Increasing Motivation, Effort and Performance through Game-Based Rehabilitation for Upper Limb Myoelectric Prosthesis Control

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Abstract— **Rehabilitation concepts for upper limb amputees traditionally rely on the execution of repetitive movements. Video game-based therapies are a stimulating way to increase patient motivation, effort and performance during those otherwise monotonous neuromuscular exercises. Myoelectric signals needed to control an upper limb prosthesis are intuitively trained and the patient benefits from increased prosthesis usability. In this study, a clinically feasible and entertaining virtual rehabilitation intervention has been developed and evaluated for short-term improvement of EMG control and engaging gameplay elements. Seven upper limb amputees completed the three assessment sessions and the video game intervention. Results show an improvement in overall EMG control, fine muscle activation and electrode separation. Patients report that racing games seem to be slightly superior regarding the fun factor, but rhythm games provide a more challenging EMG control option.**

Keywords—upper limb amputees; video games; rehabilitation; prosthesis control; EMG; neuromuscular training; motivation

I. Introduction

Learning how to control a myoelectric prosthesis can be a discouraging experience. Indeed, a lot of devices are abandoned due to complications with their control and functionality [1], [2]. Receiving sufficient training during physical therapy is essential for proficient handling of a myoelectric prosthesis [3]–[5]. Important parameters for conventional two-electrode prosthesis users are the strength of muscle contraction, proportional electrode activation, single electrode activation and voluntary activation of both electrodes [6], [7]. Even though established rehabilitation protocols address these parameters and offer direct functional benefit, their main shortcomings are the lack of patient motivation to keep up with the repetitive and lengthy process, more so without the active involvement of a therapist.

Virtual training environments can aid this process, as they provide diverse incentives to support the patient as well as the therapist to achieve a high number of exercise repetition without losing the patient's investment and perseverance [8]–[11]. Video games have been used by clinicians for motor rehabilitation especially in the fields of stroke [12], [13] and Parkinson's disease [14]. However, in the last years they also received some recognition as a method in upper limb amputee rehabilitation for myoelectric prosthesis control [15]–[22]. Delivering biofeedback using off the shelf video games is a viable low cost alternative to virtual or augmented reality, as no further equipment is needed and training can be continued at home. The commercially available video games Guitar Hero [20] and Pong [22] had been interfaced using myoelectric (EMG) signals. Another research group altered the Nintendo WiiMote control to match EMG signals to the WiiMote buttons [17]. Although those approaches are motivating, the necessary control actions are limited to two motions, that are not directly mapped to movements needed in everyday activities, and that are also not directly transferable to the handling of a prosthesis [23].

The aim of this study is to evaluate short-term effects on EMG controllability after a video game-based rehabilitation protocol and to evaluate the impact and value of those video games on the patients regarding motivation, performance and effort.

This represents a follow up study [24] targeting an amputee population, in which patients are prompted to not only conduct repetitive agonist and antagonist muscle activation, but also to perform precisely timed contractions, train and exert sustained

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contractions as well as elicit simultaneous contraction of both muscles or muscle groups - similarly to how patients would control a real prosthesis to interact with their environment.

II. METHODS

A. Participants

Seven upper limb amputees on either transradial (below elbow) or transhumeral level (below shoulder) participated in this study. Out of those, six did not have any prior experience in controlling a prosthesis. The study was approved by the ethics committee at the Medical University of Vienna, Austria under [1301/2015].

B. Experimental Protocol

Each participant was seated in front of two computer screens, one showing the EMG signals and the other showing the currently played game. Two active surface electrodes (Ottobock Healthcare GmbH 13E200) were placed on top of two prominent muscles in the residual limb, held in place either by a wrist band or by the prosthetic socket itself (see *Figure 1*). The electrodes delivered filtered, rectified and root mean squared EMG data.

Figure 1 Experimental setup with prosthesis and Step Mania 5

Participants underwent three EMG assessment sessions (pregaming, postgaming, follow-up) that each lasted 10 minutes and one video game intervention session during which the participants spent 10 minutes playing each game, thus resulting in 30 minutes intervention time overall. Every game started off with a tutorial and increased in difficulty with each level.

The EMG assessments consisted of a provisional maximum voluntary muscle contraction (MVC) used as calibration, precision control, electrode separation and muscle endurance.

After the first (pregaming) EMG assessment, the patients were presented with three different video games in randomized order as the rehabilitation intervention. After each video game, they were asked to complete a short user evaluation survey and once they finished playing all three games, also a modified intrinsic motivation questionnaire (IMI) had to be completed. After a short break, the EMG assessments were repeated for the postgaming measurement. Patients were invited again two days later to perform only the EMG assessments one last time in order to evaluate short-term retention rate.

Three video games with different control methods were played and evaluated in this study (see Table 1): (1) a game for dexterity, in which the patient had to maneuver through a 2D labyrinth with up, down, left and right movements [25]; (2) a racing game, in which the player raced against computer generated adversaries and could turn either left or right [26]; and (3) a rhythm game, in which the player needed to match the input to a beat [27]. All games were controlled with EMG electrodes that were activated through the patient's muscle contractions and involved quick and sustained muscle contractions for activating one electrode as well as simultaneous contraction of both muscles, called co-contraction, that would activate both electrodes simultaneously. Each game featured a distinct combination of electrode activation which could be translated to everyday tasks of different complexity, that patients would execute with their prosthesis.

TABLE I. OVERVIEW OF PLAYED GAMES, THEIR CONTROL METHOD AND REQUIRED MUSCLE CONTRACTION

	Electrode Activation	
Games	***Game Controls***	***Muscle Contraction***
Dexterity: *Pospos* 	Moving player left, right, up and down	Sustained and simultanous contractions
Racing: *SuperTuxKart* 	Turning car left and right	Quick and sustained contractions
Rhythm: *Step Mania 5* 	Match arrows pointing left, right and both ways	Quick, sustained and simultaneous contractions

C. EMG Controllability Assessments

To investigate the changes in overall controllability, a battery of three basic EMG assessments had to be performed before the video game intervention, directly afterwards and two days later to evaluate the short-term retention rate. As a baseline for the upcoming EMG assessments, the MVC was measured for every patient and before every session.

<u>Assessment of Precision Control</u>: This assessment evaluates the patient's ability to gradually discriminate between different fine muscle activations in the range of 10-90% MVC. The patients had to reach a total of 30 randomly preselected activation levels for each electrode and sustain them for 300ms.

The activation level is indicated by a triangular mark on the EMG activation bar. The percentage deviation around this goal mark was taken as the outcome measure.

Assessment of Electrode Separation: This assessment is integrated into the previous test for precision control and determined whether during the voluntary activation of one electrode during the tasks of the precision control assessment, the opposing electrode was also activated (co-contraction). An opposing electrode was considered active if it crossed a threshold that was calculated by 15% of the MVC.

Assessment of Endurance Control: In this assessment, patients had to closely follow a sine curve of 1/4Hz using their EMG signal until fatigued, but for a minimum of 300 seconds. The peaks of the sine curve corresponded to 60% MVC and could be reached by contracting one electrode respectively [28]. However, the more the opposing electrode was activated, the harder it was to reach the sine curve peaks, since only the difference in electrode activation was used. This way, it can also be seen as another means to assess muscle isolation.

D. Questionnaires

Patients were given three questionnaires to evaluate various aspects of motivation, engagement, fun, game control and gameplay.

Intrinsic Motivation Questionnaire - Games: A 26-item version of the IMI with 5 subscales was used to evaluate the experience of the played games [29], [30]. The subscales form scores for interest/enjoyment, perceived competence, perceived choice, felt pressure/tension and effort. The questionnaire was adapted to the study by changing the words "working" and "doing" to "playing". It included statements such as "I found the games very interesting" and "I felt tense while playing". The statements were rated on a 7-point Likert rating scale ranging from 1 ("no, not at all") to 7 ("yes, definitely").

Intrinsic Motivation Questionnaire - MyoBoy: This version of the IMI is analogue to the previous one regarding the games, with the words "doing" changed to "using the MyoBoy". It evaluates the experience the patients had while handling the Ottobock MyoBoy, a tool to visualize the activation of two electrodes in the form of two colored, moving LED bars.

User Evaluation Survey: The short user evaluation survey was presented after every game and consisted of five questions regarding rating of the played games in general, the fun factor, the input and control method and the motivational factor. They could be rated on a 5-point scale.

III. Data Analysis

All analyses were conducted using IBM SPSS 24 and Matlab 2015b. Non-parametric tests were performed on data not meeting the requirements for normal distribution, which was assessed via normal Q-Q plots and the Shapiro-Wilk test for normality. A Bonferroni correction was applied to multiple pairwise comparisons on the same data. Significance was set at $\alpha=0.05$.

IV. Results

A. EMG Controllability Assessments

Assessment of Precision Control: The possible EMG goal activation levels were divided into three equidistant intensity sections: low, middle and high; which were compared using a Bonferroni corrected paired samples t-test. In *Figure 3* the combined scores from both electrodes can be seen for each of the seven patients. Results show a significant improvement in fine accuracy and coordination from the pregaming measurement to the follow-up measurement regarding all goal intensity levels ($p<0.01$). Through the three measurement sessions, the fluctuation of deviation around the goal activation levels decreased and the overall discrepancy between patients conformed. The deviation around the goal value was most homogenous in the follow-up measurement. In all three measurement sessions, the low goal activation level was significantly easier to reach than the high goal activation level ($p<0.01$).

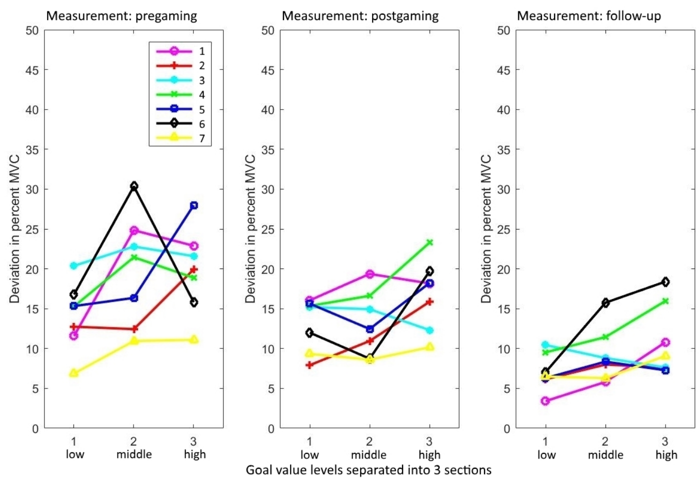

Figure 2 Deviation of the electrode activation around the goal value from the pregaming to the follow-up measurement of the Precision Control assessment.

Assessment of Electrode Separation: Threshold crossings were divided into the same intensity sections as in the Precision Control assessment - low, middle, high (see *Figure 3*). The related samples Wilcoxon signed rank test shows that the opposing electrode was significantly less activated during low goal activation levels compared to high goal activation levels for all measurement sessions (*Figure 3*a). The opposing electrode activation decreased significantly from the first (pregaming) to the third (follow-up) session for low goal activation levels (*Figure 3*b). It also decreased for middle and high activation levels, however, not significantly.

Assessment of Endurance Control: The consistency of retracing the sine curve was given as correlation r^2. A related samples Wilcoxon signed rank test determined a significant difference ($p<0.01$) between the correlation from the pregaming measurement session and the correlation from the follow-up measurement session (see *Figure 4*). All patients highly improved in endurance control and inherently also muscle isolation, except for one, who was excluded from this analysis because he could only manage to activate one electrode during the follow-up measurement session.

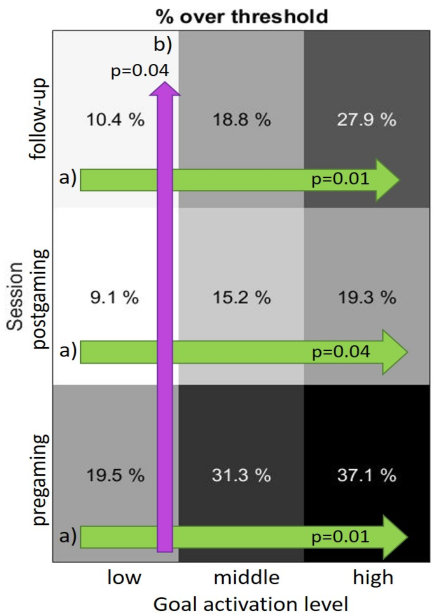

Figure 3 Percentage of the opposing electrode activation during the Precision Control Assessment, depicted for each goal activation level per measurement session. The arrows denote significant changes.

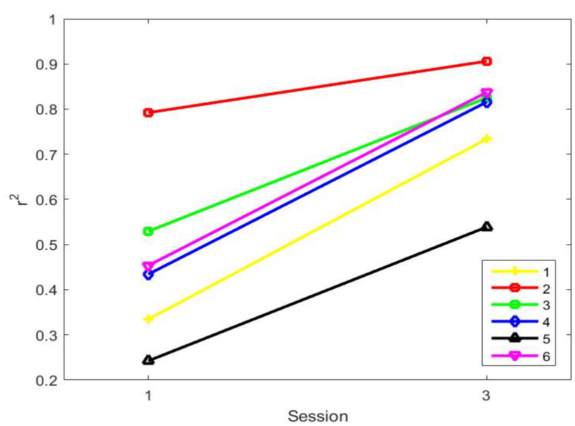

Figure 4 Improvement of the Endurance Control r² scores from the pregaming session (1) to the follow-up session (3)

B. Questionnaires

Intrinsic Motivation Questionnaire – Games: The results obtained from the IMI questionnaire can be seen as mean and standard deviation of the six categories in *Figure 5*. Patients enjoyed the games and exerted utmost effort while playing them. They perceived playing the games as their own choice and felt rather competent while doing so, even though the patients seemed to have felt some amount of pressure on them.

Intrinsic Motivation Questionnaire – MyoBoy: The results from the IMI questionnaire regarding the Ottobock MyoBoy can also be seen in *Figure 5*. The perceived pressure was significantly lower (p<0.01) while using the MyoBoy than while playing the games. However, the enjoyment while using it was significantly lower (p=0.02) than while playing the games. Patients exerted more effort in playing the games than using the MyoBoy (p=0.01).

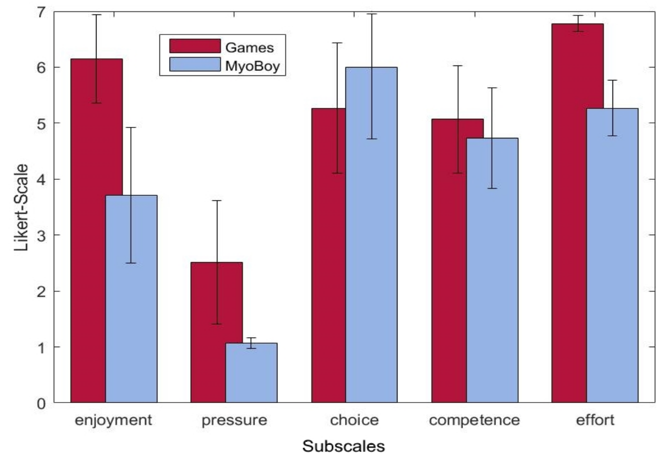

Figure 5 Mean and standard deviation for the 5 subscales of the IMI questionnaire for the games and the MyoBoy

User Evaluation Survey: The patients were asked to answer five questions (Q1 – Q5) for each of the three games (see *Figure 6*). Results showed a great variance for the dexterity game in all five aspects, while the racing and rhythm game seemed to be equally well received by the patients. However, the input and game control were rated higher in the rhythm game, whereas the fun and motivational factor where slightly, but not significantly, higher in the racing game.

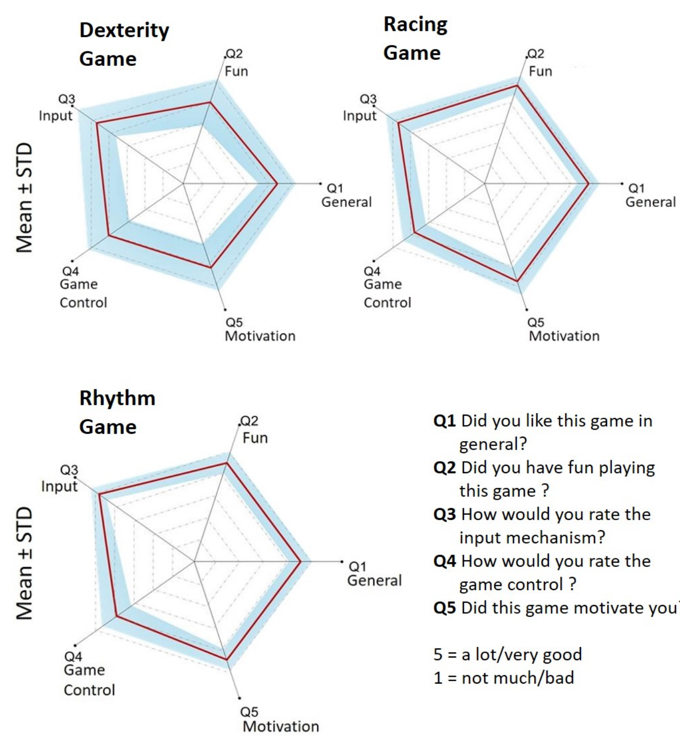

Figure 6 Results from the User Evaluation Survey sorted by game

V. Discussion

Results have shown improvement in all three basic EMG assessments, namely in fine electrode control, electrode separation and muscle endurance. Surprisingly, the MVC values, used as a baseline calibration, have also shown an increase instead of the expected decrease after playing the games, which could be attributed to warmth or sweat that would influence the electrode resistance. However, this is a solid indicator that the gaming session was not fatiguing for the patients. In fact, the patients became even more skillful during the assessments.

However, contrary to the healthy control group [24], the decrease in activation of the opposing electrode during the Precision Control test was not significant for the patient group. This could be due to the small sample size of 7 patients and should be revised with a higher patient number.

Compared to previous studies [17], [22], [23], [31] participants not only conducted repetitive flexor and extensor muscle activation, but also to trained sustained contractions over varying periods of time, perform precisely timed contractions and execute simultaneous contractions of both muscle groups - similarly to how patients would control a real prosthesis.

Contrary to initial expectations, the game for dexterity was not identified as a motivating or fun game. Even though it employed the co-contraction as it is actually used in real life: to switch between one degree of freedom (DoF). The racing game did not display such an elaborate control method, the player could only turn left or right, but it received high ratings in the categories for fun, overall affinity and motivation. Nevertheless, the rating for the EMG input and game control was comparably high in all three games, with the rhythm game receiving the best ratings for it.

The main advantage of game-based training compared to conventional therapy is clearly the motivational aspect. Though it is reasonable to assume that patients would also improve their EMG control by only being exposed to the EMG basic assessments, the continued exposure would eventually lead to a loss of interest, which could be prevented by the engaging context of a video game [32].

Since this study was a short-term intervention, consecutive research should incorporate a long-term evaluation of video game-based rehabilitation protocols, as well as additional exploration of advanced control mechanisms such as those based on machine learning approaches. Thereby more DoF could be used to control the games and prepare patients for upcoming prosthesis control methods [33]–[36]. Ideally, patients would also be able to continue the rehabilitative intervention at home, either in the form of a mobile device or as an easy stationary set-up, to achieve the maximum benefit for proficient prosthesis control [37].

VI. Conclusion

Most upper limb myoelectric prostheses are controlled via a 2-electrode interface. This study has shown that this control can be effectively trained by integrating engaging video games into the rehabilitation process. Patients significantly improved in electrode separation, fine muscle control and muscle endurance. It could be shown that playing video games is more engaging than using a standard tool for training myosignals and patients invest more effort while doing so. Based on these results, further research will incorporate also smart phone apps for long-term home rehabilitation and training for advanced prosthetic control algorithms.

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