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Exploring the impact of hand movement delays and hand appearance on myoelectric prosthesis embodiment using Immersive Virtual Reality

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Abstract. Prosthesis embodiment, the feeling of a prosthesis being part of the user, is reported by some prosthesis users. Myoelectric prostheses are electrically powered which produce a delay with fixed and variable components. The latter introduces uncertainty over hand behaviour, likely influencing embodiment. Embodiment may also be influenced by hand appearance. An Immersive Virtual Reality experimental study is currently in preparation. It involves anatomically-intact participants to systematically measure the impact of movement delays and appearance on embodiment of a virtual prosthesis. This includes a head-mounted display and motion tracking of a myoelectric prosthesis, with various virtual appearances and hand-movement delays.

Keywords. embodiment, myoelectric prosthesis, virtual reality, virtual hand illusion

1. Introduction

One definition of *embodiment* is the sense of a person's body which includes *body ownership* and *agency* [1]. That is, the feeling of ownership over one's body and being the agent of your actions, respectively. *Prosthesis embodiment* (PE) involves feeling the prosthesis being 'part of' the user, becoming more than a mechanical object, having a psychological investment into the self [2]. Unlike tool embodiment, this goes beyond a change in *body schema*, extending the body's configuration in space [3], by being incorporated into the *body image*, the thoughts and feelings towards the body [4].

Broadly, users have described their prosthesis as either feeling part of them, or as a tool but not experienced as part of their body [e.g., 2; 4; 5]. One type of upper-limb prosthetics, myoelectric prostheses, are electrically powered and controlled via electrodes measuring electromyographic (EMG) signals from muscle within the user's remaining limb. The difficulty in controlling such prostheses and their appearance have been noted by users as reasons for prosthesis rejection [6; 7], and may influence PE.

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Myoelectric prostheses are electrically powered which produce a fixed delay with fixed and variable components. The fixed delay is electromechanical. The variable delay comes from reliability of electrodes picking up the EMG signal. The latter introducing uncertainty over how the hand will behave. Thus, the predicted response of the prosthesis can be disrupted and is likely to influence embodiment as such predictions are important for the feeling of agency and body ownership [8]. This is highlighted by a version of the *Rubber Hand Illusion* (RHI), a well-established body ownership technique in psychology, where a participant moves their hand and sees a rubber hand move. Synchronised movements (as with tactile stimuli traditionally used in the RHI) can lead to ownership and agency over the rubber hand [e.g., 8] and has been replicated using virtual hands [e.g., 9].

Similar to Kalckert and Herisson [8], the delay between intended and actual movement may be one of the factors influencing whether PE occurs. Prosthetic appearance may also be a factor as it has been found to be important for a user's experience of their prosthesis [5; 10]. Supporting this, a virtual hand ownership study found that moving a human looking virtual hand produced stronger feelings of ownership than an abstract looking hand [11]. There may be an interaction between delay and appearance on embodiment. As encouraging PE has been proposed as a goal of rehabilitation [4], designers of prostheses need to understand the impact of factors on embodiment. An Immersive Virtual Reality (IVR) study is currently in preparation to systematically measure the impact of movement delays and appearance on ownership and agency of a prosthetic hand, measured via questionnaire and physiological response to a threat to the virtual hand.

2. Method

2.1. Design

A mixed design including both repeated measures and independent groups components will be used. The independent groups component involves temporal synchrony ('synchronous', 'asynchronous specific', 'asynchronous random') groups. In the synchronous group, virtual hands will move in synchrony with actual hand movements to the optimal ability of the technology, the asynchronous specific group will involve a specific delay (to be determined), and the asynchronous random group will involve a random delay between a set range of times (to be determined). The repeated measures component involves virtual prosthesis appearance (to be determined).

2.2. Participants

Anatomically-intact students and staff will be recruited from University of Salford.

2.3. Materials

A myoelectric prosthetic hand which opens and closes via EMG signals from electrodes measuring arm muscle flexes (see Figure 1). 2) IVR head-mounted display (HMD, e.g., *Oculus Rift* or *HTC VIVE*, see Figure 2) – for displaying a virtual

environment via first-person perspective tracking. 3) *Leap Motion* (see Figure 2) - for hand movement tracking and displaying virtually. This will be pointing downwards in a similar setup as used by [11] (see Figure 2). 4) *Galvanic skin response* (skin electrical activity) will be measured in response to a virtual threat. 5) A virtual hand ownership and agency questionnaire adapted from [8] to subjectively measure embodiment.



Figure 1. Myoelectric prosthetic hand.



Figure 2. Oculus Rift and Leap Motion from [11].

2.4. Procedure

Participants will be assigned to one of the temporal synchrony groups. During experiments participants will rest their arm on their leg below a table with their hand positioned below the prosthetic hand on the table. With the HMD they will have a first-person perspective looking down at a virtual prosthesis. Participants will open and close the prosthetic hand numerous times via the EMG electrodes, whilst observing the virtual hand. At the end, a virtual threat will be applied to the hand. Physiological measurement will be taken and participant behaviour filmed. After questionnaire completion the experiment will be repeated with an alternative hand appearance.

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