Test of independence model between body ownership and agency in a virtual reality environment

Asaki Kawaguchi
Tokyo Metropolitan University
Hino, Japan

Shogo Okamoto
Tokyo Metropolitan University
Hino, Japan

Masayuki Hara
Saitama University
Saitama, Japan

Abstract—Body ownership refers to the feeling that one's body belongs to that person. Agency is the sense of being able to control one's own body parts. Three major hypothetical models describe the relationship between body ownership and agency. In this study, we examined whether one of the three models—the independent model—was accurate in describing the aforementioned relationship. We prepared for two conditions using an immersive virtual reality setting. In one condition, both body ownership and agency were evoked. In the other condition, only agency was evoked. We compared the effects of motion delays between these two conditions. The effect of delay on agency did not depend on ownership intensity, supporting the independence of body ownership and agency. However, the higher the reported body ownership was, the higher the reported agency could be, negating their independence. Holistically, the results are not in favor of the independence model.

Index Terms—Body ownership, Agency, Virtual reality

I. INTRODUCTION

Body ownership refers to the feeling that the limbs and other body parts belong to one's own body. Agency refers to the feeling of being in control of a limb or a tool. To date, at least three theories have been proposed regarding the relationship between a sense of body ownership and agency [1]–[3]. In the additive model, body ownership is considered part of agency. The independent model assumes that agency and body ownership do not interfere with one another. In the interactive model, agency and body ownership interact with each other. However, researchers are still debating the validity of these models. In this study, we investigate the validity of the independent model.

In this study, both body ownership and agency were generated by displaying computer graphics (CG) of a hand linked to actual hand movements in a virtual reality environment. Additionally, we prepared a condition in which only agency was generated by displaying a banana instead of a hand. Delays between actual and CG hand movements make it more difficult to experience body ownership and agency [4]. If the independent model is valid, the effect of delay on agency should not change depending on the ownership condition. Thus far, the effects of delays on body ownership and agency have yet to be investigated under the two conditions described above. The results of this study will add positively to the literature on the understanding of embodiment.
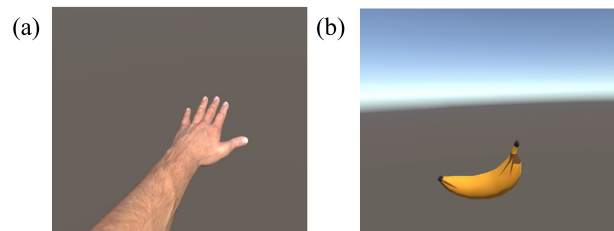

Fig. 1. Computer graphics presented to participants. (a) Authentic-looking left hand. (b) Banana displayed at the position of the actual left hand.

II. METHODS

A. Participants

Eleven university students who were unaware of the objective of this study, participated in the experiment.

B. Apparatus

Oculus Quest 2 (Oculus VR, LLC., CA, USA) was used as the virtual reality goggles. The left and right wrists and fingertips were tracked using the built-in goggle cameras. The virtual environment was implemented using Unity 2020.3.35.f1.

C. Stimuli

Two different experimental conditions were used in this study. Under the first condition, the CG of an authentic-looking hand was displayed at the position of the actual hand. In the second condition, the CG of a banana was displayed at the position of the actual hand. A sense of bodily possession was expected to occur for the authentic-looking hand CG and not for the banana CG. Under both conditions, the CG hands moved synchronously with the participants' actual left hand. Hence, similar to the moving rubber hand paradigm [5]–[7], both the body-ownership and agency can be felt for the authentic-looking hand.

The sense of body ownership and agency were barely felt, with a motion delay of 500 ms [4]. Hence, 0 ms (minimum delay) and 500 ms delay conditions were also set.

Individual participants experimented with four conditions (two types of CG $\times$ and two levels of delay), each of which was replicated three times in a randomized block design.

Q1	I felt as if the visible hand (or banana) was my own left hand.
Q2	I felt I was controlling the visible left hand (or banana).
Q3	I felt as if I had more than one left hand.
Q4	I felt that I had lost my left hand.

D. Procedure of experiment

A 1-minute adaptation session was performed to familiarize the participants with the visible left hand or banana. Participants continuously moved their left hand to trace a circle parallel to the ground for one minute, during which they gazed at the left hand or banana. During the experiment, participants were instructed to place their right hand on their lap and maintain their face and body orientation, while refraining from touching something with their left hand.

After the adaptation task, participants completed the four questionnaires listed in Table 1 on a nine-point Likert scale (1 = not agree, 5 = neutral, 9 = largely agree). Among the four questionnaires used, Q1 pertains to body ownership, Q2 focuses on agency, and Q3 and Q4 serve as control questions to minimize suggestibility. The participants took a 1-minute break before repeating the abovementioned tasks under different conditions.

E. Data analysis

For each stimulus condition and questionnaire, the mean of three repeated trials were calculated for each participant. For Q1 and Q2, the mean scores were compared between the conditions with and without delay using a t-test. Furthermore, a two-way analysis of variance (ANOVA) was applied to the results of the Q2 questionnaire, with delay and type of CG as factors.

III. RESULTS

Fig. 2 presents the results for Q1 and Q2. The delay-influenced the scores of Q1 and Q2 for both the authentic hand and banana conditions as follows: (Q1-banana: $p = 0.0022 < 0.01/4$, Q1-hand: $p = 2.0 \times 10^{-5} < 0.001/4$, Q2-banana: $p = 0.0079 < 0.05/4$, Q2-hand: $p = 0.0053 < 0.05/4$).

As shown in Fig. 2, irrespective of the delay, the Q2 scores for the authentic hand condition were greater than those for the banana condition (minimum delay condition: $p = 0.025 < 0.05/2$, 0.5-s delay condition: $p = 0.013 < 0.05/2$). Agency was felt more strongly when the realistic hand was displayed.

The two-way ANOVA did not find a significant main effect of the CG on agency ($F(1, 28) = 1.55$, $p = 0.22$), whereas the effect of delay was evident ($F(1, 28) = 17.96$, $p = 2.2 \times 10^{-4}$). The interaction between the CG and delay was not confirmed ($F(1, 28) = 0.016$, $p = 0.90$). There was no difference in the way delay lowered agency between the authentic hand and banana conditions.

IV. DISCUSSION

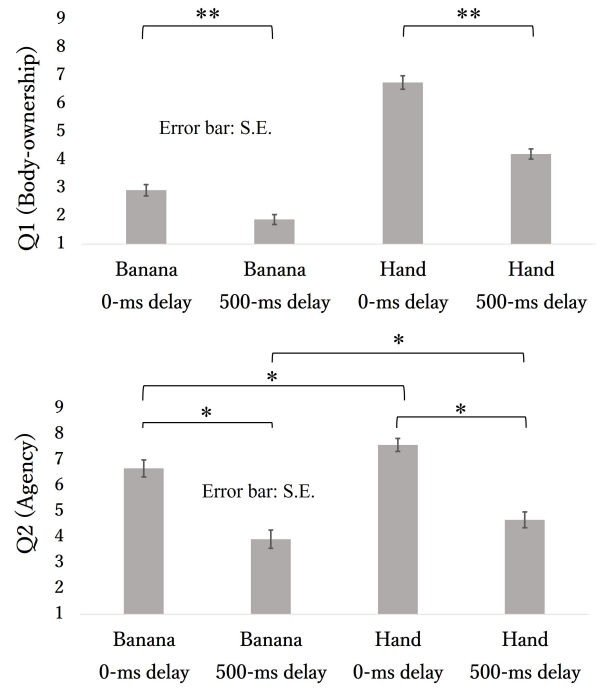The two-way ANOVA showed no interaction between delay and type of CG. Therefore, it was suggested that the delay

Fig. 2. Mean scores for the questionnaire of body-ownership (Q1) and agency (Q2). * and ** mean significant differences at $p < 0.05$ and 0.01, respectively.

reduced agency to the same extent in the authentic hand and banana conditions. This result supports the independence model. In contrast, as shown in Fig. 2, the scores for agency were greater with a sense of body ownership, suggesting that the presence of ownership affected agency. This result indicates that body ownership and agency are not entirely independent. Nonetheless, the main effect of CG was not observed by ANOVA, and the effect of CG or ownership on agency was inconclusive in the current setting.

This study had some limitations. We compared two extreme conditions in which agency was strongly felt (minimum delay) or hardly felt (500 ms delay). Moderate delay levels, such as 250 ms, should also be tested for generalization. The adaptation task could be improved further for better control of experimental tasks. Participants continuously moved their left hand to trace a circle parallel to the ground for one minute, during which they gazed at the left hand or the banana. The task was simple, and some participants may have been more engaged in the experiment with a more difficult task.

V. CONCLUSION

Between the intensive-ownership condition (authentic hand condition) and the low/null-ownership condition (banana condition), the effects of motion delay on agency were not different. However, agency scores tend to be greater in the intensive-ownership condition than in the low-ownership condition, which does not endorse the independence model of ownership and agency. Our results did not largely support the independence model.

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