EFFECTS OF AUGMENTED REALITY TRAINING ON PATTERN RECOGNITION CONTROL IN MYOELECTRIC PROSTHESES USERS: A CASE STUDY

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ABSTRACT

Myoelectric prosthesis control has seen significant advancements, with pattern recognition (PR) standing out as one of the key innovations. However, achieving a consistent level of control using PR demands extensive training. In this work, we present a case study to explore an augmented reality (AR) system for myoelectric control training. An individual with a transradial amputation underwent nine training sessions using an AR system over a month, and we assessed his progress by analyzing metrics collected during functional tasks. Throughout the training sessions, performance consistently improved, as indicated by completion rates and average task completion times. This improvement was accompanied by a reported decrease in mental workload, as measured by the PROS-TLX. These results suggest that training using AR systems has the potential to enhance myoelectric prosthesis control.

INTRODUCTION

Upper limb loss can significantly impact an individual's life and often lead to decreased life satisfaction [1]. Choosing the appropriate type of prosthesis and receiving adequate training is crucial. Advances within the field have resulted in the development of prostheses with higher degrees of motion [2]. Novel control strategies, such as pattern recognition (PR), have been introduced to provide access to these advanced devices. PR-based control is expected to lead to more intuitive operation of advanced prostheses compared to direct myoelectric control [3]. Training to use these control strategies involves both pre-prosthetic and prosthetic training. Pre-prosthetic training is done before the prosthesis fitting; it includes signals, physical strength, range of motion, and visualization training [4]. Studies suggest that users who commence myoelectric prosthesis training before prosthesis fitting have better rehabilitation outcomes [5]. Therefore, pre-prosthetic training is an essential component of the overall training process. However, there are some challenges with the current pre-prosthetic training methods, including the absence of feedback about their progress, poor motivation, and lack of training modules that directly relate to prosthesis use. These challenges can lead to prosthesis abandonment due to dissatisfaction with prosthetic control and function [4].

One of the current solutions explored is game-based training, which can increase patient motivation and provide feedback on progress through levels and scores. Other approaches expand the game-based training by integrating immersive platforms, which can further enrich motivation and feedback [6]. These tools enable patients to use a virtual arm instead of just visualizing their hand movements. Augmented reality (AR) training is an emerging rehabilitation technology that combines virtual objects with a real-world view. It involves displaying a virtual prosthesis controlled by electromyograph (EMG) signals and virtual objects manipulated by this prosthesis, all combined with the physical environment of the user. This training method has advantages over virtual reality training because the incorporation of real-world cues leads to a more accurate depth perception and reduced risk of virtual reality sickness [5]. Recent research has developed various AR systems for pre-prosthetic training [5,6]. However, the specific aspects of improvement and the optimal number of sessions required remain unclear. This case study aims to monitor and evaluate the effects of AR training on individuals with upper limb loss. The study uses AR prosthesis training with the newly developed Myoelectric Augmented Reality Training and Assessment (MARTA) system. The progress will be evaluated through the MARTA training sessions, and the training effects will be assessed using a pre-test and post-test protocol.

METHODS

Participant: The participant was a 56-year-old male with a right transradial amputation (1991; trauma). He had a corrected to normal vision and experienced phantom limb sensation with limited control. He had experience with a one-degree-of-freedom direct myoelectric control prosthesis. The participant attended the Bionic Limbs for Improved Natural Control (BLINC) lab for the training and testing sessions. Study protocols were approved by the University of Alberta Health Research Ethics Board (PRO00103131), and the participant provided written informed consent. The participant's measurements were recorded during the first visit, including his height of 187.96 cm, intact hand circumference of 23.88 cm, residual limb length of 23 cm, and circumference of 7 cm.

Equipment: The MARTA system required the participant to perform tasks in which virtual entities were rendered in the real-world environment through the Hololens (Microsoft, USA), a binocular head-mounted display. This device rendered virtual objects and a two-degrees-of-freedom prosthesis in real-time at 60 Hz, where the virtual prosthesis was overlayed on the participant's residual limb (Figure 1). Three VIVIE trackers (HTC Corporation, Taiwan) were used as a reference to map the virtual task objects in the AR environment to real-world locations. An additional VIVE tracker was placed on the participant's residual limb to allow real-time tracking of the virtual prosthesis. The virtual prosthesis hand movements were controlled by the participant using an EMG PR system (Infinite Biomedical Technologies, USA). For the real-time control of this prosthesis, the participant was fit with a Myo armband (Thalmic Labs, Canada) on their residual limb, 6 cm from the lateral epicondyle, which captured the signals from the arm and then sent them to the EMG PR system to command this virtual prosthesis.

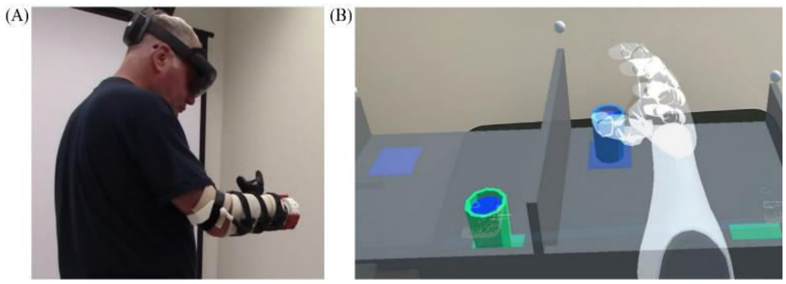

Figure 1: Experimental setup illustrating A) The participant wearing the equipment. B) The Augmented Reality task as observed from the participant's viewpoint.

AR tasks: The MARTA system consisted of three tasks: Dog Puzzle, Cup Transfer task, and Pasta Box task. The Dog Puzzle involved organizing and orienting cone-shaped objects into a 3-D dog shape. There were five levels in this task, with each level increasing the puzzle height for increased difficulty. Both the Cup Transfer task and the Pasta Box task were modelled in MARTA from the standardized tasks of the Gaze and Movement Assessment (GaMA) protocol [7]. In the Cup Transfer task, the participant was asked to move two cups over a barrier with specific grasps and then bring them back to their starting position using the same grasps. In the Pasta Box task, the participant moved a pasta box from a side table and placed it on a lower shelf in front of them, then to a higher shelf in front of them, and then back to its starting position. The Cup Transfer and Pasta Box tasks each had two levels of difficulty.

Training procedure: The MARTA system was used to train the participant, and training effects were assessed using a pre-test and post-test experimental design. Between the assessments, the participant completed nine training sessions over a period of three weeks, practicing the Dog Puzzle and the Pasta Box task. Weight was added throughout these sessions to improve the transferability of the training [5]. In session one, the socket weight was 379 g; in session four, we increased the weight to 521 g, and then to 671 g in session eight. Each training session was capped at two and a half hours, including the breaks and technical setup. For each session, the AR training tasks involved up to five trials of the Dog Puzzle, where each trial comprised a different level. Additionally, there were up to ten trials of each level of the Pasta Box task, where at least ten trials of level one were completed in any of the sessions before proceeding to level two. Each training session involved recording the placement of the Myo armband on the participant's residual limb to ensure consistency across sessions. The session started with PR calibration, where four different movements (open, close, pronation, supination) were recorded twice. After that, the recorded classifications were reviewed with the participant to confirm that he could successfully activate the classes. If not, the calibration was repeated. The participant then performed the Target Achievement Control (TAC) test to assess his control and evaluate how quickly and accurately he could achieve a specific movement. After completing this test, the participant watched demonstrational videos explaining the task, and then started the AR task. The participant wore the AR headset and practiced using the system for a maximum of ten minutes to get familiar with the AR environment, after which he proceeded with the training. After training, the participant filled out the Prosthesis Task Load Index (PROS-TLX) [8], a self-report measure designed to measure the physical and mental workload often experienced during tasks.

Assessment procedure and outcome measures: There were two assessment sessions, the baseline and the post-training. Each assessment session was capped at three hours, including breaks and technical setup time. The AR evaluations included up to 20 trials of the Cup Transfer task and ten trials of the Pasta Box task. The setup used for these sessions was similar to the training sessions, with the same calibration process. The TAC test and the two testing tasks (Cup Transfer and Pasta Box tasks) were performed after calibration, followed by the PROS-TLX at the end of each session. The study's primary outcome measures included the number of attempted and successful trials and the completion time of the successful trials for all tasks. For the Dog Puzzle, the number of object drops and attempted grips (how many times the hand completely closed) were also recorded. The results were compared across the sessions, and the averages and medians were calculated for different outcome measures.

RESULTS

Training progress: On average, the participant's active training time was one hour and 20 minutes. In the first training session, the participant had a 20% completion rate for the Dog Puzzle then his performance ramped up until he achieved a 100% completion rate by the fourth training session. The average trial completion time for the Dog Puzzle decreased from 7 minutes (one trial) in session one to 4 ± 1 minutes in session five, then to 3.60 ± 1.14 minutes in session eight. The participant started with a median of 51 grips and four drops in session two. The goal for the number of drops is zero and is ten for the number of attempted grips, as there are ten puzzle pieces in the Dog Puzzle. The participant's performance improved until it reached its peak at session five, with a median of 22 grips and zero drops. However, there was a decline in his performance during session six due to an unusual time gap between the fifth and sixth training sessions. For the Pasta Box task, the participant was unable to complete any trials in the first four training sessions due to the session time limit. He started with one successful trial of level one in session five, and then the number of completed trials and successful trials gradually increased (Figure 2A). By session eight, the participant had completed ten trials at level one, out of which eight were successful, and moved on to level two in this session and the following session. However, the participant's performance decreased in the last training session, with fewer completed and successful trials. This decrease in performance is also reflected in the average trial completion time, which increased from 1.28 ± 0.21 minutes at session eight to 3.39 ± 2.69 minutes at session nine (Figure 2B). The PROS-TLX score started at 47.99 in the first training session. It decreased until it reached the lowest point of 35.99 in session eight, demonstrating less load. The highest score was in the last training session, where it reached 64.86.

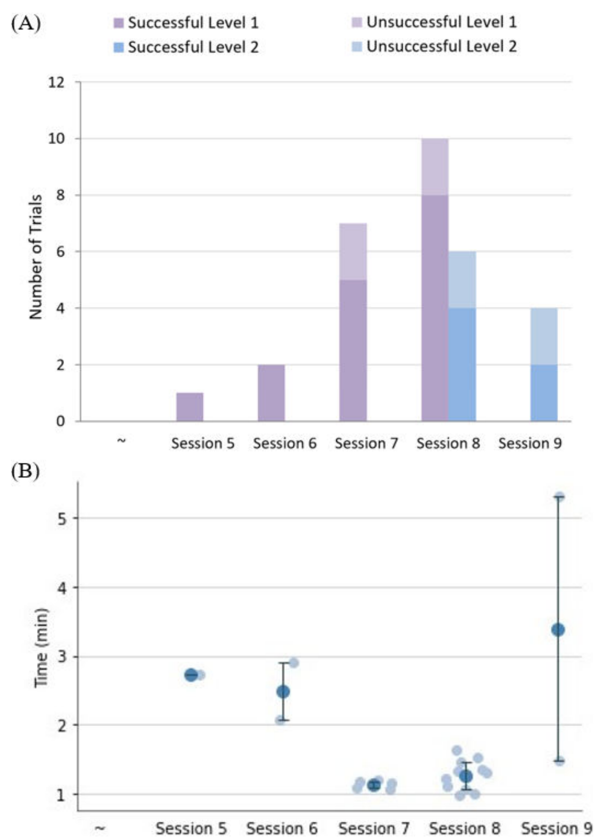

Figure 2: Outcomes of the Pasta Box task; the participant began progressing to the task starting from the fifth training session. A) Breakdown of the number of trial successes across different levels over the training duration. B) The dark colour represents the mean time taken per session. The error bars represent the standard deviation.

Pre- versus Post-training: For the Cup Transfer task, the participant's completion rate increased from 0% at the baseline to 80% at the post-training session. The average trial completion time was 1.40 ± 0.30 minutes during the post-training session. For the Pasta Box task, the performance improved as well, where the completion rate increased from 0% at the baseline to 70% at the post-training session. The average trial completion time was 1.69 ± 0.32 minutes for the post-training session. The PROS-TLX score was 56.32 at the baseline assessment, decreasing to 40.25 at the post-training assessment.

DISCUSSION

This work investigated the impact of the MARTA system on myoelectric PR control within the AR environment through metrics collected during functional virtual tasks. The results of our case study indicated that AR training positively influenced both control and motor learning aspects. Specifically, improvements were observed across the training sessions in the completion rates and times for both tasks, in addition to the number of grips and drops for the Dog Puzzle. Moreover, performance during the post-training assessment session was highly improved compared to the baseline assessment. The participant also reported a motivational and positive user experience with the system, this could be due to several factors, including the novelty of AR technology.

The participant demonstrated rapid progress during the training. As a result, in session five, we decided to increase the challenge of the Dog Puzzle by adjusting its height to keep the participant engaged and help continue his skill development. The results show that the performance achieved a peak twice during the training, in the fifth and eighth sessions. However, there was a decrease in performance between these sessions, followed by a gradual increase. We noticed a gap of four days between sessions five and six, which may have disrupted the continuity of skill acquisition, leading to fluctuations in performance during the following sessions. The PROS-TLX score of the final training session aligned with the performance outcomes, providing valuable insights into the participant's training experience.

The main limitation of this study was the prolonged technical setup time, which may have affected the participant's engagement and experience. Another limitation was the potential difficulty in perceiving objects correctly in the AR environment, which influenced the controller utilization. For instance, issues with visual perception in AR can lead to unintentional actions, such as air gripping instead of grasping the object or dropping the object through the table instead of placing it on the table, which happened during the first few training sessions. This could affect the study's results, as the number of grips in the Dog Puzzle won't be solely determined by the controller but also by the AR perception. These preliminary results are part of an ongoing study in which the number of participants and outcome metrics are expanded to explore more aspects as well as examine skill transferability to physical prosthesis function.

CONCLUSION

This preliminary data has shown that AR is promising for improving the control features important to myoelectric prosthetic training. The results demonstrated that the training was influential, as there was an improvement in performance at the end of the training. Additionally, the PROS-TLX revealed a notable reduction in mental workload throughout the training sessions, indicating a positive user experience. The study serves as a basis for the use of AR in pre-prosthetic training. A more extensive study with more participants and outcome measures is underway to allow for the exploration of the transferability to real-world prosthesis usage in the target population.

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