USER PERSPECTIVES ON FEATURES OF UPPER LIMB PROSTHESES: A QUALITATIVE CROSS-CASE COMPARISON

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ABSTRACT

Researchers and prosthesis developers aim to add or modify the functional features of upper limb prosthetic devices, such as increasing the number of available movements, developing intuitive control schemes, and providing sensory feedback. However, user experiences with these features across currently available prosthetic devices are not well understood, nor do we know what the needs and perspectives of users are regarding prosthesis features. In this study, we collected in depth interviews with sixteen prosthesis users who had experience with a wide range of prosthesis types, including body-powered, single degree of freedom myoelectric, multi-degree of freedom myoelectric, and sensory augmentation. We used a qualitative case study design to examine experiences with and perspectives on the prosthesis features of movements, controls, terminal devices, and sensation. Study findings help to elucidate the current needs and preferences of upper limb prosthesis users and provide directions for future technology development.

INTRODUCTION

Upper limb amputation (ULA) can result in adverse outcomes, including chronic pain[1]–[3], anxiety, and depression[4], [5]. Though upper limb prosthesis use can mitigate adverse health outcomes by enhancing functional independence, reducing activity restrictions, improving community integration[6], and enhancing quality of life, approximately 21-44% of adults with ULA do not use prostheses at all [7], [8]. Studies to investigate the reasons for prosthetic abandonment have described dissatisfaction with weight, function[8], [9], and the lack of sensory feedback[10], [11].

The number and complexity of prosthetic device options available to individuals with ULA have increased significantly in the past decade[12]. To improve user experience and function, many research groups and prosthesis developers aim to increase the available features of upper limb prosthetic devices. These advanced prosthesis features span several domains, including prosthesis movements, control strategies, and sensory feedback. For example, devices have been developed that provide multi-articulated finger movements, multiple grasp types, intuitive control strategies via pattern recognition algorithms, powered wrist movements, and/or sensory feedback provided through wearable or implanted interfaces[13]. However, it is unclear which additional features users want and need, and which features will have meaningful impacts on functional and psychosocial outcomes.

Prior studies to assess participant experiences with and perspectives on prosthesis features typically focus on a single prosthesis feature or technology [11], [14], [15]. In addition, many user experience studies are purely hypothetical, in which participants are asked to imagine what a technology or feature might be like in the future. To address this gap, we performed a telephone interview study investigating the perspectives of sixteen participants with transradial or transhumeral limb loss who had experience using a wide variety of both commercial and research prosthetic technologies. We performed a qualitative analysis with multiple case series design to examine their personal experiences with the prosthesis features of control scheme, prosthesis movements, sensory feedback, and terminal device type. The participants perspectives and opinions on the features were informed by their personal experience. Improving our understanding of the connection between prosthesis features and the multifaceted experiences of prosthesis users will help guide prosthesis research and development efforts to better address user needs. Improved prosthesis designs could reduce prosthesis abandonment and improve quality of life after limb loss.

METHODS

Data for this study was collected by telephone interview as part of a larger, parent study which utilized a modified grounded theory approach. Participants were recruited through mailings, advertisements and referrals from prosthetists and rehabilitation health care providers. Eligible participants were at least 18 years old and experienced an transhumeral or transradial amputation and had utilized a prosthesis for at least 6 months. A convenience sample of 16 individuals were enrolled into four groups of four participants each based on the prosthesis they used. The groups were: body-powered (BP) prosthesis, myoelectric single-degree-of-freedom (1-DoF) prosthesis, myoelectric multiple-degree-of-freedom (multi-DoF) prosthesis, and sensory augmented (SA) prosthesis. Written informed consent was obtained under the guidelines and approval of the United States Central Veterans Affairs Institutional Review Board prior to conducting the interviews.

Each participant was interviewed by telephone for two 45-60-minute sessions. The interviews were semi-structured with follow-up questions and probes to elucidate important concepts. Each interview was recorded with a digital audio recorder and transcribed verbatim. Data from the first four interviews were utilized to develop an initial code set. This code set was iteratively refined during the analysis of all interviews. Coding was conducted by M.S. and D.K. and auditing was conducted by L.R. and E.G. Analytic discussions within the team were used to identify sub-codes, determine central themes, and elucidate relationships between codes. The coding structure was iteratively fine-tuned during team meetings, leading to the final coding structure.

RESULTS

Users of BP devices used a body-powered cable system to control a voluntary open hook. The 1-DOF myoelectric users used two-site myoelectric control, with sensors embedded in their prosthesis sockets. The multi-DOF myoelectric users used either Co-apt or another pattern recognition system with 6-14 myoelectric sensors. All of the BP and 1DoF device users controlled the aperture of the terminal device. Six participants had powered wrist movements, with the remaining ten having passive wrist movements that could be made by manually turning the wrist with the intact hand. Individuals with trans-humeral amputation voluntarily operated their elbow via cabling or myoelectric power.

All of the participants with SA experienced the technology as a part of a research study, with most of these experiences occurring primarily in a laboratory environment. Two of the participants (P02 and P15) had taken part in a clinical trial utilizing implanted peripheral nerve cuff electrodes[16], [17]. By stimulating the nerve through different electrode contacts around the nerve, the participant was able to experience sensation at different locations on their missing hand[18], [19]. Additionally, P15 had implanted EMG recording electrodes. P10 and P14 had previously undergone targeted sensory reinnervation (TSR) and had participated in a trial using non-invasive SA delivered via transcutaneous stimulation and/or vibration[20], [21]. Three of the four SA users had experience receiving sensory feedback incorporated into a multi-DOF prosthetic device, while one SA user had a 1-DOF myoelectric device.

The interviews examined experiences with four prosthesis features: 1) prosthesis movements, 2) prosthesis control, 3) terminal devices, and 4) sensory feedback. The coding structure developed through our analysis revealed a total of 16 nodes across the four feature categories (Table 1).

Prosthesis Movements: Participants were asked to describe the movements of their prosthesis and how these movements played a role in the function of their prosthesis and their experience with the prosthesis. Three main themes emerged from these discussions. First, participants described the process through which they completed tasks with the prosthesis as generally consisting of multiple sub-steps, which sometimes required them to manually *pre-position* one or more joints of the prosthesis before beginning the task. Second, participants described the positions in space in which the prosthesis was most useful and most easily operated. This *functional workspace* of the prosthesis was generally limited to areas directly in front of their torso. Third, participants described the need for *compensatory movements* of the shoulder to make up for missing degrees of freedom in the prosthesis, such as a lack of wrist movements.

Prosthesis Control: Discussions about prosthesis control primarily centred on the participants' ability to control the opening and closing of the terminal device (rather than proximal joint movements). Participants spoke about their ability to *regulate the grasp force* produced by their terminal device to accomplish tasks and the *role of focus in controlling grasp force.* Additional themes that emerged included the *naturalness and ease* of their control scheme as well as the *reliability and precision* of their control.

Terminal Devices: Most participants had more than one terminal device or had previously used multiple types of terminal devices. They discussed the tradeoffs between different terminal devices or the reasons they would wear specific terminal devices. In general, participants across device categories compared hooks to hand-shaped terminal devices, and participants who used myoelectric devices also compared 1-DOF hands to multi-DOF hands.

Sensory feedback: Participants discussed whether they received any sensation from their prosthesis and their experiences with this sensory feedback. In general, participants who used multi-DOF myoelectric prostheses had the least sensation from their prostheses, while BP users expressed being able to perceive and utilize sensation from their shoulder to indicate the aperture or pressure exerted by the prosthesis. Participants who used prostheses with sensory augmentation received much more detailed and realistic sensory information than users of commercial devices. Participants also discussed the impacts of sensory feedback on their *prosthesis function*, *confidence* in using the prosthesis, *embodiment* of the prosthesis, *focus* required to use the prosthesis, and *naturalness* of the prosthesis. The SA users typically found the sensation to be functionally useful, as well as beneficial for increasing confidence, decreasing focus, and promoting prosthesis embodiment.

Table 1. Coding structure and exemplars. Participants were trans-radial (TR) or trans-humeral (TH) and used BP, 1DOF, or Multi-DOF prostheses. Four participants had prior experience using a prosthesis with sensory augmentation (SA) as part of a research study.

	Node	Definition	Exemplar
Prosthesis Movements	Functional Workspace	Comments on limb/body position impacting prosthesis operation and how the socket and/or harnessing impact range of motion or prosthesis operation in certain positions.	*Let's say I'm in an airplane and I'm reaching for the overhead container, I might have to alter my movement, just because of the way my muscles are different in an extended position. (P011, TR, Multi DOF)*
	Compensatory movement	Comments on compensatory movements needed to accomplish tasks.	*Rotating the wrist passively is task specific... I don't really use that one a whole lot. I compensate with my shoulder and elbow for that (P16, TR, 1DOF).*
	Preplanning-Prepositioning	Comments about strategies and/or series of movements to prepare the prosthesis or an object before performing a task with the prosthesis.	*You have to do everything in a consecutive manner. I'm doing this, but the [prosthetic] elbow has to be locked in order for that to happen, so I have to think about positioning, clicking in place, and then doing it. (P03, TH, BP)*
	Movement preferences	Comments about desired or preferred movements of the prosthesis.	*To be able to grab something with four fingers or something simulating fingers would be night and day. (P13, TR, 1 DoF)*
Prosthesis Control	Grasp force regulation	Comments about controlling the strength of grasp force, maintaining grasp, or varying the grasp force for a task.	*Yeah, if there's something a little loose [in the grasp of the prosthesis], I can squeeze [my muscles] where it'll tighten up the hand. (P04, TH, Multi DoF)*
	Role of focus in grasp force	Comments about how focus or visual monitoring is needed to maintain prosthesis control and how lack of focus or distraction contributes to unintended prosthesis movements.	*As long as I pay attention to what I'm holding and how hard I'm holding it, not a problem. Like I said, I can pick up a potato chip and not break it, or I can break up a glass and shatter it. It's just focus. (P06, TR, 1 DoF)*
	Naturalness of Control	Comments about the sense of naturalness of the prosthesis control system and similarities/differences between controlling the prosthesis and controlling an intact hand.	*I really am feeling like I don't have to think about the way that the muscles are doing [activating] more than what the prosthesis is doing. So when I'm using the prosthesis and it's doing what I'm asking it to do… I feel like it's almost a bit of like the natural motion now. (P9, TR, 1DOF)*
	Reliability and precision of control	Comments about the dependability of prosthesis control, situations that make control unreliable, and experiences with involuntary or unpredictable prosthesis movements.	*It's actually a sensor issue. So, for example, the TASKA and the COAPT is calibrated when your arms are at a certain position. So, as you're extending your arm, you're changing the sensor positions, and from extending your arm and bringing it back, there could be times where the sensors will read differently and release the grasp that you have. (P011, TR, Multi DoF)*
	Control preferences	Comments about features or capabilities of the control system that would make it more effective.	*I mean anything you can do to make the calibration process easier, to make the calibration process more robust so that the calibration lasts longer and is a little more tolerant of like if the socket shifts in your arm. (S07, TR, Multi-DoF)*
Terminal Device	Terminal Device Preferences	Comments about preferred terminal devices or trade-offs between terminal devices and any specialty attachments they used for task specific needs.	*"There's things that I can do with that hook that I couldn't do with my [prosthetic] hand, so the things that I do that I have done with my prosthetic hook, it would probably break my [prosthetic] fingers or my hand or wrist or something if I had the [prosthetic] hand doing the same task." (P1, TR, BP)*
Sensory Feedback	Sensation Experience	Comments about the location, modality, and intensity of the sensation provided by the prosthetic hand or prosthesis suspension/harnessing.	*I enjoyed getting that sensation back, sometimes as small as a pencil lead, and then it can be as much as my whole hand, depending on what kind and where I'm being stimulated on my nerve. (P15, TR, Multi DoF, SA)*
	Functional impact of sensation	Comments about the usefulness of information provided by sensation and how sensation helped (or did not help) with prosthesis task performance.	*I learned about how much pressure each different vibration was; it didn't take much concentration at all to be able to reach out 'cause you knew as soon as you hit that certain buzz, that was it. You just pick it up and go. (S10, TH, Multi-DoF, SA)*
	Role of sensation in confidence	Comments about how sensation enhanced confidence or how lack of sensation reduced confidence and contributed to task avoidance.	*It's [the sensory feedback] boosting my confidence, and then I know I can do this [task] where it's not going to frustrate me, and I can get it done. (P14, TH, Multi DoF, SA)*
	Role of sensation in focus	Comments about how sensory feedback impacts the need for focus and attention, and how sensory feedback reduces the need for visual monitoring during task performance.	*The sensory hand doesn't take as much focus as without it [sensation] because I can feel what I'm holding. I can feel that I'm squeezing tight enough to hold onto something, so I don't necessarily pay as much eye-contact attention as without it. (P02, TR, 1 DoF, SA)*

	Role of sensation in naturalness	Comments about how sensory feedback enhances the naturalness of the prosthesis experience and/or control. Comments about how sensation contributes to making the prosthesis feel like a real hand.	*When I've got it [sensation] on and I can feel, it feels like my hand is there. It feels like my hand's out where it should be, and I can feel when I'm touching, grabbing, and doing things, and without it, it feels like it's [my hand's] gone. (P02, TR, 1 DoF, SA)*
	Sensation preferences	Comments about preferences for the type, intensity, or amount of sensory feedback from the prosthesis.	*I don't have any sensory stuff that tells me [what my prosthesis is doing]. I wish I did. It's kind of weird; you shake someone's hand, and you can't feel it. (P04, TH, Multi DoF)*

CONCLUSION

This study is one of the first to compare user perspectives on functional features of upper limb prostheses across body-powered, 1-DoF myoelectric, multi-DoF myoelectric, and sensory augmented device groups. Use of semi-structured interviews enabled our participants to guide conversations and organically delve into topics they considered important to their lives. The themes that emerged within our analysis will help to elucidate the complex and multifaceted interplay between functional features and user experience across a diverse range of device types. Therefore, our findings provide invaluable insight into the expectations and experiences of prosthesis users and the practical utility of prosthesis functional features. Findings from this study will inform researchers, clinicians, and prosthesis developers about the impact of functional features on the use and adoption of prosthetic devices, and will enable future development of prostheses that better meet user needs.

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