Effect of Shifting Own Hand Position in Virtual Space on Mental Body Model

Hikari Kobayashi[1(✉)], Miki Matsumuro[2], Fumihisa Shibata[2], and Asako Kimura[2]

[1] Graduate School of Information Science and Engineering, Ritsumeikan University, Kusatsu, Japan
kobayasi@rm2c.ise.ritsumei.ac.jp

[2] College of Information Science and Engineering, Ritsumeikan University, 1-1-1 Noji-Higashi, Kusatsu, Shiga 525-8577, Japan

Abstract. People have knowledge and images of their bodies called the mental body model. Several studies have revealed that the mental body model is changed based on visuo-tactile information, which changes behavior. Virtual reality (VR) and Augmented Reality (AR) technologies have attracted significant attention in various fields. Here, one may identify with a virtual avatar that has a different structure than one's actual body, or one's own body may be displayed differently from the actual position. Such visual changes in a body may affect the mental body model. This paper investigates whether and what extent we could change it by manipulating the visual position of the body parts in virtual space. We answered the following two research questions by analyzing the behavioral changes of the participants. One was whether visual or proprioceptive information was more weighted to determine the movement of the body. Another was whether the participant's movement in the target action changed after they completed a task by observing their bodies at different positions than at the actual position. The results showed that people relied on visual information more than proprioceptive information for determining body movement, and larger visual image of position changes led to a larger change in latter behaviors. This study revealed the possibility that the mental body model can be changed by controlling a visual image of the body.

Keywords: Mental body model · Virtual reality · Multimodality

1 Introduction

People have knowledge and image of their bodies called the mental body model, which includes information about one's body, such as where their limbs are, what the color of their bodies are, and how much their limbs weigh. With this model, we can recognize our body states, even though our eyes are closed. By integrating mainly visual and proprioceptive information, a mental body model is updated through action and even when we do nothing [1]. This process sometimes constructs a model that is different from the actual body. Rubber Hand Illusion is an example of such an incorrect update of the body model, where the synchronous visuo-tactile stimulation makes participants feel

M. Kurosu (Ed.): HCII 2021, LNCS 12762, pp. 562–570, 2021.
https://doi.org/10.1007/978-3-030-78462-1_43

the rubber hand as a part of their body [2]. The distorted body model would affect their behavior because people usually decide their actions based on the relationship between the external world and the mental body model [3]. In some cases, it leads to their limb hitting something and fail to grab something.

In some virtual environments, users must change their mental body model. For example, one may identify with a virtual avatar that has a different structure than one's actual body, or one's own body may be displayed differently from the actual position [4, 5]. In many cases, users use their bodies to operate such an avatar or own body in virtual reality (VR). Thus, it is essential to adapt the mental body model to the avatar or body in VR to move them quickly and accurately. Using the operator's mental body model for his/her actual body may cause unexpected problems. For example, when your arm is elongated in the virtual space, if you swing your arm as usual, your virtual arm will then hit the unintended objects in the virtual space.

In this study, we focused on the position of body parts in the mental body model and explored whether and to what extent we could change it by manipulating the displayed position of the body parts in virtual space. We answered the following two research questions by analyzing the participant's behavioral changes. One was whether visual or proprioceptive information was more weighted to determine the body movement. Another was whether the participant's movement in the target action changed after they completed a task by observing their bodies at different positions than at the actual position.

2 Experiment

2.1 Experimental Settings

Figure 1 shows an experimental setup. We used a head-mounted display (HMD; HM-A1, Canon, Tokyo, Japan) to present a visual stimulus to the participants.

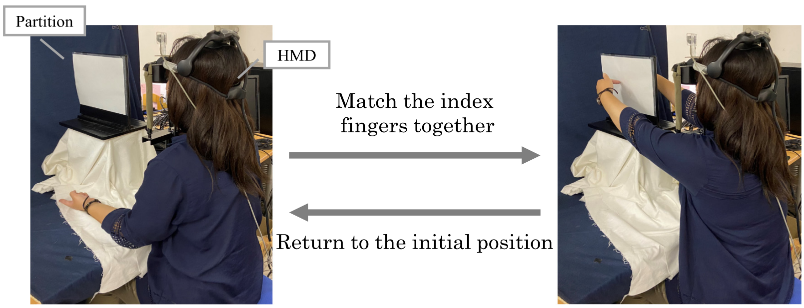

Fig. 1. Procedure of fingers touching task.

In the experiment, the participants touched their left and right fingers together at the front partition to stay at the same height (Fig. 1). Their right hand and left hand were displayed in the right half area and left half area of the participant's view from the camera on the HMD, respectively.

HMD consists of two cameras, each placed at the position of the left and right eyes. In this experiment, we used only the images acquired by one of the two cameras. The image to be used was randomly decided for each participant. We shifted the left half of the acquired image down and the right half up. We defined 0% of the shift amount as when we did not shift the image at all, and 100% as when the acquired image was displayed out of the HMD (Fig. 2). We used five levels of shift (0%, 5%, 10%, 15%, and 20%; Fig. 3).

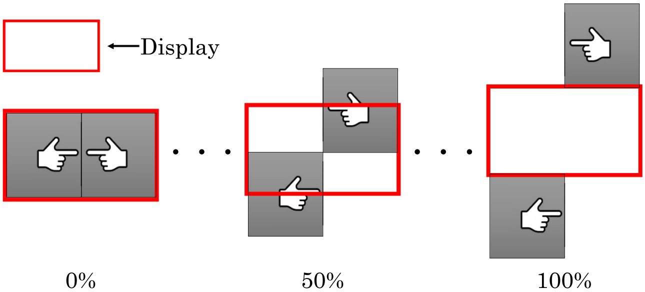

Fig. 2. Shift amount and display size.

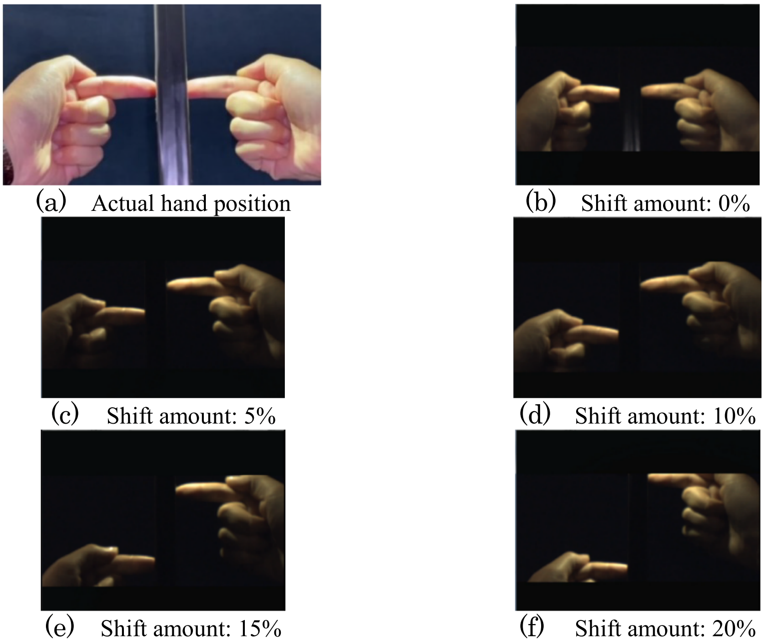

Fig. 3. Fingers in real and displayed fingers in each shift amount.

2.2 Participants

Three males and nine females participated in this experiment. All participants had normal or corrected-to-normal vision ($M = 22$ years old, $SD = \pm 0.426$). Nine participants were right-eye dominant and three participants were left-eye dominant.

2.3 Procedure

Each condition consists of three phases: pre-test, post-test, and training between them. In all phases, participants touched their left and right index fingers together at the front partition to stay at the same height as shown in Fig. 1. We recorded the positions of their left and right fingers when their fingers touched the partition.

Before the pre-test, the participants touched their left and right index fingers together at the front partition twice. In this phase, they did not wear the HMD and observed their hands carefully to align their index finger at the same height. This was conducted to cancel the effect of the preceding condition on the mental body model.

Then, the participants wore the HMD and touched their left and right index fingers together at the front partition with nothing displayed on the HMD. They were asked to move their hands based on their mental body model. This means the pre-test, measuring the baseline behavior before the training. The participants repeated this task three times.

After the pre-test, the participants touched their left and right index fingers together at the front partition while observing an image shifted with one of the shift amounts via the HMD as the training. They were not told that the images were shifted. We instructed them to move their fingers depending on their vision and proprioceptive information. We conducted this task five times.

Finally, the participants touched their left and right index fingers together at the front partition with nothing displayed on the HMD as in the pre-test. This indicates the post-test, measuring the behavioral change from the pre-test. The participants repeated this task three times.

The above procedure was conducted once for each shift amount. We randomized the order of five conditions for each participant. To reduce the effects of the preceding condition and physical fatigue, we gave five-minute rest between conditions. After completing all conditions, the participants commented on how accurately they could move their hands and whether they noticed the shifts in the images.

2.4 Evaluation

In this experiment, we analyzed the vertical difference between the left and right fingers calculated by subtracting the vertical position of the right finger from that of the left finger. The horizontal difference was not considered because we manipulated the image only in the vertical direction. The value of the vertical difference indicates how far the fingers are placed to each other. It was a negative value when the right hand was positioned higher than the left hand and a positive value when the left hand was positioned higher than the right hand. The vertical differences were averaged over in each pre-test, training, and post-test phase.

2.5 Results

The acquired data showed the same pattern regardless of the used camera and the dominant eye. Thus, we excluded those factors in the following analyses.

Training. Figure 4 shows the vertical difference in the training phase. In all conditions, the data distribution satisfied the normality assumption; all *p*-values in Shapiro-Wilk tests were larger than 0.200. ANOVA revealed a significant main effect of shift amount ($F_{(4,44)} = 222.387, p < .001$). Multiple comparisons with Bonferroni correction showed significant differences between all pairs (all $p < .010$). The vertical differences became larger as the shift amount increased.

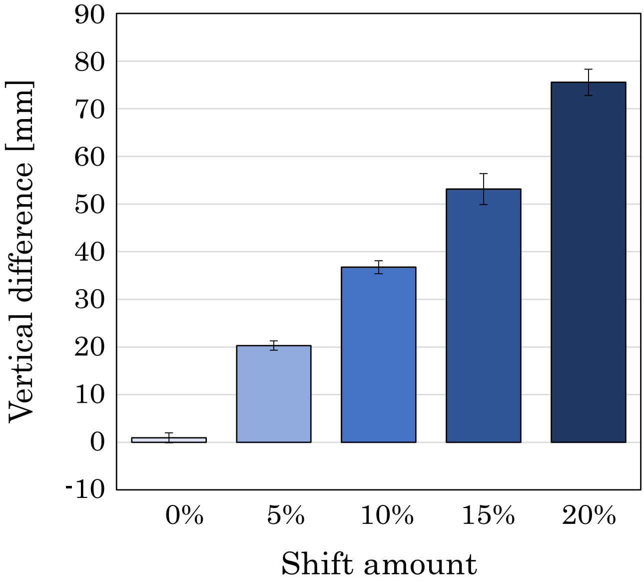

Fig. 4. Vertical difference in training phase.

Most participants moved their fingers to where their fingers matched each other in the manipulated image in the shift amounts. Only a few participants felt something strange in 15% and 20% conditions and tried moving their hands based on the proprioceptive. However, none of them could match their fingers at the same height in the shift amounts, except for the 0% condition. After the experiment, most participants answered that they did not notice the shifts in the images.

Change from Pre-test to Post-test. We calculated the change in the vertical difference from the pre-test to the post-test. Using this change, we analyzed how participant's behaviors changed through the task where they observed their bodies at different positions from the actual position. The change of the vertical difference was defined as the signed difference calculated by subtracting the vertical difference in the pre-test from that in the post-test.

Figure 5 shows the change of the vertical difference for each condition. In some conditions, the data distribution did not satisfy the normality assumption; Shapiro-Wilk tests showed almost significance ($p \leq .05$). We compared the change of the vertical difference among conditions using the Friedman test. There was a high significant effect of the shift amount (x^2 (4) = 34.929, $p < .001$). We performed multiple comparisons using the Wilcoxon signed-rank test with Holm's method to adjust the p-value. The change in 15% and 20% conditions was significantly larger than in 0% condition (both $p = .025$) and the change in 20% condition was significantly larger than that in 10% condition ($p = .031$). The differences between 0% and 5% conditions and between 0% and 10% conditions were marginally significant (both $p = .065$). There was a marginally significant difference between 5% and 20% conditions ($p = .053$), 15% and 20% conditions ($p = .076$), and 10% and 15% conditions ($p = .067$). In short, except for 5% and 10% condition, and 5% and 15% condition, the differences in all pairs were (marginally) significant.

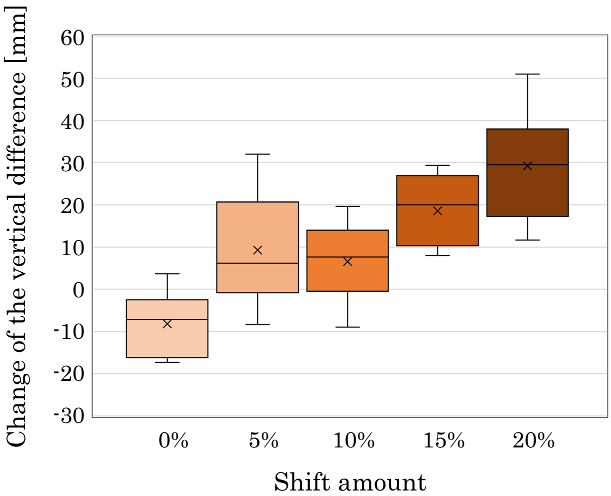

Fig. 5. Change of vertical difference from the pre-test to the post-test.

The vertical differences became bigger in the post-test in the shifted conditions (5%, 10%, 15%, and 20%) than in the baseline condition (0%), which was (marginally) significant. This result indicates that the participants started moving their hand higher through the training task where their hand had been displayed lower and vice versa. After the experiment, most participants answered that they could align their fingers at the same height more accurately in the post-test than in the pre-test.

3 Discussion

In this study, we investigated the effects of manipulating the body part's visual position on the mental body model based on behavioral changes. We had the following two research questions. One was whether visual or proprioceptive information was more weighted to determine the body movement. Another was whether the participant's movement changed after they completed the task by observing their bodies at different positions than the actual position.

3.1 Dominance of Visual Information

We analyzed the vertical difference in training to answer the first question: whether visual or proprioceptive information was more weighted to determine the body movement. If visual information is more weighted, the vertical difference would increase as the visual position of the hand shifted larger. However, if proprioceptive information is more weighted, the vertical difference would be constant regardless of the visual shift of the hand.

The experimental results showed that as the visual position of the hand was shifted largely, the vertical difference also increased. The participants moved their fingers so that the fingers displayed on the HMD were located at the same height. In the experiment, most participants answered, "I mainly used visual information to match my fingers." and "I felt that I could match my fingers at the same height more accurately using visual information." These results showed that the participants relied on visual information more than proprioceptive information for determining body movement.

This result is consistent with many previous studies demonstrating visual dominance. Researchers have shown that vision is the dominant sense and human has a bias toward visual information; e.g., visual dominance over the auditory (e.g., the McGurk effect [6]) and over haptics [7]. Similarly, visual information dominated the participants' performance in this study. They did not even notice that their vision was manipulated although the position of each hand was about 4 cm distance from the actual position in maximum.

In our experiment, we obtain that the larger the shift amount, the more the vertical difference increased. A few participants started feeling something strange in 15% and 20% conditions and tried moving their hands based on the proprioceptive information. As a result, they had smaller vertical differences in those conditions compared to the other participants. In a previous study on the RHI, if the rubber hand was placed too far from one's hand, it was not easy to induce body ownership for the rubber hand, resulting in that drift could have not occurred [8]. It means that the vertical difference could not increase or could decrease if the shift amount is greater than 20%; although we were not able to test more than 20% because of the limitation of our HMD. We need further investigations about when most participants realize the gap between the visual and proprioceptive information and rely on the proprioceptive information.

3.2 Change of Body Mental Model

By comparing the vertical difference in the post-test with that in the pre-test, we answered the second question: whether the participant's movement changed after they completed a task by observing their bodies at different positions than at the actual position. In the experiment, after they observed their hands in a higher (or lower) position than the actual, the participants started moving their fingers to a lower (or higher) position than they did before the observation. This result suggests that the hand position in the mental body model has been modified upward (or downward) by experiencing the task with visually manipulated hand position. The vertical difference could have increased because they used such a modified mental body model to estimate the hand position in the post-test where visual information was not available.

The effect of the training task with the distorted vision was strong, which could change the behavior in the dynamic task. Most previous studies used subjective position measurements of the manipulated body part without moving it after the task that corresponds to the training of this study [2, 9, 10]. When the body moved, we can acquire various and plenty proprioceptive information that might lead us to easily estimate the correct body posture. If the body mental model modification is not robust, it could not affect the post-test task behavior. The robust modification was also shown from that we observed the change in the vertical difference in all three trials in the post-test.

There were two possible reasons why such robust modification occurred. First, the participants moved both hands relatively comparing those positions, while most of the previous studies focused on a single body part. This task could permit the participants to modify their mental models by integrating relative positional information, which convinced them that the modified mental body model was correct.

The second reason was that the proposed method could keep the participants' body ownership sufficiently high. In previous studies, researchers used a fake or virtual body and only when the participants felt it was a part of their body, the drift occurred. This method was adopted because they were interested in the body ownership itself. However, inducing the body ownership was out of our interest, and we used the real-time video image of the participants' real hands (Fig. 3). Previous studies have emphasized that the reality and synchronized movement with the participants' hands were essential in increasing the body ownership of an object [4, 11, 12]. Thus, the participants had strong ownership toward the displayed hand from the beginning of the training phase and could change their mental body model robustly after five trials.

One limitation of the experiment was that our task was almost identical in all phases. It leads to the possibility that the participants learned the movement in the training phase and replicated it in the post-test. The comments after the experiment suggested that the participants did not replicate the movement in the training phase in the post-test but rather moved their fingers using their mental body model. If the participants replicated the movement in the training phase, the vertical difference in the post-test must be larger. In future work, we must use other tasks in the training phase or for the pre-tests and post-tests to confirm this point.

4 Conclusion

In this study, we focused on the position of body parts in the mental body model and explored whether and what extent we could change it by manipulating the displayed position of body parts. We answered the following two research questions by analyzing the participants' behavioral changes. One was whether visual or proprioceptive information was more weighted to determine the body movement. Another was whether the participant's movement in the target action changed after they completed a task by observing their bodies at different positions than at the actual position. We confirmed that participants relied on visual information more than proprioceptive information to determine body movement. After performing the task with hand movements, relying on distorted visual information, their behavior changed even without visual information. Such change increases as the distortion in the training task increases. This study showed that we can easily and robustly modify the mental body model through the dynamic task with both hands' movement under the distorted vision.

References

1. Carruthers, G.: Types of body representation and the sense of embodiment. Conscious. Cogn. **17**(4), 1302–1316 (2008)
2. Botvinick, M., Cohen, J.: Rubber hands 'feel' touch that eyes see. Nature **391**(6669), 756 (1998)
3. Warren, W.H.: Perceiving affordance: visual guidance of stair climbing. J. Exp. Psychol. Hum. Percept. Perform. **10**(5), 683–703 (1984)
4. Hoyet, L., Argelaguet, F., Nicole, C., Lecuyer, A.: Wow! I have six fingers!: Would you accept structural changes of your hand in VR? Front. Robot. AI **3**(27), 1–12 (2016)
5. Kasahara, S., et al.: Malleable embodiment: changing sense of embodiment by spatial-temporal deformation of virtual human body. In: CHI 2017 Proceeding of the 2017 CHI Conference on Human Factors in Computing Systems, pp. 6438–6448. Association for Computing Machinery, United States (2017)
6. McGurk, H., MacDonald, J.: Hearing lips and seeing voices. Nature **264**(5588), 746–748 (1976)
7. Ernst, M.O., Banks, M.S.: Humans integrate visual and haptic information in a statistically optimal fashion. Nature **415**(6870), 429–433 (2002)
8. Lloyd, D.M.: Spatial limits on referred touch to an alien limb may reflect boundaries of visuo-tactile peripersonal space surrounding the hand. Brain Cogn. **64**(1), 104–109 (2007)
9. Slater, M., Perez-Marcos, D., Ehrsson, H.H., Sanchez-Vives, M.V.: Towards a digital body: the virtual arm illusion. Front. Hum. Neurosci. **2**(6), 1–8 (2008)
10. Slater, M., Perez-Marcos, D., Ehrsson, H.H., Sanchez-Vives, M.V.: Inducing illusory ownership of a virtual body. Front. Neurosci. **3**(2), 214–220 (2009)
11. Ogawa, N., Narumi, T., Hirose, M.: Virtual hand realism affects object size perception in body-based scaling. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR), pp. 519–528. IEEE, Japan (2019)
12. Lin, L., Jörg, S.: Need a hand? How appearance affects the virtual hand illusion. In: Proceedings of the ACM Symposium on Applied Perception, pp. 69–76. Association for Computing Machinery, Anaheim California (2016)