



PROSTHETICS

Touching reality: Bridging the user-researcher divide in upper-limb prosthetics

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Realistically improving upper-limb prostheses is only possible if we listen to users' actual technological needs.

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There have been considerable advances in the technology for upper-limb prostheses during the past five decades. Beginning in the 1970s, researchers developed the concept of extended physiological proprioception (EPP), demonstrating improvements in dexterous control when sensory perception can extend to the distal end of the prosthesis terminal device (1, 2). This seminal work paved the path toward the use of noninvasive haptic feedback to provide the missing sensory information (3). At the same time, surgical advancements led to the development of targeted sensory reinnervation (4) and peripheral and cortical neural interfaces (5).

Still, there remains a substantial gap between the needs of users and the technologies that are available. Roughly half of upper extremity prosthesis users eventually abandon their powered prosthesis in favor of simpler body-powered devices, passive cosmeses, or no device at all (6, 7). It has recently been demonstrated that, despite our best intentions, we lack an understanding of how prosthesis users prefer to use their prosthesis (9). Moreover, we are only beginning to understand how prostheses are represented in the brain (10). Although we envision robotic limbs that are indistinguishable from natural limbs, what we have are complicated and delicate pieces of engineered metal and plastic that work best in the lab environments in which they are developed.

Engineers and scientists too often leave prosthesis users out of the innovation process, limiting their involvement to user

studies in lab-controlled conditions that, while important, lack ecological validity. Although some of the full-time research authors of this manuscript are guilty of all the above, we feel that there is a better path forward. This path must involve bringing prosthesis users into the early brainstorming phase to truly understand their needs and desires for prosthesis utility and function.

To that end, we report on the findings from a workshop held at the 2023 IEEE World Haptics Conference focused on understanding the needs of prosthesis users in the context of touch sensation. The workshop featured a panel discussion composed of prosthesis users, who were asked to complete a pre-workshop survey (survey 1; Supplementary Materials) regarding their experience using their prosthesis and their desire for improved sensory utility from their prosthesis. During the workshop, the outcomes of this survey were used as prompts for conversation. Panelists then completed a post-workshop survey (survey 2; Supplementary Materials) that asked the same set of improved sensory utility questions to evaluate any changes after the workshop conversation.

Responses from the pre-workshop survey highlighted the heterogeneity among our panelists regarding their daily usage of their prosthesis ranging from less than 2 hours to more than 10 hours a day (table S1). Panelists who spent less time using their prosthesis highlighted weight, comfort, and limited functionality as the main causes (table S2). Panelists also

reported using their prosthesis in a limited fashion or not at all for many of their daily living activities (table S3). This is consistent with previous results (8, 9).

Responses from the pre-workshop survey also highlighted that, overall, the panelists considered functionality, reliability, and comfort as the three most important aspects of an upper-limb prosthesis (table S4). Specific features that they also considered important were grip force feedback, notification of impending prosthesis damage, feedback on prosthesis hand pose, and the ability to manipulate unseen objects (table S5 and fig. S1). Other features, such as temperature and texture feedback, were generally perceived as less important (table S5 and fig. S1). Interestingly, the ranking of desired features remained essentially unchanged between the pre- and post-workshop surveys, with only the top four features changing order, indicating that the panelists were fairly set in their opinion of which features are most important. Last, panelists indicated a general preference for haptic and auditory feedback to receive information on grip force, slip, damage, and level of hand opening. The results were similar post-workshop, with fewer "not sure" responses and more in favor of haptic feedback, perhaps as a consequence of information obtained during the workshop.

For comprehensive understanding of each panelists' views regarding their workshop participation, we refer readers to statements authored by each panelist in the Supplementary Materials. Here, we summarize the main themes. Overall, what emerged most strongly was that needs and preferences can vary widely across each prosthesis user. For example, there were panelists that expressed frustration with the available level of technology and reported using their prosthesis very little. In contrast, some of the panelists reported being very satisfied with the level of technology

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in their prosthesis, expressing desire for better reliability and easier access. Similarly, most panelists expressed at least some interest in richer haptic feedback features, although there was concern regarding the impact of more features on prosthesis reliability. This sentiment was not universally shared, however: Some of the panelists expressed no interest at all in the addition of haptic feedback and instead had a strong preference for simpler prostheses that were more inconspicuous and comfortable. We refer to the text from authors A.P. and S.E. in the Supplementary Materials for more on these different perspectives.

Another aspect that was offered was that the needs of underserved individuals are not likely to be addressed with current prosthesis technology. Individuals with limb loss who lack financial means or health care coverage are unlikely to receive high-end technological prostheses, and user studies are likely to be overrepresented by individuals who have the economic ability to acquire cutting-edge prosthesis technology. Without intervention, the scientific community is in danger of focusing only on the needs of individuals from certain socioeconomic levels. Similarly, some panelists lamented the fact that high-end prostheses can be feature rich, but ultimately these features were determined by the scientific community rather than the users themselves. We refer to the text from authors E. S. and G.L. in the Supplementary Materials for more on these different perspectives.

Overall, the outcomes of this workshop indicate a pressing need for more nuanced analyses of the true needs of prosthetic users. Given the difference in opinions that emerged from the panelists who participated in the workshop, it is evident that no "one-size-fits-all" approach will enable enhanced quality of life for all individuals with limb loss. In addition, the composition of the panel itself (with more than half of the panelists being PhD holders) and the thoughts shared by the panelists highlighted the need for a more inclusive model for user study recruitment that does not alienate groups of end users purely out of convenience. To realize impactful prosthesis technology, scientists, engineers, and technologists need to intentionally seek to understand the concrete needs of users by talking to them directly and developing unique prosthesis innovations designed to address those needs. This article, which includes authors as the panelists themselves, serves as a step toward articulating user needs and expectations and seeks to motivate researchers to engage users early in the prosthesis design process.

Supplementary Materials

This PDF file includes:

Supplementary Text
Figs. S1 and S2
Tables S1 to S5

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