Development of a Mobile App for Objective Assessment of Prosthesis Rejection Rates in End-Users

Ramana Vinjamuri

University of Maryland Baltimore County

INTRODUCTION

According to the World Health Organization, there are over 30 million prosthesis users worldwide, with upper limb prostheses being especially common. In 2005, nearly 541,000 Americans suffered from upper limb loss [14]. As the number of upper limb loss cases is expected to double by 2050, there is an urgent need for functional and easy-to-use prostheses; however, to do so, providers must make significant efforts to identify potential sources of dissatisfaction and accurate estimates of rejection rates. In 1986, rejection rates upwards of 80% were present in body-powered hands [3], and, although reported prosthetic rejection rates have decreased with modern technology, over 30% of pediatric prosthetic users and 20% of adults are still unsatisfied with body-powered and electric prosthetics, respectively [12].

Rejection rates are frequently measured via questionnaires or surveys, such as European Quality of Life Five Dimension (EQ-5D), which often hold potential biases. Relying on these necessary but limited assessments over the past 25 years, researchers have found high prosthetic rejection rates. On the other hand, a more recent study examined prosthesis use and abandonment among prosthesis users with upper limb deficiencies in the US and Japan and concluded that many researchers published exaggerated results from their surveying methods. They determined that there is a 9% rejection rate, and 70% of users use their prostheses daily [12]. In this paper, we propose an objective assessment of rejection rates, through smart wearables and neuromarketing approaches, while generating a user-friendly training smartphone app. Novel neuromarketing approaches, including electroencephalography (EEG) and electrodermal activity (EDA), have been used for attention deficit hyper disorder (ADHD) diagnosis, substance use disorders (SUD), biofeedback, and direct control of prosthesis, but have not been used to measure the end user satisfaction.

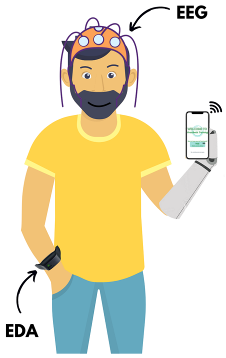
Currently, many upper limb prosthesis users are unsatisfied with the functionality, comfort, and training received for their prosthesis. In this paper, we propose a smartphone app to improve usability by balancing functionality and aesthetics. We aim to gather data from patients with two goals in mind: engagement (how long the patient is spending to learn about how their prosthetic works) and growth (the patient's progression in their engagement and overall satisfaction with the machine). Using persuasive technology and positive intermittent reinforcement, (ex. watching and posting success stories) we hope to lower prosthetic rejection rates by creating a more comfortable, user-friendly experience.

Providers frequently expect prosthesis users to use their machines daily. Nonetheless, our team also acknowledged the need for reminders and how they impact learning ability. We can manipulate and amplify the effects of the implementation of daily successes through the ACT-R (Adaptive Control of Thought Rational) theory, which proves that the effects of reminders vary based on frequency.

METHODS/ PLAN OF EVALUATION

Researchers have discovered several methods to measure responses in brain and behavior using EEG and EDA. While EEG has a poor spatial resolution, it has high temporal resolution, and when used in conjunction with TMS (transcranial magnetic stimulation), the causality of brain regions for specific mental processes can be studied effectively. In our study, we will measure each patient's current satisfaction, and then their satisfaction after using our training app. The comparison between the two will not only give us an objective measure of prosthetic users' level of satisfaction, but also the positive effects of a training app.

Figure 1. By using a combination
measure the current prosthesis
can compare this with the patients
training app. Through this proced
reports of prosthetic rejection and
app's success.



I receive reminders every morning

My amputation is at my shoulder

My overall goals
- Example 1
- Example 2
- Example 3
- Example 4

Post success videos?
With the #prosthetic to potentially be featured on our YouTube Shorts channel!

View my posted videos

View other success videos

Connect with others via Facebook

● Pouring Water
Learn how to pour yourself a fresh glass of water

○ Opening Doors
Learn how to easily twist any knob

○ Brushing Teeth
Learn how to brush your teeth with your new prosthetic!

○ Typing
Learn how to type with ease on a computer

"Always walk through life as if you have something new to learn and you will."
— Vernon Howard

Figure 2. A. In the "About Me" prototype, patients are allowed to pick custom settings for a more user-friendly experience. The page functions as a place for patient profiles, implementation intentions, and connections with other users through success videos and social media. **B.** By allowing users to pick the activities they deem as necessary in the "Learn Something New This Week?" page, we provide them with the resources they need to learn everyday skills.

To measure satisfaction through EEG, electrodes will be placed across the patient's scalp, with several frequency bands: alpha, beta, theta, gamma, and delta. Each signal's intensity and frequency are then compared and used to create indexes. These indexes can measure vigilance (through the alpha band), emotion, approach and avoidance of motivation (through alpha asymmetry), arousal (through the beta band), pleasantness (through the alpha and beta bands), and/or activation (through the alpha and beta bands) [2]. EDA will be used to measure stress, and emotional states of the user.

Additionally, based on the results we expect to see from consistent training, we plan to use the ACT-R theory to create an implementation intention app. We took inspiration from social media platforms' aesthetics, to generate an application that would positively impact prosthetic users' lives and attract their attention. It will gather information from the patient (including when the patient would like to receive reminders, the amputation location, and any specific personal goals) in an "About Me" page (Figure 2A). The patient can choose to make this page "public" or "private." If they choose to make a public profile, they can connect their social media platforms to the app so fellow prosthesis users or experienced members can communicate with them. On the other hand, if they choose to leave their profile private, they still can connect with experienced users through "Success Stories," a feature filled with positive reinforcement and helpful information. Success stories will be set up in a similar manner to that of TikTok or Instagram Reels, in which users will feel more inclined to continue watching the short snippets. Many studies establish how it is not necessarily the content that drags users' attention, but rather the appealing design that app makers use [6].

Features like "Success Stories" and the public "About Me" page are essential to the success of our proposed app, as watching and meeting mentors is incredibly helpful in all settings, especially healthcare. While no studies have explored the effects of success stories in a prosthesis setting, they have investigated the value in shared experience. For example, one study analyzed the benefits of a shared-learning approach from fourth year to third-year medical students. The results revealed that more than 75% of the third-year students concluded that the shared learning approach provided a unique opportunity to practice communication skills and become increasingly effective healthcare workers [13]. Ultimately, these conclusions highlight the importance of shared experiences and the relationships between novices and veterans in any field, including prosthesis.

APP/PROGRAM NAME
LEARN SOMETHING NEW ABOUT YOUR __!
It's time for you to expand your knowledge 😄

APP/PROGRAM NAME
PRACTICE! PRACTICE! PRACTICE!
Click here to acknowledge your daily reminder

If _____ (situation), then I will _______!

Figure 3. A. Example messages and reminders for practicing new skills. By displaying frequent reminders, patients will experience the quickest turnaround in learning ability, maximizing the power of implementation intentions. **B.** An example implementation intention can also be seen in an if-then format with positive images and messages.

The app gives users four new learning concepts to choose from (for example, how to pour water into a glass, open a door, brush their teeth, or one of the personal goals set by the patients in their "About Me" page), of which one will be the concept for the week (Figure 2B). Then, every day for that week, patients will receive a notification with a positive message as a reminder to practice the new skill (Figure 3A). When users click on the reminder notification, an implementation intention (related to the skill set for that week) will appear with a runner graphic and more positive reinforcement to encourage prosthetic comfortability and growth. For example, an implementation intention could be "If I need to drink water, then I will point my thumbs upward, grip a pitcher, and pour" or "If I need to enter my home, I will point my fingers inward, grab the knob, and rotate” (Figure 3B). To test the effectiveness of the implementation intentions, we will use the ACT-R theory in conjunction with Python to build neurocognitive models of the patients. If, for instance, the implementation intention refers to pouring a glass of water, ACT-R would reflect five steps [8]: 1) face thumbs out, 2) squeeze muscles, 3) lift water pitcher, 4) turn wrist over, and 5) pour water into cup (Figure 4).

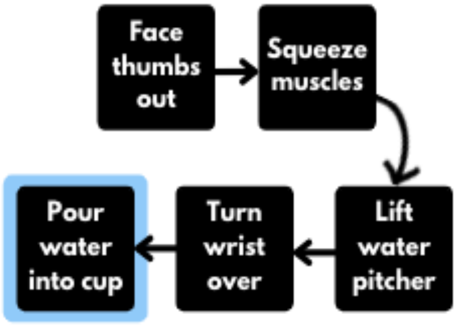


Figure 4. ACT-R model of example goal: pouring water. Each step is highlighted and will be shown and taught to the user if the goal is selected. Implementation intentions will mirror each step, as well.

Finally, to give and receive effective feedback, we encourage patients to add their daily and weekly logs (Figure 5). As explored in one study, patient feedback in healthcare settings is essential, providing healthcare workers with insight into what is working well and what needs to be improved [7]. In our application, prosthesis users will have the opportunity to “rate the usability”; they will rate their difficulty to complete the skill for that on a 10-point-scale, with full score representing complete ease. They will also log the number of days in the week that they completed their goal and practiced their skill. If at any point they poorly rate the prosthesis’s usability, they will receive a troubleshooting page, with several drop-down options (such as not understanding how to complete the skill, the prosthesis not feeling normal, and more). When the patient clicks on the drop-down, there will be useful resources and a chat-box to connect with clinicians/prosthetists for assistance. On the other hand, if they positively rate their weekly logs, they will receive a “So glad to hear that!” page, where they will get the option to move on to their next skill. They will then be linked back to the “Learn something new this week” page (Figure 2B).

DISCUSSION

Neuromarketing is the application of neuroscience for behavioral analysis in markets and marketing exchanges to measure satisfaction. It began with the System 1-System 2 Model by Daniel Kahneman, which explains the two types of processing and decision-making systems in the brain. (System 1 is the automatic response, while System 2 is the voluntary response.) Traditional research regarding prosthesis rejection rates is based on surveys which employ System 2; thus, they are at risk of patient or proxy bias. On the other hand, neuromarketing approaches, including EEG and EDA testing, address research objectively via System 1, aiming to reduce or remove bias.

The ACT-R theory, created in 2004, is a complete account of the role of implementation intentions in changes in behavior and action-taking. The theory proves that reminders have time varying strengthening effects and implementation intentions eventually lead to deliberate goal-striving behavior becoming habitual. As explained previously, the theory models several modules, which process different kinds of content and store information in buffers. Buffers act as the connections between the procedural memory system (the central component) and the other modules. Procedural knowledge is the memory a person displays “naturally” and without conscious awareness, while declarative knowledge is the type of memory, from which someone can attend to, but must reflect upon. The procedural memory module includes the cerebellum, and the declarative memory module includes the temporal lobe and the hippocampus. Declarative memory also stores a patient’s consciously formulated implementation intentions [10].

RATE THE USABILITY

DID YOU COMPLETE YOUR GOAL TODAY?

● Yes

○ No

HOW DIFFICULT WAS IT FOR YOU TO COMPLETE THIS GOAL TODAY?

1 2 3 4 5 6

HMM.. WHAT'S WRONG?

● I still don't understand how to use it ▼

○ It doesn't feel normal ▼

○ I don't feel motivated to learn about it ▼

○ Other ▼

SO GLAD TO HEAR THAT!

Thank you so much for your submission!

Click here to learn another skill

No thank you, I wouldn't like to learn more. I would rather get a notification at my regular times.

Figure 5. A. The “Rate the Usability” page provides users with personal logs, in which we can not only get feedback on their growth, but also on our application’s ability to accelerate proper training. **B**. The prototype displays what the user would see if they selected a low usability score or did not complete their goal. Then, the user will be presented with some actionable steps they can take to improve their learning. **Figure 5C.** This is the page that will be shown if the patient is satisfied with the usability and ready to move on to the next goal.

One study examined the effects of implementation intentions on daily success of healthy behavior changes. Each of the 64 adult participants were assigned to one of two groups (reminders present or absent), and their respective progress was tracked. The researchers found that the neural circuitry underwent changes as habits were acquired and strengthened. Each time an implementation intention was reminded and put into practice, the patient received an increment of activation; however, this decayed as time passed, highlighting the importance of frequent reminders. Distributed, high-frequency reminders have the most effective base-learning implementation intentions. Not only that, but acknowledged reminders showed even stronger effects [12]. Through our training app, we plan to include many of these concepts, including encouraging reminder acknowledgement (through notifications) and only giving distributed, frequent reminder options (every day or every other day).

CONCLUSION

In this paper, we have proposed to develop a user-friendly mobile application (a smartphone app) for objective assessment of rejection rates, through smart wearables and neuromarketing approaches. We will recruit and measure current rejection rates of prosthesis users through EEG and EDA. This will provide us with an unbiased measure of prosthesis rejection, which is necessary to generate apt solutions. Then, we will have each patient use our training application regularly. We will then use these same neuromarketing approaches to measure their post-application satisfaction rates. Thus, our study will also provide us with an accurate measure of the success of our application in a real-life setting.

ACKNOWLEDGEMENT

This work was supported in part by the National Science Foundation. Grant No# NSF CAREER Award HCC-XXXXX.

REFERENCES

[1] Balconi, M., Venturella, I., Sebastiani, R., & Angioletti, L. (2021). Touching to Feel: Brain Activity During In-Store Consumer Experience. *Frontiers in psychology*, *12*, 653011. https://doi.org/10.3389/fpsyg.2021.653011

[2] Bazzani, A., Ravaioli, S., Trieste, L., Faraguna, U., & Turchetti, G. (2020). Is EEG Suitable for Marketing Research? A Systematic Review. *Frontiers in neuroscience*, *14*, 594566. https://doi.org/10.3389/fnins.2020.594566

[3] Biddiss EA, Chau TT. Upper limb prosthesis use and abandonment: a survey of the last 25 years. Prosthet Orthot Int. 2007 Sep;31(3):236-57. doi: 10.1080/03093640600994581. PMID: 17979010.

[4] Cherubino P, Martinez-Levy AC, Caratù M, Cartocci G, Di Flumeri G, Modica E, Rossi D, Mancini M, Trettel A. Consumer Behaviour through the Eyes of Neurophysiological Measures: State-of-the-Art and Future Trends. Comput Intell Neurosci. 2019 Sep 18;2019:1976847. doi: 10.1155/2019/1976847. PMID: 31641346; PMCID: PMC6766676.

[5] Colzato, Lorenza & Nitsche, Michael & Kibele, Armin. (2017). Noninvasive Brain Stimulation and Neural Entrainment Enhance Athletic Performance—a Review. Journal of Cognitive Enhancement. 1. 10.1007/s41465-016-0003-2.

[6] Firth, J., Torous, J., Nicholas, J., Carney, R., Pratap, A., Rosenbaum, S., & Sarris, J. (2017). The efficacy of smartphone-based mental health interventions for depressive symptoms: a meta-analysis of randomized controlled trials. *World psychiatry : official journal of the World Psychiatric Association (WPA)*, *16*(3), 287–298. https://doi.org/10.1002/wps.20472

[7] Hardavella, G., Aamli-Gaagnat, A., Saad, N., Rousalova, I., & Sreter, K. B. (2017). How to give and receive feedback effectively. Breathe (Sheffield, England), 13(4), 327–333. https://doi.org/10.1183/20734735.009917

[8] *How to use a Hero Arm: Pouring & Drinking Water.* (2020, March 10). [Video]. YouTube. https://www.youtube.com/watch?v=B-f0egEgKms

[9] *Introduction to cognitive modeling*. (2020, September 13). [Video]. YouTube. https://www.youtube.com/watch?v=vS8o4Da3boU

[10] Pirolli P, Mohan S, Venkatakrishnan A, Nelson L, Silva M, Springer A. Implementation Intention and Reminder Effects on Behavior Change in a Mobile Health System: A Predictive Cognitive Model. J Med Internet Res. 2017 Nov 30;19(11):e397. doi: 10.2196/jmir.8217. PMID: 29191800; PMCID: PMC5730820.

[11] Resnik L, Borgia M, Heinemann AW, Clark MA. Prosthesis satisfaction in a national sample of Veterans with upper limb amputation. Prosthet Orthot Int. 2020 Apr;44(2):81-91. doi: 10.1177/0309364619895201. Epub 2020 Jan 21. PMID: 31960734.

[12] Yamamoto, M., Chung, K. C., Sterbenz, J., Shauver, M. J., Tanaka, H., Nakamura, T., Oba, J., Chin, T., & Hirata, H. (2019). Cross-sectional International Multicenter Study on Quality of Life and Reasons for

Abandonment of Upper Limb Prostheses. *Plastic and reconstructive surgery. Global open*, *7*(5), e2205. https://doi.org/10.1097/GOX.0000000000002205

[13] Zakaria, S. F., & Awaisu, A. (2011). Shared-learning experience during a clinical pharmacy practice experience. American journal of pharmaceutical education, 75(4), 75. https://doi.org/10.5688/ajpe75475

[14] Ziegler-Graham, K., MacKensie, E. J., Ephraim, P. L., Travison, T. G., and Brookmeyer, R. (2008). Estimating the prevalence of limb loss in the United States: 2005 to 2050. *Arch. Phys. Med. Rehabil.* 89, 422–429. doi: 10.1016/j.apmr.2007.11.005