Minimal Impact of Tangible Objects on Body Ownership Transfer in Immersive Virtual Reality

Yutaro ABE*, Asaki KAWAGUCHI*, and Shogo OKAMOTO*

* *Department of Computer Science, Tokyo Metropolitan University,6-6 Asahigaoka, Hino-shi, Tokyo 191-0065, Japan*

Abstract: Researchers have discussed the impact of tactile stimuli on the embodiment within virtual reality environments. We conducted experiments under conditions akin to the rubber hand illusion, where tactile stimuli are known to enhance illusory bodily awareness, within an immersive virtual reality setting. Participants were required to touch spheres that appeared randomly under two conditions: with and without tactile stimulation. The condition incorporating tactile stimuli provided cotton balls at locations that were spatially congruent with the virtual spheres. Although we anticipated that tactile stimulation would enhance embodiment, no significant differences in reported embodiment were observed between conditions with and without tactile objects. The results imply that when visual stimuli alone are sufficient to generate embodiment, tactile stimuli do not significantly affect embodiment.
Keywords: *Body-ownership, sense of agency, virtual reality, embodiment.*

1. INTRODUCTION

One of the key concepts in current virtual reality (VR) techniques is embodiment, whereby the observed avatar or virtual body parts are perceived as part of the operator's own body. Identifying conditions that effectively facilitate embodiment is crucial for developing immersive VR environments. Furthermore, there has recently been a demand for the representation of physical stimuli in immersive VR environments, leading to the increased use of haptic stimuli and interfaces in many VR applications, such as [1, 2].

Previous studies have shown inconsistent results regarding the necessity of haptic stimuli for enhancing embodiment. For instance, Hanashima and Ohyama [3] found that tactile stimuli were crucial for increasing the sense of ownership felt for an avatar in third-person perspective conditions. Slater et al. [4] observed that haptic stimuli, when congruent with visual stimuli, slightly enhanced the sense of ownership for the avatar. Conversely, Maselli and Slater [5] demonstrated that when the avatar featured realistic skin and body segments, incongruent haptic stimuli did not impair the transfer of body ownership. Therefore, the impact of haptic stimuli on embodiment varies depending on the experimental conditions. It is essential to identify the conditions under which haptic stimuli effectively influence embodiment.

Experiments on body ownership transfer in VR environments are often compared to those involving the rubber hand illusion in real space [6]. In rubber hand illusion experiments, a rubber-made artificial hand is perceived as the actual hand [7]. Within this framework, the effectiveness of haptic stimuli is widely acknowledged by many researchers [8, 9]. We conducted an experiment analogous to the rubber hand illusion within an immersive VR environment, where the embodiment is experienced with a computer graphics (CG) hand. In such a condition, we anticipated that the presence of haptic stimuli would effectively enhance the embodiment of the CG image.

2. METHODS

2.1 Apparatus and systems

The Oculus Quest 2 (Oculus VR, LLC., USA) was utilized as the virtual reality headset. The display resolution was 1832 × 1920 pixels per eye, with a refresh rate of 72 Hz in the environment we used. The motion of the left hand, from the wrist to the five fingertips, was

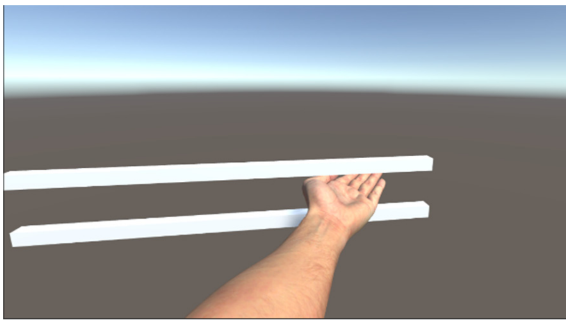

Figure 1: Adaptation task in the virtual reality environment. Participant's view from the headset.

Figure 2: Reaching task. Top) Participant's view. Bottom) Arrangement of tangible spheres covered with cotton.

tracked by cameras integrated into the goggle's chassis.

The virtual space was developed using Unity 2020.3.35f1. As illustrated in Figure 1, the computer graphics (CG) representation of the left hand, including the parts extending from the elbow, was displayed in the same position as the actual left arm. The fingers and hand of this CG model moved synchronously with the real ones, utilizing a motion tracking function. A similar setup was also employed in [10, 11].

2.2 Participants

Seven university students in their 20s participated in the study after providing a written informed consent. They were unaware of the objectives of the study.

2.3 Procedures

During the experiments, participants maintained the positions and orientations of their head, body, and right hand. After launching the software, participants positioned their left hand approximately 30 cm in front of their chest. They ensured that the left hand did not touch their body. The camera system then recognized the left hand, and the CG hand was rendered in a position spatially consistent with the actual hand. Throughout these initialization processes, participants were instructed to close their eyes. Subsequently, as depicted in Figure 1,

Table 1: Questionnaire items to investigate the embodiment to the CG hand. Each item was answered by using a 10-graded scale.

	Question	Category
Q1	The seen hand was felt as if it were my own left hand.	Ownership
Q2	I felt the presence of the seen hand.	Ownership
Q3	The seen hand could be controlled as I wanted.	Agency
Q4	I felt as if the hand was controlled by someone else.	Dummy
Q5	I felt as if my left hand had disappeared.	Dummy

Table 2: Means and standard errors among the participants for Q1–Q5 and significant probabilities for the differences between conditions with and without tangible spheres.

	Without tangible spheres	With tangible spheres	*p*-value
Q1	7.28 (±0.71)	7.85 (±0.55)	0.56
Q2	7.42 (±0.40)	7.42 (±0.34)	1.00
Q3	8.14 (±0.95)	8.14 (±0.43)	1.00
Q4	0.86 (±0.59)	2.29 (±1.13)	0.17
Q5	1.57 (±1.11)	1.00 (±0.53)	0.49

participants performed an adaptation task. In this task, they moved their left hand along a long bar and across a deformed plate suspended in the air, spending 30 seconds on each activity.

After the adaptation task, as illustrated in Figure 2, participants performed a reaching task. Each participant positioned their hand 10 cm in front of their chest as a starting or home position. They then touched spheres that appeared randomly, aiming to do so as quickly as possible. After touching a sphere, the participant returned their hand to the home position and awaited the appearance of another sphere. In a single set, a sphere appeared randomly 15 times. Each sphere was 3 cm in diameter and appeared at one of three random locations in the air. Each location was 10 cm away from the others

The above reaching task was conducted under two conditions in a random order. The one condition was with tangible spheres, where cotton balls were arranged at the positions of virtual spheres such that the participant would feel their sense of touch. The other condition was without the tangible balls.

After the reaching task completed in each condition, the participant answered to the five questionnaire items listed in Table 1 using 10-graded scales from 0 to 9. Zero indicated that the question item would not be applicable to the experiment at all. The greater scale values indicated the item was applicable with the greater intensity. Q1 and Q2 were about the body-ownership. Q3 was about the agency. The body-ownership and agency are factors composing the embodiment [12, 13]. Q4 and Q5 were items to examine how well the experiments were controlled, and the scores for these items should not be as high as those for Q1–Q3. These questionnaire items are commonly used in the study of body-ownership transfer [5, 6].

2.4 Analysis

For each questionnaire item, we compared the mean scores between the conditions with and without tangible objects by using *t*-tests with one sample.

3. RESULTS

Table 2 lists the means and standard errors of the scores for Q1–Q5 under the conditions with and without the tangible objects. The significance probabilities for the differences between the two conditions are also listed.

Regarding Q1, the means and standard errors were 7.28 ± 0.71 and 7.85 ± 0.55 for the conditions without and with tangible objects, respectively. For Q2, these values were 7.42 ± 0.40 and 7.42 ± 0.32, respectively. For Q3, they were 8.14 ± 0.95 and 8.14 ± 0.43, respectively. For these questionnaire items, i.e., Q1–Q3, the mean values were not significantly different between the two conditions.

Regarding the control items, the values for Q4 were 0.86 ± 0.59 and 2.29 ± 1.13, respectively, and those for Q5 were 1.57 ± 1.11 and 1.00 ± 0.53, respectively. The mean values were small and not significantly different between the two conditions, indicating that the participants were not suggested the objective of the experiment.

4. DISCUSSION

The experiment aimed to assess whether tactile stimulation enhances embodiment. However, the results revealed no significant enhancement in the subjective responses to questionnaire items related to embodiment. A likely explanation for the minimal impact of haptic cues is that the high-quality visual stimuli provided by current virtual reality headsets are sufficient for achieving embodiment, a finding that aligns with [3]. The average scores for the questionnaire items without tactile stimulation were 7.86, 8.14, and 7.43 for Q1, Q2, and Q3, respectively, which are already high and approach the maximum score of 9.

Some participants reported a noticeable discrepancy between the positions of the virtual and real spheres in their introspective reports after the experiment. This discrepancy could have led to a discernible visuo-tactile mismatch, rendering the tangible spheres ineffective in enhancing embodiment. Moreover, we found no evidence suggesting that this mismatch negatively impacted embodiment.

Some participants noted that in the tangible condition, the physical presence of the seen spheres was more pronounced than in the non-tangible condition. Their comments indicate that while the tangible condition may have enhanced the sense of immersion in the virtual space, it did not increase the embodiment of the seen hand. Regrettably, we did not include questionnaire items about the presence of the spheres in our experiment, and thus, we lack data to support this observation.

5. CONCLUSION

In this study, we were unable to confirm a positive effect of tactile stimulation on the operator's hand regarding embodiment with the CG hand in the virtual reality environment. These experimental results suggest that under typical conditions of use, body ownership of the CG hand is sufficient without tactile stimulation. However, we hypothesize that under certain conditions, the presence of tangible objects may enhance embodiment in virtual spaces. We intend to explore these conditions in future research.

ACKNOWLEDGMENT

This study was in part supported by MEXT Kakenhi (23H04360 and 20H04263).

REFFERENCES

[1] V. Yem, R. Nashiki, T. Morita, and Y. Ikei, Vehicle-ride sensation sharing system with stereoscopic 3D visual perception and vibro-vestibular feedback for immersive remote collaboration, Advanced Robotics, 36(20), pp.1087–1099, 2022.

[2] K. Shimatoh, Y. Goto, and S. Okamoto; Drone rider: Enhanced feelings of flying using a vibratory and passively inclining foot plate, Proceedings of IEEE/SICE International Symposium on System Integration, pp. 1217–1218, 2024.

[3] R. Hanashima and J. Ohyama; How to elicit ownership and agency for an avatar presented in the third-person perspective: The effect of visuo-motor and tactile feedback, Proceedings of International Conference on Human-Computer Interaction, pp. 111–130, 2022.
[4] M. Slater, B. Spanlang, M. V. Sanchez-Vives, and O. Blanke; First person experience of body transfer in virtual reality, Plos One, 5(5), p. e1056 4, 2010.
[5] A. Maselli and M. Slater; The building blocks of the full body ownership illusion, Frontiers in Human Neuroscience, 7, p. 83, 2013.
[6] M. Slater, D. P. Marcos, H. Ehrsson, and M. V. Sanchez-Vives; Towards a digital body: the virtual arm illusion. Frontiers in Human Neuroscience, 2, p. 6, 2008.
[7] M. Botvinick, J. Cohen; Rubber hands 'feel' touch that eyes see, Nature, 391, p. 756, 1998.
[8] H. Hasegawa, S. Okamoto, K. Itoh, M. Hara, N. Kanayama, and Y. Yamada; Self-body recognition through a mirror: Easing spatial-consistency requirements for rubber hand illusion; Psych, 2(2), pp. 114–127, 2020.
[9] M. Hara, P. Pozeg, G. Rognini, T. Higuchi, K. Fukuhara, A. Yamamoto, T. Higuchi, O. Blanke, and R. Salomon; Voluntary self-touch increases body ownership, Frontiers in Psychology, 6, p. 1509, 2015.
[10] A. Kawaguchi, Y. Abe, S. Okamoto, Y. Goto, M. Hara, and N. Kanayama; Asura hands: Own and control two left hands in immersive virtual reality environment, Proceedings of IEEE International Conference on Robot and Human Interactive Communication, pp. 1347–1352, 2023.
[11] A. Kawaguchi, S. Okamoto, and M. Hara; Test of independence model between body ownership and agency in a virtual reality environment, Proceedings of IEEE Global Conference on Consumer Electronics, pp. 698–700, 2023.
[12] Patrick Haggard; Sense of agency in the human brain. Nature Reviews Neuroscience, Vol. 18, pp. 196–207, 2017.
[13] M. Tsakiris, G. Prabhu, and P. Haggard; Having a body versus moving your body: How agency structures body-ownership. Vol. 15, No. 2, pp. 423–432, 2006.