Asura Hands: Having Two Independently Controlled Left Hands in Virtual Reality Environment

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***Abstract*—Body ownership, the sensation that a body part belongs to oneself, can extend to fake body parts and those depicted through computer graphics (CG). In exploring the transfer of body ownership to artificial body parts, we examined whether this ownership could be felt towards two visible left hands within an immersive virtual reality (VR) environment. One CG hand was synchronized spatiotemporally with the participant's actual left hand. The other CG hand, displayed close to the actual left hand, was created by inverting the right hand to appear as a left hand. Participants completed questionnaires following an adaptation task, reporting a high sense of ownership for the CG hand controlled by the left hand. The CG hand operated by the right hand elicited a moderate sense of ownership. The CG hand controlled by the right hand was perceived equally as both a left hand and a right hand. Moreover, while participants felt that one of the two left hands was their left hand, they did not simultaneously perceive both as their own left hand.**

***Index Terms*—Body ownership, Virtual reality, Self-body awareness**

I. Introduction

Body augmentation aims to extend human bodily functions by attaching additional mechanical body parts to humans [1]–[5]. For example, Parietti and Asada developed robotic extra arms to help the wearer perform assembly tasks [1]. Most of these studies involving robotic limbs largely focused on their control methods. Similarly, using VR environments, body augmentation can be experimented with bodies displayed in computer graphics (CG) [6]–[8]. If a supernumerary part installed on the human body can be felt as part of one's own body, achieving a sense of body ownership [9]–[12], then human-friendly body augmentation can be realized. In this study, as a new attempt at body augmentation, we investigated whether people feel a sense of body ownership towards a CG left hand that moves in sync with the actual left hand and a CG left hand that moves in reference to the right hand.

In order to study the bodily extension toward a supernumerary hand, Kawaguchi et al. displayed two computer-generated images of a left hand, synchronized with the real left hand in a VR environment [13]. They reported that a sense of body ownership also occurs in the replicated hand. In this study, we extend the previous study [13] and investigate the conditions under which the two left hands are controlled independently. Specifically, we address the following questions: When the right hand controls the extended hand that appears to be the left hand, does a sense of body ownership occur in the extended hand? Additionally, does the extended left hand feel like the left hand or like the right hand? To answer these questions, we tested whether a sense of body ownership occurs in the extended left hand controlled by the right hand.

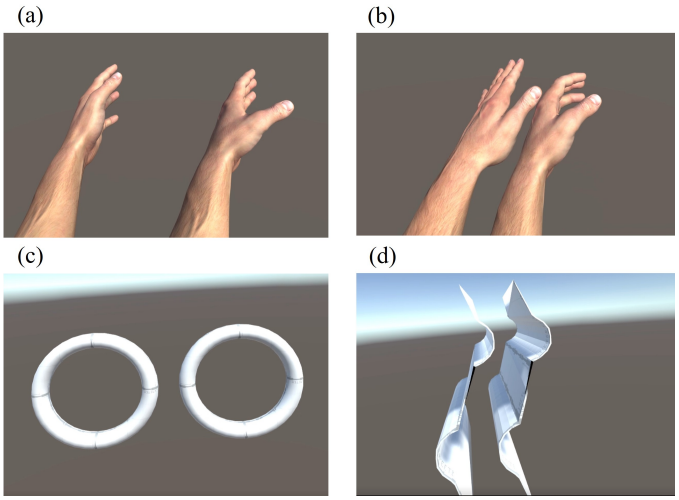

Fig. 1. Computer graphics used in the experiment. (a, b) Two left hands seen in the virtual environment. One spatiotemporally synchronised with the actual left hand, and the other referred to the actual right hand. (c, d) Shapes traced by the two left hands during the adaptation tasks.

II. Methods

A. Participants

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

B. Apparatus

Meta Quest 3 (Meta Platforms Inc., CA) was used as the VR goggles. The left and right wrists and fingertips were tracked using the cameras installed in the goggles. The VR environment was implemented using Unity 2020.3.35.f1 (Unity Technologies, CA).

C. Stimuli: Dual visible left hands

Fig. 1(a) and (b) show the CG representations of two left hands displayed to the participants in the VR environment. One hand was displayed at the position of the participants' actual unseen left hand, referencing the 18 feature points of the real left hand. The fingers of the CG hand moved in synchrony with the participant's left hand.

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TABLE I
QUESTIONNAIRE ITEMS

	Question
Q1	The seen hand operated by the right hand was my hand.
Q2	I occasionally felt one visible hand belonged to me. That goes for the other visible hand, too. However, not simultaneously.
Q3	Both visible hands were my left hand at the same time.
Q4	The hand operated by the right hand was my left hand.
Q5	The hand operated by the left hand was my left hand.
Q6	The hand operated by my right hand was my right hand.
Q7	The hand operated by my left hand was my right hand.

The other CG hand was a left-right inversion of the right hand, also referencing the 18 feature points of the real right hand. The fingers and hand movements were synchronized with the actual right hand, but the left and right sides were reversed. However, the back and forth, up and down, and left and right movements of the entire arm were identical to the actual right hand movements. This CG hand was displayed 40 cm to the left of the actual right hand.

Although we targeted duplicated left hands in this study, there was no substantial effect of the laterality on the results in a preliminary test.

D. Procedures of experiment

When the experiment started, the goggles displayed the VR environment, the CG of the two left hands, and the CG for the adaptation task. Fig. 1 (c) and (d) show the CG used in the adaptation task. The participant traced the two rings and two wound boards by using the two seen left hands simultaneously. Each hand touched each of the two seen object. The task lasted 1 min for each type of object.

After the above task, the participants completed seven questions on a 10-point Likert scale (0: not applicable at all throughout the task, 1: apply in the slightest degree, 9: strongly agree). Table I lists the questionnaire items. Q1, Q4, and Q6 concerned the body ownership of the hand operated by the right hand. Q2 and Q3 addressed the body ownership of the two CG left hands. Q5 focused on the body ownership of the hand operated by the left hand. Q7 served as a control question. Unless the participants are influenced or suggested by the experimental settings, this item is not applicable, meaning the expected score is close to zero. In this experiment, we focused on body ownership, although both ownership and agency are often discussed for simulated hands [6], [14], [15].

E. Data analysis

The mean score of each questionnaire item was judged to be greater than zero using t-test. To compare the intensity of body ownership for the hand operated by the left hand (Q5) and the hand operated by the right hand (Q1), the results for Q1 and Q5 were compared using a paired t-test. In addition, Q4 and Q6 were compared using a paired t-test to determine whether the extended hand was perceived as a left-hand (Q4) or a right-hand (Q6).

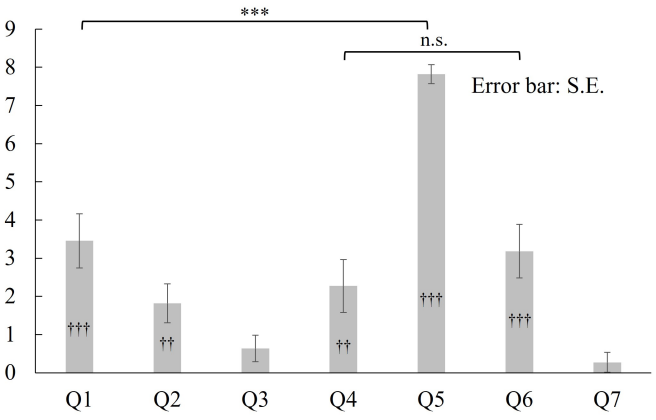

Fig. 2. Mean scores for the questionnaires. *** means significant difference at $p = 0.001$. †, ††, and ††† mean significant differences from 0 at $p = 0.05$, 0.01, and 0.001, respectively.

III. RESULTS

Fig. 2 shows the results of the questionnaires. Except for Q3 and Q7, the mean of the scores was significantly higher than 0 (Q1: $p = 4.5\times10^{-4}$, Q2: $p = 3.4\times10^{-3}$, Q3: $p = 0.055$, Q4: $p = 5.3\times10^{-3}$, Q5: $p = 2.2\times10^{-11}$, Q6: $p = 7.6\times10^{-4}$, and Q7: $p = 0.17$). From Q1, body ownership also occurred for the left hand operated by the right hand. However, the score was significantly lower than for the left hand operated by the left hand (Q1 vs. Q5: $p = 2.4 \times 10^{-5}$). The sense of body ownership was strongest for the left hand operated by the left hand.

There was no significant difference between Q4 and Q6 scores ($t(10) = -0.88$, $p = 0.40$). The left hand operated by the right hand was felt equally as both the right and left hands.

IV. DISCUSSION

In this study, we investigated whether body ownership could be felt for two left hands: one synchronized with the left hand and one operated by the right hand. The experimental results showed that the two visible left hands were not simultaneously felt as left hands. However, body ownership was still generated for the left hand operated by the right hand, though the intensity of this sense of ownership was inferior to that of the seen left hand synchronized with the actual left hand. Additionally, the left hand operated by the right hand was perceived as both a right hand and a left hand.

Based on these results, the two questions of this study can be answered as follows. The first question is: "When the right hand controls the extended hand that appears to be the left hand, does a sense of body ownership occur in the extended hand?" The answer is "Yes." The second question is: "Does the extended left hand feel like the left hand or like the right hand?" The answer is: "It feels like both the left hand and the right hand to the same degree." Since the extended hand moved with reference to the right hand, it did not completely feel like the left hand.

V. Conclusion

In this study, as part of exploring body augmentation techniques, the left hand was duplicated in a VR environment and operated by the right hand. The left CG hand controlled by the participant's left hand was strongly felt as part of their body. The additional left CG hand, operated by the actual right hand, was also felt as a body part, though not as intensely. It was perceived equally as both the participant's left and right hand. Although self-body awareness was confirmed for both visible left hands, they were not simultaneously recognized as left hands. Further research is needed to understand the conditions that foster such perceptions.

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