A PSYCHOPHYSICAL APPROACH TO MEASURE THE SENSE OF AGENCY

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ABSTRACT

Increasing a prosthesis user's sense of agency over their device may lead to improved patient outcomes. Measuring agency, however, can be difficult. Widely used questionnaires may be prone to cognitive biases and an established proxy for agency, the intentional binding paradigm, can be attentionally demanding. In this study, we present and test a novel psychophysical time discrimination task to detect the intentional binding effect, i.e. the perceived compression of the time interval between a controlled action and its effect. The task uses a two-alternative forced choice time comparison task to avoid the attentional demands associated with temporal estimation using an auxiliary clock display (such as a standard Libet clock protocol). We show that the psychophysics protocol can detect the intentional binding effect during voluntary movements in a small pilot study (n=4). Participants also completed a standard Libet clock protocol that showed inconsistent results. We conclude with a discussion of protocol improvements. The psychophysical time discrimination assessment shows promise for use as an objective sense of agency metric suitable for prosthesis users.

INTRODUCTION

Users of myoelectric prostheses sometimes reject their devices, a choice that can attributed to a reduced sense of embodiment [1]–[3]. Embodiment involves several interrelated components such as the sense of localization, ownership, and agency [2]–[5]. In prosthesis users, the sense of ownership is elicited by coherent sensory feedback, whereas the sense of agency arises when there is consistent control of the device [1], [6]. Typical hand movements have intact sensation and control, generating a sense of ownership and agency, leading to a strong sense of embodiment [6]. However, in a prosthesis user, one or both of these contributing factors to embodiment may be deficient dependent on accessible sensory information or the fidelity of the control system.

Sense of agency (SoA), the focus of this work, is defined as the feeling of control over one's actions, which involves distinguishing self-generated actions from actions generated by others [3], [7]–[11]. When an action and its effect are temporally and spatially congruent, a stronger SoA is generated; however, when incongruent, the resulting error in sensory prediction reduces the likelihood that the SoA will arise [9], [10]. The SoA can still be modulated by other agency cues beyond sensorimotor integration such as sensation within the residual limb or the functionality and fit of the device [1], [2], [9], [12].

Existing approaches to measure the SoA are susceptible to various limitations and potential biases. Explicit measures of agency rely on conscious awareness as individuals directly report their agentic experience during movement trials on questionnaires [8], [10], [11], [13]. Subjective questionnaires are prone to both experimenter and cognitive biases through the influence of social desirability and impression management, and its heavy reliance on conceptual and evaluative self-awareness [7], [8], [14]. Frequently these questionnaires are paired with implicit measures in an attempt to avoid these associated demand effects, but implicit methods have not been well adapted to motor contexts.

The most widely used implicit measure of the sense of agency is the intentional binding paradigm [3], [8], [11], [13]–[17]. An intentional binding effect occurs between a voluntary action and its sensory consequence where an individual will perceive the time interval to be smaller than it actually was (Figure 1) [6], [8]. This warped time perception is attributed to delayed awareness of the active action and early awareness of the consequence, which temporally shifts these elements towards each other [11], [14]. Intentional binding is often measured using a clock reading paradigm, such as the Libet clock, in which participants report the end of an action-effect trial using the position of a rotating dot. A major limitation of the Libet clock approach, especially in motor contexts, is that the individual has to split their attention between the action and the position of the clock hand which can bias the estimation of event timing [10]. Attending to the dynamic clock display is visually and cognitively demanding, which could lead to reduced engagement in the motor task [14].

Figure 1: The intentional binding effect. Active movements are perceived to be temporally shorter than passive movements.

Here we propose and test a novel implicit measure of the SoA based on the intentional binding effect. We implement a two-alternative forced choice time discrimination task with an adaptive staircase to estimate the intentional binding-driven time compression observed during active movements. The temporal discrimination task between an active and a passive movement removes potential subjective bias seen with standard agency questionnaires and eliminates the need for Libet clock reporting, which may not be suited to prosthesis user experience assessment due to attentional demands. Here we tested this novel assessment and a traditional Libet clock protocol on four participants in a computer-based cursor movement task. This objective approach forms the basis for a potentially more reliable assessment of agency for prosthesis users as it provides a new measure that avoids limitations associated with previous methods.

METHODS

Four able-bodied Acadia University students were recruited for this study (two females, two males). Written informed consent according to Acadia University REB was obtained from participants before conducting the experiment. The experiment was run using a custom MATLAB program (ver. 2021, The MathWorks, Inc., Natick, Massachusetts, United States). All visual stimuli were presented on a 27-inch monitor with 1920 x 1080 resolution. Participants controlled on-screen movements with a wireless mouse (Logitech G703) set to 400 dots per inch sensitivity (the Windows mouse sensitivity setting was set as the third tick from the left on the linear adjustment slider). A barrier was placed over the participant's right forearm and hand to block visual movement cues of the arm throughout the experiment. Participants wore foam earplugs underneath over-ear noise-cancelling headphones playing Brownian noise to block any ambient audio cues.

Experimental Protocol

While seated, participants moved a small blue square cursor along a line from left to right to hit a red square target 22.4 cm away. The movement was initiated with a mouse click and concluded with a second mouse click. The experimental protocol consisted of the following 5 blocks:

Block 1 & 2: Familiarization trials of active and passive movements with no Libet clock present. Participants began with a training block of 25 cursor movement trials. In Block 2, participants watched 25 cursor movement trials (passive trials) recorded during Block 1 played back in a random order by the computer. Each participant's moving hand and arm were obscured from view while they focused on the screen.

Block 3: Psychophysics method testing. Participants completed an active cursor movement trial followed by a passive movement. The passive movement played back by the computer matched the trajectory of the preceding movement except its speed was modified. Participants were then asked to select the movement that was slower (i.e., longer duration) (Figure 2 - 1). The temporal stretch (or compression) of the passive movement was updated over subsequent trial pairs using an adaptive staircase [18]. Staircase parameters were set to determine the 50% discrimination threshold of the just noticeable difference (JND) of the magnitude of temporal adjustment between active and passive movements (Figure 2 – 2). The block continued until either the adaptive staircase hit 23 reversals, or the participant completed 200 total trials, whichever occurred first. The final temporal adjustment reached indicated the participant's perceived action-effect intervals for voluntary control with respect to their perceived action-effect intervals for involuntary control.

Block 4 & 5: Libet clock testing. Participants were asked to make the same action as before, but now a Libet clock (as in [16]) was positioned around the target. During the movement, a black dot rotated around the clock face. After a variable period of additional dot rotation following movement completion, participants were asked to estimate the position of the dot when the action ended. The difference between the actual movement end time and the clock-reported end time was recorded for each of 40 trials. In Block 5, participants were asked to watch 40 passive movements (recordings from Block 4 played back in a random order) and use the Libet clock to make the same estimation of movement end time.

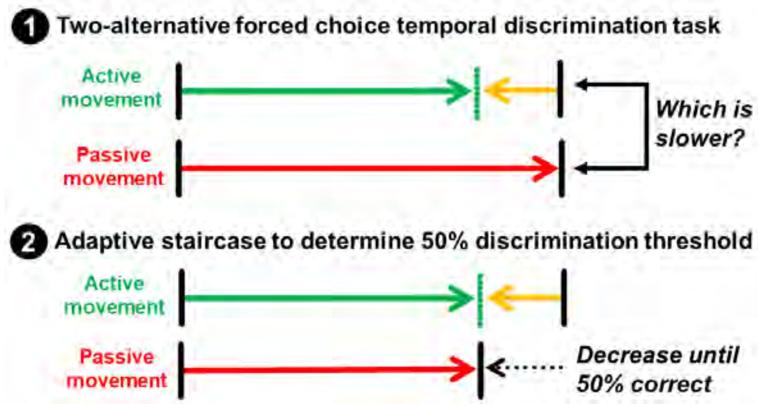

Figure 2. Psychophysical assessment to measure the intentional binding effect.

RESULTS

For three of the four participants, the psychophysics protocol detected an intentional binding effect during active movements. Pereived time compression of the active movement compared to the passive movement was more than 156 ms in these participants (Table 1). The adaptive staircase seemed to converge to the 50% discrimination threshold as evidenced by slopes of the best fit line over the final 8 reversals approaching zero (Figure 3). However, Participant 4's perceived time compression was vastly different (+374 ms). This participant made a mistake on the first JND trial pair selection and made comments about the initial difficulty of the task. The slope of the best fit line over the last 8 reversals was largest in this participant (Table 1), suggesting that the staircase may have still been converging at the end of their psychophysics block.

The traditional Libet clock assessment showed inconsistent detection of an intentional binding effect as active trials were perceived as similar to or longer in duration than passive trials (Table 1). A coding error resulted in an inaccurate data record for Participant 1.

Table 1: Summary of experimental results for Psychophysics and Libet clock assessments

	Psychophysics protocol		**Libet clock**
Participant #	*JND (ms)*	*Slope of last 8 reversals*	*Estimate-Actual (ms)*
1	-363	5.29	N/A
2	-164	-18.5	+2.9
3	-156	14.6	+105.85
4	+374	-29.4	+347.25

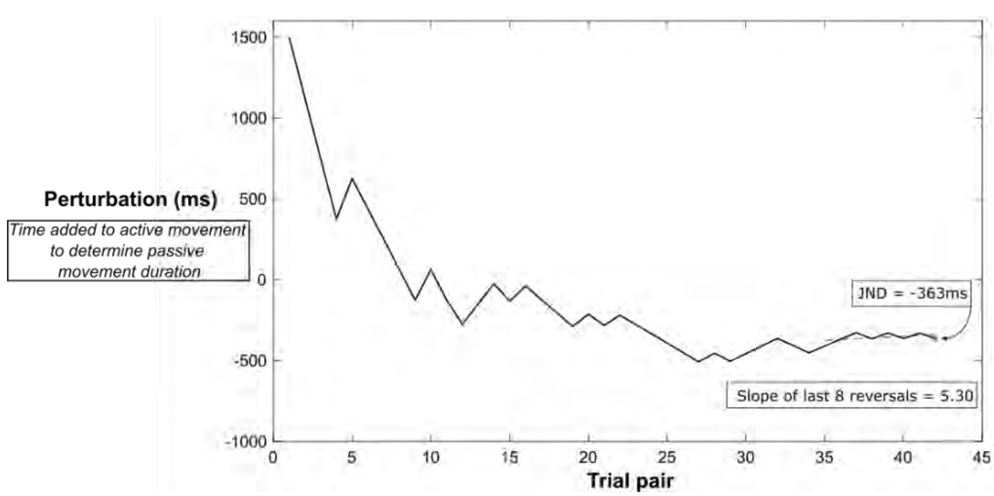

Figure 3. Representative adaptive staircase to determine temporal discrimination threshold for Participant 1.

DISCUSSION

Here we have demonstrated the feasibility and potential for a psychophysical approach to measure the sense of agency in people making movements. A robust intentional binding effect was observed in three of four participants. In the fourth participant, the initial task settings seemed to be too difficult for proper psychometric characterization. In an upcoming validation study of the protocol, we will add a JND familiarization block of 3 trial pairs and we will adjust the parameters of the adaptive staircase to ensure initial task success and increase the average staircase length to improve convergence.

The traditional Libet clock protocol produced unexpected results: active movements were perceived as longer than passive ones. Attentional demands of the task may explain this observation. In active movement trials, participants may focus their attention on the moving cursor resulting in delayed observation of the rotating clock. In passive movement trials, participants could focus more intently on the clock, reducing any response delays. Traditional Libet studies often involve key presses in response to auditory stimuli in which these attentional issues may be a nonfactor [16]. In future work we could test this attentional demand hypothesis by tracking gaze fixations during Libet motor trials. An interval estimation method where participants are required to verbally estimate the temporal interval between an action and its outcome may be more suitable to motor tasks [10], however, our earlier work suggests that similar approaches produce highly variable results [3].

Our novel psychophysical approach shows promise in objectively measuring intentional binding in a motor context. The assessment can be adapted for prosthesis users to provide detailed insight into the sense of agency in patient populations.

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