Avatar Embodiment beyond Individual Body: Invisible, Asymmetric, Scrambled, and Shared Bodies

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ABSTRACT

Virtual reality (VR) enables us to have illusory body ownership of avatar in various forms. Psychological studies were performed on an invisible, asymmetric, scrambled, and remapped bodies using VR avatars. A shared body avatar controlled by two individuals was created, and its embodiment and motor behavior were investigated. These studies could update our perspective of the body in a future.

1 Introduction

What is the self? It is one of the fundamental issues in cognitive sciences and psychology. Gallagher (2000) divides the self into two concepts, the minimal self and the narrative self [1]. The minimal self is the self at a certain point in time, and its minimal components are considered to be the sense of agency and the sense of body ownership. The sense of agency is the feeling that one acts by oneself with intention [2]. The sense of body ownership is the feeling that the body you are experiencing belongs to you [3]. The narrative self, on the other hand, includes memories of the past and intentions for the future. In particular, research on the former has gained attention and is rapidly progressing due to the development of cognitive neuroscience and virtual reality (VR) [4,5].

There are two methods to induce illusory body ownership: One is visual and tactile integration, and the other is visuo-motor synchrony. The rubber hand illusion is induced by the visual and tactile integration [6]. When participants observe the rubber hand without seeing the actual hand, and both the rubber hand and the actual hand are stroked by paint brushes synchronously, they feel as if the rubber hand is their own hand. When participants observe their avatar in the first-person perspective and in a mirror in front of them in a virtual environment, they feel as if the virtual avatar is their own body if the movements of the avatar is synchronized with the participants' actual movements [7]. The VR technology enables us to synchronize various avatars' movements with participants motor action. Changing one's appearance in VR can change one's behavior and social attitude [8] so that studies on the sense of body ownership in VR are increasing.

We can have illusory ownership to various bodies of virtual avatars in virtual environments (Avatar Embodiment). This paper introduces psychological studies on avatar embodiments towards invisible, asymmetric, scrambled, re-mapped, and shared bodies.

2 Invisible body

Only the hands and feet (gloves and socks) were presented in a virtual environment and observed on a head-mounted display (HMD), and the participant performed full body movements for 5 min. Then, participants perceived a transparent full body as interpolated between the hands and the feet, and they had a sense of body ownership to it (Fig. 1) [9]. When the limb-only avatars were synchronized with the body movements, both the sense of body ownership and the sense of agency were induced, and higher than in the asynchronous condition. In this study, since the participants were presented with the limb-only avatar 2 m in front of them, they had a feeling of illusory our-of-body experience similar to Lenggenhager, et al. (2007) [10]. Proprioceptive self-localization as a behavioural measurement significantly drifted toward the limb-only avatar. The sense of body ownership of the invisible body had no significant difference from that of a full-body avatar. However, there was no significant difference in the skin conductance response (SCR) to a threat stimulus as a physiological measurement between synchronous and asynchronous conditions.

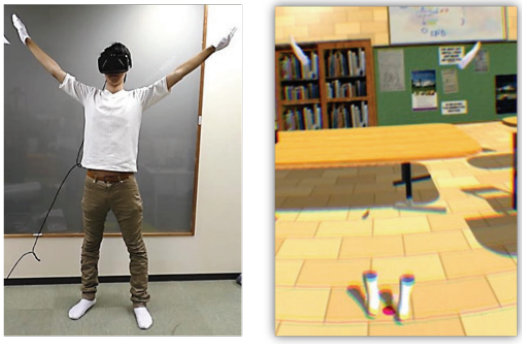

Fig. 1 Invisible body [9]. (Left) Participant's posture. (Right) Only the hands and feet were presented.

3 Asymmetric body

The advantage of limb-only avatar is that the whole

body does not need to be rendered, and top-down strange feeling or uncanniness caused by difference or mismatch between the own body appearance and the avatar appearance is less likely to occur. Since the body between the hands and feet is automatically interpolated by the participants' brain, it is presumed that the optimal body image is generated by each participant.

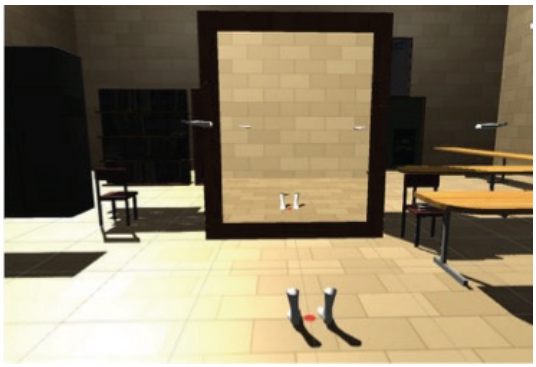

Fig. 2 Asymmetric body avatar with the hands and feet [11]

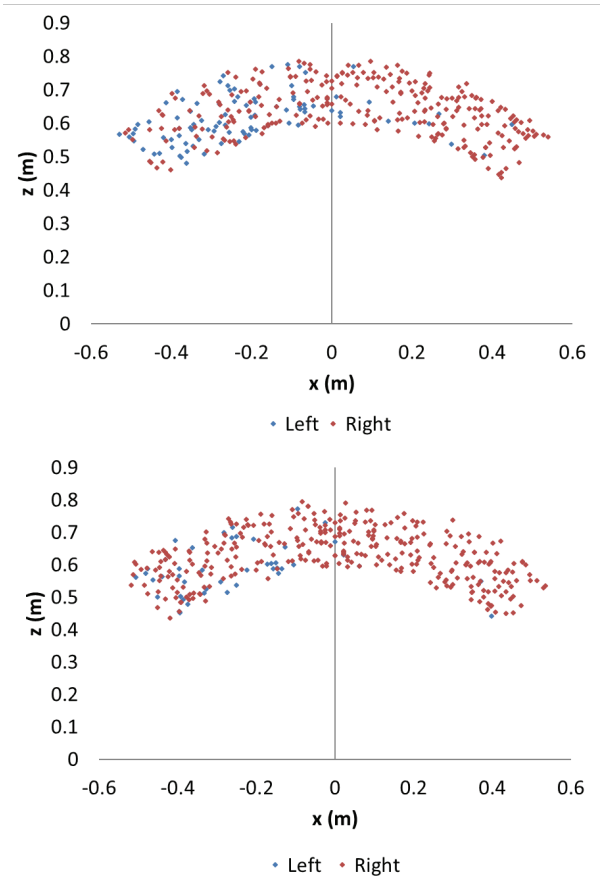

Fig. 3 Reaching locations of the long right arm condition during learning. Red points were reached by the right (long) arm, blue points were reached by the left arm. The top is the first period and the bottom is the final (fourth) periods.

Therefore, we investigated whether it is possible to possess and use a body with different left and right arm lengths by placing only one hand farther away from the other (Fig. 2) [11]. We found that the participants were able to feel a sense of ownership of the body with different left and right arm lengths if their visual image and own movement were synchronized, and they gradually changed their behavior to use the longer arm more in the task of reaching balls that appeared around the body (Fig. 3). In other words, the participants acquired a body scheme with different limb lengths, and their behavior was optimized for it.

4 Scrambled body

Although a sense of whole-body ownership of a transparent body was obtained from visual-motor synchronization of only the limbs, it is unclear whether visual-motor synchronization is a necessary and sufficient condition. Therefore, we conducted a study based on the hypothesis that a global limb arrangement/layout is necessary for whole-body ownership, while only visual-motor synchronization is sufficient for ownership of limb parts [12]. We conducted an experiment using a stimulus with scrambled limb positions (scrambled body) as a comparison stimulus to a normal limb-only avatar (with global arrangement) (Fig. 4).

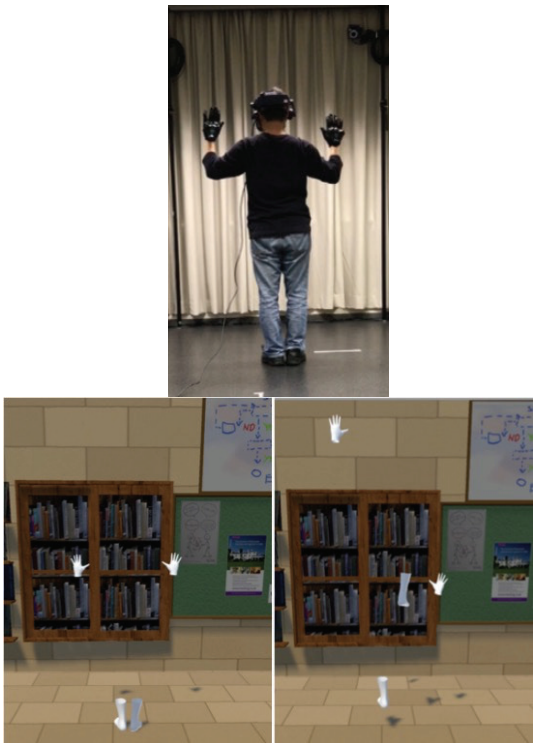

Fig. 4 Scrambled body [12]. (Top) Participant's posture. (Bottom left) Normal arrangement of the hands and feet. (Bottom right) Scrambled arrangement of the hands and feet.

We found that a sense of ownership of body parts but not of the whole body was perceived when the scrambled body was synchronized with participants' motion, while both a sense of ownership of body parts and a sense of ownership of the whole body were induced by the limb-only avatar with the same global arrangement as usual. In both cases, when the limb-only avatar and the participants' body movement were asynchronous, the sense of ownership did not occur. In other words, we succeeded in separating the whole-body ownership from the body-part ownership depending on whether there is a global arrangement of limbs or not [12]. These phenomena occur both in avatars from the first-person perspective and in out-of-body experiences from the third-person perspective, suggesting that the synchronized motion of limbs plays an important role in the sense of body ownership.

5 Re-mapped body

The bodies we have introduced so far are controlled by virtual hands and feet by actual hands and legs, respectively. On the other hand, in MetaLimbs, the third and fourth arms (robot arms) are controlled by the feet [13]. We investigated the possibility of remapping such body parts. When the right thumb was mapped to the virtual left arm and synchronized movements were performed, a sense of ownership was induced in the virtual left arm, and the right thumb felt like the left arm (Fig. 5) [14]. This suggests that remapping is possible to some extent even when the body parts are on contralateral sides of the body, and even when the body hierarchy is different between fingers and arms. This might be due to the fact that the number of joints is matched and the direction of motion of the hand is similar to that of the arm. When the finger motion and the virtual arm motion were asynchronous, no sense of body ownership was perceived.

Fig. 5 Body parts remapping [14].

6 Shared body

In most embodiment studies, one participant manipulates or has a sense of ownership of one avatar. Hagiwara et al (2020) used a full-body motion capture to precisely measure the whole-body movements of two participants and fuse them into a single avatar that is called as shared-body avatar [15]. The whole-body movements of two participants were averaged into the shared-body avatar, and allows each participant to observe the shared avatar as if it were their own body (Fig. 6) [15].

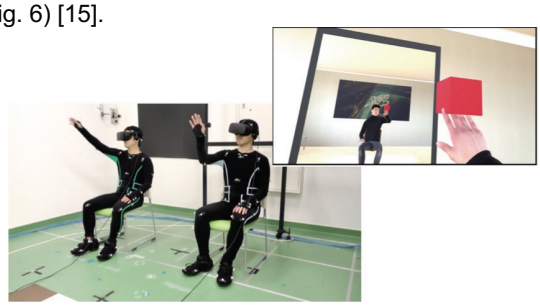

Fig. 6 Setup of the shared-body avatar [15].

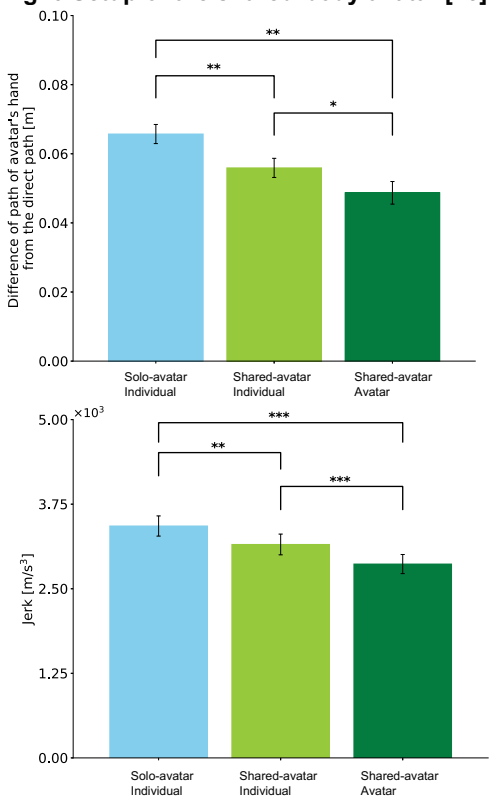

Fig. 7 Reaching results of the shared-body avatar. (Top) Difference between the reaching path length and the direct path. (Bottom) Jerk of reaching movements.

The participant's task was to reach an object that appeared at a random position, and there were two conditions: one in which the participant 's own movements were reflected 100% (individual body avatar), and one in which the participant s movements were reflected 50% each with a partner (shared-body avatar). We found that the sense of agency for the shared-body avatar was lower than that for the individual body avatar, but the percentage of agency reflected in the shared body avatar was evaluated to be higher than 50%, and a certain degree of body ownership was also induced. The

movements of the shared body avatar became more linear and the jerk was smaller than the movements of the individual participant operating it or the individual body avatar (Fig. 7). Thus, the movements of the shared-body avatar became straighter and smoother. This suggests that the participants implicitly optimize and prioritize the movement of the shared-body over their own movement.

7 Discussion

I introduced various types of avatar embodiments. Invisible full-body ownership can be induced by synchronous movements of only the hand and feet. Body ownership can be induced to the asymmetric body avatar by re-locating one of the hands, and participants' reaching behavior gradually changed to optimize actions. Virtual left arm controlled by the actual right thumb was perceived as own body, and re-mapping of body parts can be realized. Beyond individual, the shared body controlled by two persons induced the illusory sense of body ownership, and the shared-body avatar's motion was straighter and smoother than the individuals. Participants implicitly optimize and prioritize the movement of the shared-body over their own movements.

When people own a new body different from their original one, and their appearance and the mode of its operation change, there will be an update in the view/perspective of the body [16,17]. It is important to investigate human mind and society after updating our perspective of the body. Such study can be performed by integrating virtual reality and cognitive sciences.

8 Conclusions

VR enables us to have a sense of ownership to various bodies such as the invisible, asymmetric, scrambled, remapped, and shared bodies. We should investigate how our mind, behavior, and society are affected by utilizing such various bodies.

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