A Three-Dimensional Evaluation of Body Representation Change of Human Upper Limb Focused on Sense of Ownership and Sense of Agency

Shunsuke Hamasaki†, Atsushi Yamashita† and Hajime Asama†
† Department of Precision Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656
Japan

Abstract:

To develop more effective and efficient rehabilitation therapies for certain disease which are linked to a mismatch between the real body and the body representation, it is important to understand the mechanisms underlying the changes in body representation. We focused on the changes in the body representation of the upper limb as a large part of the body and conducted a three-dimensional evaluation of body representation change of human upper limb. The participants were subjected to four conditions relative to sense of ownership and sense of agency. In the experiment, the participants with head mounted display were required to make circular movements in front of motion capture system. We found that the change of the body representation of the elbow occur only with sense of agency and the change occur only in the direction of Z axis.

1. INTRODUCTION

Recently, our country faced the issue of aging population and the movement disorders caused by brain diseases is becoming more and more serious problem. It is considered that they relate to a mismatch between the real body and body representation: one's own model of the body in the brain. To develop effective and efficient therapies, it is important to understand the relationship between the real body and body representation.

It is known that the mirror therapy improves the movement disorders such as hemiplegia resulting from stroke [1,2]. The mirror therapy is the rehabilitation based on a mirror image of healthy body parts and it can be regarded as a rehabilitation of eliminating the mismatch between the real body and body representation. The mechanisms underlying such changes have not been elucidated. The problem is that this form of rehabilitation has been conducted by rule of thumb. In order to the realization of the more efficient and effective rehabilitation, it is important to understand the mechanisms underlying the changes in body representation. In this paper, we defined the body representation as the location and locational relationship of perceived body parts because we consider that the body representation changes are most clearly related to the location.

Human subjective perception relevant to their own body is divided into two types, sense of agency and sense of ownership [3]. The sense of ownership is the feeling that "the object is my own," while the sense of agency refers to the feeling that "the agent who causes this action is me.". In the mirror therapy, it is assumed that the patients feel the sense of ownership and sense of agency on a mirrored image of a healthy body parts, and this therapy is effective for eliminating a mismatch between the body representation and the real body. It is implied that body representation is changed through feeling of sense of agency and sense of ownership. The aim of our research is to investigate how the change of body representation is affected by feeling of ownership and agency.

Some previous researches address the body representation change with proprioceptive drift; the shift of the perceived proprioceptive position [4,5]. In these publications, perceived proprioceptive position of the hand or finger changes from the one of the real hand to that of a fake hand with the application of synchronous stimuli on both invisible real hand and visual fake hand. The proprioceptive drift of hand or finger occurs with visual or tactile information, that is, the body representation of the hand or finger changed under the influence of visual or tactile information.

Some results of the experiments suggest that the body representation of a large body part can be changed by sensory input [6,7]. However, these experiments evaluated the proprioceptive drift of whole body. It is questionable whether one can assume that the body representation of the whole body moved while maintaining its shape in these experiments. Tsakiris affirmed that the body representation of the finger without intentional motion changes only with sense of agency by the experiment focused on the finger [8]. Even though it would be natural to assume that the changes in the body representation of larger body parts have the same effect, this remains unclear Furthermore, these researches conducted only two-dimensional evaluation.

Based on the above, we propose a hypothesis: First, the body representation of the larger body part can be changed and the changes differ according to the body part. Second, the change of the body representation without intentional motion occur only with sense of agency. We focused on experimental conditions relative to the movement and visual

hand position as the factors related to the sense of agency and that of ownership. We propose that such conditions have an influence on the changes in body representation of the large body parts and perform the experiment to measure the three-dimensional body representation changes.

2. METHODS

2.1 Concept of Experiment

In this research, we conducted the experiment to measure the three-dimensional changes in perceived hand and elbow locations to investigate the body representation change of the upper limb. In this experiment, the body part without intentional motion is elbow. The experiment was designed to prompt the change of body representation under several experimental conditions. The participants made a simple movement and received the altered visual information during the movement. To measure the changes in the perceived location, we measured it before and after the upper limb movement.

2.2 Experimental Apparatus

The participants were seated in a chair in front of a motion capture censor (Optitrack V120 Trio, Natural Point Inc.). Before the experiment, motion capture markers were placed on participants' right elbow, the back of the right hand and the tip of the left index finger. The visual information the participants were exposed to was a virtual image on head mounted display (Oculus Rift DK2, Oculus VR Inc.) and the participants could not see real world. On the head mounted display, the virtual image of right hand and the guide circle of the movement was shown. The size of the virtual image was adjusted to be similar to that of the real hand and the diameter of the guide circle is 0.1 m. Figure 1 shows the virtual hand and guide circle.

Figure 2 shows the experimental device. The real position of the hand and elbow of the participants could be observed at all times, and the position of the virtual image was controlled by a computer based on the position of the marker on the real right hand. The virtual image was displayed 0.12 m ahead from their real right hand throughout the experiment. We considered that 0.12 m is appropriate distance to prompt the change of body representation based on previously published research [9]. In order to keep the duration of the movement as constant as possible, periodic pure tones (500 Hz in frequency and 100 ms in duration) were presented during the movement period.

2.3 Task and Condition

At first, the participants were required to set their hand in order to the virtual hand would overlap with the start point on the guide circle. Next, the participants started the circular movement of their hand along the guide circle. The control by the indicated sound is performed by 3 seconds per 1 lap. Their movement lasted for 1 minute.

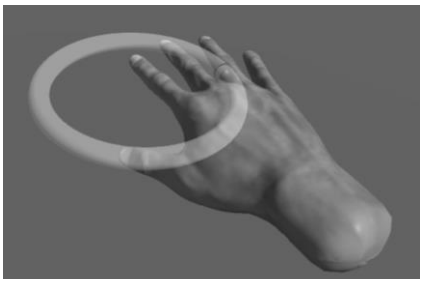


Figure 1 Virtual hand and guide circle

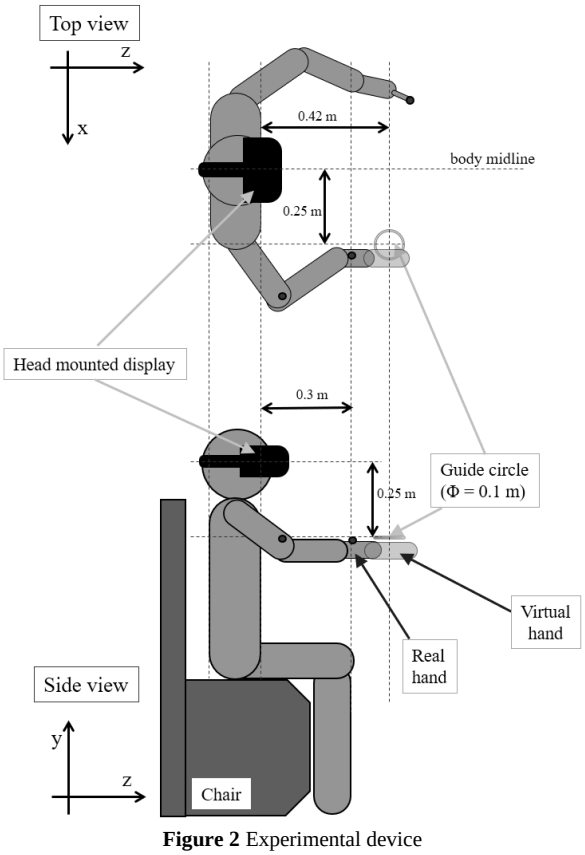


Figure 2 Experimental device

In order to test our hypothesis, we set up experimental conditions relative to the sense of ownership and sense of agency. The condition was selected from a two-by-two factorial design. One factor was the posture congruency of the virtual hand (i.e., congruent and incongruent). Under congruent condition, the virtual hand was shown as the correct position, while the reversed position was shown under incongruent condition. This factor was designed to manipulate the sense of ownership. The other factor was movement mode (i.e., normal and delayed). Under normal condition, the movement of the virtual hand reproduced the exact movement of the real hand. On the other hand, the virtual hand moves after a delay of 600 ms from the real hand. This factor was designed to manipulate the sense of agency.

2.4 Sense of Ownership and Sense of Agency

The questionnaire relevant to the sense of ownership and sense of agency was conducted. The participants were asked whether they felt the sense of ownership and sense of agency (1 - 7). This kind of questionnaires have been commonly used in the literature to investigate the sense of ownership and the sense of agency.

2.5 Pointing Judgement

To evaluate the human body representation, we measured the perceived position of the right hand and right elbow by "pointing judgment". The participants were required to point the location where they perceived their right elbow and the right hand marker using the left fingertip. The location where they required to point was not the perceived position itself but the mirror-symmetric locations with respect to the body midline. The placement of the left fingertip was recorded to identify the three-dimensional location of the perceived elbow and hand using the motion capture system. During pointing judgement, the virtual hand and guide circle was not shown.

2.6 Procedure

Before the movement, the participants were seated in a chair in front of a motion capture censor and were required to conduct pointing judgements. They were required to point the perceived hand and positions three times. This task was considered as the prior judgement. After the prior judgement, the participants were instructed to initiate the movement. After a minute movement, participants were required to conduct a pointing judgement and answer the questionnaire relevant to the sense of ownership and that of agency. The movement, pointing judgement and, the questionnaires were sequentially repeated five times for each condition. Between the conditions, the participants were given five minute breaks. The experiment lasted for ninety minutes per participant. The sequences of the conditions varied depending on the participant.

2.7 Participants

Total 6 (5 males and 1 females) healthy volunteers (mean age 23.8 years, SD = 1.5) participated in the experiment and provided informed consent. One of the participants was left-handed and the others were right-handed. The average score of Edinburgh Handedness Inventory was 66.7. This study has been approved by the research ethics committee of the University of Tokyo; the identification number is KE18-18.

3. Results

3.1 Questionnaire

The results of questionnaire are shown in Fig. 3. The error bar indicates the standard error. We used a two-way repeated measures ANOVA. In the questionnaire relevant to the sense of ownership, the main effect of congruency [$F(1, 5) = 21.65$, $p < .01$] and movement condition [$F(1, 5) = 21.93$, $p < .01$] was significant. Moreover, the main effect of movement condition [$F(1, 5) = 849.72$, $p < .01$] was significant in the sense of agency questionnaire. No significant interaction was detected in either questionnaire.

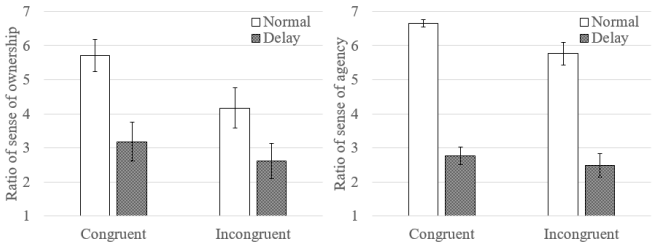


Figure 3 Results of questionnaire

3.2 Body representation change

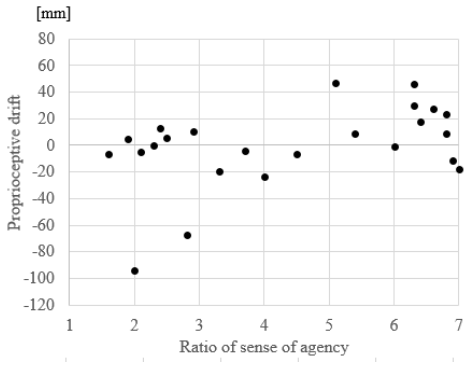
We evaluated the body representation change by comparison between the perceived position before and after the movement. We analyze the body representation change by calculating the changes in the perceived hand and elbow positions in the direction of the X axis, Y axis and Z axis. The axes are shown in Fig. 2. We used a three-way repeated measures ANOVA. First factor refers to the virtual hand congruency condition, second factor to the movement condition, and third factor to the timing of the pointing judgement (before vs. after the movement).

In the direction of the X axis and Y axis about the body representation change of hand and elbow, there was no significant second-order interaction and no main effects or significant interaction were observed. In the direction of the Z axis about the body representation change of hand and elbow, there was no significant second-order interaction and no main effects of were observed. The interaction between movement condition and the timing of pointing judgement was close to significance about body representation change of the hand [$F(1, 5) = 4.25$, $p = .09$] and elbow [$F(1, 5) = 4.91$, $p = .07$].

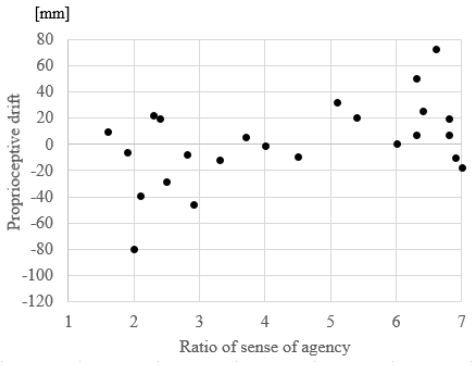
4. Discussion

The hypothesis of this paper was "The body representation of the larger body part can be changed and the change of the body representation without intentional motion occur only with sense of agency.". Then, we tried to manipulate the sense of ownership with congruency condition (congruent or incongruent) and to manipulate the sense of agency with movement condition (normal or delay). However, both congruency condition and movement condition affect sense of agency and of ownership, that is, we could not dissociate the effect of congruency and movement condition.

According to ANOVA results of body representation change, the body representation of hand and elbow show a



(a) Hand



(b) Elbow

Figure 4 Correlational analyses between proprioceptive drift and sense of agency

tendency to change in the direction of Z axis on normal condition. Therefore, we performed correlation analysis between the ratio of sense of ownership and of agency and proprioceptive drift: body representation change. The results show in Fig. 4 and Table 1. The ratio of sense of agency correlated significantly with body representation change of hand [$r = 0.44$, $p < 0.05$] and elbow [$r = 0.48$, $p < 0.05$] in the direction of Z axis. On the other hand, no significant correlations were found between the ratio of sense of ownership and the body representation changes.

The finding of this paper is that the change of the body representation of the body part without intentional motion (elbow) occur only with sense of agency. This support our hypothesis. Moreover, the change occurred only in the direction of Z axis. On the other hand, the sense of ownership did not relate to the body representation change in spite of our expectation that the body representation changes of the hand occur with sense of ownership as with sense of agency. The reason is suspected that the sense of ownership was not manipulate well by experimental condition. We have to reconsider the experimental condition carefully and increase number of participants.

5. CONCLUSION

In this study, we conducted a three-dimensional evaluation of body representation change of human upper limb focused on sense of ownership and sense of agency. We found that the change of the body representation of the body part without intentional motion occur only with sense of agency. These results contribute to understanding the mechanisms underlying the body representation change and to development of rehabilitation therapies for movement disorders caused by a mismatch between the real body and the body representation.

Table 1 Correlations between proprioceptive drift and sense of agency. (* p<.05)

	Hand			Elbow		
	x	y	z	x	y	z
Sense of ownership	-0.28	-0.03	0.09	-0.30	0.40	0.33
Sense of agency	-0.09	-0.20	0.45*	-0.12	0.11	0.49*

ACKNOWLEDGMENTS

This work was supported in part by JSPS KAKENHI Grant Number 26120005.

REFERENCES

[1] Ramachandran V.S., Ramachandran D.S. and Cobb S., “Touching the phantom limb”, Nature, Vol.377 (1995), pp.489-490

[2] Michielsen M. E., Selles R. W., van der Geest J. N., Eckhardt M., Yavuzer G., Stam H. J., Smits M., Ribbers G.M. and Bussmann J. B.J. “Motor Recovery and cortical reorganization after mirror therapy in chronic stroke patients a phase II randomized controlled trial. ” Neurorehabilitation and neural repair, Vol. 25 Issue 3(2011), pp.223-233

[3] Gallagher S., “Philosophical conceptions of the self: implications for cognitive science”, Trends in Cognitive Sciences, Vol. 4(2000), pp.14-21

[4] Botvinick M. and Cohen J., "Rubber hands 'feel' touch that eyes see", Nature, Vol. 391 (1998), pp.756

[5] Tsakiris M., Carpenter L., James D. and Fotopoulou A., "Hands only illusion: multisensory integration elicits sense of ownership for body parts but not for non-corporeal objects", Experimental Brain Research, Vol. 204, No.3 (2010), pp.343–352

[6] Lenggenhager B., Tadi T., Metzinger T. and Blanke O. "Video ergo sum: manipulating bodily self-consciousness." Science, Vol. 317 Issue 5841(2007), p. 1096-1099.

[7] Ehrsson H. H., "The experimental induction of out -of-body experiences.", Science, Vol. 317 Issue 5841(2007), pp.1048

[8] Tsakiris M., Prabhu G. and Haggard P., "Having a body versus moving your body: How agency structures body-ownership", Consciousness and Cognition, Vol. 15 (2006), pp.423–432

[9] Kalckert A. and Ehrsson H. H., “The spatial distance rule in the moving and classical rubber hand illusions.”, Consciousness and Cognition, Vol. 30(2014), pp.118-132

A Three-Dimensional Evaluation of Body Representation Change of Human Upper Limb Focused on Sense of Ownership and Sense of Agency

Shunsuke Hamasaki, Atsushi Yamashita and Hajime Asama
Department of Precision Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

To develop more effective and efficient rehabilitation therapies for certain disease which are linked to a mismatch between the real body and the body representation, it is important to understand the mechanisms underlying the changes in body representation. We focused on the changes in the body representation of the upper limb as a large part of the body and conducted a three-dimensional evaluation of body representation change of human upper limb. The participants were subjected to four conditions relative to sense of ownership and sense of agency. In the experiment, the participants with head mounted display were required to make circular movements in front of motion capture system. We found that the change of the body representation of the elbow occur only with sense of agency and the change occur only in the direction of Z axis.