

Designing Game-Based Myoelectric Prosthesis Training

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ABSTRACT

A myoelectric prosthesis (myo) is a dexterous artificial limb controlled by muscle contractions. Learning to use a myo can be challenging, so extensive training is often required to use a myo prosthesis effectively. Signal visualizations and simple muscle-controlled games are currently used to help patients train their muscles, but are boring and frustrating. Furthermore, current training systems require expensive medical equipment and clinician oversight, restricting training to infrequent clinical visits. To address these limitations, we developed a new game that promotes fun and success, and shows the viability of a low-cost myoelectric input device. We adapted a user-centered design (UCD) process to receive feedback from patients, clinicians, and family members as we iteratively addressed challenges to improve our game. Through this work, we introduce a free and open myo training game, provide new information about the design of myo training games, and reflect on an adapted UCD process for the practical iterative development of therapeutic games.

Author Keywords

Prosthetics; myoelectric; training; games; UCD

ACM Classification Keywords

H.5.m. Info interfaces & presentation (e.g., HCI): Misc.

INTRODUCTION

Amputees, or limb different individuals, are people who are missing a limb due to amputation or a congenital limb difference. A myoelectric-controlled upper-limb prosthesis (myo) is an electrically-powered device that restores some of the missing dexterous movement in the arm and hand, e.g., by providing wrist rotation and hand closing. Myos typically offer greater functionality than passive or body-powered prostheses because they provide improved dexterity, a larger range of movement, a more natural appearance, and enhanced performance of daily tasks [7].

Myos also have drawbacks (including high cost and weight

[7,12,22]), which have led to a high rate of abandonment; rejection rates of up to 75% have been reported [7]. Rejection is a complex, multi-factor process, but one of the key contributing factors is poor early myo operation ability arising from inadequate training [12].

Myos work by detecting electrical signals from residual muscle contractions. These signals act as input to control the artificial limb. Precise control and activation of particular muscle groups is required in order for the device to be used effectively. However, due to lack of experience, unfamiliarity, and muscle atrophy, precise activation of specific muscle groups can be very difficult [8].

Occupational Therapists (OTs) employ training activities to improve patients' muscle activation skills, helping them to learn how to operate and adapt to a myo. Learning to use a myo presents a unique challenge; unlike other therapeutic or rehabilitative programs, the goal of myo training is not to relearn forgotten tasks or regain lost functionality (as would be the case with stroke or physical injury rehabilitation), but is instead to learn to operate a device using muscles in a new and unfamiliar way [8].

The experts interviewed in this study agreed that current myo training approaches limit success for three main reasons. First, they are *boring and unengaging*. Training activities are often utilitarian and amount to little more than simple visualizations of muscle signals. Second, they are often *more difficult than using a real prosthesis*. Overly difficult training activities that provide primarily negative feedback are a source of frustration and discouragement. Further, this causes OTs to question the benefit of training given the potential for unintentionally introducing self-doubt. Third, they are *not accessible outside of the clinic*. Commercial training tools cost thousands of dollars, and require professional placement of sensors and interacting with complex software to set up training activities.

Game-based training tools [4,8,11,12,14,25] have been proposed to address the limitations identified above. Games seek to provide a more engaging experience and stronger extrinsic motivation (e.g., rewards, points, leaderboards) to help offset frustration. When coupled with appropriate technology, games can make training more accessible, allowing training to occur at home.

However, previous work has not engaged limb-different patients while designing games; very little work has explored how training games should be designed to best suit the specific needs of trainees and clinicians. While

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research considering the needs of end users is prevalent in other therapeutic settings [1,20,21,38], academic efforts towards designing myo training games have focused exclusively on technical issues, and not on the concerns and needs of the people involved (e.g., [4,11,12,14,25]). This direction of focus becomes apparent when considering commercial myo training games, which are widely used [9] but provide few of the motivating elements of game design that create a fun and engaging experience for players [16].

Much like the work of Hernandez et al. [21], our study is a qualitative exploration of game-based myoelectric training, leaving technical and performance issues to future work. First, we developed a prototype based on requirements gathered from previous work, observation of the training process, and discussions with a clinician from a local prosthetics clinic. We then iteratively refined our initial prototype using feedback and observations from a series of adapted user-centered design (UCD) sessions with limb different patients who have previously participated in myoelectric training. We transcribed and thematically analyzed audio recordings of the sessions, which we validated through interviews with subject matter experts. Our themes contribute domain expertise and encode current best practice for the design of future myoelectric training games, as well as therapeutic games in general.

This paper makes four contributions: First, we develop a new game – *The Falling of Momo* – as a starting point for game-based myoelectric training discussions within an adapted UCD process. Second, we present thematic analysis of interview and observation data from limb-different individuals and other stakeholders as a contribution to future work in this area. Third, we outline the process of integrating stakeholder feedback into our iterative game development process. Finally, we discuss the benefits and drawbacks of our adapted UCD process developed for situations when participants are difficult to recruit and follow-up visits are infeasible.

BACKGROUND & RELATED WORK

Myoelectric Control

Myoelectric signals are electrical impulses that occur naturally as we contract our muscles. Myoelectrically-controlled powered prosthetic devices (or myos) read muscle signals (using electromyographic sensors – EMG) from residual muscle tissue, and use them as control for motion [28,29]. The simplest myos open and close based on the presence of inner- and outer-forearm muscle activity (known as flexion and extension, respectively). However, many other control schemes exist and can work in combination, including proportional (adjusting the speed of motion proportionally with the intensity of muscle contractions), mode-switching (to enable selection between different types of movement), and pattern recognition techniques (for more natural control mappings) [17,33]. In this study, we focus specifically on proportionally-



Figure 1. (Left) A myoelectric upper limb prosthesis – myo. (Right) The Thalmic Labs Myo Armband – Myoband.

controlled myoelectric devices (as can be seen in Figure 1), since these are by far the most common type of myo.

Typically, surface sensors are positioned within the sleeve of myos (just visible within the sleeve of the device shown in Figure 1) such that they sit flush against the surface of the skin, directly above the ideal targeted muscle site (identified by the prosthetist or clinician during the fitting process). Accurate placement of these sensors is critical because inconsistency in placement can negatively affect muscle readings [9]. In many myoelectric muscle training tools, the same EMG sensors are used that are employed in prostheses, which are expensive (a training kit for proportional control consisting of 2 sensors and control box costs ~4000USD) making them unfeasible for use outside of the clinical environment [9].

In our study, we work with a consumer-grade EMG sensing armband, the Thalmic Labs Myo Armband (referred to as the ‘Myoband’ and shown in Figure 1), to assess its viability for use with myoelectric training tools. The Myoband is an off-the-shelf input device that costs under 200USD, and even though the fidelity of its EMG sensors is lower than medical-grade equipment, it is likely more than capable of being used for myo training. Even though the Myoband samples at one-fifth the rate of medical grade devices (Myoband: 200Hz, medical grade: ~1000Hz), the Nyquist theorem states that this is adequate to achieve an accurate representation of the underlying EMG signal [25]. The sensors of the Myoband also sample with a lower signal resolution (Myoband: 8-bit, medical-grade: ~16-bit), but research has shown that such a reduction results in only a marginal loss in control accuracy [31]. Further, there are recent examples of the Myoband being used to successfully operate prostheses in a lab setting (e.g., <https://goo.gl/o6p2OE>).

Myoelectric Prostheses Training

Traditional Training

The time between amputation and receipt of prosthesis is known as the pre-prosthetic phase, and is recognized as being a crucial period for training [7]. Experts interviewed agreed that building strength in the patient’s musculature during this phase, in turn instilling confidence in use of their residual limb is key to ensuring long-term success. While the best training approach for many is direct use of a prosthesis, this is often not initially possible (e.g., post-surgery recovery, insurance processing, fabrication times). To fill this gap, training tools can be used. Many clinics use the Ottobock PAULA [9,27] software, which allows EMG

sensors to be affixed directly to the affected limb without the need for a final prosthetic socket. The PAULA suite (Figure 2) provides feedback tools for visualizing raw EMG activity, a virtual hand simulator, and a game involving navigating a car through a series of gaps.

Game-based Training

Past findings related to game-based myoelectric training tools have been conflicting. In one study using the PAULA software suite, it was suggested that game-based training tools are just as effective as traditional techniques, and that training tools could be used interchangeably at the discretion of the clinician or patient [9]. However, a subsequent study suggests that certain training games are no more effective than a total lack of training [13]; the study suggests that while learning may occur within the context of gameplay, these acquired skills might not translate to improved prosthesis use. These conflicting results suggest that the specific challenges associated with designing training games for amputees are not fully understood.

Therapeutic Games

Therapeutic games have recently received a lot of attention, and have been created for people with cerebral palsy [21,40], multiple sclerosis [20], paralysis [34], and who have had a stroke [5,24,32,37]. Findings from research into the participatory design of games for individuals with visual impairment [38] and young people using wheelchairs [19] makes clear that there are no one-size-fits-all solutions for populations that have a wide range of physical capabilities. Balancing the aspects of challenge required for the game to be exciting and effective with the potential vulnerabilities of the intended audience is rarely easy.

While training games should push players to improve their abilities, they should not highlight the player's weaknesses or limitations [18]. To be most effective for therapists, therapeutic games should be easy to start up and configure (ideally, saving configuration settings in a user profile so they can be easily loaded in future sessions), allow the therapist to change difficulty settings on the fly (to adapt to the patient's current needs), easily allow therapist to provide support during gameplay, and track and report patients' performance over time [3].

While myo training games have been created, these have largely focused on technical and performance issues (e.g., [4,11,12,14,25]), and have not involved limb different patients (e.g., [4,11,14]). Very little focus has been given to creating engaging and enjoyable training experiences, and

little is known about what game design challenges are unique to myo training games. Despite varying results in past research [6,9,11,18], the experts interviewed expressed that games are important, as they help engage and motivate their patients and can serve as a troubleshooting tool when a patient's prosthesis is behaving unexpectedly.

Game Design Principles

Challenge, theme, reward, and progress are known to be key elements that keep players excited and engaged during gameplay [16]. Throughout the design of our game, we have kept these concepts in mind, and we highlight below how our game incorporates these elements. Further information about our game can be found in [35,36].

Research has also shown that strong game design can lead to more than an increased level of engagement. In a study comparing games for psychoacoustic therapy, it was found that players could detect smaller tone frequency modulations when playing a game that was enjoyable and engaging [1], a task which is believed to involve skills related to genetic ability, and not believed to improve through training.

DESIGNING A MYOELECTRIC TRAINING GAME

To facilitate the exploration of myo training, we designed and implemented a training game [35,36]. This game was shown to participants during playtest-interview sessions (introduced below) and served as a concrete example to stimulate feedback and discussion. As the study progressed, the game allowed us to easily explore the ideas, criticism, and suggestions that surfaced, and was iteratively improved throughout the study. While it is not customary to begin with a full solution in user-centered design, we felt that this choice would allow us to get the most out of our design sessions, given the extremely limited number of participants available. We recognize that this decision can be viewed as limiting, and we emphasize that the game was a starting point meant to stimulate conversation, and was therefore expected to change considerably throughout the study.

Initial Design Requirements

We worked closely with a local prosthetics clinic based at our university. Our main point of contact was an occupational therapist, Linda (pseudonym). Linda specializes in myoelectric prosthetics and training. She works closely with patients first learning to use a myo, and maintains contact with continuing myo users.

Our initial game design was based on requirements



Figure 2: Ottobock PAULA training suite (raw muscle activity, prosthetic hand simulator, and car game, left to right)

gathered through conversations with Linda, in addition to a demonstration of a typical muscle training session with one of her patients. During our initial requirements gathering, we discovered several insights into myo training:

1. Training focuses on specific aspects of muscle control.
2. The “ideal” outcome of training is isolated control over two opposing muscles. However, this is not always achieved in practice, and control strategies exist to accommodate an individual’s capabilities.
3. A co-contraction impulse (a quick, simultaneous “burst” with both muscles) is used as a mode switching instruction (e.g., to alternate control between grip aperture and wrist rotation).
4. Existing tools provide primarily negative feedback.
5. Current training tools are inaccessible outside of the clinical environment due to high cost.

We observed that certain aspects of myo training differ from other types of therapy, resulting in unique challenges when designing in this space. Unlike other therapeutic processes, the goal of myo training is not to regain lost functionality, range-of-motion, or bodily control (as is the case in stroke and physical-injury treatments), but is instead to adapt to a new reality. Limb-loss is irreversible, and learning to use a myo involves working with unfamiliar muscles and mastering new control techniques. Furthermore, while other therapeutic programs focus solely on bodily movement, myos use proportional control and require the user to additionally have precise control over the duration and intensity of muscle contractions.

From our observations, it was clear that the training process could be improved through the use of established game design principles. It was also clear that games would need to incorporate the mechanics found in the existing control strategies and provide adjustable difficulty suitable for players with a wide range of skill and ability. Finally, games accessible beyond the clinical environment would allow trainees to continue improving between clinical visits, ultimately achieving “ideal” muscle control more quickly.

Initial Game Design: The Falling of Momo

Our initial design, *The Falling of Momo* (Figure 3) [35,36], is a casual, survival-style game, where players earn points by descending through a series of rising platforms to avoid being squished by spikes across the top of the screen. Players collect coins that can later be used to purchase new characters, themes and unlockables. We based our design on a casual, familiar style of game because our intended audience spans a wide demographic with varying preferences. The left/right game mechanics were selected because they mapped intuitively to the flexion/extension movements being trained, allowing the desired behavior to be targeted in a natural way.

Gameplay

Players control their avatar using the Myoband, and controls mirror those of typical prostheses. Momo’s

movements correspond to the intensity (for speed) of forearm flexion and extension (for direction). The player can also jump (to avoid obstacles) by performing a co-contraction impulse. Icy (low-friction) and sticky (high-friction) platforms were added so that players would need to use the full range of proportional control. By providing in-game collectables and unlockable items, we were able to provide replay value and positive feedback while still encouraging the player to train their muscles. The rising platforms (which progressively get faster) introduce a time-pressure mechanic, which creates excitement during game play. While certain guidelines may discourage time-pressure [6,15], Momo incorporates suggestions from past research on accessible action games [21] to ensuring both an exciting and accessible experience.

Game Evolution

The game was iteratively improved throughout the course of the study using observations, feedback, and suggestions collected during playtest-interview sessions (described below). New features were added on an ad hoc basis as issues were discovered or when explicit feature requests were made. The changes that were made throughout the study include crumbling platforms (for practicing muscle quietness), disappearing coins (to encourage quick collection), a bonus level (for game depth and performance assessment), an over-exertion warning (to indicate when muscle contractions are stronger than necessary), and a second screen containing raw EMG visualization (to allow clinicians to better assess muscle signals during gameplay). We include the motivation and details of several of these new features in our Results section as illustrative examples of how the findings of this study have helped shape the game and a full timeline explaining game evolution can be found in supplementary materials. It was interesting to note that the in-game calibration tools evolved as much as the game mechanics throughout the study; a timeline explaining the evolution of calibration tools can also be found in supplementary materials.

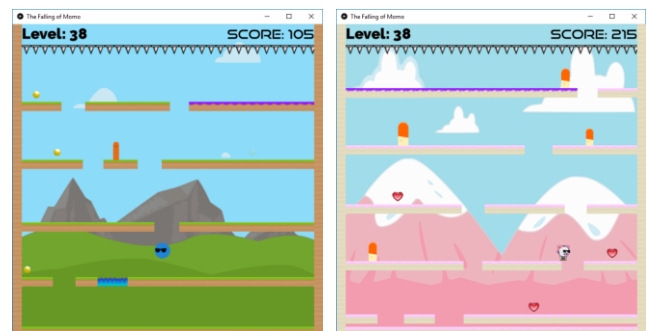


Figure 3: The Falling of Momo myo training game with the default theme (left) and the unlocked cat theme (right).

STUDY METHODOLOGY

To learn more about designing games that provide fun, engaging, and effective myoelectric muscle training, and to assess the viability of the Myoband as a training tool, we conducted a series of 9 playtest-interview sessions with 6

current/past myo users (referred to as patients) and 3 subject matter experts (referred to as experts), each of whom are introduced in Participant Profiles.

Games

Two myoelectric muscle training games were used during playtest-interview sessions: Momo (described above), and a game currently used in our local clinic (referred to as the “car game”), that was developed by the European prosthetics company, Ottobock [27].

The “car game” is part of Ottobock’s [9,27] PAULA software training suite (Figure 2) and is controlled using the company’s MyoBoy USB peripheral EMG sensors. Players control the height of a red and blue car using flexion and extension contractions, respectively, as the cars drive forward at a constant speed through a course consisting of a series of walls. The game has no score, but keeps a tally of the number of crashes that occur, so the goal of the game can be inferred as minimizing the total number of crashes. The player avoids crashing into walls by aligning each car height with a gap in the approaching wall. The gaps appearing in the series of walls are positioned in such a way that encourages the player to repeatedly sustain a controlled muscle contraction (to get through a high gap) followed by a brief period of rest (to get through a low gap). If the height of the car is not such to allow it to pass through the gap, a red ‘X’ and a cartoon crash appear on the screen at the location of the crash, but game-play continues.

The game can be configured so that the player is either responsible for controlling a single car (easier), or for controlling both cars simultaneously as they drive through the course in tandem (harder). Additional configuration options allow the player to adjust the speed at which cars drive forward, the size of gaps in walls, and the duration of time that each round lasts. Feedback is also provided to players by a trail (line) that is drawn from the back of the car (creating a line graph effect).

Procedure

Patients

Each patient session consisted of a semi-structured conversation focused on the patient’s history and experience with both myo training and video games followed by a demo of each game (with presentation order balanced across sessions) where patients were introduced to each game and given a chance to play for 10 to 15 minutes. Following each demo, patients were asked a series of questions about the game and were asked to rate it in terms of frustration, effort, fun, and perceived effectiveness. Patients were then given a chance to provide any additional feedback. To conclude the session, patients were asked to compare and contrast their experiences with both games.

All patient sessions occurred in the examination room at the clinic, with Linda present to ensure that patients were comfortable and to help with game setup (e.g., positioning EMG sensors, setup of car game). At least 2 researchers

were present for each session, with one researcher leading the session while the other captured detailed notes. Several patients were accompanied by family members or care-givers (specified in “Participant Profiles”) and, in these cases, their opinions and feedback were also considered.

Experts

Expert sessions also consisted of a semi-structured conversation followed by a gameplay demo where feedback on both games was collected. Conversation with experts focused on their experience with training in the clinical setting, the ideal and practical outcomes of training, and their views and opinions on game-based training. Experts were given a demo of Momo, but since every expert was already familiar with the car game, no demo was needed. Two expert sessions occurred in person, and in these cases experts were given a chance to play Momo. Due to geographic distance, the other expert sessions occurred over the phone and a video demo providing an overview of the features and mechanics of Momo was used instead (similar to the video-figure accompanying this paper).

Two researchers were present for each expert session, with one leading while the other captured detailed notes. Linda was the subject of one expert session, but was not present during any of the others.

Participants

Linda initiated contact with all participants. Patient participants came from Linda’s existing client-base, and were recruited based on availability (i.e., making a visit for unrelated clinical purposes), willingness to participate, and discretion of clinical staff. Expert participants were recruited through Linda’s professional contacts.

Participants were not remunerated for their time, and were aware that their participation was voluntary and that they were free to withdraw from the study at any time without implication on their clinical standings. All participants read and signed an ethical consent form (verbal consent was used during expert phone sessions) which explained the purpose, procedure, and voluntary nature of the study. For participants younger than the legal age of consent, a parent read and signed the consent form on their child’s behalf, and was present for the duration of the session.

Participant Profiles

A total of 6 patient and 3 expert participants were included in the study. Four of the patients were accompanied by a family member. A brief summary of each participant is provided below. The information is factual, but names have been modified to maintain anonymity.

Kyla is an 11-year-old female who plays video games every day for several hours on her PS4, Xbox, and iPad. Kyla uses two myo arms (not worn while playing games) and a powered wheelchair as the result of an amputation, and has some cognitive deficit. She was accompanied by both her mother and caregiver, who helped answer some of the

questions. Kyla's mom told us that since using her myos (~1 year) she has been doing much better in school.

Stanley is a 50-year-old male, who has been using a myo for over 30 years. Stanley was born without a right forearm, and believes that his myo has become an integrated part of his body; he uses it very naturally (e.g., twiddling fingers, fidgeting with a pen). Stanley had minimal training when he first received his myo (which was common practice at the time), and does not frequently play video games.

Mark is a 20-year-old male born without a left forearm. Mark used a myo when he was younger, undergoing training with Linda. At the age of 12, he stopped using his myo because the weight of the device made it too difficult to use effectively. Mark casually plays Xbox with his friends without the use of a prosthesis or special equipment. Mark is going to college this year, and is reconsidering using a myo to support independent living. During the interview session, Mark was joined by his father.

Justine is a 24-year-old female who was born without a left forearm, and was accompanied by her boyfriend Jon. Justine underwent training and received her myo as a toddler, but stopped using it at age 11 because she preferred the aesthetics of her passive prosthesis. Justine recently started using a myo again to benefit from the additional functionality it provides her and to alleviate repetitive-use injuries that were sustained in her right arm, and completed further muscle training exercises when she received her new arm. Justine casually plays MarioKart and Donkey Kong with her boyfriend and daughter.

Glen is a 50-year-old male who has been using a myoelectric arm for 32 years. As a result of an accident, Glen had surgery removing his left forearm at the age of 17. Glen trained through practical use, and during his stay in a rehabilitation center following the accident he spent many hours practicing with his new myo arm. Glen enjoys playing cards casually with friends and family, and occasionally plays solitaire on his phone.

Belle is a 10-year-old female (accompanied by her Mom), who was born without a right forearm. She first started using a myo at age 16 months, and continued to use it for several years. Belle more frequently uses a passive arm than her myo, because the weight of the myo is uncomfortable, the passive arm allows her to do physical activity (cheerleading and gymnastics), and she often gets frustrated with her myo because of frequent control problems. Belle casually plays games on her wii and iPad with friends.

Linda is an occupational therapist as described above in the Initial Design Requirements section.

Stuart is a research engineer who has specialized in the field of myoelectric control of prosthetics for 22 years. Stuart's research focuses on using pattern recognition to create more advanced and natural control strategies.

Ruth is an occupational therapist (OT) with 10 years' experience working with two large prosthetics companies. She has also worked in clinics training myo patients, and in teaching prosthetists and other OTs myo training practices.

Data Collection and Analysis

Data collected during each session consisted of a complete audio recording in addition to notes taken during the session capturing the researchers' observations. All patient sessions were transcribed, and then independently coded by two authors. The resulting codes were analyzed with a thematic analysis [10]. To remain patient focused, expert sessions were not included in the thematic analysis, but were instead used to help validate themes identified.

Our thematic analysis adopted a deductive approach where findings were organized around predetermined ideas. The three concepts were based on our initial work with Linda establishing requirements for our game and included: the challenges experienced in training, the role of feedback (positive or negative) on patient/player experience, and the impact play may have on the therapeutic process.

RESULTS

Core Challenges in Training

Most importantly, analysis identified a number of themes that fell into views on and challenges in training, with sub-themes addressing training practices, and patient needs.

Increasing Access to Training

Patients raised issues related to training practices and access to training; a focus also supported by expert feedback.

The most common response within this theme was the **lack of training programs for patients**. Patients reported receiving little to no training, but there was some evidence that they managed to make do with limited opportunities. For example, Stanley had minimal training and has been successfully using his prosthesis for more than 30 years by learning through practical use. However, experts pointed out that a lack of training may sometimes place important limitations on the functionality that is available to a patient or change how they can operate their prosthesis: This was evident in Stanley's gaming session, where we observed his therapist Linda uncover that he had adopted a non-standard control technique. She noticed this by first watching him play the games, and then confirming with muscle signal visualizations. Rather than contracting continuously to create smooth movement of the prosthetic hand or wrist, Stanley had been using a rapid series of pulses (a quick contraction and release) to control his myo. While Stanley used his myo very naturally, Linda commented that this is not strictly correct and could be limiting if he had a newer myo with a different control scheme.

In this context, experts pointed out that ideally **games should be designed to support a pre-prosthetic training phase** (before receiving a prosthesis), in order to make patients aware of how to contract the muscles that will be used to control their prosthesis. Having a broader

perspective on the issue of training practices, experts stressed that the actual process can differ greatly depending on the availability of and access to services. At the local clinic, the clinician had a primary role to work with patients in a training and troubleshooting capacity, however many other facilities do not provide this level of service and only introduce patients to basic prosthetic maintenance.

A possible solution that came up in patient feedback and expert interviews alike were **game-based opportunities for out-of-clinic myo training**. Bella's mom explained that training outside of the clinic wasn't an option: "...we haven't really done any sort of training outside the [clinic]... we tend to come in here and let the professionals do it.". Experts agreed that learning (and mastering) the use of a myo is something that takes time and substantial training, but training occurs in short, intermittent sessions. Currently, experts don't have anything that they can send home with patients so that they can continue to train their muscles between visits, with Stuart pointing out that "*it's difficult to use one of these [myos] ... improvement comes in stages ... it doesn't all come in the first 3 days...*". While our work was not directly focused on at-home training, experts were keen on the idea of a robust, low-cost training solution, agreeing that it would be extremely valuable.

Managing Muscle Fatigue

Many patients' responses evolved around the **management of muscle fatigue** and the creation of a positive, empowering player experience. In training, patients are asked to activate and use muscles that they have either never used before (in the case of congenital limb differences), or are vastly different from what they have grown accustomed to (in limb loss due to surgical removal). This poses two specific problems. First, certain patients might need to spend a substantial amount of time exploring methods for creating muscle signals that can be usefully detected by a myoelectric sensor. Second, since these muscles have rarely/never been used or are physically limited, patients can tire quickly.

For example, Justine pointed out that fatigue was challenging for her when playing the car game, "*[...] my muscles would get really, really tired, like tired to the point where I couldn't even do it, like I had to take a break ... I'd have to stop and I couldn't do it for a minute*", which could negatively affect her experience and therefore engagement with the game in the long run. Likewise, experts voiced the concern that patients would get overly involved in the game and **lose focus on their level of exertion**, straining their muscles more than necessary resulting in premature fatigue.

In order to better make patients aware about when they have reached the maximum input threshold, we added the over-exertion warning, a feature that programmatically draws a red warning around Momo when the player contracts harder than they did during calibration. This was beneficial because it allowed both patient and clinician to identify when over-exertion occurred.

Creating an Empowering, Positive Player Experience

Themes concerning the two games often focused on aspects relevant to therapy and how games could contribute to an empowering positive experience and, most importantly, maintain appropriate levels of difficulty to create an encouraging player experience and broaden the appeal of games through adaptable themes.

Importance of Appropriate Level of Difficulty

A common theme across patients was the importance of **appropriate levels of game difficulty**. Patients clearly found Momo to be easier and, as a result, less frustrating than the car game. For example, Bella's feelings about the car game were made quite clear, "*I don't understand how this is helping me... It's too hard... I keep smashing into the wall, I'm not very good at this game already.*".

While a positive player experience as the result of gameplay that is perceived as easier is generally desirable, this creates some issues with respect to therapeutic goals, but also patient perspectives on the game. Some patients felt that Momo was more suitable for children or younger players. Mark, for example, acknowledged that the game was probably more appealing to a younger audience, "*Umm, maybe not me, but I guess if you were a kid*". Even when this feeling was expressed, patients still felt that it was an appealing game, with Stanley pointing out that "*In the eyes of a [child]... there's no question, right?... it even brings out the competitiveness in me, right? The old guy.*".

A sub-theme that was prominent among experienced myo users focused on **difficulty differences between the games and real life**, stating that playing either of the training games is more strenuous than day-to-day prosthetic use. In terms of training, there are conflicting interests at play. On one hand, practicing more strenuous exercises can help to build strength and stamina, both of which are important for effective prosthetic use. For example, Justine commented that "*[...] it's probably more work than I have to do when I'm doing regular things using my arm, but... it really gets you practicing using the muscles...*". On the other hand, patients just starting to use a myo may find the strenuous activities discouraging and deter them from further practice, with Glen commenting that "*[...]you're using [your muscles] a whole lot more here [in the game]... for somebody learning, I think that would be very frustrating.*".

This suggests that games must carefully balance creating an appropriate amount of exertion with what is achievable for new patients, and should consider how realistic in-game difficulty maps onto using a myo in the real world.

Adopting Positive Perspectives on Player Performance

A common theme among all patients that was also backed by expert feedback was the importance of **positive perspectives on player performance**. Overall, patients and experts alike found that Momo offered a positive experience, where the car game, in contrast, did not. While the car game doesn't stop after a crash, the simple red 'X'

that is displayed seemed to be enough to create negative emotions among players. For example, Glen pointed out that he was “[...] no good, I [only] got one through... Agh, I crashed again. I’m trying, but they’re coming too fast... I’m [just] trying to crash now”. Yet, other patients didn’t seem to mind crashing often because they didn’t necessarily see the car game as a game, with Stanley commenting that “[...] it’s no different than going home and doing exercises, right – to get weight off... I would think of it as more of a tool.”. In this context, Linda (expert) pointed out that “the risk is that [patients] start having a negative opinion about using myo, or that the prosthesis is going to be frustrating too, and then they start with a negative bias”, underlining the importance of **positive, encouraging player feedback**. In agreement with Abeele [1], this suggests that adding game-like aspects without creating the right experience can be detrimental to patients’ views of their own abilities to control a myo successfully.

Perceived Self-Efficacy Through Play

Throughout analysis, the importance of providing playful experiences that **allow patients to increase perceived self-efficacy** emerged.

Within the car game, we observed all patients having difficulty sustaining the exact level of muscle contraction that would cause the car to stay at the right level to pass through the gap. Cars would bounce up and down rapidly, because their movement was mapped directly to noisy sensor readings. This caused patients to feel like they had little control, with Stanley pointed out that “It’s hard for me to hit the [gaps] ... I find the longer that I try to maintain the more it goes down”. Patients identified the speed of the action and the fact that they had to keep track of two cars at once to be overwhelming elements of the car game, with Justine commenting that “It got overwhelming I feel – I just got so tired and overwhelmed by the 2 cars”. Furthermore, we observed a challenge related to time-pressure in games previously commented on by Hernandez and colleagues [21] in the context of game accessibility, recommending not to remove action and challenge from games, but to ensure that it is appropriate and manageable: while both games employ time as a central mechanic, players felt less frustrated when playing Momo, suggesting that balancing and maintaining achievable player goals is crucial when leveraging games for prosthesis training. Generally, Momo achieved higher levels of perceived self-efficacy by smoothing in-game representation and reaction to often noisy EMG signals. This highlights an interesting challenge for our project: While Momo’s responses to player input are – strictly speaking – less accurate, the game provided a more encouraging overall experience. However, one advantage of the car game is that it explicitly displays muscle signals, which is useful to clinicians during a training session, information which is lost when smoothing EMG input as done in Momo. In response, visualizations to support therapists were added to Momo during design

iterations (discussed below), but the simplified control scheme was maintained to preserve player experience.

Increasing Player Engagement Through Flexible Themes

A theme that was frequently touched upon by patient feedback was the desire to **personalize game themes**.

While Momo offers theme elements around monsters, aliens and castles, one patient expressed clearly what she would like to see: “I want cats... why wouldn’t they make cats? ... I really, really, really, really, really, want cats... I love cats! I have 3 cats at my home.” (Kyla), a change to the game that was also appreciated by other patients.

For others, customization wasn’t an important feature, but they still recognized the value in it, for example Glen commenting that “I guess [it’s] not for me personally, but I can see that the options to customize it, to make it fit...”.

Given the **broad audience of game-based myo training** (e.g., having to accommodate players of different ages and with different levels of gaming experience), we believe that customization should be further explored as a means of maintaining continuous patient engagement through being able to offer individually relevant game themes.

Improving Therapy through Play

The final set of themes that emerged throughout analysis focuses on the improvements that game-based myo training can bring to therapy by making new information available to patients and therapists alike.

Therapy-Relevant In-Game Feedback

Besides encouraging patient engagement with therapy, results suggest that **in-game feedback also offered additional feedback on therapeutic progress**, a feature which was particularly appreciated by patients who otherwise struggle to see little improvements. Stanley explained that the “...game tells -- tells all of us a little about my control, right? ... I’m learning a little bit about -- about myself, but also about the capabilities of the hand.”. While this effect can also be accomplished through a simple visualization of muscle signals, or using the car game, there were some instances in the use of Momo where its specific mechanics made particular problems more salient. For example, causing Momo to jump in the presence of muscle co-contraction served as an indicator for when patients were having trouble isolating their contractions. This gave a very tangible way for the occupational therapist to convey instructions and feedback, and for the patient to understand what was happening, for example illustrated by a sequence where Linda (expert) pointed out to Justine (patient) that “When you jump, it usually means that you’re using both muscles at the same time... if he’s jumping when you don’t want him to, just kind of relax, and then try again.”.

Even effective myo users could benefit from feedback as the **games exposed areas where the patients could further improve** their muscle control, and achieve additional/more reliable myoelectric control. For example,

Stanley explained that “[...] it’s good to visually see where you stand and it also tells you if there is room for improvement... I could [only] be at 60% and I wouldn’t know, right?”. Without this feedback, patients would have remained unaware of hidden issues in their muscle control.

Increased Patient Knowledge About Myos

This theme focuses on the increase of **patient understanding of how their prosthesis works** that can be accomplished through the deployment of games. Initially, we had very few feedback mechanisms to allow patients and clinicians to see their calibrated muscle signals in real time. Immediately, we observed that this was problematic when calibration issues arose – minor adjustments to the calibration were important for both Momo and the car game. We added several features to make the calibration and real time muscle signals visible immediately after calibration and selectively available during gameplay. This immediately facilitated calibrating the device and identifying calibration problems, but also changed how the patients worked with their device. The visualization tools helped patients to better understand their device, and we immediately saw patients and clinicians engage in conversation to work out small problems, for example with Justine commenting that *“I feel like this one [sensor] might be a little high *pointing to the on-screen bar growing with muscle contractions*, because he’s going that way *points left* when I try to go the other way sometimes”*.

This interaction can be beneficial for patients because it allows them to **get more familiar with how their myo works**, and **engage about it with clinicians in more technical ways**, possibly facilitating troubleshooting and creating a more personalized approach to therapy.

Facilitating Myo Training at Home

Beyond its application in clinics, a theme that emerged from analysis was the potential of the Myoband to **enable patients to carry out prosthesis training in their own homes**. Patients responded well to the idea of using the Myoband as a training device, and expressed comfort when asked about home use, for example with Glen pointing out that *“[...] with the armband, I can slide it on, twist it around to where it needs to be, and do the calibration with some training, but yeah, that would be the way to go.”*. At-home training could facilitate the initial adaption to myo use, as underlined by Kyla’s mother, who stated that she wished her daughter would have had more training opportunities as it was *“a big challenge for her.”*. To this end, the use of more affordable off-the-shelf consumer hardware could enable the wider application of training games such as Momo, adding another layer to the training opportunities currently offered through clinics.

When discussing the home use of the Myoband, one concern expressed by the experts was being able to position sensors appropriately on the arms of all patients, which vary widely in terms of size, shape, and the location of sites used for sensing muscle contractions. Training sessions utilizing

Momo showed that our prototypical approach was suitable for all participants, demonstrating that the Myoband can be adapted to be viable for many limb-different patients.

DISCUSSION

We now reflect on our adapted UCD process, the importance of having a positive empowering experience, and the viability of the Myoband as a training tool.

Reflections on our Design Process

We adapted the typical UCD approach for several reasons. Most importantly, we were working with a sensitive population that was difficult to access. Our patients came from a wide geographical area to the clinic for reasons other than our study. As such, our sessions were short (60-90 minutes), with one patient at a time, and there was little opportunity for follow-up. Basing our design sessions on a partially-formed solution proved to be incredibly valuable for both eliciting feedback and encouraging discussion. Having a tangible ‘thing’ to examine and critique was viewed constructively by our patients and experts, and patients willingly discussed game aspects that were available for them to use, but struggled to conceptualize and reflect on features that were not yet available.

Our adapted design process worked extremely well for us and for our patients. Patients who came later in the process had the benefit of new functionality that allowed them to more quickly address calibration issues, play a more richly-featured game, and receive feedback that ensured their play better aligned with targeted training behavior. While other therapeutic game studies have had the benefit of engaging in a participatory design process and working with a set of patients over an extended period of time (e.g., [18,19]), we feel that this is not practical for many populations such as ours. While more work needs to be done to generalize our approach, we feel that it holds promise as a practical means of balancing the constraints of an understudied population with gleaned meaningful new design knowledge.

Therapeutic Games Need Not Be Unpleasant

Part of the motivation for working with our clinic was that they reported to us the negative feelings that many of their patients have when using previously-developed training tools. While patients usually did not enjoy their training exercises, the clinic still made use of them because they were relatively easy to set up and provided meaningful feedback to both patients and clinicians. However, the experts we spoke with all recognized the potential pitfalls of providing a negative experience to myo patients (hence their focus on facilitating patient success). Part of the reason for this sensitivity to negative feelings is likely due to the extremely high rate of abandonment of myos (up to 75% [7]). While there are many issues that can lead to abandonment (e.g., aesthetics, weight, convenience [22]), frustrations that arise from lack of control over the myo also contribute [12]. While our work does not directly address abandonment, we anticipate that any improvements to the

training process will help reduce frustrations due to lack of control, thereby reducing abandonment.

Patients were receptive of Momo for many of the reasons discussed in our results: they felt more in control, negative feedback was minimal, the game started at an appropriate level of difficulty, and it felt more like a genuine game. While both Momo and the car game facilitated practicing the same basic muscle activity, the mechanics of the car game left patients feeling more tired and frustrated. We leave quantitative comparison (e.g., movement precision, training outcomes, abandonment) of Momo to future work, but we are encouraged that both patients and experts felt that Momo provided a better experience.

Myoband Viability and Implications for Home Training

While we started this project assuming that we would only focus on improving Momo's design, we quickly learned that the calibration functionality of our game was of equal importance. Without having easy access to, and meaningful feedback from the calibration, patients would not be able to play our game. Furthermore, without real-time access to performance data, clinicians could miss important information about potential problems with both the calibration settings and a patient's performance. As our tools to calibrate and make use of the Myoband improved, so too did our confidence that it is a viable solution.

As we described earlier, both patients and clinicians were receptive of the Myoband as a training tool. The importance of this finding cannot be understated. Currently, the only other myo training technology costs \$4000USD, is more complex, and requires two people to attach (by positioning the electrodes and securing them with a tensor wrap). In contrast, the Myoband, although not designed for this use, has been at least as robust, provides sufficient signals, is easily positioned by a single patient, and costs less than \$200USD. Because Momo is free and open source (<https://github.com/hcilab/Momo.git>), this means that we have a viable training tool at a fraction of the cost of the leading commercial solution. We hope that others will be encouraged to start developing myo training games based on our findings, and that others might use and extend Momo in their own myo training research.

Limitations and Future Work

The adapted UCD process described in this work arose out of the needs of the local clinic and patients. While our process is likely to have confounded some of our findings (as compared to a more traditional approach), it enabled us to introduce quick iterations that maximized the impact of input with a small number of participants and within a short timeframe. We gave careful consideration to the choices in our study design; however, our results must be taken in light of our adapted process. Beginning with a partially developed game may have inadvertently directed/narrowed our exploration of myo training games, and additional results may be found through further exploration.

Likewise, the small number of participants needs to be considered when generalizing our findings. While we believe, our findings can help inform the work of designers along with future research, we are planning to continue our collaboration with the clinic to develop a refined training tool that can be used on an on-going basis with patients.

This study has provided evidence that sending Momo home with patients is an important path forward. In further collaboration with the clinic, we are planning to provide Momo at home on a trial basis to further explore challenges and opportunities associated with home-based myo training. In this context, we plan to investigate pathways to maintain long-term player engagement; e.g., through multiplayer features that could connect patients in remote locations.

CONCLUSION

This paper presents our work on developing a new myo training game, the Falling of Momo. While games for myoelectric training have been previously proposed, research has focused on technical issues, not on the needs of patients and clinicians to provide a positive, empowering experience that targets key training objectives. Our game was initially developed based on requirements gleaned from our interactions with a local prosthetics clinic. Through an adapted UCD process, we then refined Momo to better meet the needs of both patients and clinicians by adding features that 1) facilitate the training process, 2) provide meaningful feedback on target behavior, and 3) increase engagement.

Our findings provide guidance for the design of myo training games and therapeutic games in general. We highlight that patients perceive a felt need for out-of-clinic training tools and that there is a 'fine line' between striving for targeted training behavior and providing a positive, engaging experience. Through play, patients can better understand their progress, both on areas where they can improve and about the device they are training to use.

Our work opens the door for myo training to be more readily available and accessible outside of the clinic by showing the viability of a low-cost input device and an adapted UCD process that focuses on patient needs and experience, while making rapid progress in the development of an engaging training game.

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