Asura Hands: Ownership of Three Left Hands Enhanced by Vibrotactile Feedback to Fingertip

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***Abstract*—This study investigates whether tactile feedback can enhance the sense of body ownership over multiple virtual hands in a virtual reality (VR) environment. Participants controlled three virtual hands while receiving either no tactile feedback or vibration feedback delivered to the index finger corresponding to virtual touch events. The three virtual hands were displayed equidistantly in VR, with the middle hand aligned with the participant's real hand and the other two positioned to the left and right. A user study involving ten participants revealed that the presence of tactile feedback significantly increased the perceived ownership of both the medial and lateral virtual hands. Behavioral data also showed a trend toward more balanced use of the virtual hands under the vibration condition, although this effect was not statistically significant. These findings suggest that synchronized tactile stimulation is an effective method for reinforcing body ownership of augmented limbs in VR, with potential applications in bodily extension and immersive gaming.**

***Index Terms*—body ownership, embodiment, bodily extension.**

I. Introduction

Body ownership illusions have been extensively studied in scenarios involving a single artificial limb, most famously in the "Rubber Hand Illusion [1]." However, the question of whether multiple additional limbs can be incorporated into a user's body schema remains relatively unexplored [2]–[5]. For example, Kawaguchi et al. [2] investigated whether two realistic virtual left hands moving in synchrony with the actual left hand could both be perceived as one's own. They found that a strong sense of ownership rarely occurred for both hands simultaneously. In contrast, Mashiyama et al. [5] reported that participants experienced ownership even toward multiple virtual hands that were unrealistic and not ergonomically congruent.

Addressing this gap is crucial for advancing VR applications and robotic augmentation technologies. Recent research suggests that providing real tactile feedback corresponding to virtual touch events can enhance the sense of body ownership [6], [7]. This study investigates whether users can perceive three virtual arms as their own by applying synchronized tactile feedback when interacting with virtual objects.

II. Experimental Setup

Participants wore two small vibration motors (FM34F, TPC Mechatronics Co., Ltd., Korea) on their left index finger, as shown in Fig. 1. One motor was attached to each side of the index fingertip to deliver intense tactile stimulation. Using a head-mounted display (Meta Quest 3, Meta Platforms, Inc., CA), three virtual left hands were presented in the VR environment, spaced 10 cm apart, with the central hand spatially aligned with the participant's real left hand. The VR environment was developed using Unity (2020.3.35.f1, Unity Technologies, CA).

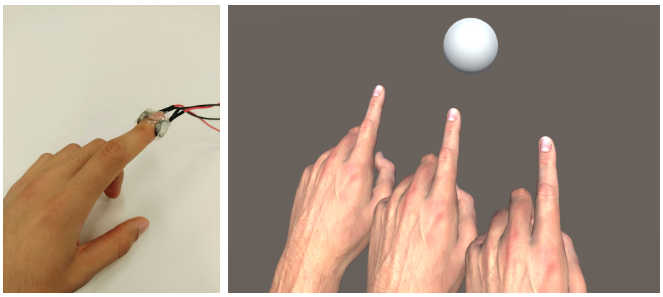

Fig. 1: Experimental setup. Left) Vibration motors attached to the index finger of a participant's left hand. Right) The participant controlled three left hands in the VR environment.

III. Experiment

A. Participants

Ten university students (two females and eight males, aged 20–29, right-handed) participated in the experiment after providing signed informed consent.

B. Ethical Statement

This study was approved by the institutional review board of Hino Campus, Tokyo Metropolitan University (R6-009).

C. Vibratory Feedback Conditions

Two feedback conditions were tested: no vibration and vibration on all three virtual hands. In the no-vibration condition, the vibration motors worn on the index finger were not activated.

In the vibration condition, when the index finger of any virtual hand made contact with a spherical object in the VR environment (Fig. 1), vibrotactile feedback at approximately 200 Hz was delivered for 50 ms. This stimulation was intended to simulate the sensation of physical contact between the finger and the object.

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TABLE I: Questionnaire items rated on a 8-point scale (0–7).

Item	Description	Label
Q1	Felt all three virtual hands as own	Own three hands
Q2	Felt middle virtual hand as own	Own middle hand
Q3	Felt right virtual hand as own	Own right hand
Q4	Felt left virtual hand as own	Own left hand

Each participant experienced both conditions with two trials for each. To minimize potential order effects, the presentation order was counterbalanced across participants.

D. Procedures

After having a 1-minute period of habituation to the VR environment and three virtual hands, participants were tasked with touching virtual balls as soon as possible when they appeared at random positions. All balls could be reached just by reaching hands.

Virtual target spheres appeared at a distance of 40 cm in front of each virtual hand, spaced consistently parallel to the frontal plane. The diameter of each sphere was 3 cm. This spatial configuration ensured that each virtual hand had a corresponding target space at an equivalent depth and spacing, and that the closest hand to any given sphere was uniquely defined.

In each of the two conditions that were tested in random order, participants completed a total of 15 ball touches, after which they answered four questionnaire items listed in Table I. These items were designed to assess their subjective sense of body ownership. Responses for individual questionnaire items were recorded on an 8-point Likert scale ranging from 0 ("did not feel at all"), 1 ("felt a little") to 7 ("felt very strongly").

E. Data Analysis

The primary focus of the data analysis was the comparison of the scores for each questionnaire items between the test conditions with and without vibrotactile feedback. For each participant, the average scores were calculated across repeated trials separately for each vibration condition. For each questionnaire item, the mean scores between the two conditions were then compared by using paired t-test with Bonferroni adjustment of p-values with the factor of four.

In addition to the ownership ratings, behavioral data regarding hand usage were also collected. The total number of times each virtual hand (left, middle, and right) was used to touch the balls was recorded for each participant under each condition. We compared these numbers between two conditions by using chi-square test of independence.

IV. Results

The analysis of questionnaire responses revealed that the average score for Question 1 ("I felt all three hands as my left hand at the same time") increased by more than one point in the vibration condition compared to the no-vibration condition, showing a marginal difference ($t(9) = 3.72$, $p = 0.024$). Significant increases were observed in the average scores for Questions 3 and 4, which assessed the sense of ownership for the medial and lateral virtual hands, respectively (Q3: $t(9) = 4.86$, $p = 0.005$; Q4: $t(9) = 4.68$, $p = 0.006$).

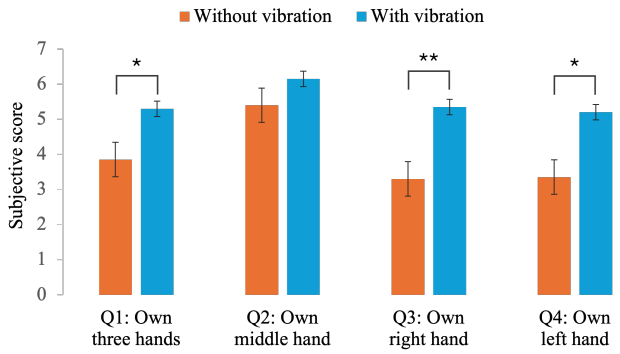

Fig. 2: Questionnaire scores. Means and standard errors. Questionnaire labels correspond to those in Table I. * and ** indicate significant difference at $p < 0.05$, and 0.01 with Bonferroni correction, respectively.

In contrast, the sense of ownership for the central virtual hand (Q2) did not significantly differ between conditions ($t(9) = 2.00$, $p = 0.32$). This may be attributed to the central hand's spatial alignment with the participant's real hand in the VR space, resulting in a high baseline sense of ownership. Consequently, the addition of vibration feedback did not further enhance ownership for the central hand to the same extent as for the lateral and medial hands.

Behavioral data also indicated differences in hand usage patterns across conditions. In the no-vibration condition, participants exhibited a clear preference for the central hand, with mean usage counts of 4.85, 6.5, and 3.65 for the left, center, and right hands, respectively. In the vibration condition, hand usage was more evenly distributed (left: 4.80, center: 5.45, right: 4.75). However, this difference was not statistically significant across feedback conditions ($\chi^2(2) = 2.37$, $p = 0.31$).

V. Discussion

The results demonstrated that providing tactile feedback could strengthen the sense of body ownership across all three virtual hands. Participants consistently reported a stronger feeling of ownership when vibration feedback was applied. In the vibration condition, the usage of the outer hands (left and right) tended more balanced compared to the no-vibration condition, suggesting that consistent haptic feedback not only enhances subjective perception but also influences the motor control over the three virtual hands during the task. However, this trend was not statistically supported.

Future research could explore the effects of varying the intensity or timing of feedback to further optimize multisensory integration in bodily extension systems.

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