

Expert opinions on success factors for upper-limb prostheses

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Abstract—The goal of this study was to gather the opinions of prosthetics experts on the most important factors for the successful use of upper-limb (UL) prostheses, compare them with those of prosthesis users, and ultimately direct research efforts in this field. UL prosthetics experts were asked to compare the importance of the comfort, function, and cosmesis of a prosthetic device for a transhumeral amputee. Categories were subdivided into weight, socket-interface comfort, power, agility, color, and shape. The majority of those who responded viewed comfort as the most important factor for a unilateral amputee and considered socket-interface comfort to be more important than weight. Function was considered to be the most important factor for a bilateral amputee, with agility considered more important than power. Cosmesis was consistently reported as being less important than comfort and function, and shape was considered more important than color.

Key words: bilateral amputee, comfort, cosmesis, function, prosthesis, rehabilitation, success factors, survey, transhumeral amputee, unilateral amputee.

INTRODUCTION

Many new and exciting research efforts are underway to improve upper-limb (UL) prostheses. Perhaps the largest in history is the recent program of the U.S. Department of Defense, Defense Advanced Research Projects Agency (DARPA), to revolutionize UL prostheses. Research on clinical products should be driven by clinical demands, with the most energy invested in areas of greatest need. While many areas for UL prosthesis

improvement exist, what the greatest needs are or how efforts should be directed are not clear. The opinions of two populations should be considered when studying factors that affect prosthesis use and needs for improvement: prosthesis users and prosthetics experts.

Several surveys have been carried out in the past to identify the research priorities of amputees. In 1987, Reid and Fay reported the results of a survey of 38 congenital child amputees [1]. The suggested improvements listed in the report were less weight, more durability, greater resistance of cosmetic gloves to wear and discoloration, and a need for sensory feedback. The following year, Melendez and Leblanc reported the results of a survey of 25 unilateral amputees who did not wear prostheses and compared the results with those from a similar survey of prosthesis users [2]. They found that 81 percent of wearers and 82 percent of nonwearers felt that harness and socket-interface comfort needed improvement and that 100 percent of wearers and 71 percent of nonwearers felt that function of terminal devices needed improvement.

Abbreviations: DARPA = Defense Advanced Research Projects Agency, MEC = Myoelectric Controls, SD = standard deviation, TIRR = The Institute for Rehabilitation and Research, UL = upper limb.

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They also found that 82 percent of wearers and 67 percent of nonwearers felt that improvements to overall appearance were needed. Wearers ranked function as the most important aspect of a prosthetic device, followed by comfort, appearance, and control system. Nonwearers ranked comfort as the most important aspect, followed by function, control system, and appearance. The identified research needs listed were increased comfort of the socket and harness, more durable cosmetic gloves, decreased weight of the device, increased socket ventilation, and improved appearance.

In 1996, Atkins et al. reported the results of a survey carried out by The Institute for Rehabilitation and Research (TIRR) of 1,575 individuals with UL loss [3]. Respondents were asked to prioritize a list of improvements compiled by the surveyors. For transhumeral amputees using body-powered prostheses, the most important short-term improvements chosen were increased durability of cables, more comfortable harnesses, and better glove material. The most important long-term improvements were more wrist movement, better control that reduced need for visual attention, and control to allow coordinated movement of multiple joints. The short-term priorities of electric prosthesis users (all levels) were better glove material, longer-lasting batteries and recharging units, and greater reliability of electrodes. Long-term priorities were a greater range of finger movements, less need for visual attention, and more wrist movements.

The second population of interest is that of experts in our field. Every professional has a unique perspective that represents a synthesis of feedback and observations from patients, research subjects, and clients. Experts can also compare issues across patients and weigh the relative importance of success factors differently than an individual amputee. We took the opportunity to survey a large number of UL prosthetics experts at the Myoelectric Controls (MEC) Symposium held at the University of New Brunswick, Fredericton, New Brunswick, Canada, in August 2005. The attendees of this conference included prosthetists, manufacturers, researchers, engineers, therapists and physicians—a diverse group of people with a wealth of experience. The survey divided the factors of success into three major categories with six subcategories, roughly corresponding to those chosen by other researchers [2–4]. An obvious bias of this study was toward issues of powered prostheses. This was an acceptable bias for us because one of our main goals was to contribute to research efforts in this area.

This study had several goals. First, we wanted to study the perceived importance of different factors for successful prostheses use. Second, we wished to see whether experts had a marked majority opinion or discernible differences in their opinions based on experience or discipline (such as clinician versus engineer). Finally, we wanted to compare experts' opinions with previously collected opinions of UL amputees.

METHODS

An initial survey was drafted and distributed to a test group of 10 prosthetics experts with diverse backgrounds. After all of their suggestions had been considered, we gave the revised survey to a professional marketing research analyst for review. The final version of the survey was distributed at the 2005 MEC Symposium. We chose only one amputation level to shorten the survey and increase the response rate. We selected the transhumeral level of amputation because it is the focus of the current DARPA initiative. It is common enough that experienced professionals would have reasonable exposure to this level of amputation. It is also a difficult level to fit, requiring several prosthetic components (elbow, wrist and terminal device), and allows for many different fitting approaches.

Participants were asked to report their occupation and the number of years they had been working in the prosthetics field. They were then asked to answer a set of four questions about success factors for prostheses for unilateral transhumeral amputees (**Figure 1**) followed by the same set of four questions for bilateral transhumeral amputees. Prosthetic success was defined as the sum of comfort, function, and cosmesis. Comfort was subdivided into socket-interface comfort and the weight of the prosthesis. Function was subdivided into the agility and power of the elbow, wrist, hand, and fingers. Cosmesis was subdivided into the color and shape of the device. The survey required the subjects to rank and score the major categories (comfort, function, and cosmesis) and the subcategories (socket-interface comfort, weight, color, shape, agility, and power). We compiled the survey results and used a two-sided paired *t*-test to determine statistical significance.

For the purposes of this survey, we have defined prosthetic success as a function of the following equation.

Prosthetic success = $X + Y + Z$, where X = comfort, Y = cosmesis, Z = function.

As professionals in the field, we all need to consider how much the amputee will like and use the prosthesis as it relates to these factors.

X is how important is comfort of the prosthesis, which is a function of

- b = comfort of the socket-interface, and
- c = weight of the arm.

Y is how important is cosmesis, which is a function of

- d = color depth; color matching, etc. (like a quality custom glove); and
- e = shape of the hand or arm.

Z is the functionality of the prosthesis, which is a function of

- f = agility, dexterity, or ability to do fine manipulations, and
- g = power or strength of the elbow, wrist, hand, and fingers.

In summary,

$$\begin{aligned} X(\text{comfort}) &= b(\text{interface}) + c(\text{weight}), \\ Y(\text{cosmesis}) &= d(\text{color issues}) + e(\text{shape}), \text{ and} \\ Z(\text{function}) &= f(\text{agility}) + g(\text{power}). \end{aligned}$$

1. First, for UNILATERAL transhumeral amputees, please rank the factors X , Y , and Z in order of importance. Please generalize based on your experience with amputees.

1st _____ 2nd _____ 3rd _____

2. Next, for UNILATERAL transhumeral amputees, rank which is more important.

b (socket-interface comfort) or c (weight) _____
 d (color issues) or e (shape) _____
 f (agility) or g (power) _____

3. Now, if you had 100 points to distribute, how many would you assign to each of these factors according to their relative importance (more points = more important).

First, the overall factors:
 X (overall comfort) _____
 Y (overall cosmesis) _____
 Z (overall function) _____ (Total should = 100 points)

4. Begin again with 100 points total. Please distribute these 100 points across the following subfactors according to their relative importance (more points = more important).

b (socket-interface comfort) _____
 c (keeping weight low) _____
 d (color issues) _____
 e (shape) _____
 f (agility) _____
 g (power) _____ (Total should = 100 points)

Figure 1.

Sample section of survey presented to prosthetics professionals who attended 2005 Myoelectric Controls Symposium in Fredericton, New Brunswick, Canada.

RESULTS

Of the 130 people attending the MEC Symposium, 51 responded to the survey, which yielded a response rate of 39 percent. Respondents included 25 prosthetists, 14 therapists, 10 researchers, 8 engineers, 2 physicians,

and 1 who did not specify his or her role. Subjects could check more than one role in the field of prosthetics (e.g., 6 respondents checked both “engineer” and “researcher”). Respondents had been working in the prosthetics field for up to 48 years, with a mean \pm standard deviation (SD) of 15 ± 11 years.

Respondents were asked to rank comfort, function, and cosmesis in order of importance for unilateral transhumeral amputees and bilateral transhumeral amputees. Comfort was ranked first for unilateral amputees by 70 percent of respondents, while function was ranked first for bilateral amputees by 75 percent of respondents. Cosmesis was ranked third by 76 percent of respondents for unilateral amputees and 98 percent of respondents for bilateral amputees.

Respondents were asked to further elucidate their views by distributing 100 points over the three main categories, assigning them their relative importance (more points = greater importance). The average scores (**Figure 2**) resulted in an order of importance consistent with the ranking data. However, for unilateral amputees, scores for comfort and function were not significantly different. Respondents placed a higher value on comfort and cosmesis for unilateral amputees than for bilateral amputees ($p < 0.05$ and $p < 0.01$, respectively). Function was valued higher for bilateral amputees than for unilateral amputees ($p < 0.01$).

Respondents were asked to select which of the subcategories in each main category were most important. Under comfort, they were asked to select either socket-interface comfort or weight; under function, they were asked to select either agility or power; under cosmesis, they were asked to select either color or shape. The percentages of respondents who chose each subcategory are shown in the **Table**. The majority of respondents ranked socket-interface comfort over weight, agility over power, and shape over color for both unilateral and bilateral amputees. The preference of agility over power was more pronounced for bilateral than for unilateral amputees (82% vs 59%).

Respondents were then asked to distribute 100 points over all six subcategories (**Figure 3**). The average responses were consistent with the majority rankings discussed previously: socket-interface comfort scored significantly higher than weight for both unilateral and bilateral amputees ($p < 0.01$) and agility scored signifi-

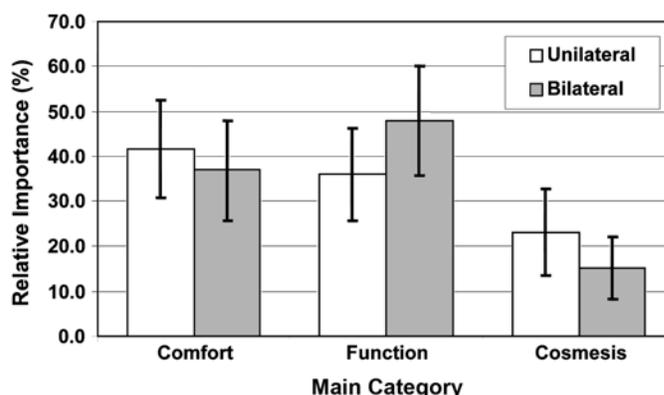


Figure 2.

Mean relative importance scores of factors of prosthetic success for unilateral and bilateral transhumeral amputees. Respondents were asked to distribute 100 points over three categories. Higher score corresponds to greater importance. Error bars represent ± 1 standard deviation.

cantly higher than power for both unilateral and bilateral amputees ($p < 0.05$ and $p < 0.01$, respectively). Scores for shape and color were not significantly different. Socket-interface comfort scored slightly higher for unilateral amputees than for bilateral amputees ($p < 0.05$), while weight scored similarly for both. Agility and power scored higher for bilateral amputees ($p < 0.01$ and $p < 0.05$, respectively). Shape and color scored higher for unilateral amputees ($p < 0.01$). Apart from the movement of agility to top priority for bilateral amputees, the order of importance of the subcategories was the same for both groups.

We also examined whether the number of years the professionals had been working in the prosthetics field significantly affected their opinions. The only difference between the more experienced (mean \pm SD = 24.2 \pm 7.9 years) and less experienced (mean \pm SD = 6.3 \pm 4.1 years) respondents was that those with less experience scored function higher for bilateral amputees than those with more experience (52% vs. 44%, $p < 0.05$).

Table.

Percentage of respondents who chose each subcategory as being most important within each major category for unilateral and bilateral transhumeral amputees.

Type	Comfort		Function		Cosmesis	
	Socket-Interface	Weight	Agility	Power	Shape	Color
Unilateral	67	33	59	41	67	33
Bilateral	62	38	82	18	76	24

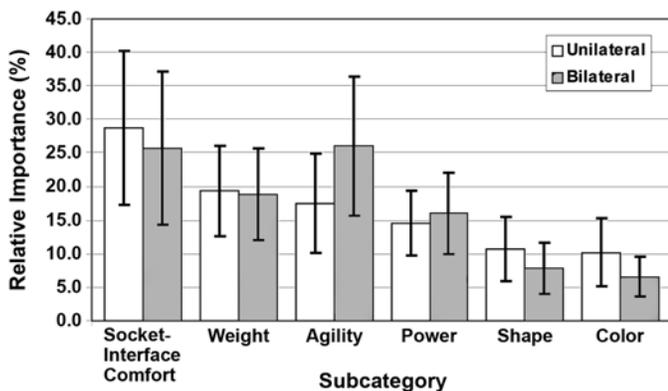


Figure 3.

Mean relative importance scores of subcategories of factors of prosthetic success for unilateral and bilateral transhumeral amputees. Respondents were asked to distribute 100 points over six subcategories. Higher score corresponds to greater importance. Error bars represent ± 1 standard deviation.

The number of respondents in each individual group was too small to make broad conclusions with respect to discipline, a limitation of the low response rate. However, we still noted several interesting observations. The majority of those surveyed in each discipline ranked comfort first for unilateral amputees; the group with the smallest percentage choosing this option was prosthetists (prosthetists 67%, therapists 77%, researchers 90%, engineers 100%, and physicians 100%). The preference of socket-interface comfort over weight for unilateral amputees seemed to be driven by the opinion of prosthetists, which was the largest group in the survey: 90 percent of prosthetists chose socket-interface comfort over weight, while a smaller percentage of the other groups did the same (therapists 57%, researchers 40%, engineers 57%, and physicians 50%). The percentage of those who choose socket-interface comfort over weight for bilateral amputees ranged from 45 percent for therapists to 86 percent for engineers (physicians 50%, researchers 60%, and prosthetists 75%). In all other categories, respondents' background did not appear to affect their response.

DISCUSSION

Results of the survey showed that the opinions of experts on the importance of comfort and function with regard to unilateral amputees differed from their opinions with regard to bilateral amputees. The majority of

respondents considered comfort to be the most important factor for successful prosthesis use by a unilateral transhumeral amputee. This opinion was not particularly strong; the average score given to comfort (42%) was not statistically different from the score given to function (36%). The choice of function as the first priority for bilateral amputees was a clear majority, and scores for function were significantly higher than the scores for both comfort and cosmesis ($p < 0.01$).

Cosmesis was consistently ranked below comfort and function for both unilateral and bilateral amputees by 76 and 95 percent of respondents, respectively. The average score given to cosmesis was significantly lower than the scores given to comfort and function for both groups ($p < 0.01$). We should note that this does not mean that cosmesis is not important, only that our respondents felt that comfort and function were the dominant issues.

These different opinions in regard to unilateral and bilateral amputees may reflect assumptions about the different needs of these populations. For instance, unilateral UL amputees are able to learn one-handed techniques for accomplishing many necessary tasks; therefore, one could assume that an uncomfortable prosthesis that offers only a small functional advantage may not be worth the effort. Bilateral amputees, on the other hand, may be willing to withstand a certain amount of discomfort in order to regain even a small amount of function.

Analysis of the subcategories offers more focused insights. The rankings gave a clearer separation of category importance, and the relative importance of each subcategory showed consistency with these rankings. Twice as many respondents chose socket-interface comfort over weight than vice versa. An obvious implication is that amputees can better tolerate the weight of the device if they have a more comfortable socket system. For the unilateral amputee, 59 percent of respondents ranked the agility of the prosthesis as more important than its power, while 83 percent held this opinion for the bilateral amputee. This result suggests that mechanical improvements should be focused on dexterity, such as increased degrees of freedom in the hand and wrist, rather than on increasing the power of the existing components. Finally, in regard to cosmesis, shape was ranked more important than color. Interestingly, more respondents chose this option for bilateral amputees than for unilateral amputees (76% vs 67%). This result indicates that more focus should be placed on designing anthropomorphic prostheses that are custom-fit to each patient than on color-matching the gloves.

One of the major goals of this survey was to create a means of comparing the opinions of prosthetics experts with those of the population they intend to serve. Major contrasts could indicate a lack of communication. Although our survey did not follow the form of any previous survey of amputees, some comparisons can be made between the opinions of the professionals surveyed here and those of amputees surveyed in the past. In the survey by Melendez and Leblanc, unilateral prosthesis wearers ranked function first, comfort second, and cosmesis third, in agreement with 48 percent of those surveyed in this study [2]. Unilateral nonwearers ranked comfort first, function second, and cosmesis third, in agreement with 28 percent of those surveyed in this study. Both groups in the Melendez and Leblanc study listed cosmesis after comfort and function, in agreement with 76 percent of those surveyed here. Of note, the Melendez and Leblanc survey included an additional factor, control, and did not include the opinions of bilateral amputees.

Atkins et al. asked respondents to rank desired improvements from a predefined list that was heavily weighted toward function and agility improvements [3]. To compare this survey with ours, we needed to assign each of these concerns to our general categories and subcategories. In some cases, this was not possible; for instance, the cosmesis subcategories "shape" and "color" were not listed as options and no mention was made of socket-interface comfort as an issue. For transhumeral respondents using a body-powered prosthesis, the apparent order of the major categories reported in Atkins et al.'s survey was function, comfort, and cosmesis, in agreement with 48 percent of those surveyed here in regard to unilateral amputees and 23 percent in regard to bilateral amputees. For electric prostheses users, the apparent order of importance was function, cosmesis, and comfort, which was not chosen by a single respondent in our survey. These rankings suggest that electric prosthesis users felt function and cosmesis to be relatively more important than did the expert respondents of this survey. In the TIRR survey, agility issues were given a higher priority than power issues by both body-powered and electric prostheses users, in agreement with the majority of those surveyed here (59% for unilateral amputees and 83% for bilateral amputees).

Clearly, as efforts to improve prosthetic devices and increase their acceptance by the end user move forward, more work must be done to understand the needs of the amputee population and align the goals of research and

healthcare professionals with theirs. A possible step in accomplishing this would be to give amputees a survey identical to the one here. Such a survey would also compare the views of unilateral and bilateral amputees, which is data not yet available in the literature. The limitations of the current study would be better addressed by a follow-up study that included a more detailed and comprehensive survey of prosthetics experts, similar in format to that of Atkins et al. [3]. Adding questions to the survey about the perceived feasibility of implementing each improvement would be important and would allow the industry to be more efficient in addressing the wide variety of concerns. Other important factors such as maintenance, reliability, durability, training, and cost issues could also be added. A more extensive survey with wider distribution could uncover significant differences between the opinions of professionals in different disciplines, something only hinted at in this study.

CONCLUSIONS

A survey of 51 professionals in the prosthetics field revealed their views on the most important factors for successful prosthesis use by unilateral and bilateral transhumeral amputees. Comfort, specifically socket-interface comfort, was considered the most important factor for a unilateral amputee, while function, specifically agility, was considered the most important factor for a bilateral amputee. Socket-interface comfort was considered more important than weight, and agility was considered more important than power for both unilateral and bilateral amputees. The lack of agreement between the professionals surveyed here and prosthesis users surveyed in the past indicates that more work should be done to ascertain the opinions of prosthetics professionals and align their goals with those of the amputee population. In addition, a larger number of responses are needed to make broad conclusions. Because of this, the opinions presented here should be used in tight conjunction with the opinions of amputees, such as those presented in Atkins et al.'s survey [3], to guide future work in this field.

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