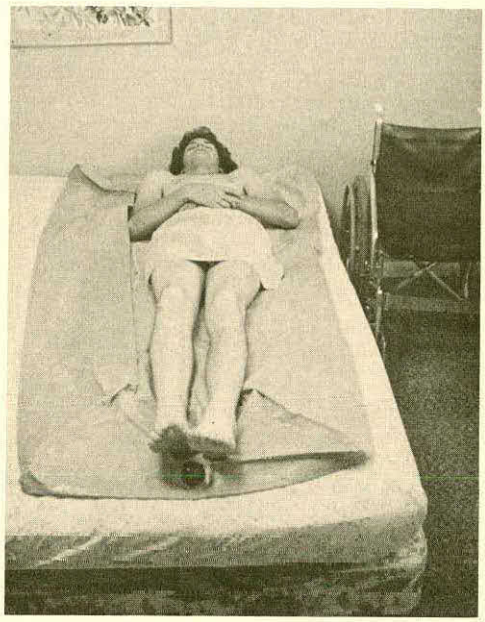

Figure 1

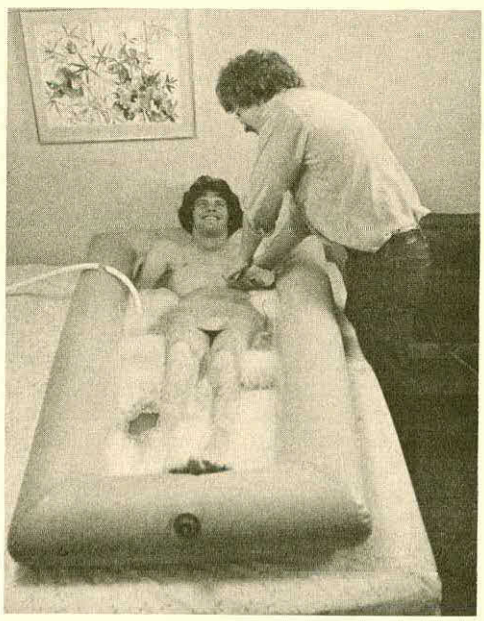

Figure 2

The amount of water used will, of course, depend on bather size and bath preference -- a sufficient amount might be three cubic feet (187 pounds). Figure 3 illustrates the Venturi pump which both fills and drains the bathtub. With a line pressure of 40-50 pounds per square inch, filling and draining this amount of water take about five minutes each. Deflation of the bathtub is accomplished in less than one minute utilizing the vacuum side of the blower.

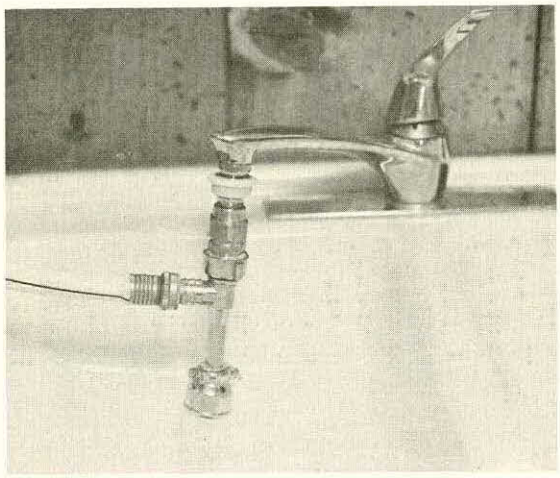

Figure 3

The bathtub is extremely stable on a bed, with no tendency to spill water or tip. In addition, the tubular air ring and the mattress provide a very comfortable support for the user. An inside dimension of sixty inches provides considerably greater leg room than most conventional bathtubs. Early models utilized an 8.5 inch diameter ring. Under the influence of bather and water weight, the mattress depresses several inches, providing a maximum depth of 10½-11 inches. Although no one has mentioned depth as a problem, a 9.0 diameter model is presently being designed.

Choice of bathtub material has been the biggest problem. Original prototypes were hand-fabricated from vinyl coated nylon cloth. Such a material presented good structural integrity and puncture resistence. However, it was not an appropriate choice for production models. A switch to easily sealable, unsupported vinyl proved to be a mistake. The units simply could not withstand the handling punishment, and a higher than acceptable percentage suffered seam leaks. To remedy this problem, a decision has been made to return to a supported material -- this time the extremely high quality, urethane-coated pack cloth. The toughness and durability of this fabric should make the inflatable bathtub a durable, long-lasting device, even under the severest of conditions.

The general compactness and portability of the bathing system make it ideal for traveling. The total weight of the complete unit (bathtub, hose, pump, inflator, etc.) is approximately fifteen pounds, and easily fits in a 13" x 15" x 9 carrying bag.

CONCLUSION

A method for bathing the severely disabled has been described. It utilizes an inflatable bathtub positioned under the bather on the bather's bed. Water is pumped in and out from the nearest source. Does it work? Is it worth it? Is there a market? Perhaps it is best to end with a quotation from a user: "Until it arrived last April, I hadn't enjoyed a bath in over fifteen years, other than the old-fashioned bed bath used for the bedridden. This invention has made it possible to immerse in water each week, contributing to a vast improvement in the condition of my skin. The tub really works..."

EVALUATION AND TRAINING BATHROOM FOR THE PHYSICALLY DISABLED

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A major aspect of personal hygiene care is the person's ability to make use of the bathroom facilities. These primarily include the bathtub, sink and toilet. Special bathroom fixtures were designed and fabricated that permitted a rehabilitation hospital to simulate numerous bathroom situations. The primary goal of these bathroom fixtures was to make them able to simulate the different bathroom environments as they presently existed in each individual's home. It was then desired that all of this equipment be adjustable to permit possible evaluation and training of the fixtures at optimized locations. The bathtub, toilet, and sink, were all made to be adjustable in height and able to be situated and moved about a room. With the use of this type of equipment, a therapist could teach an individual how best to cope with their hygiene needs once they return to their home setting. The therapist could also make recommendations as to the best modification to make a fixture more accessible to an individual's disability. Each fixture was designed to be at a minimum of cost and to be able to be functional as it would be in a home setting.

INTRODUCTION:

The Sheltering Arms Hospital in Richmond, Virginia desired bathroom fixtures that would allow them to simulate, at their facility, the home bathroom environment of various clients. This necessitated the design and fabrication of a bathtub, toilet, and sink that could be located in various places with respect to each fixture as well as with respect to the walls of the room. Each fixture was also adjustable in height and each could be installed to be functional. Here, functional means that the water supplies could be connected and the waste water removed.

With the use of this equipment the therapy staff could closely simulate a disabled client's home bathroom for training purposes. In addition, potential remodeling recommendations could be assessed by the therapist.

It was not feasible to make each fixture show a common, realistic, home situation and optimal for access to the physically disabled simultaneously. Therefore, some features, such as control fixtures, were a compromise between optimal design and a demonstration of a simple conversion.

THE BATHTUB

The review of existing products showed that there was already a design of an elevating bathtub fixture (1). This fixture was primarily intended to make the chore of bathing a person easier for an attendant. It did not resemble the commonly available bathtub in the home setting. It was also not designed to be able to be easily moved to varying locations in a room. A common bathtub design was chosen to be a bathtub with a spout at the foot of it with the lip of the bathtub approximately 16 inches from the floor, approximately 5 feet long and about 3 feet wide with sides that extended from the top edge of the tub down to the floor. The edges of the tub serve as a barrier in a transfer situation and it was desired to make the rehabilitation setting as real as possible. At the onset it was decided that all the fixtures would be able to be functioning and this lead to the design compromise of having the lowest possible tub height be 19 inches from the floor to the lip of the tub. This was brought about by the fact that in a home situation the bottom drain out of the tub goes through the floor. However, in order to have the tub able to be moved about in different locations within the simulated bathroom it was necessary to leave room for the drain pipe to protrude below the bottom of the tub. Within the constraint of making the tub actually functioning, the bathtub fixture then had as low as possible edge.

It was also desired to have the tub accessible for transfer from either side. The only tub available in our geographic location within the designated time frame, was a tub that was Kohler model - Carribean K-800S. All other commonly available tubs were either right or left handed and therefore had the wall side edge turned up and this interfered with transfer on that side. Although the selected model of bathtub has some desirable features such as being roomier and additional handgrip rails, these rails and the additional, one foot length were necessary compromises from the standard to allow transfer from either side of the bathtub. The water control fixtures were chosen to be operable by somebody with limited hand function. The water control was chosen to be of the type that needed a single control for a mixture of hot and cold water. The hand held shower was also selected to be the type that attached to the standard bathtub spout (Fig. 1). This was done to show that a bathtub,

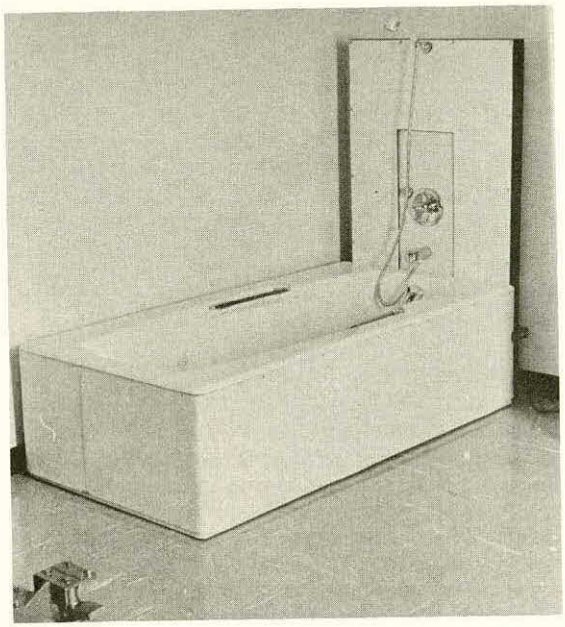

Figure 1
Completed bathtub in lowered position

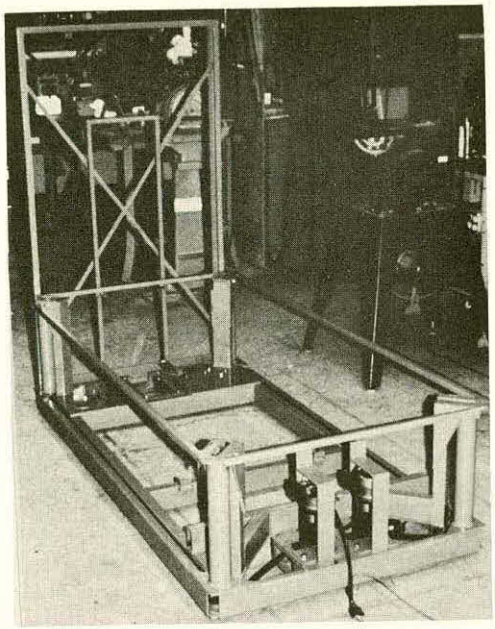

Figure 2
Elevation framework for bathtub

without an existing shower, could be easily converted to have a hand held shower. A high and low mounting location was used to illustrate the variability of height that the shower could be located. All of the faucets and fittings remained in the same relative location to the bathtub edge as the bathtub elevated. The bathtub went from the lowest possible working height of 19 inches to an elevation where the upper edge of the bathtub was 29 inches off the floor. This elevation could illustrate the added ease of bathing someone at an elevated height and it was able to simulate the 27 inch floor to lip height found on older, foot supported (steeping) tubs.

The elevating mechanism for the bathtub basically consisted of two steel frames. An outer steel frame served as the basic support when the tub was elevated and the inner steel frame served to directly support the bathtub (Fig. 2). The inner steel frame was connected to the outer steel frame by screw jacks. The screw jacks were telescoping thick walled tubing, supported by an internal threaded rod, that was in turn supported on a thrust bearings. A gear was attached to the bottom end of each rod. The four corner jacks were driven by two reversible torque motors connected to the gear on each telescoping jack by means of a steel chain. Each motor was a 1/12 horse power, 90 rpm, 115 volt, 60 Hz AC motor. It had an internal gear reducer of 19 to 1. It was also thermally protected and had adjustable limit switches. The reversible torque motors were mounted on adjustable slots to allow for tensioning of the drive chain.

The torque motors were wired together and then to a switch mounted on the fixtures wall. The switch was a momentary type and the travel of the bathtub was limited by the adjustment of the limit switches on the motor. The electrical bonding necessary to make meet safety codes was to be accomplished by the hospital electricians.

An additional restraint on all the bathroom fixtures was that they had to be transportable through a 32 inch door. This restricted the size and weight and necessitated a subassembly approach for the bathtub fixture. For assembly, the inner frame was lifted and bolted on to the outer support frame. The upright fitting wall was then attached. The steel tub was then lifted in to inner support frame.

The entire fixture could be moved by bringing the inner frame down to a point that casters mounted on it would protrude beyond the outer support frame. The sequence of function, starting with the bathtub resting on its swivel casters, would be that the inner frame would move in respect to the outer support frame until the outer frame came in contact with the floor. After this point, the outer frame would then support the tub at any height so as to be extremely stable for any occupant. It was not envisioned that the bathtub would actually be filled with water in an elevated position (there was a concern about the dynamic loading of sloshing water at an elevated height of 29 inches). The tub could, however be filled at the lowered position.

THE TOILET

The design features desired for an evaluation toilet were that it modeled the bowl type toilet with a tank back. A survey of commercial devices showed that there was a design of an elevating toilet available from Matthew-Matic Corporation. This design used electrically controlled screw jack actuaters to elevate a wall mounted tank toilet (Fig. 3). The water closet/urinal adjusted

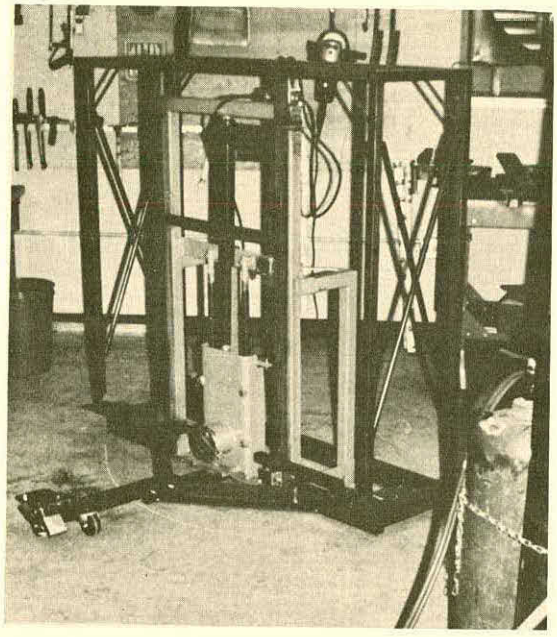

Figure 3
Framework and elevating mechanism for movable toilet fixture

in height from 16" to 28" by switch activation. It was decided to modify this existing elevating frame work and enclose all of the apparatus (Fig. 4). A three point support was chosen to

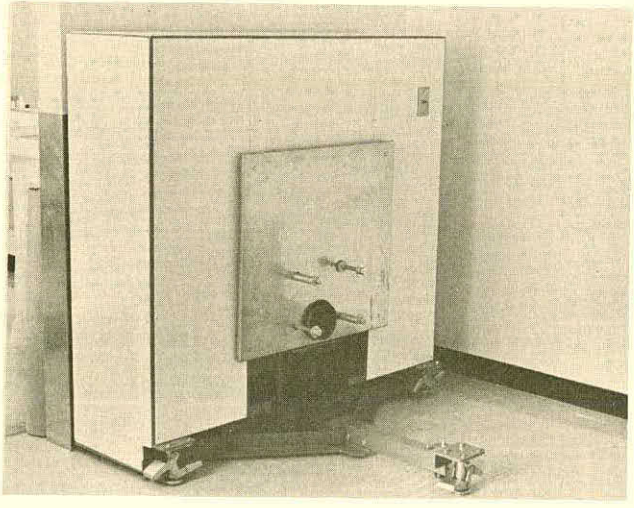

Figure 4
Elevating toilet fixture completed (except toilet attachment) for adjustable height movable toilet

make the toilet as accessible as possible to somebody approaching from either side in a wheelchair. The supports consisted of three swivel casters with an accompanying truck-lock. These truck-locks essentially are a non-skid support than can be locked in a down or an up position. The actuating of the position is done by the foot pedal. The incorporation of the caster and truck-lock allowed the toilet fixture to rest on three fixed, sturdy supports when it was being used for evaluation of transfers between the toilet and a wheelchair. The fixture could then be let down on three casters to be moved to other desired locations.

THE SINK

The third piece of bathroom fixture that was designed and fabricated was a sink cabinet. There was an existing design available of an elevating height sink, however, the sink was a wall mount design and the water control fixtures were not of a standard home variety (2). Therefore an elevating sink was needed that simulated the type of bathroom counter and mirror arrangement that could be found in a large number of homes. The width of the sink counter was chosen to be 24 inches to permit close situation of wall and other obstacles found in a home setting. In order to keep the cost at a minimum, the elevating mechanism for the bathroom sink made use of two elevating, overbed-table, screw jack mechanisms (Fig. 5). These screw

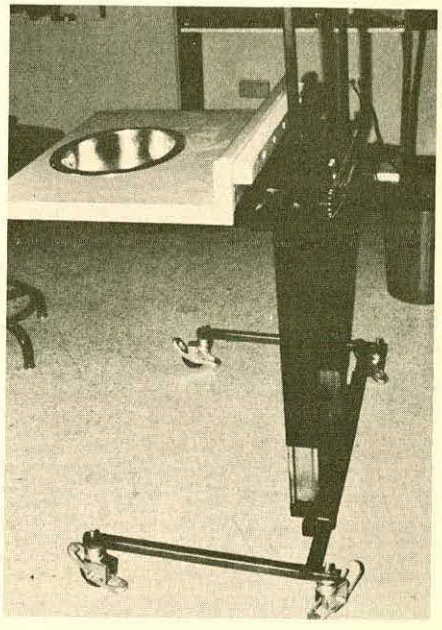

Figure 5
Framework and elevating mechanism for movable sink fixture

jack mechanisms were modified to be driven by a single lever. The two mechanisms were linked together by a chain and an adjustable idler gear permitted tensioning of the chain. The drive shaft was then brought out to the front of the sink where a removable lever could be inserted for height adjustment. The original design of the sink fixture was done with telescoping leg supports. It was hoped that these telescoping legs would permit close as possible location of the sink with respect to other items in the bathroom, and still permit access from either side by a wheelchair. However the telescoping leg design proved to be relatively unstable due to the

cantilever of the sink shelf. The support legs were then welded at a fixed position chosen to be at a compromise between as a narrow as possible (to allow close proximity of the sink) and wide enough to permit access to the sink at an angle by someone in a wheelchair. The swivel and locking type casters were mounted to the four corners of the frame. Within the time constraints of the desired completion, the most shallow, drop-in sink fixture available was 5½ inches deep. It was oval and stainless steel. A drop in sink design was used so that the difference in height between the the under-sink clearance and the top surface height could be minimized. A goose neck spout and wrist control handles were used for fittings. Since a single control was used for the bathtub water fixture it was decided to provide dual control handles for hot and cold water on the sink. The sink counter elevated from a height of 28 inches to a height of to 40 inches. This was to permit demonstration of the minimum recommended floor-to-under-sink clearance of 30 inches. It could also demonstrate how a high elevation would be beneficial for people that had a disabling condition that would not allow them to stoop or be seated to use the sink. The mirror was mounted with a hinge at the bottom and a friction lever at the top. This permitted the mirror to be angled for easy viewing of the interior of the sink by someone seated in a wheelchair (Fig. 6).

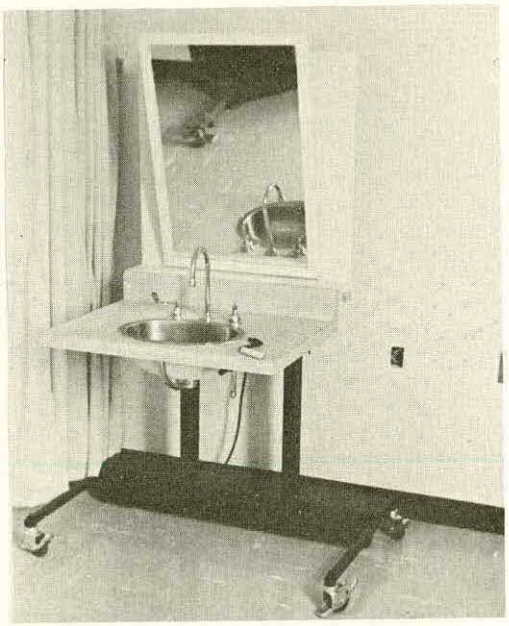

Figure 6

Completed adjustable height, movable sink fixture

CONCLUSION

It should be reiterated that these bathroom fixtures were not designed to show the best possible design characteristics of a bathroom for a handicapped individual (3). These fixtures were designed to permit therapists and a client to simulate, as close as possible, a wide variety of individual home bathroom settings. This lead to the necessary for each fixture to be able to be moved to a different locations in the room. This also necessitated that variable height be attainable for each of the fixtures mentioned. Whenever possible, features were included that would permit demonstration of desirable features to be incorporated in any remodeling for future purchase of bathroom fixtures. The difficulty in trying to demonstrate an actual home setting and then try and illustrate possible improvements lead to the mentioned design compromises. Other constraints that bore heavily on the design was the completion time. The design to product delivery time was desired to be three and a half months and the budget was to be $3,000. In retrospect, the actual cost of the three pieces would be closer to $7,000. Of course this cost would vary considerably depending on the price of labor since the construction of the fixtures is very labor intensive.

RECOMMENDATIONS

The designed features were a cooperative effort between the staff of Sheltering Arms Hospital in Richmond and the authors. It is the author's opinion that any duplication of these bathroom fixtures should consider the elimination of the requirement that the fixtures be functional. Again, functional means running water with the drain in the bathtub, hot and cold running water with the drain in the sink, and a toilet that has running water and is able to dispose of waste. The authors feel that the it would be more important to have the edge of the bathtub at the standard bathtub height of 16 inches rather than have the bathtub be able to hold and drain water. The overall cost would also be reduced by not requiring that each fixture function.

ACKNOWLEDGEMENT

This project was supported in part by National Institute for Handicapped Research Grant PGN-23-P-577995/3.

The authors would like to acknowledge Nancy Dawe and Valerie Young of Sheltering Arms Hospital for their contribution to the design features.

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TRACTOR MODIFICATION FOR BILATERAL A/K AMPUTEE

Robert H. Jackson & Gerda L. Flanigan

R.J. Mobility Systems, Inc.
Mobility Consultants, Inc.

This paper will describe the process by which a farmer who sustained a bilateral A/K amputation in 1978 has now returned himself to fully gainful employment. The major tool which he required to accomplish this goal was a modified tractor. This paper will aescribe these modifications and how they were accomplished.

INTRODUCTION

Statistically, the likelihood of an A/K amputee utilizing double prosthesis, actively engaging in the heavy work required in a dairy farming operation is small. In this case, however, because of good health, strong motivation, client's physical and psychological strength, excellant family support, creative technology and cooperation among all parties concerned, the outcome was optimal.

The client was able to negotiate an agreement with International Harvester to purchase a new 1979 Model #186 Hydrostatic tractor at their cost with a low cost internal loan with Harvester.

Through the efforts of Illinois Department of Rehabilitation Services (D.O.R.S.), International Harvester, R.J. Mobility Systems and the client, the following information is developed.

The major thrust of this overall project was developed by R.J. Mobility Systems in Maywood, Illinois. The follow-up design and finished product was also developed by this company.

INITIAL EVALUATION BY R.J. MOBILITY SYSTEMS, INC.

Client Background

On Thursday, June 26, 1980 and Friday, June 27, 1980, R.J. Mobility Systems visited the farm of Mr. Robert Petrea for the purpose of evaluating his vehicle mobility equipment needs. The vehicle in question is an International Harvester Hydrostatic drive tractor (Model #186). All evaluating procedures for the objective were established based on acceptable criteria.

Mr. Petrea is a bilateral A/K amputee as a result of a farming accident. The client has completed his rehabilitation work and is ambulatory (with crutches) on his prosthesis. The client is an extremely competitive person and has most definitely surmounted his disability with a high degree of success. He has gone to college and does have a Bachelor's degree in Dairy Science. It is quite evident that with his family background and educational follow-up that he has selected dairy farming as his career. The Petrea family also owns two other farms and combination leases and share crops three other parcels of land. Total acreage to be considered for the client's application is approximately 460 acres. This area is of immediate concern for the following reasons: A) Overall terrain is rocky, hilly and follows many unbroken patterns. B) Distance to be travelled via tractor, pickup truck, all-terraine vehicle or car is severe due to strict timetable of dairy farming operation(s). C) Source of family income is based on products developed from the dairy operation.

In addition to the family farm(s), the father owns an oil parts and accessories type business in the town of Iuka. Mr. Petrea's wife, Susan, acts as bookkeeper for the family's farm operation thus enabling the client maximum time for dairy farming. The bookkeeping chore was previously done by Mr. Petrea's brother. It is projected that some of Mr. Petrea's other brothers and sisters will be leaving the farming environment in the near future. With this fact in mind, total mobility and complete accessibility is necessary so that the client can maintain his current income projections, be an active partner in the operation and pull his own weight. Mechanical adaptations to the aforementioned International Harvester tractor will accomplish these goals of: A) Client be utilized in overall dairy farm operation much more so than now; and B) Income projections increasing with addition to farm of speciality adapted tractor.

Description of Client's Vehicle

Vehicle in question is International Harvester's new 1979 Model #186 Hydrostatic Drive Tractor. The vehicle is diesel propelled and possesses a fully automatic type transmission, power steering, power brakes and air conditioning. There is a self enclosed cab on the tractor which contains the control center of the vehicle. All controls (i.e. engine, RPM, engine exhaust gas temperature and ground speed) are of digital read out type. This "data center" also relays on to the operator such key information as engine hours and tire size to ground calibration for accurate measuring of the vehicle's forward speed. All controls are of modular design and can be changed in a matter of minutes to guarantee peak performance and operator safety. The tractor has a dual rear wheel braking system mounted on the right side, activated by the right foot of the operator. These two items will be reviewed in the speciality

equipment recommendation section. Acceleration is performed by a single lever control mounted on the dashboard. The speed shift levers are mounted to the left of the seat and all hydraulic controls are mounted to the right side of this seat. In a farming situation all operations such as mowing, grading, plowing, etc. are initiated on the right of the driver and accomplished on the left side. This shall also be important in our equipment recommendations. The cab of the tractor is 53" above grade/ground level. The overall weight of this vehicle is 10,900 pounds without ballast and consumes 7.1 gallons of fuel per hour.

It is our opinion that after reviewing the client's tractor, meeting with the staff of International Harvester and our engineering/mechanical personnel, with modifications to the controls of this tractor and constructing a speciality lift, that Mr. Robert Petrea can drive, operate and utilize this vehicle to it's maximum abilities.

Speciality Equipment Recommendations

We propose to design, engineer and fabricate a speciality lift constructed of rigid steel and have an expanded metal platform. This lift will be powered by the existing batteries of the tractor and be hydraulically operated to raise and lower the required 53" from grade to cab level. The lift shall have sealed roller bearings and teflon type finish on the vertical slide tubes. The platform shall be approximately 24" in width and shall be gusset welded for additional strength. The lift is to be mounted on the left side of the tractor and shall collapse as close to the motor as possible. This speciality lift shall also have the capacity to be removed for servicing of both engine and lift. Support braces for the lift shall project to the front and rear of this vehicle. All electrical switching for the operation of this lift shall be contained in all-weatherproof boxes within reach and ease of control by client. The hydraulic pump for the lift will also be enclosed and have a performance range of 500 PSI to 2000 PSI.

The interior of the cab shall be made accessible via a short 'catwalk' type platform from the lift. The access door to the cab shall be removed and remounted to swing and lock opposite to it's current design. The clutch pedal, which in essence operates a hydraulic valve, shall be remounted on the dash in a "push-pull" hand operated type control. The dual braking system shall be converted from foot operation to hand control style operation. The headlight dimmer switch shall also be relocated from the floor to the dashboard. Approximately ten (10) grab bars are to be utilized from the top station of the lift, down the catwalk, through the access door and into the operator's seat. A ball type spinner knob shall be mounted on the steering wheel for ease of control. Relocating the vehicle's tool kit shall also be done to provide maximum utility. Floor modifications are to be implemented to permit maximum accessibility to client throughout cab with his two prosthesis. All dashboard control switches are to be within ease of reach of client. A two way citizens band style radio shall be supplied and mounted in the cab area in case of emergency of client for safe reliable parties to help render assistance. The tractor will be utilized to it's maximum by the client as he can now use this vehicle as his principal means of conveyance from one farm to another. The speciality tractor lift is essential to the timely operation of the client and his ability to become an active, participating and viable contributor to the overall farming operation.

Summary and Projections

As the era of improved mechanization for the farming industry approaches, Mr. Petrea will be able to survive, compete and participate fully with the previously mentioned adaptations to his International Harvester tractor. In the client's individual dairy farming situation, the tractor is the hub of the entire scheme of events, functions and activities. This equipped tractor will avail Mr. Petrea to fully participate in the mowing, discing, plowing, planting, et.al. His improved assistance should lend to a more efficient operation with his brother as they begin to assume more and more responsibilities of the farm. The client's own personal motivation to return to a principal role in this family operation after suffering his injury is quite indicative of what fruits his labor will bring. The specially equipped tractor will be his vehicle to return to society as a functioning economic entity.

DOCUMENTATION OF PROBLEMS ENCOUNTERED DURING ACTUAL DESIGN AND CONSTRUCTION OF PROJECT

The Lift

Several areas of concern emerged as the project began. The distance that Mr. Petrea would need to be elevated from grade to the floor of the tractor was 53". A left hand mount was decided on for the following reasons: 1) Completed farm work is visualized from the left. 2) Farm work in progress is visualized on the right. Therefore a left hand mount would accomplish the following objectives: a) Allow access and egress at all times without interfering with implement attachments and work in progress. b) Reduce overall abuse to equipment. c) Reduce visual obstruction of work in progress on the right by placing the lift mast on the left.

Structurally, the only location the lift could be appropriately mounted was on the main horizontal frame. This frame was already pre-drilled by the factory for mass production purposes. Therefore, existing bolt holes had not weakened the frame and were previously factory tested for strength and stress tolerances.

All existing holes and mounting points were utilized so that there would be no opportunity of weakening the structure by new alterations. (It is important to note that the cab of the tractor as part of a super-structure could not, as was instructed by International Harvester be drilled, welded, tapped, bored or altered in any way. The only alternative was to clamp around it's members.)

The cab itself sets on isolators and has certain hypothetical movement in it. Therefore, we were limited in how rigid we can accomplish any kind of supporting in the actual cab. At this point we realized that we must separate the lift section from the proposed catwalk section. We decided to mount the lift to the front main frame section of the tractor. The catwalk system would be mounted underneath the actual cab. In this fashion, flex and movement between the lift and the catwalk are in concert.

We then decided that the lift should work in a straight vertical motion. Originally we had thought to use a fold up type of design. This idea was discarded when the rigid vertical lift design mount idea emerged. The vertical lift provides more

strength and endurance in the system than that of the fold-up design.

The lift moves on a horizontal plane vertically utilizing a self contained pump motor assembly. It is powered by the batteries of the tractor. The lift is hydraulic. We chose a hydraulic operation rather than electric. This was chosen for strength and endurance of the system. It was also felt that the simpler the design, the more ease of maintenance that could be sustained.

The lift system was designed to be self contained and easily removable. This design takes into consideration the operational maintenance needs of the tractor itself. This mount was accomplished by utilizing a super-structure angle that supports the main section of the lift on the side of the main frame of the tractor.

By utilization of this method, the actual weight and thrust of the lift will be taken by the frame. The lift yolk that holds the lift up against the tractor traverses the hood and through a downward vertical path on the other side picks up its lateral support from the opposite frame member of the tractor.

The lift utilizes a pump cylinder assembly that drives a roller-link chain. The pump must be able to produce a pressure between 1200 to 1500 PSI to be able to drive the cylinder that is horizontally mounted on the actual frame. The pump, the cylinder, the chain and total adjustment is all designed to break away from the tractor for ease of maintenance of tractor.

CATWALK, RAILINGS, DOOR

The catwalk was fabricated using the same expanded metal grating as that used on the lift platform. It was framed with steel. The catwalk had to attach underneath the door to allow door swing clearance. The catwalk gets its main support from the secondary frame members underneath the cab, again allowing for motion as earlier described.

The door itself was redesigned and rehung from the opposite direction to allow direct access into the cab.

Support and safety railings were fabricated of solid steel at waist high level around the catwalk and affixed to the cab. A special receiver for Mr. Petrea's crutches was designed and attached to the platform of the lift.

INTERIOR CONTROLS

Main Drive Lever

The main drive lever which was positioned to the left of the seat was blocking access for Mr. Petrea. It was reheated, reformed, repositioned back so that it now rests agains the inside fender when not in use. This change gained 3½" of additional passage access.

Clutch

The clutch pedal in this operation is really only used for close tolerance motion when attaching or detaching other equipment. Therefore this pedal was modified using a lever action which can be locked in either the up or down position, depending on function required. Because it is on the left, it also breaks down to allow Mr. Petrea outside access when leaving the tractor.

Brake

The braking system consists of two pedals. This unit operates somewhat similar to a crawler cat in design for maneuverability in tight turning configurations. When using the brake pedals individually it is possible to brake one wheel while powering the other to facilitate a tight turning radius. At the same time there is a locking mechanism to lock the pedals allowing for even braking or powering when traveling a highway or other straight surfaces.

Mr. Petrea had no trouble reaching the existing factory locking device. It was not changed. However, a set of adjustable linkages was attached to these pedals and extended into two hand levers at his lap height to allow him use of the braking function. By designing this type of system, others can operate the unit without obstruction. The tolerances of linkage, operating rods and handles are close to prevent unnecessary play in the operating handles.

Miscellaneous

The unit had a small switch on the floor that operated one of the hydraulic units in the operation of the tractor in the rear. This was moved to the dashboard and is now being used by hand.

Two large grab bars 1½" in diameter were placed on each side of the seat. This is to assist Mr. Petrea in positioning and weight shifts during transfer.

A CB radio was also installed for purposes of emergency communication either with his house or the general community.

CONCLUSION

One March 25, 1981, Mr. Petrea test drove the completed tractor. He was satisfied and the completed unit was shipped to his farm on March 26, 1981. He is fully functional in his dairy farming operation at this time. The result is obvious. Through creative design, engineering and fabrication, a difficult situation has been resolved. Care was taken not to overdesign the tractor. It would have been counter-productive to design a system so sophisticated that it would not be durable, or that would preclude use by other family members.

Although there were changes as the project became operational, the original objectives of R.J. Mobility Systems evaluation and recommendations have been met.

Visual slide documentation will be included when paper is presented.

AN OVERVIEW OF VA-ACCEPTED DRIVING AIDS FOR THE HANDICAPPED

ANTON J. REICHENBERGER, B.S.M.E.

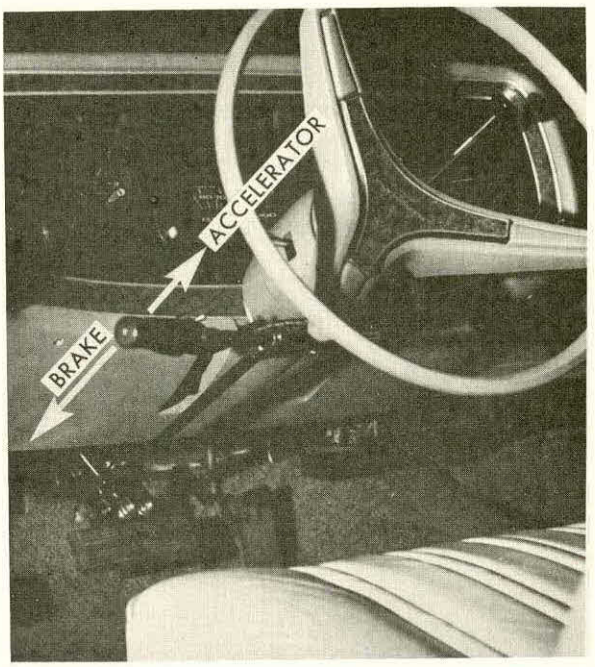
VA REHABILITATION ENGINEERING CENTER, NEW YORK, N.Y.

Since passage of the first public law (PL91-666) came about, the VA Rehabilitation Engineering Center, New York, has been heavily involved in standards development, testing, and evaluation of a wide variety of adaptive systems and devices for handicapped drivers. Ongoing work has resulted in VA-acceptance of some brake-accelerator hand controls, van-type wheelchair lifts, and sensitization of vehicle steering control systems, as well as a highly customized van for seriously handicapped drivers. Detailed information is given to provide handicapped motorists with sources of VA-accepted driving aids.

Since 1975 the Veterans Administration has conducted annual compliance tests of adaptive automotive hand controls in accordance with VA standards and specifications. These yearly tests result in an address list of accepted manufacturers who supply VA beneficiaries with a variety of "add-on" brake-accelerator hand controls for their personal motor vehicles. All commercially available hand control systems are designed to that both the throttle and the brakes can be operated with one hand, leaving the other hand exclusively for steering. Left-hand operation of a control system offers maximum driving comfort and is therefore the preferred mode, although many adaptive equipment manufacturers can provide a right-hand operated control system on request. All vehicles in question must be equipped with an automatic transmission, power steering, and power brakes.

Installation of "add-on" automotive adaptive equipment to passenger motor vehicles should be done by a qualified mechanic, who must comply fully with the manufacturer's installation instructions.

A detailed description of commercially available equipment can be found in Program Guide, M-2, Part IX, G-9, Add-On Automotive Adaptive Equipment for Passenger Motor Vehicles. The program guide (Stock No. 051-000-00118-4) can be purchased for $2.25 each copy from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.



TYPICAL BRAKE-ACCELERATOR HAND CONTROL

ADD-ON BRAKE-ACCELERATOR HAND CONTROL MANUFACTURERS IN COMPLIANCE WITH VA REQUIREMENTS (APRIL 1981)

1. Blatnik Precision Controls, Inc.
   1523 Cota Avenue
   Long Beach, California 90813
   (213) 436-3275

2. Drive-Master Corp.
   16 Andrews Drive
   West Paterson, N.J. 07424
   (201) 785-2204

3. Ferguson Auto Service
   1112 North Sheppard Street
   Richmond, Virginia 23230
   (804) 358-0800

4. Gresham Driving Aids
   P.O. Box 405
   Wixom, Michigan 48096
   (313) 624-1533

5. Handicaps, Inc.
   4335 South Santa Fe Drive
   Englewood, Colorado 80110
   (303) 781-2062

6. Kroepke Kontrols, Inc.
   104 Hawkins Street
   Bronx, New York 10464
   (212) 885-1547

7. Manufacturing & Production Services
   4664 Mercury Street
   San Diego, California 02111
   (714) 292-1423

8. Mobility Products and Design, Inc.
   709 Kentucky Street
   Vallejo, California 94590
   (707) 642-8967

9. Nelson Medical Products
   5690 Sarah Avenue
   Sarasota, Florida 33583
   (813) 924-2058

10. Smith's Hand Control
    1420 Brookhaven Drive
    Southaven, Mississippi 38671
    (601) 393-0540

11. Wells-Enberg Co.
    P.O. Box 6388
    Rockford, Illinois 61125
    (815) 874-6400

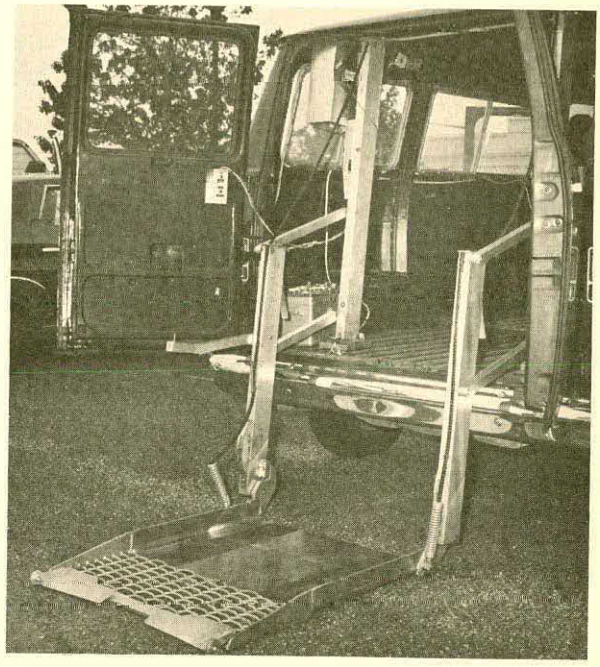
12. Wright-Way, Inc.
    P.O. Box 40907
    Garland, Texas 75040
    (214) 278-2676

Automatic Wheelchair Lifts for Vans

Vans operated by handicapped drivers are normally equipped with wheelchair lifts, brake-accelerator hand controls, and a variety of other systems and devices that might be needed. Wheelchair lifts operate at either the right side or the rear doors of the van. An electric motor is used as either a direct source of power for the lift, or as a source of power for a hydraulic component, which in turn is used to power the lift.

The Veterans Administration has conducted compliance tests of commercially available automatic wheelchair lifts for passenger motor vehicles in accordance with VA standards and specifications. Work is still ongoing to test and evaluate approximately (17) seventeen "add-on" wheelchair lift systems from different manufacturers. For a copy of the most recent list of VA-accepted automatic wheelchair lifts, please contact:

Anton J. Reichenberger
VA Rehabilitation Engineering Center
252 7th Avenue
New York, N.Y. 10001



TYPICAL AUTOMATIC WHEELCHAIR LIFT

Power augmented steering and brake systems might enable some handicapped individuals to operate a specially equipped van. A brief explanation of typical modifications is offered:

Sensitized Steering Systems

The reduction of power steering effort at times referred to as "sensitized steering" is usually achieved by modification of the stock vehicle power steering gear. The result is a substantial reduction in the operating force requirements of the steering wheel, without changing the method of operation, or grossly affecting the range of motion. Several van modifiers have introduced new phrases like

Zero Effort Power Steering (ZEPS) and No-Effort Power Steering (NEPS), essentially meaning the same thing.

It is necessary that each power steering conversion also include an appropriate backup system to assure driver safety in emergency situations. Without an acceptable backup system, use of a sensitized steering system should not be attempted. For example, stalling of the engine and subsequent loss of primary steering power would be a likely emergency. The availability of a dependable power steering backup system is therefore absolutely necessary.

Low Effort Power Brake Systems

There are several approaches to lower the operator effort of a power boosted brake system, depending to some extent on the design and operating characteristics of the stock system. All stock brake systems usually require pushing the brake pedal, opening a booster vacuum valve, and allowing power assist to occur. The brake conversion essentially lessens the opposition of pushing the brake pedal, and therefore reducing the required effort to depress the brake pedal. A Low Effort Power Brake (LEPB) uses a conventional mechanical hand control for driver input effort. All stock brake boosters have a built in vacuum reserve, enough for several brake pedal applications in the event of engine vacuum loss. In order to avoid the depletion of vacuum without warning to the handicapped driver, a vacuum indicator mounted on the instrument panel of the vehicle becomes a necessary part of a LEPB system. There currently are two (2) van modifiers whose power augmented steering and brake systems are available to VA beneficiaries:

1. Drive-Master Corp.
   16 Andrews Drive
   West Paterson, N.J. 07424
   (201) 785-2204

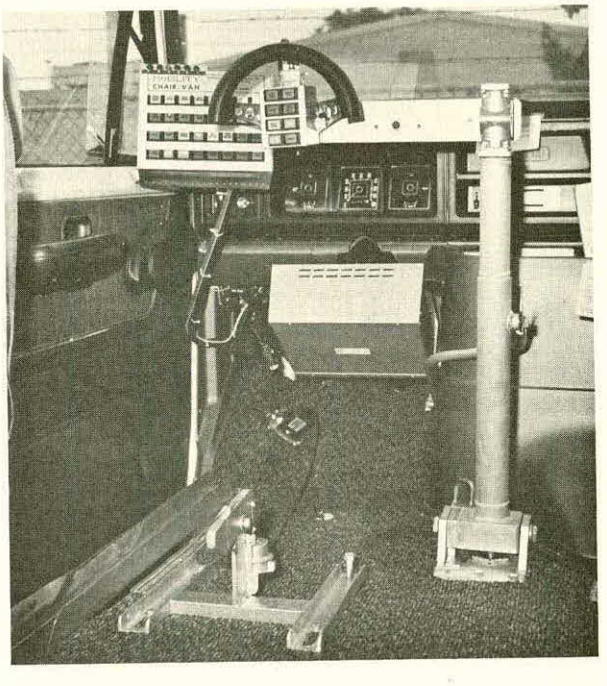
   No-Effort Power Steering
   Emergency Backup System
   Low Effort Power Brakes

2. Target Industries, Inc.
   55 Newberry Road
   Warehouse Point, CT. 06088
   (203) 626-9329

   Zero Effort Power Steering
   Hydraulic Backup System
   Low Effort Power Brakes

Severely handicapped drivers who cannot operate conventional hand controls and a standard steering wheel may require a special control system to operate a personal motor vehicle. The Veterans Administration recently completed the evaluation of a van that might be a suitable alternative for some individuals. The MED Van (Mark IX) features a most unique joystick-type servo control. Operation of the ignition and all accessories, including the rear-mounted wheelchair lift and doors, is controlled by push buttons mounted on a panel facing the driver. Acceleration is achieved by pushing the joystick forward, and braking occurs by pulling backward. Rotating a small wheel through an approximate range of 180° steers the vehicle. For additional information please contact:

Mobility Engineering & Development, Inc.
7131 Hayvenhurst Ave.
Van Nuys, California 91406
(213) 785-0958



MED VAN (MARK IX) VIEW OF DRIVING CONTROLS

In summary it should be said that efforts must continue to assure the availability of driving aids for handicapped motorists. Self-sufficient motor vehicle operation is the only choice for many individuals unable to use public transportation.

AUTHOR INDEX

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Technology that Enables