USER ASSESSMENT OF PERFORMING DART THROWERS MOTION TASKS WITH PROSTHETIC ARMS AND DESIRED IMPROVEMENTS

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ABSTRACT

A total of 15 subjects aged 25-64 years with trans-radial amputations completed a Likert-like survey over the internet to determine whether members of this population face greater challenges performing tasks with their prostheses that involve a combination of wrist flexion-extension and radial-ulnar deviation known as the "Dart Thrower's Motion" (DTM) than the normal population and asked what improvements they would want in a new device. Results showed that respondents were less satisfied performing these tasks than tasks that do not use the DTM and that people with acquired limb loss found DTM tasks to be more difficult. Respondents also said they were interested in having flexion and deviation in a device but not rotation. These results are representative of the upper limb deficient population and should influence researchers designing new prosthetic upper limb devices.

BACKGROUND

Designing a prosthetic device for the 100,000 Americans with upper limb deficiencies is a great challenge. We are attempting to replace a system which has evolved over millions of years to perform both dexterous and gross movements using 30 muscles in the hand and forearm, 27 bones, and 18 joints resulting in 27 degrees of freedom (DOF) in the hand and wrist and an additional 7 DOF in the arm [Weir 2003]. Loss of any of these DOF creates a functional deficiency. At present we lack the ability to control all of these joints mechanically and so a core question of prosthesis design must be to determine which of the DOF are essential for activities of daily living (ADL) and which can be ignored. In this study we propose to question users of upper limb prosthetic devices about difficulties using their devices to perform ADL tasks to determine which, if any, of its three DOF should be prioritized in prosthesis design and incorporated into a controllable prosthetic wrist.

An ideal prosthetic arm would be able to mimic all the functionality of a human arm, but each additional feature, control site, and DOF, adds to the volume, mass, and complexity of the device. Childress described the seven requirements for a device to be accepted by the user, which he later reduced to the idea that a device must be simple to use, comfortable and intuitive [Childress 1992]. Current devices fail these criteria as evidenced by the persistent high rejection rates among unilateral amputees (30%), particularly among people with wrist disarticulations (80%) [McFarland 2010]. Designing an overly complex and difficult to use device will not alleviate this problem.

In 1985 Palmer measured the range of motion (ROM) of wrist flexion-extension (F-E) and radial-ulnar (R-U) deviation of ten normal subjects performing a series of fifty-two activities of daily living (ADL) ranging from personal hygiene and food preparation to tool use and secretarial tasks [Palmer 1985]. In most activities involving tools (carpentry, culinary, and some personal hygiene) subjects used a significant amount of F-E and R-U deviation. This suggests that for a terminal prosthetic device to be useful it should incorporate these DOF. Without these DOF, users must perform gross body movements in order to compensate and complete a specified task. Past studies [Palmer 1985, Morimoto 2007], have also demonstrated that many of these activities use a "dart-throwers motion", a combination of F-E and R-U deviation which creates an angular DOF in a plane 20-40 degrees rotated from the sagittal plane. This motion is particularly important for tool use. The lack of this motion in prosthetic wrists may severely limit users' ability to perform these tasks, negatively affecting their ability to get jobs in these fields.

The two DOF, F-E and R-U deviation, could be combined in a wrist device to create the DTM which would improve functionality while limiting complexity. To determine whether such an improvement would be useful to users we asked about tasks which specifically utilize or do not utilize the DTM and, based on the responses, will be able to determine if incorporating the DTM into a prosthetic has the potential to be advantageous to users.

PURPOSE

The purpose of this study was to answer two research questions

1. Do people with trans-radial amputations have more difficulty, lower satisfaction, and ascribe greater importance to completing activities of daily living (ADL) tasks that utilize the DTM than tasks that do not?

2. What specific improvements in prosthetic devices are people in this population hoping to see?

METHOD

Subjects

A convenience sample of 15 adults with trans-radial amputations aged 24-65 was used for this study. Only non-sedentary subjects (>4 hours activity per week) who had experience using at least one prosthetic device were included. Anyone with non-normal vision or hearing or anyone with cognitive disabilities were excluded from the survey. Subjects were recruited via email and website with the help of several organizations that serve this population.

Survey Design

Subjects completed a survey over the internet using SurveyMonkey.com. Subjects were asked to rate their difficulty performing 30 ADL tasks, the importance of being able to complete those tasks, and their satisfaction completing those tasks with their device. The task list was based on the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire. A Likert-like scale from 1-5 (least to greatest) was used and the order of questions was randomized to minimize respondent fatigue. To account for people who compensate for limitations of their device by making gross body motions, we included questions about typical ADL tasks, tasks that are difficult to compensate for, and two handed ADL tasks.

Subjects were also asked to give their opinions on the usefulness and difficulty of several proposed improvements to devices including increased degrees of freedom of the fingers and wrist, stronger grip, and sensory feedback.

Analysis

A student's t-test was performed on the difference between each subjects ratings for DTM and non- DTM tasks. T-tests were also performed on subgroups of subjects representing common population subgroups (body or powered devices and acquired or congenital limb loss).

All analysis was performed using Matlab (The MathWorks, Inc, Natick, MA). Statistical tools were used on the recommendation of the Colorado Bioinformatics Consortium.

RESULTS

Dart Thrower's Motion Tasks

15 adult subjects with trans-radial limb deficiency (mean age 46.8 ± 10.6) responded to the survey giving us 95% confidence. All respondents had experience with powered or unpowered prosthetic devices or with both (1 only powered, 9 only unpowered, 5 both). Sample included both subjects with congenital (20%) and acquired limb deficiencies (80%). Respondents with acquired limb deficiency had used prosthetics for an average of 23 years (mean 23 ± 19.5). Overall, users reported that they found their devices to be somewhat easy to use (mean 3.71 on a scale of 1=very difficult to 5=very easy). There was no correlation between responses to satisfaction, importance, and difficulty.

The average of each subject's responses to DTM tasks was subtracted from the average of their responses to non-DTM tasks. This difference was averaged across all subjects. The total population and the subsets describing the most common populations (acquired limb deficiency (n=12) and body powered device users (n=12)) rated their satisfaction performing DTM tasks lower than their satisfaction performing DTM tasks (one-sample, 2-tailed t-test: p=0.043, 0.041, 0.033) (**Error! Reference source not found.**). The acquired amputation subgroup also reported significantly higher difficulty performing DTM tasks than non-DTM tasks (p=0.045). No other population or response showed a significant difference. A weighted average was created by multiplying each subject's difficulty and satisfaction responses by how important they rated each task, but no significant difference was found (p=0.326, 0.555). Finally, subjects with acquired limb deficiency reported that it was significantly more important to them that they be able to perform all tasks than subjects with congenital limb deficiency (p=0.011) [Table 1].

Table 1: Significance values of one-sample t-test on the difference between the average response to DTM tasks and non-DTM tasks. Green highlights indicate significantly (p=0.05) lower satisfaction, higher importance, or higher difficulty between DTM and non-DTM tasks. Overall, and the subset of users of body powered devices and those with acquired limb deficiencies reported lower satisfaction with DTM tasks than non-DTM tasks. The acquired deficiency subgroup also reported higher difficulty performing DTM tasks than non-DTM tasks. The sum of subjects in body powered and myoelectric devices is greater than 15 because some subjects used both types of devices.

Sample group	n	One-sample t-test vs mean of 0 (p-values)		
		Δ Satisfaction	***Δ Importance***	***Δ Difficulty***
All subjects	15	0.042939	0.37951	0.13449
Body powered	12	0.04124	0.64936	0.050913
Myoelectric	6	0.15331	1	0.16271
Acquired	12	0.033042	0.83406	0.044615
Congenital	3	0.88453	0.2697	0.5101

Table 2: User responses to the question: "Please rate how USEFUL you think each option would be". Leading suggestions were individual control of fingers, ab/adducting thumb, stronger grip, faster grip, and increased degrees of freedom in the wrist. Notably, users responded that they were interested in wrist flexion/extension and radial/ulnar deviation but not the most common degree of freedom: pronation/supination.

Suggested Improvement	Response				
	Not at all useful	Slightly useful	Somewhat useful	Very Useful	Extremely Useful
Individual control of fingers/hook components	2	1	3	2	6
Rotating thumb to allow a pinch motion (Ab/adduction of thumb)	1	0	1	4	7
Sensory feedback from fingers/hook	4	1	3	0	6
Faster finger/hook motion	1	1	0	0	9
Stronger grip	2	0	2	2	9
Wrist with only powered rotation (Pro/Supination)	2	3	3	5	1
Wrist with only up/down motion (Flexion/Extension)	4	1	0	10	0
Wrist with rotation and Flexion/Extension	2	2	0	3	8
Wrist with powered side to side motion (Radial/Ulnar deviation)	3	2	2	5	3
Fully functional wrist with rotation, Flexion/Extension, and Radial/Ulnar deviation	2	1	1	1	10
Passive wrist that can be positioned in anatomical positions	3	1	3	3	4

Desired Improvements

Subjects had varying opinions to the questions about proposed improvements to the devices [Table 2]. Notably, a majority of subjects thought individual control of fingers, ab/adducting thumb, stronger grip, and faster grip would be useful or very useful (8, 11, 9, and 10 out of 14). Ten subjects responded that adding flexion/extension would be very useful, 11 thought flexion/extension plus rotation would be useful or very useful, and 10 subjects felt that a fully functional wrist with flexion/extension, radial/ulnar deviation, and rotation, would be extremely useful.

Discussion and Conclusion

We found that subjects were less satisfied using their device to complete DTM tasks than non-DTM tasks and that users with acquired limb deficiencies also found these tasks to be more difficult. We also found that users desired more functionality in their wrist in general. Current devices

typically do not include this DOF. We suggest that new prosthetic arms include the DTM to provide the desired improvements without drastically increasing the complexity of devices.

Paradoxically, subjects rated many tasks as difficult and important but also claimed that they were satisfied performing them with their device. This suggests that they have developed compensatory motions that may lead to long term injury and would still benefit from an improved device. This question will be addressed in the in-person interviews.

The results of the "Improvements" question show what improvements users are looking for in new devices and will be interested in trying. Users responded that they were interested in flexion and deviation in wrist devices. Notably, users were not strongly interested in having a device with powered rotation. This is an interesting result considering that, typically, powered rotation is the first DOF added to a device after a gripping unit.

These results inform the direction of future research into improving prosthetic devices.

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