Observation of Mirror Reflection and Voluntary Self-Touch Enhance Self-Recognition for a Telexistence Robot

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ABSTRACT

In this paper, we analyze the subjective feelings about the body of the operator of a telexistence system. We investigate whether a mirror reflection and self-touch affect body ownership and agency for a surrogate robot avatar in a virtual reality experiment. Results showed that the presence of tactile sensations synchronized with the view of self-touch events enhanced mirror self-recognition.

Keywords: telexistence, body ownership, agency, self-touch, mirror recognition

Index Terms: H.5.1 [Human-centered computing]: Interaction paradigms—Virtual reality

1 INTRODUCTION

Telexsitence [1] can be realized using a remote-controlled humanoid robot that replicates the body movement of the operator; therefore, it is an important that the operator be able to control the robot as naturally and skillfully his/her own body. To achieve this result, a remote surrogate robot for telexsitence systems must possess similar dynamic characteristics to a human body. However, it is unclear how much similarity is necessary to provide operators with the feeling that the robot as can be used as his/her own body. To clarify this issue, the author focuses on three subjective feelings about the body: sense of body ownership (SoO), sense of agency, and mirror self-recognition.

Sense of body ownership is a subjective awareness that body parts seen within one's view belong to oneself [2]. Body ownership is normally applied to one's real body, but it is sometimes illusorily misapplied to artificial objects, as in the rubber-hand illusion [2] [3]. Recent studies using virtual reality (VR) techniques have shown that similar illusions can occur with many other body parts, and even with the whole body [4]. These studies have revealed that congruency of visual, tactile, and somatosensory information is essential to establish body ownership. Therefore, telexistence systems should allow the operator to experience multisensory congruency, as experienced with his/her real body.

In addition, the mobility of the robot is another crucial issue in the development of telexistence systems because it has significant influence on the sense of naturalness of voluntary movement. Humanoid robots can be controlled using the operator's actions (i.e., master-slave manipulation), meaning that the operator can understand how to move the robot without special training. However, because of limitations in mechanics and signal communication, a temporal delay between motor input from and sensory feedback to the operator's body is inherent in the control system. If the system delay is short enough that the operator's motion is replicated immediately, the correspondence between motion execution and visual feedback is obvious to the operator. Such sensory-motor coupling leads to a sense of agency (SoA), which is the operator's subjective awareness that the robot can be controlled by his/her will [2]. Conversely, when the delay is too long, normal expectations of sensory-motor coupling collapse and the operator's SoA of the robot declines. Therefore, motor input and sensory feedback response speed plays crucial role in constructing telexistence systems.

Furthermore, in telexistence systems, the appearance of the robot body differs from that of the operator's real body, even if the robot has a similar kinematic configuration to a human body. This aesthetic difference makes it difficult for the operator to identify with the robot. In particular, when watching the robot's body in a mirror, the operator feels uncanny because his/her face has changed, which may lead to a decrease in the sense of body ownership. However, considering that real-time mirror reflection of a virtual avatar affects body ownership [5], it is probable that mirror self-recognition arises for the robot's face instead of the operator's real face. The mark test paradigm, which is a standard method for verifying the presence of mirror recognition [6], can be applied to test this assumption.

2 METHOD

Aims: We investigate whether the presence of self-related information in telexistence systems affects the operator's subjective feelings of his/her body. More specifically, we evaluate how SoO, SoA, and mirror self-recognition ratings change based on robot mobility and sensory-motor congruency when performing a motor task in a behavioral experiment.

Participants: Eight healthy adults with normal vision were recruited for participation in the experiment. After receiving instructions and explanation, they gave written informed consent. This research was approved by the ethics committee of the University of Tokyo.

Apparatus: An optical motion-capture system (Optitrack Prime13W $\times$ 6) and a wide field-of-view dead-mounted display (Oculus DK2) were used to construct a VR environment. Seven tracking markers were attached on the participant's body to record his/her upper-body movement. Data gloves for both hands (5DT, Data Glove 14 Ultra) were worn to measure their finger movements. The physiological response of participants was recorded using a skin conductance measurement unit (NIHONSANTEKU AP-U030m). Two wet gel electrodes were attached to the palm of the participant's left hand. The VR environment was created in Unity 5.3.1 working on a Windows PC (Intel Core i7-6700, NVIDIA GeForce GTX 980). The avatar used in the experiment was an elaborate 3D model of the existing telexistence robot, "Telesar V," which has the same hierarchical structures of mechanical linkages, joint mobility, and body shape [7].

Procedure: In VR, participants held a virtual mirror in their left hand; using the mirror reflection, they were able to watch the

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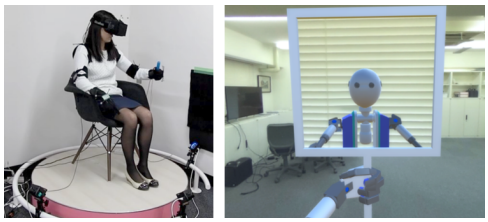

Figure 1: Experimental setup (left) and VR image (right)

robot's body instead of their own. The task for participants was to find a small cube around the robot body in the VR environment and to whisk them off using their right hand. The cube randomly appeared at one of four positions near a body part (left cheek, centre of chest, left shoulder, and left forearm) every 4 seconds. Participants continued the motor task for 60 seconds and then responded to the six statements below: Q1: "*I felt as if my body became a robot*", Q2: "*I felt as if the robot moved according to my will*", Q3: "*I felt as if I watched my body in the mirror*", Q4: "*I felt as if there were two bodies there*", Q5: "*I felt as if the robot moved independently*", and Q6: "*I felt as if there was another robot in the mirror*". Q1 and Q4 are statements that address body ownership, Q2 and Q5 concern agency, and Q3 and Q6 are related to mirror self-recognition. Participants made a subjective rating for each statement based on a 7-point Likert scale ranging from -3 (strongly disagree) to +3 (strongly agree). One trial consisted of the motor task and evaluation described above, which was repeated four times with changing experimental conditions in a 2×2 within-subjects design. One factor was motor delay (the right hand either moved immediately or was delayed by 500 ms); the other was self-touch sensation (the cube appeared either on or distant from the surface of the robot. Note that the virtual cube was presented only visually, therefore tactile sensation was absence when touching those distant from body. Each condition was presented to participants in a random order. The procedure above was one experimental block. Participants performed four experimental blocks with five minutes intermission between each.

After finishing all trials, participants performed an extra trial regarding mark test. In this trial, the mirror reflection temporarily disappeared, though the frame was still in their hand. While the participant waited for the recovery of the mirror reflection, an experimenter covertly rubbed the participant's cheek using a urethane stick; simultaneously, a gash appeared on the robot's face. Three seconds after the rub stimulus, the mirror reflection appeared again and participants noticed the gash on the robot's face. After watching the face, they were instructed to answer two additional questions: Q7: "*I felt as if my face got hurt*" and Q8: "*I felt as if there was a wounded robot there*". During this trial, the participant's skin conductance response (SCR) was recorded. These data were analyzed offline and the change in SCR before and after the mark test were extracted for each participant to evaluate the correlation between physiological sweating caused by face changes and responses to Q7 and Q8 regarding mirror recognition.

3 Result

Questionnaires: The scores collected for each questionnaire were summarized within body ownership (Q1 and Q4), agency (Q2 and Q5) and mirror recognition (Q3 and Q6). Repeated-measure two-way ANOVAs were performed for these three categories and showed that the main effect of motion delay was significant for the agency score ($F(1,7) = 8.04$, $p < 0.05$, Figure 2B). Additionally, there was significant interaction between delay and touch on the mirror recognition score ($F(1,7) = 6.09$, $p < 0.05$, Figure 2C). There were no significant differences or interaction for the body ownership score (Figure 2A).

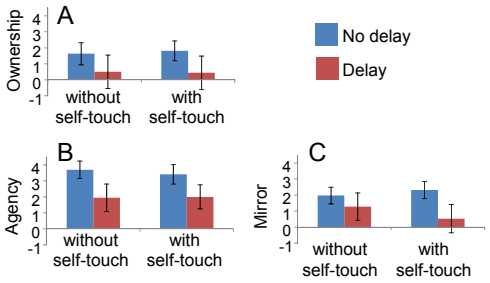

Figure 2: Summarized questionnaire scores for body ownership (A), agency (B), and mirror recognition (C)

Correlation between SCR and questionnaire: Correlation analysis was performed for the change rate of SCR against the summarized scores of Q7 and Q8; moderate correlation was found between them ($r = 0.630$).

4 Conclusion

In this study, we found that observation of a mirror reflection affected body recognition for a telexistence robot, especially when performing voluntary self-touch and observing this event with consistent sensory-motor feedback. With motion delay, the presence of tactile sensation through self-touch degrades mirror self-recognition, probably because motion delay breaks the consistency between visual, tactile, and motor information. This finding is analogous to previous studies emphasizing the effect of mirror observation [5] and self-touch [8], though direct evidence of improvement of body ownership was not observed in this experiment. A mark test paradigm was introduced to investigate whether a threat reaction occurs through mirror reflection and correlation between SCR and subjective evaluation was found, meaning that operator's subjective acceptance/repudiation about the robot body can be evaluated using this paradigm.

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