

The Sense of Agency, Sense of Body Ownership with a Semi-autonomous Telexistence Robot under Shared / Unshared Intention Conditions

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Abstract

With the increasing popularity of robots such as teleoperated semi-autonomous robots, sense of agency (SoA) and sense of body ownership (SoBO) with semi-autonomous robots is becoming increasingly important. This study investigates the changes in the SoA and SoBO when the user control weight of the robot is altered in human-robot collaboration. Through an experiment, we compared the SoA and SoBO in a pick-and-place task using a robotic arm under the conditions in which the autonomous robotic arm shared and unshared the target with the participant. The results showed that the SoA and the SoBO increased with the increase of user control weight. However, the user control weight of 75% achieved a slightly higher SoA than that of 100%.

CCS Concepts

• **Human-centered computing** → **Collaborative interaction**; • **Computer systems organization** → **Robotic autonomy**;

1. Introduction

A Telexistence robot can be controlled by the body movements of an operator in a remote location to conduct various physical activities. Semi-autonomous behaviors of robots can contribute to operating such Telexistence robots. When we control a Telexistence robot, if the operator can operate it the same way as if they are moving their bodies while maintaining a sense of agency (SoA) [Gal00] and sense of body ownership (SoBO) [Gal00], that can be an ideal condition. At the same time, the semi-autonomous robot can predict the operator's intention and assist at various levels.

This study investigates how the SoA and SoBO are changed by the control weight between a user and a semi-autonomous robot. Through an experiment, we examine the SoA and SoBO with a semi-autonomous robot considering shared and unshared intention conditions. We built an experimental environment for the pick-and-place tasks that allowed the participants to collaborate with the robot. We experimented the Inagaki's 11 automation level 2 (Using the system to move the robot, a person determines the target object and executes its movement) [IMI98]. In addition, we set the condition in which the target was shared and unshared between the participants and the semi-autonomous robot.

2. Experiment

We investigated how the automation level changed the SoA and SoBO through a pick-and-place task using a robotic arm. The robotic arm moved according to a hand-worn tracker position.

Fig. 1 a shows the experimental setup. We placed the balls for the pick-and-place task in concentric circles 30 degrees apart. We set the goal to place the balls in the initial position of the robotic arm. We evaluated the SoA and SoBO when the participants and the semi-autonomous robot shared/unshared the target. In the unshared condition, the semi-autonomous robot recognized the ball next to the participants' target as the target. There were nine experimental conditions: the shared and unshared conditions, where the fusion ratio between the semi-autonomous robot and the participant was 100:0, 75:25, 50:50, and 25:75, and the completely participant's motion condition, in which the fusion ratio was 0:100.

At first, the participants did a training session, and then they performed the task in each condition. The condition order was randomized for each participant. After each condition, the participants filled out the embodiment questionnaire (Table 1). There were 20 participants (17 males and 3 females; age was $M = 23.8$, $SD = 3.8$).

3. Result and discussion

Fig. 1 b, c show the results of SoA and SoBO, respectively. Using one-way ANOVA, the SoA results under the shared condition showed that the effect of the proportion of user control was significant ($p < 0.001$). Tukey-Kramer test for the SoA results under the shared condition found significant differences between 0% and 100% ($p < 0.001$), 0% and 75% ($p < 0.001$), 0% and 50% ($p < 0.001$), 25% and 100% ($p < 0.001$), 25% and 75% ($p < 0.001$), and 50% and 75% ($p < 0.05$). Steel-Dwass test for the SoBO under the shared condition revealed significant differ-

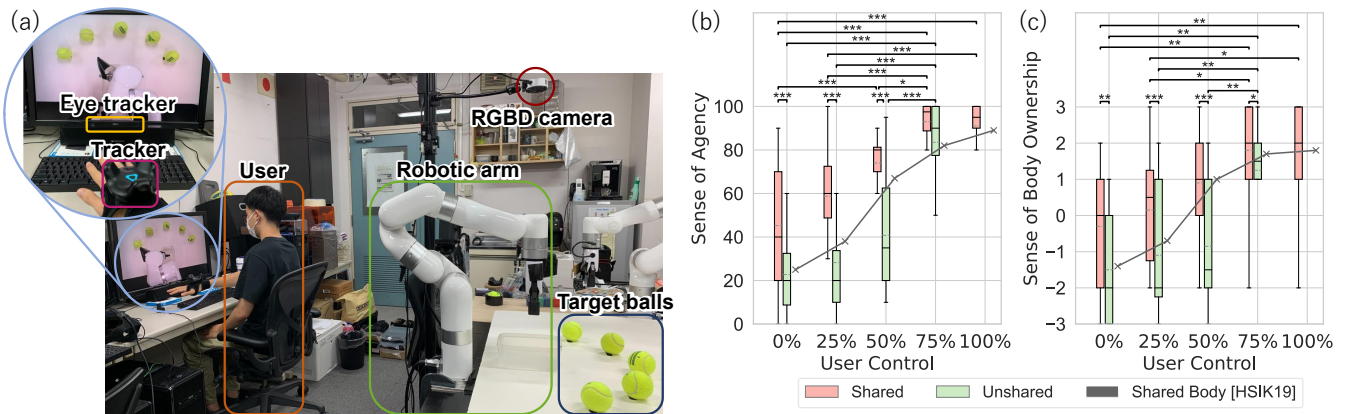


Figure 1: (a) Experimental setup. (b) The SoA result. The red and blue boxes indicate the results under the shared and unshared condition, respectively. The yellow lines indicate the previous study's result [HSIK19]. *, **, and *** indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. (c) The SoBO result.

Table 1: Embodiment Questionnaire. Following the previous study on the shared body [HSIK19], questions 1 and 2 were asked to be answered on a 100-point scale, and questions 3, 4, and 5 were asked to be answered on a 7-point Likert scale.

Q1	I felt as if I was in control of the robotic arm's movements.
Q2	I felt as if my movements were controlled by the robotic arm.
Q3	I felt as if the robotic arm was like a part of my body.
Q4	I felt as if my right hand was like a robot.
Q5	I felt the task was easy.

ences between 0% and 100% ($p < 0.01$), 0% and 75% ($p < 0.01$), 25% and 100% ($p < 0.05$), and 25% and 75% ($p < 0.05$).

Using one-way ANOVA, the SoA results under the unshared condition found that the effect of the user control ratio was significant ($p < 0.001$). Tukey-Kramer test for the SoA results under the unshared condition revealed significant differences between 0% and 100% ($p < 0.001$), 0% and 75% ($p < 0.001$), 25% and 100% ($p < 0.001$), 25% and 75% ($p < 0.001$), 50% and 100% ($p < 0.001$), and 50% and 75% ($p < 0.001$). Steel-Dwass test for the SoBO results under the unshared condition showed significant differences between 0% and 100% ($p < 0.01$), 0% and 75% ($p < 0.01$), 25% and 100% ($p < 0.01$), 25% and 75% ($p < 0.01$), 50% and 100% ($p < 0.01$), and 50% and 75% ($p < 0.01$).

The t-test showed significant differences in the SoA between shared and unshared conditions when the user control ratio was 0% ($p < 0.001$), 25% ($p < 0.001$), and 50% ($p < 0.001$). The Wilcoxon's signed rank test revealed significant differences in the SoBO between shared and unshared conditions when the user control ratio was 0% ($p < 0.001$), 25% ($p < 0.001$), 50% ($p < 0.001$), and 75% ($p < 0.05$).

The results show that the unshared condition achieved significantly lower SoA than the shared condition when the user control ratio was 0%, 25%, and 50%. When the user control ratio was 0%,

25%, and 50% under the unshared condition, all participants could pick up only the semi-autonomous robot's target, not their own in all trials, which caused the SoA decrease.

The user control ratio of 75% and 100% achieved a higher SoA than the other conditions under the shared and unshared conditions. Surprisingly, the median of SoA in the user control ratio of 75% was slightly higher than in that of 100%. This implies that the user control ratio of 75% let the participants feel that they controlled the robotic arm better than that of 100%.

Compared to the previous study [HSIK19], we found that our results reached higher SoA than the previous study. The shared body was controlled by two people, while our system shared the robotic arm between a user and a semi-autonomous robot, which indicates that only the participant could determine whether to move the robotic arm. Therefore, it is considered that our SoA results were higher than the previous study [HSIK19].

Acknowledgment

This project was supported by JST ERATO Grant Number JPM-JER1701.

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