

Evaluating Effect of Sense of Ownership and Sense of Agency on Body Representation Change of Human Upper Limb

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Abstract:

To improve rehabilitation of the diseases which are caused by the mismatch between real body and body representation, it is necessary to understand the mechanism of body representation change. It is assumed that sense of agency and sense of ownership are closely-related with body representation and influence body representation change of the body parts without visual information. We focused on human upper limb and performed experiment with participants on four condition related to sensitivity of agency and ownership. We measure perceived position change of elbow and finger by pointing judgement using motion capture. Visual stimulation which participants given is only virtual hand. Our experiment has revealed that sense of agency influence the body representation change on the body parts which is invisible to participants.

1. INTRODUCTION

Phantom limb is known as phenomenon that patients who lost their extremities often feel exists of their lost extremities. Phantom limb also occurs in patient with other diseases such as motor stroke. Phantom limb patients often feel pain on lost limb. It has been called phantom limb pain. It is regarded that phantom limb pain is caused by the mismatch between real body and own model of body in human brain [1]. In order to improve this situation, it is necessary to understand the relationship between the body model (body representation) in brain and real body. In this paper, body representation is defined as the location and locational relationship of perceived body parts that make up human body.

It is well known that the mirror therapy (rehabilitation using virtual information) is effective for treatment of phantom limb pain [2][3][4]. In mirror therapy, duplicated image of hand movement is shown to patients in the mirror and they feel as if the mirrored hand is their own hand. This rehabilitation can be regarded as eliminating mismatch between real body and body representation by intervening change of body representation. It can be considered that

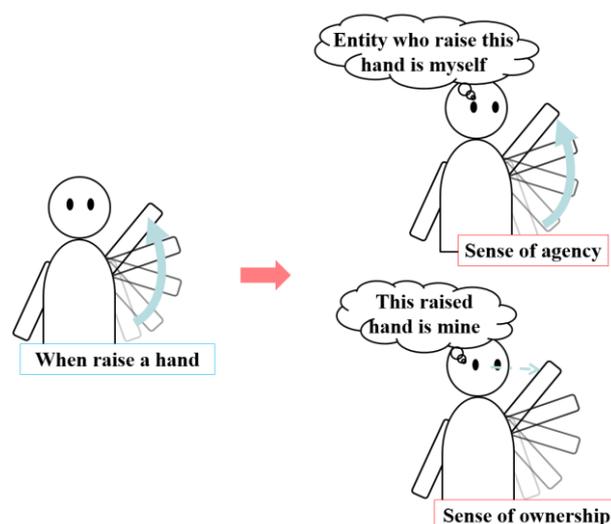


Fig.1 Sense of agency and sense of ownership

body representation change is influenced by the human perception; however, the mechanism has not been clarified.

Human subjective perception relevant to their own body is divided into two types, sense of agency and sense of ownership [5]. Sense of agency is the sense that “I am the one who is causing this action”, and sense of ownership is the sense that “this object is in fact my own”. Figure 1 shows the idea of sense of agency and sense of ownership. That is, in mirror therapy noted above, patients feel sense of agency and sense of ownership on a virtual hand and it is effective for eliminating mismatch between real body and body representation. It is implied that body representation is changed through feeling of sense of agency and sense of ownership.

As explained above, body representation is closely related to sense of ownership and sense of agency. The principal aim of our research is to investigate how the change of body representation is affected by feeling of ownership and agency. Some previous research address the body representation change in connection with sense of ownership and sense of agency with proprioceptive drift. Proprioceptive

drift is one of the phenomenon of body representation change. When human received synchronous stimulus on their invisible real hand and visual fake hand, it has been confirmed that human perceive hand position would move closer to a fake hand from the real hand position [6][7]. This drift has been called proprioceptive drift and it can be interpreted as the body representation change which is occurred by altered visual information and tactile information. In this case, altered visual information is the vision of stimulated fake hand at different position from invisible real hand and tactile information is the synchronized stimulus with the stimulus on fake hand.

Tsakiris et al. have reported that proprioceptive drift occurs only on a stimulated finger when participants do not feel sense of agency [8]. When participants felt sense of agency with voluntary movement, proprioceptive drift occurred across the whole hand. They had concluded that sense of agency is responsible for the coherence of body ownership. Their research was referable to the relationship between the body representation change and sense of agency or sense of ownership. However their investigation was limited only to hand and fingers. They compared proprioceptive drift between stimulated finger and unstimulated finger; however their experimental system could not eliminate the influence of visual information which is regarded as the most important information for human perception, because they used the fake hand which represents the whole hand. Furthermore, they had designed some experimental conditions; however, they did not consider the case that participants felt sense of agency and did not feel sense of ownership.

In this work, we focus on body representation change of body parts which is invisible to participants. To address the body parts which is invisible to participants, we focused on a human upper limb.

We propose a hypothesis that sense of agency and sense of ownership have an influence on body representation changes on the body parts without visual information. Moreover, sense of agency have larger effect on body representation change than sense of ownership. In order to test our hypothesis, we perform experiment with participants.

2. METHODS

2.1 Design

To investigate the change of the body representation, we designed experiment with participants. To prompt the change of body representation, participants were asked to make

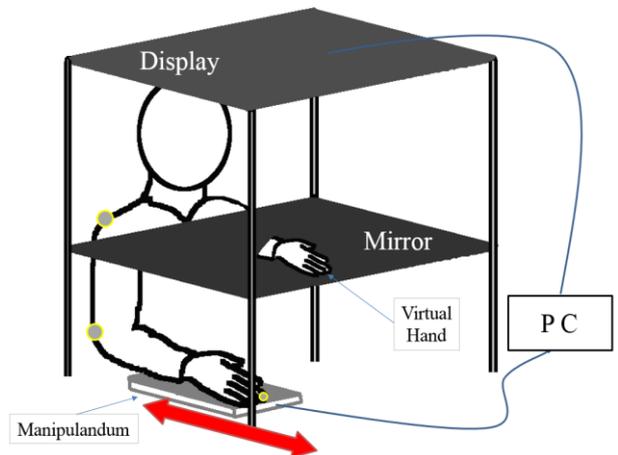


Fig. 2 Experimental device

some movement and the visual information which was displayed for participants during the movement was altered. Moreover, in order to test our hypothesis, it was necessary to setup experimental condition which affected the sensitivity of agency and ownership. We designed four conditions that humans feel both of sense of agency and sense of ownership, only one of them and neither of them. To evaluate the influence of sense of agency and sense of ownership, we compared the change of the body representation between four conditions.

2.2 Experiment

To focus on the upper limb, participants were asked to make larger movement than simple finger action. Therefore, we used manipulandum. Their hand on the manipulandum could move freely on 2D surface. We used virtual vision hand as altered vision feedback. A virtual hand was displayed on the mirror which was looked like existing 0.12 m ahead from their own real hand. Figure 2 shows the layout of experimental device.

To investigate the body representation change of upper limb, we examined the position of elbow. Before experiment, motion capture markers were put on participants right elbow, tip of the right middle finger and left index finger. We perform pointing judgement to investigate the perceived position of upper limb. In pointing judgement, participants were required to point a location which they perceived the position of the markers on their right upper limb were below with tip of left index finger. Experimenter measured the perceived position with the marker on participants left fingertip using motion capture.

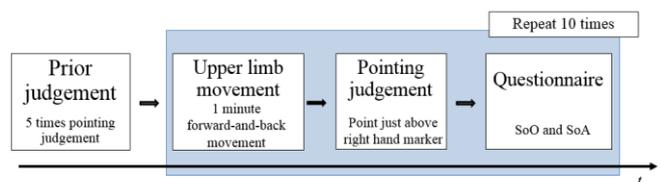


Fig. 3 Time line of the experiment

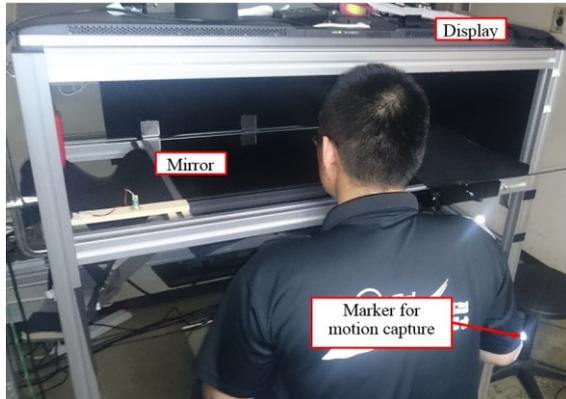


Fig. 4 Photograph of the experiment device

The experimental design was 2×2 factorial. First factor was the posture of the virtual hand (congruent and incongruent), second factor was agent of the movement (active or passive movement). Factors were designed based on previous research [9].

Figure 3 shows the timeline of the experiment in a condition. Prior to the movement, participants were required five times pointing judgement before displaying virtual hand (prior judgement). After prior judgement, participants started the movement. Participants moved their right upper limb on the manipulandum at a constant pace for 1 minute. The required movement was forward-and-back movement and it was controlled by indicator sound. During upper limb movement, the virtual hand was displayed. After upper limb movement, pointing judgement was performed. After pointing judgement, participants were required to answer questionnaire about whether participants felt sense of agency and sense of ownership (+3 - -3). Participants performed 10 repetition for each condition. The experimental design resulted in four conditions, all possible combinations of factors were performed in a different random order. The photograph of the experiment device is shown in Fig. 4.

2.3 Participants

Eleven right-handed healthy volunteers (mean age 36.8 years, $SD = 10.7$) participated on the basis of informed

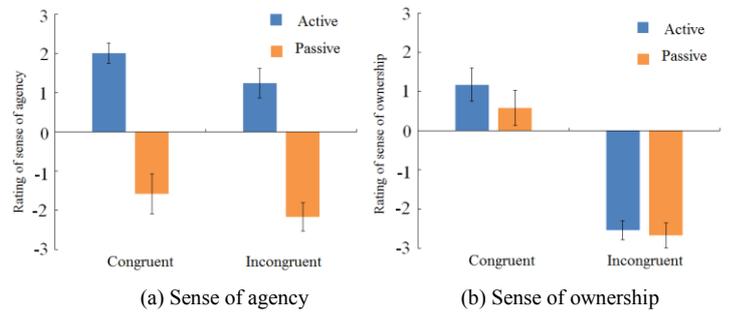


Fig. 5 Results of questionnaire

consent.

3. RESULTS

3.1 Reasonableness of factor

First, we assessed the result whether the experimental factors affect sense of agency and sense of ownership by comparing the results of questionnaire judgement for each condition, using 2×2 repeated measures ANOVA. Figure 5 shows the results of questionnaire and error bars indicate standard error. In questionnaire about sense of agency, only the main effect of movement condition (active or passive) was significant ($F(1, 10) = 37.12, p < .01$). In contrast, only the main effect of posture condition (congruent or incongruent) was significant ($F(1, 10) = 65.67, p < .01$) in sense of ownership questionnaire. There was no significant interaction in both agency and ownership. These results of analysis show that our experimental factors were affect sense of agency and sense of ownership. It is reasonable to support that participants feel both sense of agency and sense of ownership in congruent and active condition. Likewise, they feel only sense of ownership in congruent and passive condition, only sense of agency in incongruent and active condition and neither sense of agency nor sense of ownership in incongruent and passive condition.

3.2 Body representation change

We next investigated body representation change from the change of the positional relationship between perceived fingertip and elbow from the results of pointing judgement.

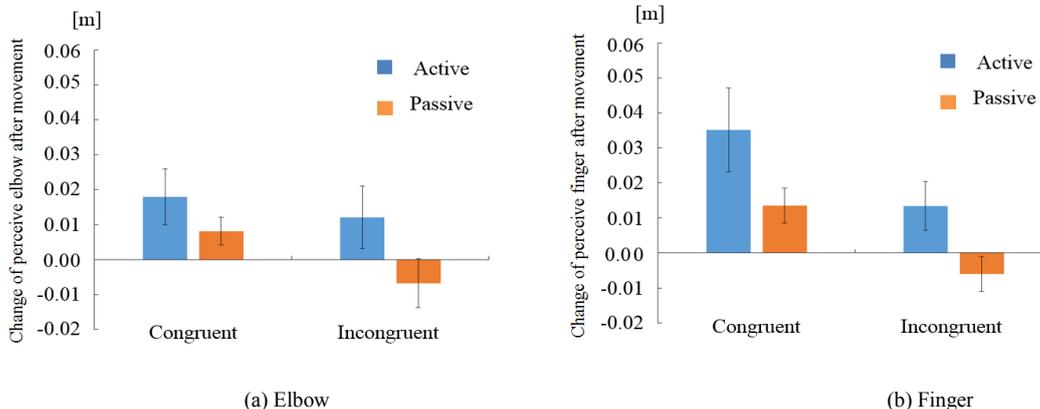


Fig. 6 Results of position judgement

To perform this analysis, we calculated the difference between pointing judgement results and prior judgement results. Prior results show the positional relationship of upper limb before the movement with distorted visual feedback. The difference between pointing judgement results and prior judgement results represent the change of the positional relationship among perceived upper limb generated by each experiment trial. We evaluated anterior-posterior difference because the factors affecting participants were only anterior-posterior such as the gap between real hand and virtual fake hand or posture of motion.

Both of the main effect of posture condition ($F(1, 10) = 13.01, p < .01$) and movement condition was significant ($F(1, 10) = 6.42, p < .05$) in the change of perceived position of finger after movement. On the other hands, only the main effect of movement condition was significant in the change of perceived position of elbow after movement ($F(1, 10) = 8.23, p < .05$). There was no significant interaction in both finger and elbow. Figure 6 shows the result of pointing judgement. Error bars represent standard error.

4. DISCUSSION

The hypothesis of the present study was that sense of agency and sense of ownership had an influence on body representation changes on the body parts without visual information. We manipulated the sense of agency and sense of ownership on the presented virtual hand by changing the orientation of the hand (congruent or incongruent with the real hand) and the type of movement (active or passive). We examined changes in body representation, for not only the body part (i.e., finger) that is presented in the visual stimulus, and also the body part (i.e., elbow) that is invisible in the stimulus. As the results, both the sense of agency and the sense of ownership influenced the change of body representation for visually presented body parts. In contrast, for the change of body representation for invisible body parts, only the sense of agency played a critical role. The results of the analysis showed that when humans felt agency and ownership, their perceived position of fingertip change larger. Furthermore, the perceived position of elbow changed larger when participants felt sense of agency. Whether participants feel sense of ownership had no effect on the change of the perceived position of elbow.

The primary finding of this paper is that only sense of agency had an influence on body representation changes on the body parts which are invisible to participants. It is suspected that body representation of human changes during active body movement. With active movement, body representation changes even on the part which human have no visual information and do not feel sense of ownership.

We evaluate sense of ownership with questionnaire; however, sense of ownership is very delicate subject and some researchers predict that sense of ownership has some

different form. The difference among sense of ownership must be considered in further research.

5. CONCLUSION

In this study, we investigated the effect of the sense of ownership and sense of agency on body representation change of human upper limb. Sense of ownership influence only the change of perceived fingertip position and it had no influence on the change of whole perceived upper limb. Positions of whole perceived upper limb change larger when participants feel sense of agency. That is, feeling sense of agency have larger effect on body representation change than feeling sense of ownership. These results advance understanding of the mechanism of body representation change

ACKNOWLEDGMENTS

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