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# Sensation of Dual Body through Visual-Haptic Stimulation by Two Remote Spaces

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## I. Introduction

Advances in generative AI and robotics have enabled more complex and human-centered tasks, including the simultaneous control of multiple remote robots [1]. While fully autonomous systems face inherent limitations, a key challenge is achieving seamless human-robot collaboration. In particular, operating multiple robots simultaneously poses significant cognitive and bodily coordination demands. To systematically explore the cognitive basis of such control, this study uses Virtual Environments (VEs) as experimental platforms that simulate remote multi-robot operation.

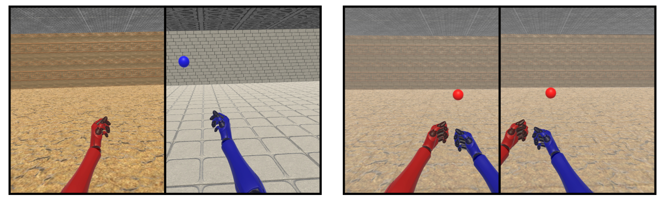
Miura et al. [2] explored multiple full-body avatar control and showed that participants can experience embodiment across them. However, all avatars were synchronized as replicas of a single physical body, limiting interaction diversity. This design did not examine how bodily awareness emerges when avatars act in perceptually distinct environments and receive spatially distinct visual and haptic stimuli.

As an initial step toward understanding bodily cognition in multi-robot control, this study focuses on a scenario in which a single operator simultaneously controls two remotely located avatar robots. Building on this dual-control scenario, we propose the concept of Dual Body — an integrated bodily sensation in which the operator concurrently perceives the body states and spatial environments of both robots and actively engages in parallel tasks through them [3] [4]. This integrated bodily awareness may improve task coordination and temporal efficiency in human-robot collaborative environments.

Despite its potential societal relevance, the cognitive underpinnings of Dual Body have not been systematically investigated. Therefore, this study explores the possibility of generating and enhancing the sense of Dual Body within two controlled VEs, as a preliminary step toward real-world systems.

## II. Experiment to Evaluate Dual Body Sensation

This experiment examined whether Dual Body can be elicited and modulated as participants perform reaching-and-walking tasks in two VEs (Space L and Space R). A 2 × 3 factorial design was used, combining two types of visual presentation and three types of haptic feedback conditions. Participants reached for randomly appearing balls while walking in two VEs to encourage full-body engagement and exploration.



(a) Independent-view condition: separate views shown to each eye

(b) Superimposed-view condition: overlapping images shown to both eyes

Fig. 1: Two types of visual presentation conditions

### A. Visual Presentation Conditions

Two types of visual presentation conditions were employed: the independent-view condition and the superimposed-view condition. In the independent-view condition, each eye received visual input from a different VR space: Space L to the left eye and Space R to the right (Fig. 1a) [5]. In the superimposed-view condition, visual elements from both spaces were rendered with transparency and presented in a single merged visual field (Fig. 1b) [6].

### B. Haptic Feedback Conditions

Footstep feedback was delivered via vibrators (Vp2, Acouve Laboratory, Inc., Fig. 2) on the soles of participants' feet, synchronized with avatar walking. Three haptic feedback conditions were tested: no haptic feedback condition, bilateral haptic feedback condition, and unified haptic feedback condition. In the no haptic feedback condition, no tactile stimuli were presented. In the bilateral haptic feedback condition, the left and right foot of the participant received tactile stimuli from the corresponding footfalls of the avatar robots in Space L and Space R, respectively. In the unified haptic feedback condition, each participant's foot received overlapping feedback from both robots' footfalls, creating a shared tactile experience.

### C. Experiment Procedure

The study involved four participants (2 female, 2 male; age range: 21–22, $M = 21.75$, $SD = 0.43$). Each participant completed one session per condition. Prior to the experiment, informed consent was obtained, and participants were given a briefing on the procedure. They were then trained in a set

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Fig. 2: Photograph of the experimental setup

of practice VEs. After each session, participants completed a Visual Analogue Scale questionnaire. Unless otherwise noted, responses were rated from ”Not at all” (left) to ”Very much” (right).

Q1. Did the robot controlled with your left hand feel like your own body?
Q2. Did the robot controlled with your right hand feel like your own body?
Q3. Did you feel in control of the robot operated with your left hand?
Q4. Did you feel in control of the robot operated with your right hand?
Q5. How did you perceive spatial immersion? (Scale: One fused space – Two separate spaces)
Q6. Did you feel duplicated across the two robots?
Q7. How difficult was it to perceive both environments at once?
Q8. Did you experience cybersickness?
Q9. Did you feel a sense of Dual Body?

## III. Results & Discussion

Statistical analysis was conducted on the questionnaire data. Prior to the main analysis, the assumptions of normality and homogeneity of variance were tested using the Shapiro–Wilk and Levene's tests, respectively; both assumptions were met ($p > 0.1$). Subsequently, two-way repeated-measures ANOVAs were performed with visual and haptic feedback conditions as within-subject factors. The results revealed significant or marginal effects for Q8 and Q9.

### *A. Q8 - Cybersickness*

A marginal main effect of visual presentation condition was found ($p < 0.1$). As illustrated in Fig. 3, Holm-corrected post hoc comparisons indicated that the independent-view condition yielded higher cybersickness ratings than the superimposed-view condition ($p < 0.1$). This suggests that presenting spatially incongruent images to each eye may impair perceptual coherence, contributing to cybersickness.

### *B. Q9 - The Sense of Dual Body*

Haptic feedback condition had a main effect on the sense of Dual Body ($p < 0.05$). As shown in Fig. 4, Holm-corrected post hoc analysis revealed that the unified haptic feedback condition yielded marginally higher scores than the bilateral condition ($p < 0.1$), and significantly higher

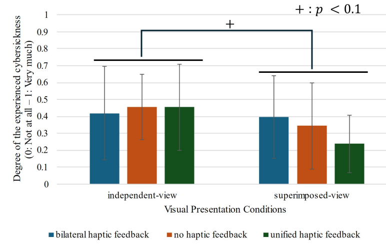


Fig. 3: Mean ratings of cybersickness

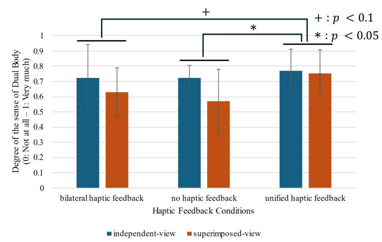


Fig. 4: Mean ratings of the sense of Dual Body

than the no-feedback condition ($p < 0.05$). These findings suggest that integrated yet spatially blended tactile cues can enhance the sense of Dual Body. This may be because unified feedback provides a coherent tactile experience, making it easier to interpret both avatars as parts of a single body.

## IV. Conclusion

We proposed and evaluated the concept of Dual Body in a dual-avatar control scenario across two VEs. The subjective results suggest that spatially coherent visual input reduces cybersickness, while unified haptic feedback enhances the sense of Dual Body. These findings offer initial insights into how multimodal feedback supports the sense of Dual Body.

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