LIMITATIONS TO THE SENSE OF AGENCY OVER MYOELECTRIC CONTROLLED MOVEMENTS

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ABSTRACT

Prosthetic embodiment, the extent to which individuals perceive their prosthesis as an integral part of their body, is associated with lower prosthetic abandonment and is seen as a measure of how satisfied users are with their device. While there is no gold standard method to quantify embodiment, measurement techniques from the field of Human Computer Interfaces might allow us to quantify embodiment, and allow us to parse where reductions in embodiment originate. As muscle signals have a higher variance than movement patterns, it is possible that this increase in variance lowers people's sense of ownership over their actions when they use myoelectric control. Sense of agency is a measure that refers to the experience of feeling in control of one's actions, and the outcome those actions have on the environment. We compared the sense of agency over myoelectric and joystick controlled movements of 10 participants through a tracking task. While performing the tracking task, different levels of noise were added to the control signal before feedback was given to the participants, allowing us to impose different levels of control. We found that people rated their sense of agency over myoelectric controlled movements significantly lower than over joystick controlled movements ($p < 0.001$), and that this decrease was not only dependent on lower accuracies during the tracking task. These results suggest there might be an upper limit to the sense of agency over myoelectric controlled movements.

INTRODUCTION

Upper limb prosthetics aim to restore functionality and improve the quality of life of their users. One of the aspects of prosthetics that has been studied is 'embodiment', the extent to which individuals perceive their prosthesis as an integral part of their body. Embodiment is important as poor body image due to amputation is correlated with increased depression, and decreased life satisfaction, quality of life, activity and psychological adjustment [1]. Although embodiment serves as a metric for user acceptance and experience, no gold standard method has been established to quantify embodiment, with most studies relying on questionnaires [2-3]. The field of human computer interfaces could provide quantitative measures with a neuronal basis to study embodiment [4].

Sense of agency (SoA) refers to the experience of controlling one's actions, and through them, events in the outside world [5]. This sense of agency can be broken when your intended movement does not line up with either the movement of your body, or the outcome that you perceive. As a result, changes in how your body controls movement and changes to how it senses itself and the environment impact the SoA. To date, it is not clear if movements performed through myoelectric control can lead to the same SoA as those performed by people without limb difference. When performing goal-oriented movements, such as picking up an object, our brain and bodies will perform these movements in such a way that it minimises variance in the movement, and therefore error [6]. One of the strategies used to reduce variance is that movements will be controlled by more muscles than strictly necessary [6]. Not only will antagonists be activated to increase stiffness, and therefore lower variance, but agonist activity will be spread over multiple muscles due to signal dependent noise [6]. In essence, these strategies are adopted as the activity in our muscles is more noisy than the activity in our movement. As myoelectric control decodes movement from muscle activity, it is possible that it inherits some of that noisiness despite the signal processing filtering out most of the noise. If that is the case, then intended movements will not line up with executed movements more often, and lead to a reduction in SoA, representing a limitation to achieve high SoA and therefore embodiment.

In this study, we compared the SoA of joystick and myoelectric controlled movements. To investigate how sensitive the SoA is, we added noise to people's control signals before presenting them back to them.

METHODS

Participants

Ten participants (5 male, 5 female) without limb difference and free from neurological or motor disorders were recruited. The study was approved by the local ethics committee at University College Dublin (ref: LS-22-46-Dupan), and participants provided written informed consent prior to the start of the experiment.

Experimental setup

Participants performed a tracking movement on the screen through joystick control and 2-channel myoelectric control. Two EMG channels were placed on the extensor carpi radialis and the flexor carpi radialis of the right hand of participants. Signals were acquired using Trigno wireless EMG system (Delsys Inc, Natick, MA, USA), and signals were processed in real time using the AxoPy Python library. Muscle signals were sampled at 2000Hz, and updates were sent to the computer every 50ms. A fourth-order Butterworth bandpass filter (10-500Hz) was applied, after which the muscle signals were smoothed using the mean absolute value with a window length of 750ms. EMG channels were calibrated for each participant:

$$\hat{y} = (y - y_r) / (y_c - y_r)$$

where $\hat{y}$ is the normalized muscle activity, y the MAV, y_r the activity when the participant is at rest, and y_c represents a comfortable contraction. Participants controlled the position of a cursor on the screen, which was determined by subtracting $\hat{y}$ of the flexor muscle from $\hat{y}$ of the extensor muscle.

When participants controlled the cursor on the screen through the joystick (Flightstick pro, CH Products, Vista, California, USA), the position of the joystick was sampled every 50ms. The position of the joystick was calibrated so that moving the joystick fully to the right or left resulted in doubling the maximum necessary deviation on the screen.

Experimental design

Participants were tasked to perform a tracking task on the screen. A sinusoid function represented the goal line, and moved up over the screen, while the participant's cursor could only move in the left-right direction. Trials lasted 8s, and the sinusoid had a period of 4s and amplitude normalized to 1 (see the dotted black line in Fig. 1a). Participants performed 4 blocks of 20 trials, with blocks alternating between myoelectric and joystick control. Prior to starting the experiment, participants completed 4 familiarisation trials for each control method. If they had trouble completing the myoelectric controlled trials, then the calibration of the EMG channels was repeated.

Different levels of noise were added to the control signal of the participants. Noise signals were sinusoids with a period of 4s and amplitudes of 0, 0.1, 0.2 or 0.3 (see Fig. 1a). Levels of noise were randomised over the trials. Noise started 1s into the trial and ended at 7s, where the start and end of the noise were equal to 0, resulting in a phase shift of $\pi/2$ between the noise and the goal line. The noise was added to the control signal (both myoelctric and joystick control) before the data was presented on the screen. The choice of starting and ending the noise at 0 ensured that participants did not realise the visual feedback of the cursor did not represent their actual movement. Fig. 1b and 1c represent joystick and myoelectric trials where the dotted black line is the goal line, and the solid black line the feedback participants received. This feedback is a combination of their actual control (solid blue line) and the noise (dotted blue line).

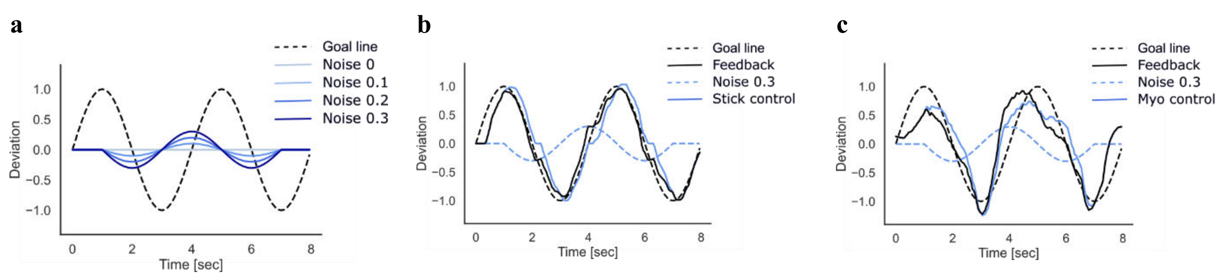

Figure 1. (a) Different noise levels added to the control signal. (b) Representative example of a trial for joystick control. (c) Representative example of a trial for myoelectric control.

After each trial, participants were asked to rate their SoA over that trial on a Likert scale from 1-9. Participants were reminded that this score should represent how much they felt in control of the cursor on the screen, not how well they performed the trial.

Analysis

The outcome measures of this study were participants' SoA and score. The score was defined as *1 – MAE*, with MAE the mean absolute error between the goal line and the visual feedback. We performed a 2-way ANOVA to investigate the effect of noise levels and control modality on SoA and scores, and post-hoc Tukey tests if any significance was found at group level.

RESULTS

The 2-way ANOVA presented in Fig. 2a tested the effect of the noise levels and control modalities on SoA. The test showed no interaction effect between the noise levels and control modalities ($p = 0.22$), but significant differences for the noise levels ($p < 0.001$) and control modalities ($p < 0.001$). Pairwise post-hoc Tukey tests showed that the SoA was significantly different for noise levels 0 vs 0.3 ($p = 0.001$), 0.1 vs 0.3 ($p = 0.001$) and 0.2 vs 0.3 ($p = 0.01$). These tests show that participants rated their SoA of myoelectric controlled movements lower than those controlled by the joystick. Additionally, participants gave lower scores to trials with high noise levels, even if conversations after the experiment made clear that none of them realised the feedback they received had additional noise added to it.

A similar story was present for the effect of the noise levels and control modalities on the score (Fig. 2b). The 2-way ANOVA showed no interaction ($p = 0.4$), and the mains effects showed significant differences in the score based on the noise levels ($p = 0.001$) and control modality ($p < 0.001$). Post-hoc Tukey tests showed that the only significant difference in score was between noise levels 0 and 0.3 ($p = 0.04$). This shows that participants were able to account for the noise that was added during the trials, and adjusted their myoelectric and joystick control accordingly.

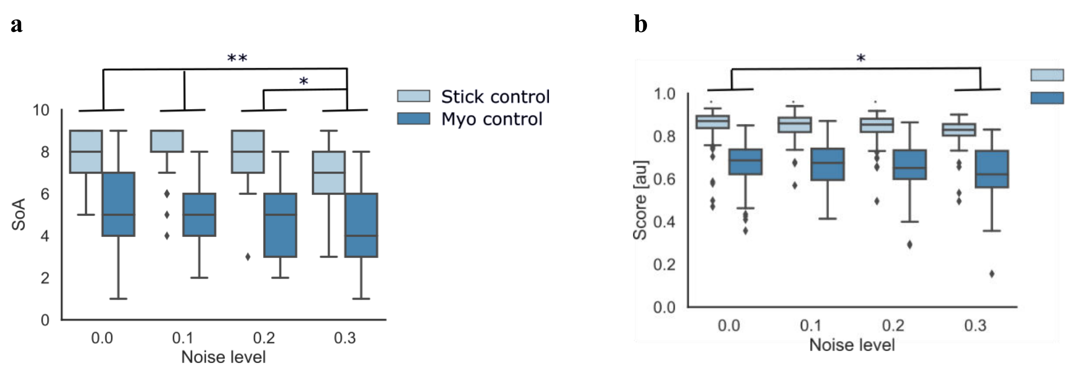

Figure 2. (a) Effect of noise levels and control modality on SoA. (b) Effect of noise levels and control modality on score.

While participants were asked to specifically rate their SoA and not how well they completed the tracking task, our results might still be biased through the difference in performance based on the control modalities. Therefore, we analysed how the SoA and control modality were related to the score, i.e. how well participants performed the task. Fig. 3a shows that decreases in reported SoA were related to decreases in score for both myoelectric control and joystick control. Two-way ANOVA analysis showed no interaction effect ($p = 0.3$), but significant differences based on reported SoA ($p < 0.001$) and control modality ($p < 0.001$). However, participants rated higher scoring joystick control trials with lower SoA than myoelectric control trials with a lower score. This suggests that participants did rate SoA and not how well they completed the tracking task. It is important to point out that the distribution of the reported SoA values was not even (Fig. 3b), so the current analysis of the relationship between reported SoA and scores should only be interpreted as a trend.

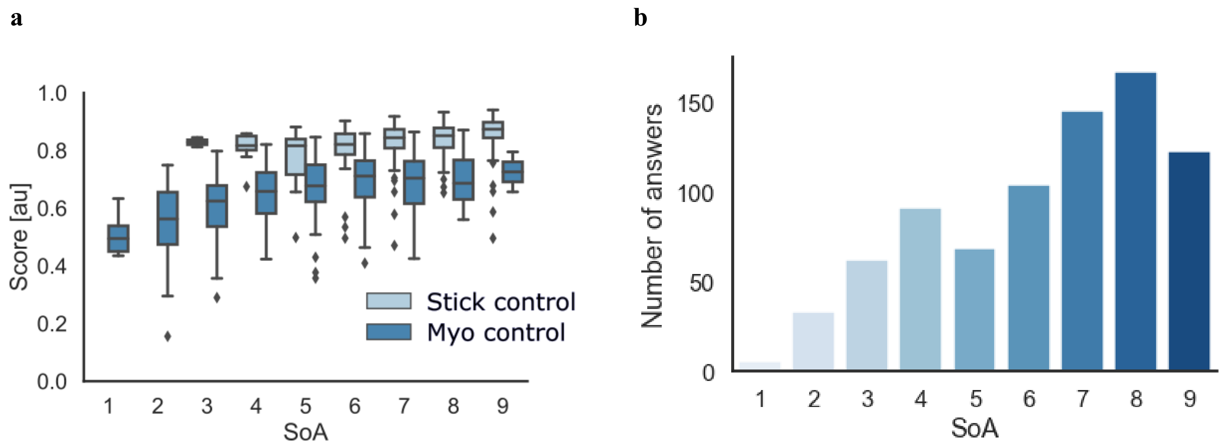

Figure 3. (a) Relationship between SoA and score for joystick and myoelectric control trials. (b) Amount of trials that received a certain value for SoA.

DISCUSSION

In this study, we investigated the SoA of movements that are controlled by joystick and myoelectric control. We found that (1) myoelectric control significantly lowered the SoA, and that (2) adding noise to the control signal before presenting it as visual feedback to the participants lowered the SoA. Participants were not aware that some trials had added noise, but the results showed they felt less in control of those trials. This was not only related to the actual performance in the trials, as trials with better performance in joystick control led to lower reported SoA than trials with myoelectric control.

This study used a tracking task to investigate SoA, a measure used previously to investigate SOA in stroke [7]. This approach allowed us to compare the SoA of joystick control and myoelectric control, and investigate how much the differences in SoA are related to tracking performance. Myoelectric control consistently led to poorer tracking performance, and people reported a significantly lower SoA over myoelectric control than joystick control. However, the reduction in SoA was not solely based on poorer performance, as joystick control trials received lower SoA ratings, even when performance was better. Therefore, it seems that myoelectric control inherently led to a lower SoA, which could be related to the difference in movement variance between joystick and myoelectric control [6]. As all participants in this study were naïve to myoelectric control, it is important to study SoA with experienced users as well. However, if the difference between joystick and myoelectric controlled movements holds, it might be an indication that there is an upper limit to the SoA one can feel over myoelectric movements. This might have repercussions on the level of embodiment people can feel over their myoelectric prostheses.

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