

Embodiment from Virtual Hands-and-feet Movements during walking

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Abstract

This study investigated the influence of global self-motion (walking) on the sense of whole-body ownership induced by virtual hands-and-feet stimuli that moved synchronously with participants. Participants were exposed to normal and scrambled arrangements of hands and feet, while performing reaching tasks with or without walking. Results showed that scrambled hand-and-feet arrangements significantly decreased the sense of part-body ownership, whole-body ownership, invisible body perception, and agency. It did not significantly improve whole-body or part-body ownership. These findings suggest that global self-motion might not be a crucial factor in enhancing body ownership, and further research is needed to explore alternative methods for improving the embodiment.

CCS Concepts

• *Human-centered computing* → *Virtual reality*;

1. Introduction

The synchronization of vision and tactile stimulation, or visual-motor synchronization, induces a sense of embodiment [MS13]. The rubber hand illusion is caused by the synchronous brushing of an invisible hand and a rubber hand in front of the participant with a brush [BC98]. The virtual embodiment resulting from an avatar in a virtual mirror moving in synchrony with the observer's own body is attributable to visual-motor synchronization [GFPMS10]. This method can induce a sense of embodiment in bodies of varying colors, shapes, and sizes [IUK*22] [CLN*23]. The presentation of only the hands and feet in synchronization with body movements results in the generation of a sense of ownership of the transparent whole body [KSM*18]. However, when the limbs are scrambled, a sense of limb ownership is perceived, but not of the whole body [KTS*20]. It is therefore proposed that the global spatial relationship of the limbs is a key factor in the experience of whole-body ownership. In addition to the sense of body ownership and agency, the sense of self-location has been identified as a constituent of the minimal self [LMB09] [BSS15]. It was therefore hypothesized that enhancing the sense of self-location would result in enhanced whole-body ownership.

We aimed to examine the effects of short walk or global self-motion on the whole-body ownership from virtual hands-and-feet stimuli synchronously moving with participants. We predicted that even in the scrambled arrangement, the sense of whole-body ownership could be enhanced by the short walk because the global self-motion improves the sense of self-location.



Figure 1: Normal hands and feet (Left) and its scrambled stimulus (Right).

2. Methods

Twenty-four participants performed the experiment after providing informed consent. The experiment was approved by the Ethical Committee for Human-Subject Research at the Toyohashi University of Technology. Participants observed the stimuli on a head-mounted display (HMD, HTC VIVE Pro EYE) and their body movements were measured by HTC VIVE trackers placed on the left and right wrists and ankles. In the normal body condition, the hands and feet were consistently located with the par-

participant's body. In contrast, in the scrambled condition, the hands and feet were randomly located within a certain range (Figure 1; [KTS*20]). In the constant condition, the participants reached balls that randomly appeared with hands or feet at a constant location. In the walk condition, they reached balls while walking left and right at a distance of two meters. After 3 min reaching task, they were asked to answer the 6-item questionnaire (Q1: It felt as if the virtual hands and feet were my hands and feet. Q2: It felt as if the virtual hands and feet were someone else's hands and feet. Q3: It felt as if the space between the virtual hands and feet was my body. Q4: I felt as if I could perceive an invisible whole body between the virtual hands and feet. Q5: The movement of the hands and feet seemed to be my movement. Q6: The movement of the hands and feet seemed to be someone else's movement.) All four conditions (normal/scramble bodies x constant/walk conditions) were performed in random order. We calculated the scores of part-body ownership (Q1-Q2), whole-body ownership (Q3), invisible body perception (Q4), and agency (Q5-Q6).

3. Results

We performed repeated measures ANOVA (Figure 2). The results showed that the scramble condition significantly decreased the sense of part-body ownership ($F(1,23)=52.50, p<0.001, \eta_p^2=0.70$), whole-body ownership ($F(1,23)=58.11, p<0.001, \eta_p^2=0.72$), invisible body perception ($F(1,23)=115.82, p<0.001, \eta_p^2=0.83$), and agency ($F(1,23)=24.01, p<0.001, \eta_p^2=0.51$). The short walk enhanced the sense of agency ($F(1,23)=10.57, p=0.004, \eta_p^2=0.32$), but did not have a significant effect on the whole-body ownership or the others.

4. Discussion

The normal arrangement of hands and feet induced higher embodiment of body parts and the whole body compared to the scrambled hands and feet. This is in line with the previous study [KTS*20]. Contrary to our prediction, the walking or global self-motion did not significantly improve either part-body or whole-body ownership. These results suggest that the sense of self-location might not affect the sense of embodiment. However, we should also be concerned that the short walk might not improve the sense of self-location. Another experimental manipulation of the sense of self-location should be applied in the future experiment.

5. Conclusions

We tested the effect of walking on the sense of ownership of body parts or the whole body using the virtual hands and feet that were moved synchronously with the participants. Embodiment was worsened by the scrambled hands and feet, which is consistent with the previous study. Walking did not affect the sense of body ownership.

Acknowledgements

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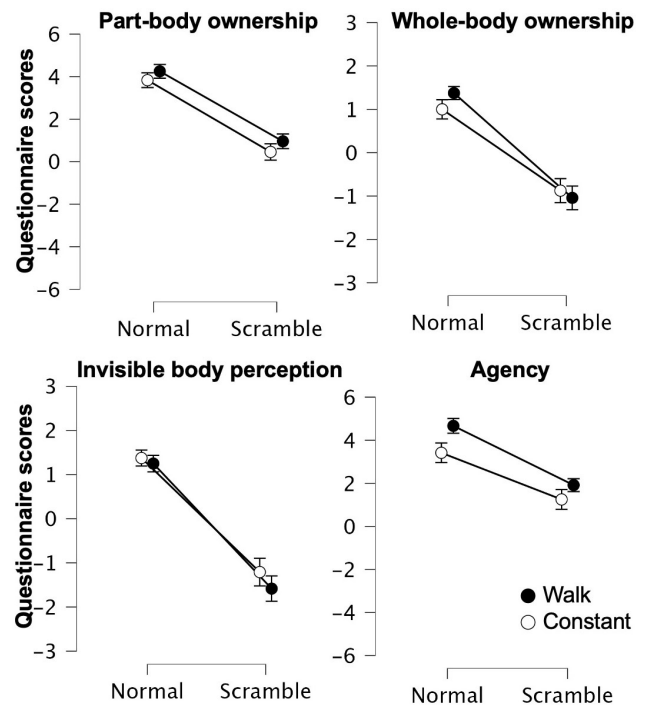


Figure 2: Results of the part-body ownership, whole-body ownership, invisible body perception, and agency.

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