EFFECTS OF VISUAL SELF-REFERENTIAL FEEDBACK ON BODY OWNERSHIP AND USABILITY IN HMD-BASED ROBOT TELEOPERATION

Dokyung KIM [a], and Shinichi KOYAMA [b*]
[a] *Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan*

[b] *Institutue of Art and Design, University of Tsukuba, Japan*

ABSTRACT

This study examines how visual self-referential conditions influence body ownership and affective responses during remote robot operation using a head-mounted display (HMD). In the experiment, 24 participants (aged 21–34) were recruited. Participants placed their chin on a chin-rest, wearing an HMD connected to a camera mounted on a robot, which transmitted real-time forward-view images. They moved the robot (a modified radio-controlled toy car) in a straight line within 3 seconds toward a target using control levers. Participants were divided into two groups, a self-referential group and an external-object group. Both groups completed three robot-operation trials using self-face feedback and two different types of dolls: a lion doll (A) and a penguin doll (B). In the self-referential group, participants first moved the robot toward doll A, second toward their own face wearing HMD, and third to doll A again. In the external-object group, participants first moved the robot toward doll A, second toward a doll B, and third to doll A again. After the first and third run, both groups completed a questionnaire assessing body ownership (self, other, separate) and usability (ease, difficulty, control, comfort, stress, enjoyment, boredom). The differences in scores between the first and last questionnaire was computed and independent-samples t-tests were conducted to examine group differences. Participants in self-referential group who directed the robot toward their own face showed a significant decrease in body ownership ($p < .05$), along with a tendency toward increased stress and decreased enjoyment. These findings suggest that presenting one's own face may reduce body ownership. Body ownership may reduce stress and increase enjoyment. The results are consistent with prior studies showing that body ownership arises from multisensory integration (Botvinick & Cohen, 1998; Ehrsson, 2007). Robot interface design adjusting the sense of body ownership through visual self-referential conditions may change user experience.

Keywords: *Robot Teleoperation, Body Ownership, Usability, Visual Self-Referential Condition*

[*] Corresponding author. 1-1-1 Tennnodai, Tsukuba, Ibaraki, Japan. skoyama@geijutsu.tsukuba.ac.jp

1 INTRODUCTION

In human–robot interaction (HRI), improving user experience has become a central research objective. With advances in virtual reality (VR) and head-mounted display (HMD) technologies, robots are no longer used merely as remote control devices. In particular, body ownership—perceiving a robot as part of one's own body—is gaining attention. Previous research suggests that embodied experiences are closely related to body ownership and the sense of agency, including feelings of control over bodily actions (Kalckert & Ehrsson, 2012). Previous cognitive neuroscience research suggests that body ownership can extend to teleoperation contexts through multi-sensory integration (Lenggenhager et al., 2007). For example, the Rubber Hand Illusion showed that synchronized visual and tactile stimulation can induce body ownership toward a rubber hand (Botvinick & Cohen, 1998; Ehrsson, 2007). In HRI research, human-like virtual bodies have been shown to enhance body ownership (Shin, 2020). However, prior research has not clearly compared self-body and external-object experiences in robot teleoperation. This study examines whether an intermediate stimulus under self-referential and external-object conditions influences users' body ownership and usability responses in HMD-based robot teleoperation. Participants were divided into two groups and completed three trials using self-face feedback and two different types of dolls as stumuli: a lion doll (A) and a penguin doll (B). Self-referential group moved the robot toward doll A, then toward the participant's own face viewed through the HMD, and doll A again. External-object group moved the robot toward doll A, doll B, and doll A again. After Trials 1 and 3, both groups completed a questionnaire on body ownership, and usability. Change scores (Trial 3 minus Trial 1) were compared between groups to examine which group showed greater changes. An independent-samples t-test was conducted to examine whether these differences were statistically significant.

2 METHOD

2.1 Participants

A total of 24 university students were recruited through on-campus advertisements at the University of Tsukuba. All participants completed the experiment (age range: 21–34 years; 17 males, 7 females). Only one participant had expert-level knowledge of robotics, while the others reported limited or no prior experience.

2.2 Environment

Participants received an information sheet describing the study purpose, procedures, duration, risks, data handling, and voluntary nature of participation. They were informed of their right to withdraw at any time without penalty. All participants reported having normal or corrected-to-normal vision. A chair and a chin rest were used to stabilize the participants' heads. A straight cardboard corridor (length: 120 cm) was placed in front of each participant for the robot to move through. The robot was a modified radio-controlled car (6 × 10 cm) equipped with a camera. Its outer shell was 3D-printed and covered with a fur-like textile. The camera was connected to an HMD (Big Eyes 2), providing real-time forward visual feedback. Part of the fur was visible in the camera view, reinforcing the perception of the robot as a non-human external object (Figure 1).



Figure 1. A modified radio-controlled car equipped with a camera

2.3 Procedures

Participants sat and placed their chin on a chin rest. They wore an HMD that provided real-time forward visual feedback from a camera mounted on the robot. They were instructed to use a controller to move the robot forward and backward. Participants moved the robot in a straight line through the corridor toward a stimulus within 3 secsonds with a 40 BPM metronome. Three stimuli were used: a lion doll (A; 70 × 100 mm), a penguin doll (B; 120 × 70 mm), and the participant's own face viewed via the HMD. Participants (n = 24) were divided into two groups: Self-referential group (n = 12) and External-object group (n = 12). Both groups completed three trials and questionnaires on body ownership and usability after Trials 1 and 3. In the self-referential group, participants moved the robot toward doll A (Trial 1), their own face viewed through the HMD (Trial 2-1), and doll A again (Trial 3). In the external-object group, participants moved the robot toward doll A (Trial 1), doll B (Trial 2-2), and doll A again (Trial 3). For both groups, change scores between Trials 1 and 3 were calculated (Figure 2, Figure 3).

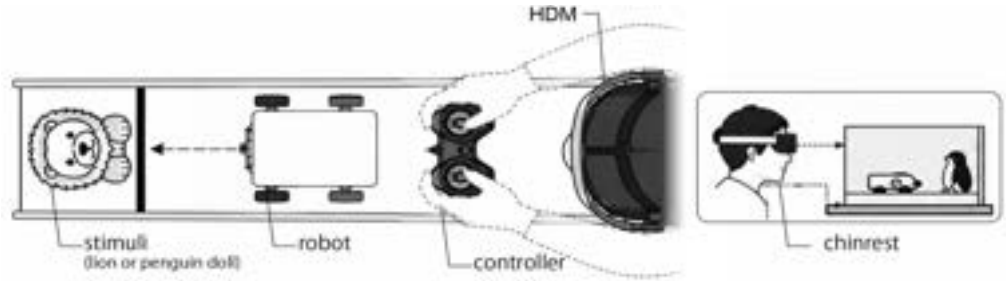


Figure 2. Overview of the HMD-Based Robot Teleoperation Experiment

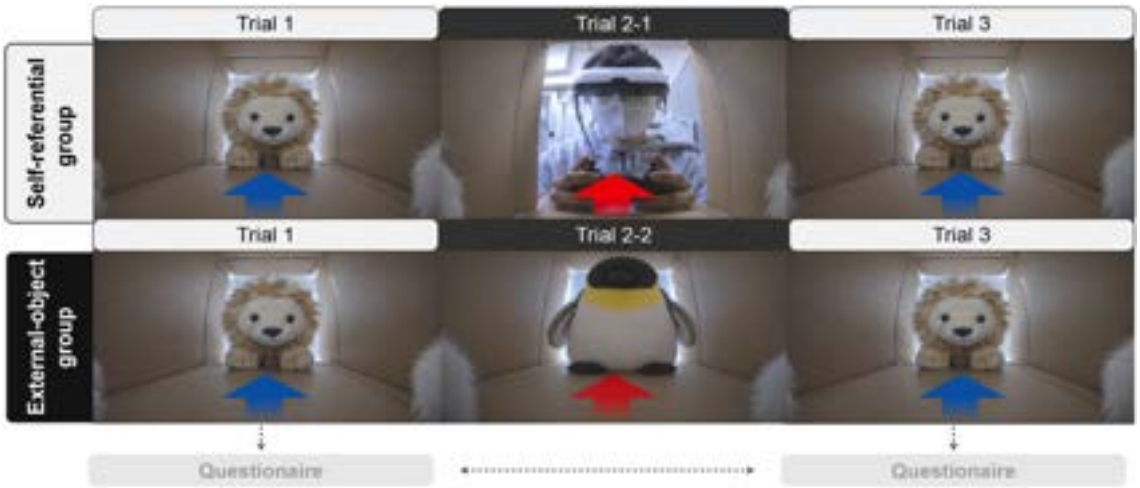


Figure 3. Three trials of robot operation in self-referiantial group and external-object group

2.4 Questionaire

Both groups completed the same questionnaire after Trials 1 and 3. The questionnaire consisted of 10 items assessing body ownership (self, other, separate) and usability (ease, difficulty, control, comfort, stress, enjoyment, boredom). Items included the following questions: (Q1) To what extent did you feel that the robot was part of your own body? (Q2) To what extent did you feel that the robot was another person's body? (Q3) To what extent did you feel that the robot was a separate entity from yourself? (Q4) How easy was it to operate the robot? (Q5) How difficult or complex was it to operate the robot? (Q6) To what extent did you feel in control of the robot? (Q7) How comfortable did you feel during the operation? (Q8) How much stress did you experience during the operation? (Q9) How enjoyable was the operation? (Q10) How bored did you feel during the operation? Responses were recorded on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The experiment lasted approximately 20–30 minutes, after which participants reported demographic information and prior experience with robotics. Items were adapted from established embodiment scales and prior HRI studies (Longo et al., 2008; Kalckert & Ehrsson, 2012; Bartneck et al., 2009).

2.5 Analysis

The data were analyzed using IBM SPSS Statistics 29.0. For each participant, change scores were computed for each item as Trial 3 minus Trial 1. These change scores were compared between two Groups to examine which group showed greater changes. An independent-samples t-tests were conducted to assess whether between-group differences were statistically significant.

3 RESULTS

All participants completed the same 10-item questionnaire on body ownership and usability after Trials 1 and 3. Change scores (Trial 3 − Trial 1) were compared between the self-referential group and the external-object group using independent-samples t-tests (Table 1). Embodiment (Q1) showed a significant decrease in the self-referential group (ΔM = −0.91, t = −2.27, p = .03). Other-body sensation (Q2) increased, but was not significant (ΔM = 0.50, t = 1.01, p = .32). Perceived separateness (Q3) increased, but the change was not significant (ΔM = −0.09, t = −0.17, p = .87). Ease of operation (Q4) decreased, but the change was not significant (ΔM = −0.16, t = −0.48, p = .64). Perceived complexity (Q5) decreased, but the change was not significant (ΔM = −0.25, t = −0.52, p = .61). Sense of control (Q6) increased, but the change was not significant (ΔM = −0.09, t = −0.17, p = .87). Comfort (Q7) increased, but the change was not significant (ΔM = 0.00, t = 0.00, p = 1.00). Stress (Q8) increased, but the change was not significant (ΔM = 0.17, t = 0.48, p = .63). Enjoyment (Q9) decreased, but the change was not significant (ΔM = −0.25, t = −0.81, p = .43). Boredom (Q10) increased, but the change was not significant (ΔM = 0.00, t = 0.00, p = 1.00). Only embodiment (Q1) showed a significant decrease (p < .05). All other measures showed no statistically significant changes (all ps > .05). Other-body sensation and perceived separateness increased, whereas ease of operation and perceived complexity decreased. Sense of control, comfort, stress, and boredom increase, while enjoyment decreased.

Table 1. Independent-samples t-test results (Trial 3 -Trial 1)

variable		Self-referential(M, SD)		External-object(M, SD)		ΔM	$t(22)$	p
		pre	post	pre	post			
body ownership	embodiment (Q1)	3.25, 0.97	2.67, 1.23	2.92, 0.88	3.25, 0.97	-0.91	-2.27	.03*
	other-body (Q2)	2.75, 0.97	3.58, 1.00	2.67, 1.03	3.00, 0.74	0.50	1.01	.32
usability	separate (Q3)	3.33, 1.15	3.92, 1.08	3.50, 0.97	4.17, 0.57	-0.09	-0.17	.87
	ease (Q4)	3.58, 1.31	3.50, 1.17	3.17, 1.03	3.25, 1.07	-0.16	-0.48	.64
	complexity (Q5)	2.25, 0.97	2.08, 1.08	2.08, 0.88	2.17, 0.94	-0.25	-0.52	.61
	control (Q6)	3.75, 1.14	3.83, 0.94	3.67, 0.95	3.83, 0.67	-0.09	-0.17	.87
	comfort (Q7)	2.92, 1.24	3.17, 1.11	2.92, 0.99	3.17, 0.92	0.00	0.00	1.0
	stress (Q8)	1.83, 0.58	2.50, 1.00	2.08, 0.74	2.58, 0.97	0.17	0.48	.63
	enjoyment (Q9)	4.00, 0.95	3.92, 1.00	3.42, 0.85	3.58, 0.70	-0.25	-0.81	.43
	boredom (Q10)	1.75, 0.62	2.00, 0.85	2.00, 0.94	2.25, 0.95	0.00	0.00	1.0

4 DISCUSSION

This study examined how visual self-referential conditions influence body ownership and usability in HMD-based robot teleoperation. A total of 24 participants were divided into two groups and completed three trials under either a self-face condition or an external-object condition. In the self-referential group, the robot was moved toward doll A, the participant's own face viewed through the HMD, and doll A again. In the external-object group, the robot was moved toward doll A, doll B, and doll A again. After Trials 1 and 3, participants completed a questionnaire assessing body ownership (self, other, separate) and usability (ease, difficulty, control, comfort, stress, enjoyment, boredom). Change scores (Trial 3 minus Trial 1) were compared between groups to examine which condition produced greater changes. Independent-samples t-tests were conducted to examine whether these differences were statistically significant. Previous HRI research has suggested that embodiment experiences during robot interaction may influence users' body ownership and usability, and that such mechanisms may extend to teleoperation contexts (Lenggenhager et al., 2007). Previous research has also reported that human-like virtual bodies can enhance body ownership (Shin, 2020). The present findings suggest that the self-referential condition may have reduced embodiment by shifting the robot perception as a human-like virtual body from a self-body to an external object. Increases in stress and boredom, along with decreased enjoyment, may reflect intensified self-awareness and emotional tension under the self-face condition.

5 LIMITATIONS

This study is limited by its small sample size, and the observed trends should be interpreted as preliminary. The experiment used a simple linear movement task and static stimuli, limiting generalizability to more complex interactive contexts, such as obstacle avoidance, directional changes, navigation through dynamic environments, and the execution of diverse tasks. Possible learning or fatigue effects across repeated trials may not have been fully controlled. The novelty effect of viewing one's own face as an experimental stimulus may simply reflect random variation.

6 CONCLUSION

In HMD-based robot teleoperation, embodiment significantly decreased only when participants viewed their own faces rather than external objects, suggesting that self-referential experiences may reduce robot embodiment and body ownership. Increased stress and boredom suggest that self-referential conditions may regulate user–robot affective distance. Depending on visual feedback conditions, the user–robot relationship can dynamically shift between perceiving the robot as an extension of the one's own body and as a separate external object. Users' affective experiences and psychological engagement during robot teleoperation may also be influenced.

ACKNOWLEDGMENTS

This study was supported by JSPS Grant-in-Aid for Challenging Research (Exploratory) (Grant Number 20K21823) to Shinichi Koyama.

REFERENCES

Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. International Journal of Social Robotics, 1(1), 71–81. https://doi.org/10.1007/s12369-008-0001-3

Botvinick, M., & Cohen, J. (1998). Rubber hands 'feel' touch that eyes see. Nature, 391(6669), 756. https://doi.org/10.1038/35784

Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. Science, 317(5841), 1048. https://doi.org/10.1126/science.1142175

Kalckert, A., & Ehrsson, H. H. (2012). Moving a rubber hand that feels like your own: A dissociation of ownership and agency. Frontiers in Human Neuroscience, 6, Article 40. https://doi.org/10.3389/fnhum.2012.00040

Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum: Manipulating bodily self-consciousness. Science, 317(5841), 1096–1099. https://doi.org/10.1126/science.1143439

Longo, M. R., Schüür, F., Kammers, M. P. M., Tsakiris, M., & Haggard, P. (2008). What is embodiment? A psychometric approach. Cognition, 107(3), 978–998. https://doi.org/10.1016/j.cognition.2007.12.004

Preston, C., & Ehrsson, H. H. (2014). Illusory changes in body size modulate body satisfaction in a way that is related to non-clinical eating disorder psychopathology. PLOS ONE, 9(1), e85773. https://doi.org/10.1371/journal.pone.0085773

Preston, C., Kuper-Smith, B. J., & Ehrsson, H. H. (2015). Owning the body in the mirror: The effect of visual perspective and mirror view on the full-body illusion. Scientific Reports, 5, Article 18345. https://doi.org/10.1038/srep18345

Schubert, T., Friedmann, F., & Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. Presence: Teleoperators and Virtual Environments, 10(3), 266–281. https://doi.org/10.1162/105474601300343603