# MultiSoma: Distributed Embodiment with Synchronized Behavior and Perception

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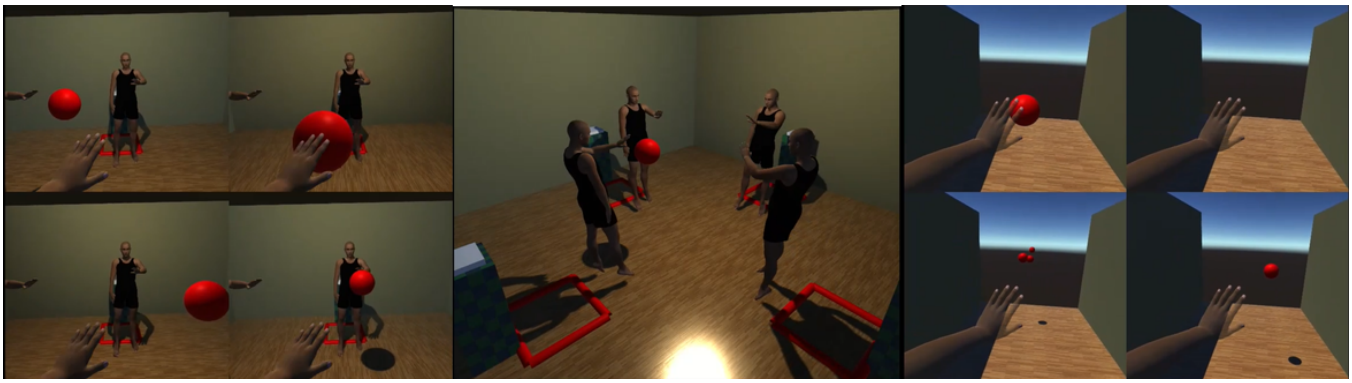


**Figure 1: Synchronized Behavior and Visual Perception in the Reaching Task and the Flow Task**

## ABSTRACT

Human behavior and perception are optimized for a single body. Yet, the human brain has plasticity, which allows us to extend our body schema. By utilizing technology like robotics or virtual reality (VR) , we can modify our body parts or even add a new body to our own while retaining control over these parts. However, the update of body cognition when controlling multiple bodies has not been well examined. In this study, we explore the task performance and body cognition of humans when they have multiple full bodies as an extended embodiment. Our experimental system allows a participant to control up to four bodies at the same time and perceive sensory information from them. The participant experiences synchronizing behavior and vision perception in a virtual environment. We set up two tasks for multiple bodies and evaluated the cognition of these bodies by their task performances and subjective ratings. We found that humans can have the sense of body ownership and agency for each body when controlling multiple bodies simultaneously. Distributed embodiment has the potential to extend human behavior in cooperative work, parallel work, group behavior, and so on.

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## CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**.

## KEYWORDS

virtual reality, augmented human, embodiment, multiple bodies

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## 1 INTRODUCTION

Due to the nature of the human body structure, our behavior and perception are optimized for a single body. Yet, the human brain allows us to extend our embodiment beyond our own body. In a previous study, it was shown that people can feel and manipulate

a virtual body as if it were their own by synchronizing their vision and movements[4, 11]. This is called the sense of embodiment, which includes the sense of self-location, the sense of body ownership, and the sense of agency. People can also have the sense of embodiment for a body with extended structures [13, 15] and partial representations [16]. Research has explored various possibilities of the sense of embodiment with extended body structures, such as third arms [22], long arms [13, 15], and partial representations [16]. Furthermore, the sense of embodiment can be held in a body shared with another person[5] or swapped to another body[21]. In terms of the sense of self-location, there have been studies on bi-location, which means to exist in two places at the same time [1, 6, 8, 19, 24]. The question arises: Can we have a sense of embodiment for multiple bodies simultaneously?

This study focuses on the sense of embodiment with directly synchronized vision and movements with multiple bodies. In the field of robotics, interaction with multiple robots by a single operator has been studied [7, 14], but the sense of parallel embodiment into multiple bodies has not been investigated. On the other hand, techniques of visual sharing with others have been studied [9, 10, 17, 18, 20, 23]. We applied the method of splitting the visual field to share visions with multiple bodies.

The human body is unique in the physical environment. We envision that, if we can control multiple bodies simultaneously, we can interact with multiple environments in parallel, which may improve efficiency in tasks and show the possibility of cooperative work and group behavior by one person.

In this study, we attempt to provide direct control for distributed embodiment and explore how body cognition changes with multiple bodies and how the user controls them.

We used a Virtual Environment (VE) to make distributed avatars. In our system, the user's movements are synchronized to multiple bodies, and the user can perceive visual sensory information from them simultaneously. We can synchronously control up to four virtual bodies and use split views to display the First Person Perspective (FPP) of the bodies (similar to Kasahara et al. [9]).

In Experiment 1, we asked participants to touch balls while changing the number of avatar bodies. We evaluated the differences in body cognition between single embodiment and multiple embodiment based on the task performances and subjective ratings. Then, in Experiment 2, we asked participants to catch flying balls that were thrown toward the avatar bodies under conditions with four distributed embodiments to see the limits of controlling the bodies simultaneously.

The main contribution of this work is to explore the following items:

- The effects of synchronization with multiple bodies on task performance and the sense of embodiment.
- How people operate multiple bodies when synchronized with them.
- The limits of operating multiple bodies directly in parallel.

## 2 RELATED WORK

### 2.1 Bi-location in virtual reality

Wissmath et al. [24] conducted a user study in a VE displayed on a TV screen to examine whether it is possible to feel localized at two distinct places at the same time. Participants rated their self-localization in their "immediate environment" (i.e., the real room) and in their "mediated environment" (i.e., the VE). The authors compared the two ratings and showed that participants equally distributed their self-localization between both environments (after 30s, about 50% immediate environment and 50% mediated environment).

Furlanetto et al.[6] reviewed bi-location works and argued for decomposing bi-location into three components: self-localization; self-identification (i.e., a concept similar to body ownership); and FPP. These components are closely related to the sense of self-location and sense of body ownership from the sense of embodiment [12]. A related study was conducted by Aymerich-Franch et al.[1], who developed a system to embody a robot and conducted a user study. Participants rated their self-location and self-identification as they observed themselves (i.e., their real body) from the robot. The authors showed that it is possible to be bi-located when embodied in two bodies.

Recently, Nakul et al. [19] compared two self-location tasks in a Third Person Perspective (TPP) fully immersive VR setup: a so-called Mental Imagery Task (MIT) based on perception, where participants guessed when a ball moving at constant speed would hit them; and a Locomotion Task (LT) based on motion, where participants walked with their real body toward a fake body. The authors showed that bi-location was only felt in the MIT task.

### 2.2 Operating multiple robots

Glas et al. [7] developed a user interface for operating with multiple social robots and evaluated the system. This system optimally sorts the operation requests from the robots to a single user. While the user operates one robot, the other robots are controlled in the background. The results of the evaluation experiment show that the system is useful for operating multiple social robots with a single operator. However, the user controls the robots by entering commands into the interface. Embodiment in multiple robots has not been considered.

Kishore et al. [14] developed a system that allows a user to fully control a humanoid robot using full body tracking and switch a subjectof control freely to control multiple robots. The user can feel an audiovisual perception of each robot with a Head Mounted Display (HMD) and two-way audio communication. The study showed the possibility of eliciting a full body ownership illusion over not one but multiple artificial bodies concurrently. We investigate the sense of embodiment with synchronized vision and movements in parallel with up to four multiple bodies.

### 2.3 Sharing Multiple Fields of View

Several view sharing systems have been developed, such as View Blending; View Swapping (i.e., you see another user's view); View Cycling (i.e., you cycle through all the users' views, including your own); and View Splitting (along the horizontal line, the vertical line, or in a grid).

Kawasaki et al. [10] developed an HMD blended shared view system for two users. While their system supported the blended view, they conducted a user study with view swapping (i.e., your own view has 100% transparency [= not visible] and your partner's view

has 0% transparency). This study showed view sharing was significantly better than no view sharing at transmitting/acquiring motor-skills. From the same team and with the same system, Kurosaki et al. [17] conducted a user study with view blending (i.e., your own view has 50% transparency and your partner's view has 50% transparency). This also showed view sharing was significantly better at transmitting/acquiring motor-skills than no view sharing.

Mitchell et al. [18] developed an HMD view swapping system for two participants where only one participant was able to see something (here, his/her partner's view). They tested their system in several workshops (running, throwing, etc.) where the participants had to stand back to back. The participants reported it was enjoyable but difficult to find their orientation.

Kasahara et al. [9] developed an HMD split view sharing system for four participants. The four views were displayed side by side along a 2x2 grid. They tested their system in several workshops (drawing, shaking hands, etc.) and noted (among other things) that: (i) participants developed their own viewing behavior (i.e., looking at the others' views to know what to do); and (ii) participants lost sight of their own body. Similarly, Sypniewski et al. [23] (from the same team as [18]) conducted several workshops with four participants, but they used an HMD with a view cycling system. The participants reported (among other things) that: (i) they developed their own viewing behavior (i.e., waited for their own view before moving); and (ii) they focused more on non-visual perceptions.

Pan et al. [20] compared three HMD shared view implementations for two participants: blended views, split views along a horizontal line, and split views along a vertical line. They showed that blended and vertical split views significantly provided the best sense of body ownership.

## 3 CONCEPT

The main purpose of this study is to explore cognition and behavior changes on distributed multiple bodies with simultaneous motion and visual perception sharing. This chapter describes the concept of the disturbed embodiment with synchronized behavior and perception.

Our body is a single instance in our physical space, but, it is possible to extend it with virtual reality or robotics technology. To have multiple bodies with a single user can be considered as an implementation of human augmentation. Fig. 2 shows a snapshot of distributed embodiment. By having multiple bodies, we are able to consider various scenarios.

**Working in multiple places:** Multiple bodies allow the user to show their skill to other people as a trainer in multiple remote locations. Distributed embodiment allow us to existing and interact with multiple places in parallel.

**Self co-working** A mirrored body is able to cooperate with the original one to held both ends of a heavy or long item and move it.

**Maze** To find a route in a maze is a possible scenario for the user with the multiple bodies. The user is able to perform speculative search to use the advantage of the distributed embodiment.

We are able to think about various possible use cases. But, in this study, we focus on investigating user cognition and behavior on such multiple bodies with synchronized behavior and perception through task based user experiments.

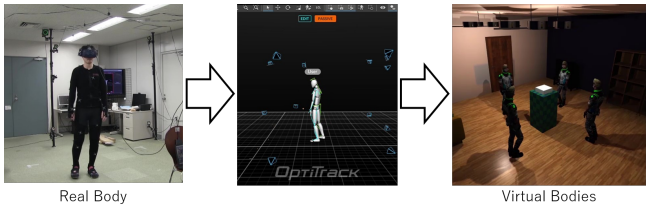



**Figure 2: Snapshot of Distributed Embodiment in Virtual Environment**

## 4 IMPLEMENTATION

Our VR system allows a participant to be distributed in multiples bodies (1 to 4) in real-time.

### 4.1 Material

The participant's body motions were tracked with 24 Optitrack cameras[1] in a tracked area of ≈ 4.37m × 2.37m. We implemented the VR application in Unity3D[2]. To display the VE, we used the HTC Vive Pro Eye HMD[3].

It has 1440 x 1600 pixels per eye, a 90 Hz refresh rate and 110 degrees of viewing angle. By Motive, OptiTrack control software, the participant's skeleton data was generated from the marker pattern of the tracking suit and streamed to Unity.

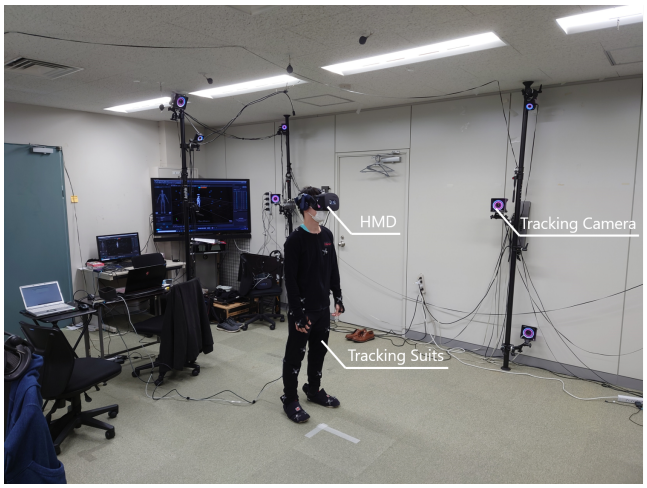



**Figure 3: A participant standing in the tracked area.**

### 4.2 Multiple bodies

The avatar body used in the application was one of avatars of Daz Studio[4]. Since the bodies were copies of each others, they were indistinguishable from each others.

[1] https://www.naturalpoint.com/
[2] https://unity.com/
[3] https://www.vive.com/eu/product/vive-pro-eye/overview/
[4] https://www.daz3d.com/

The bodies moved relatively to the participant's motion. In order to synchronize the motion of the multiple bodies and the participant, we used skeleton data streamed from the motion capture system. The skeleton data is segment information defined hierarchically. We copied the positions and rotations of the corresponding segments to the multiple virtual avatars. The position of each body was moved relative to the actual participant's movement from each initial position.

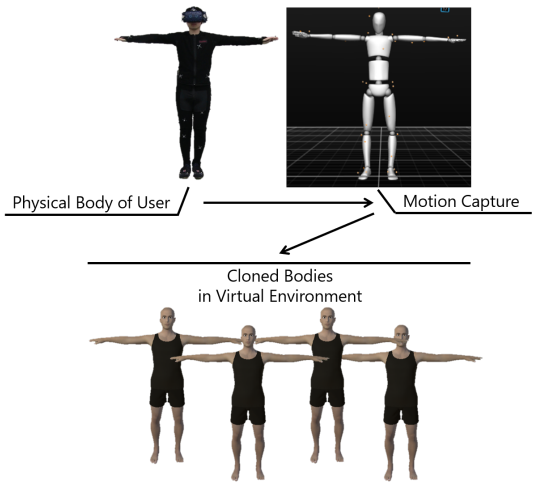



**Figure 4: Configuration of Virtual Bodies: All bodies are synchronized with the real-time motion of the user.**

*4.2.1 Views sharing.* There are several methods to share the views of multiples bodies, such as view cycling, view swapping, view splitting, etc. (c.f., Sec.2). Here we used view splitting in a 1x2 or 2x2 matrix (respectively if there was 2, or 4 avatars).

The user's view was split to the number of bodies and each split view is the first person view from each avatar. To make binocular cues, we combined visual information from avatars for left and right eye independently in consideration of view dependency. This approach allows us to make stereoscopic perception from synchronized bodies.

## 5 EXPERIMENT 1

Experiment 1 focused on the effects of multiple bodies on task performance and the sense of embodiment.

### 5.1 Method

We asked participants to complete a reaching task for virtual balls. There were three conditions: the one-body condition; the two-body condition; and the four-body condition. In the two-body condition, the bodies were rotated 180 degrees in the horizontal plane (so they were facing each other), and in the four-body condition, the bodies were rotated 90 degrees in the horizontal plane to face each other.

*5.1.1 Participants.* Twelve participants (all male, age: $M = 23.0, SD = 1.7$, 10 right-handed) joined the experiment. All of them had normal vision and motor ability.

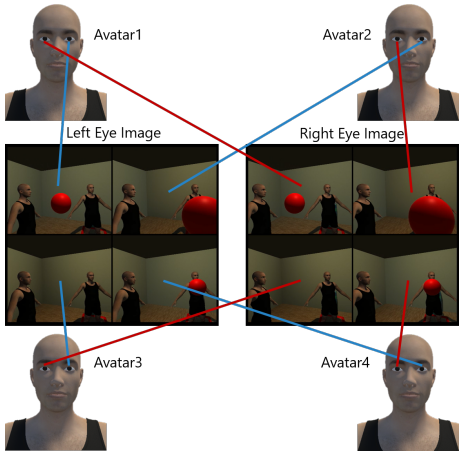



**Figure 5: View Synthesis of Binocular Images: Synthesized images are displayed on HMD.**

*5.1.2 Reaching Task.* We set up a reaching task in a square room of ≈ 5.5m×5.5m (fitting within the tracked area). There were 20 trials. In each trial, participants were asked to press a button in front of the view where all views (four or two) were identical . Once the button was pressed, the virtual target ball appeared for the reaching task (Fig. 5). Participants then looked back toward the center of the room (Fig. 5-B). In this situation, the four or two views were not identical since the virtual ball was not symmetrically located. Then participants reached for the virtual ball (Fig. 5 - C).

We prepared 20 positions that were arranged evenly within 1.0m from the center of the square room, and a ball appeared at one of the positions in random order.

In this task, we measured the moving distance of the participant and the completion time in each trial to evaluate the task performance. During the task, the position of the ball was not moved. Thus, we could observe the behavior and cognition with a static environment in this experiment.

*5.1.3 Procedure.* The participant wore the HMD and the tracking suit. Body tracking was calibrated at the beginning of the session. After receiving instructions for the experimental procedure, the participant performed the task under one of the three conditions. After completing the task, the participant answered a questionnaire on a 7-level Likert scale of -3 (very strongly disagree) to 3 (very strongly agree). This was repeated for each condition. The order of the conditions was randomized and counter balanced between the participants. The participants were asked to respond to the following after each condition:

- Q1 I felt as if all the virtual bodies were my bodies.
- Q2 I didn't feel as if some virtual bodies were my bodies.
- Q3 I felt as if I controlled all the virtual bodies.
- Q4 I felt as if I wasn't the one in control of some of the bodies.
- Q5 I was able to perform the task efficiently.
- Q6 It was difficult to operate.
- Q7 What did you think about when you performed the task? (Free Answer)
- Q8 What were your thoughts on the task? (Free Answer)

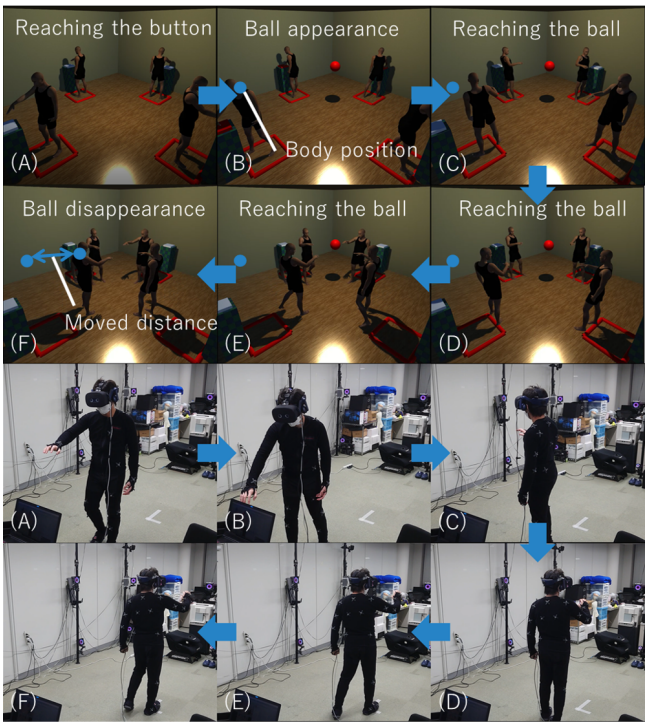



**Figure 6: The Reaching Task: When the participant touched the button, a ball appeared and the participant reached for it. Top: Virtual Environment. Bottom: Real Environment**

The following questions were asked only for multiple body conditions (two-body condition & four-body condition):

Q9 I felt as if I was controlling all the virtual bodies at the same time.

Q10 . I felt as if I was controlling a body of the view I was paying attention to.

## 5.2 Result

*5.2.1 Task Performance.* To see the effects of synchronization with multiple bodies on task performance, we evaluated the moving distance and time in each trial. The result of moving distance is shown in Figure 7. As an objective measurement, we found that the moving distance in the task decreased as the body count increased. For the experimental setup, if a participant utilized distributed embodiment efficiently, moving distance in the multiple-body conditions was reduced compared to the one-body condition. The result suggests the participants took advantage of the distributed embodiment and manipulated multiple bodies to complete the task. Consequently, the moving distance in the multiple-body conditions was reduced. The moving distance was shorter in the two-body condition than in the one-body condition ($p < 0.05$) and shorter in the four-body condition than in the one-body condition ($p < 0.05$) and two-body condition ($p < 0.05$). The Tukey-Kramer test was used as a statistical test for the performance analysis of this study.

On the other hand, task completion time in the multiple-body conditions increased more than in the one-body condition. Figure

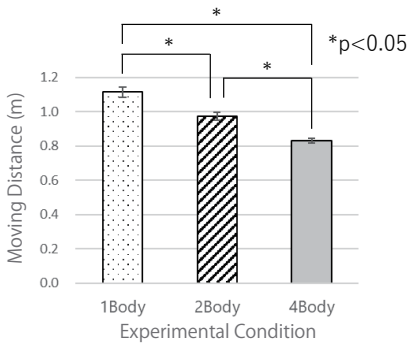



**Figure 7: Result: Average moving distance in each trial**

8 shows the result of task completion time. The task completion time was shorter in the one-body condition than in the two-body condition ($p < 0.05$) and four-body condition ($p < 0.05$). This could be due to the cognitive load of sharing multiple views and choosing an appropriate behavior, which increased the task completion time while the moving distance decreased in accordance with the number of bodies.

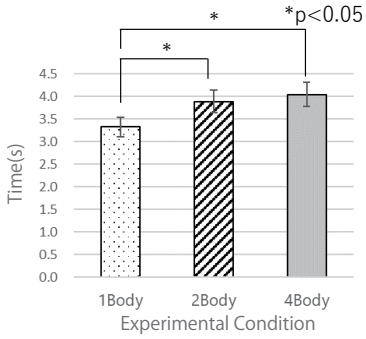



**Figure 8: Result of Task Performances: Average task time in each trial**

*5.2.2 Sense of Embodiment.* To see the effects of synchronization with multiple bodies on the sense of embodiment, we analyzed subjective responses from the participants.

We performed Steel-Dwass test on Q1-Q4 among the body conditions. Figure 9 shows the results of Q1 and Q2 regarding the sense of body ownership. The score of Q1 was higher in the one-body condition than in the two-body condition ($p < 0.05$). The score of Q2 was lower in the one-body condition than in the two-body condition ($p < 0.05$).

Figure 10 shows the results of Q3 and Q4 regarding the sense of agency. We compared the results of the sense of agency (Q3, Q4) between the body conditions. The Q3 score was higher in the one-body condition than in the two-body condition ($p < 0.05$) and four-body condition ($p < 0.05$). The Q4 score was lower in the one-body condition than in the two-body condition ($p < 0.05$).

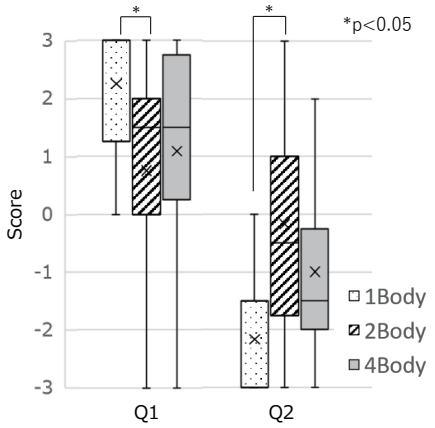



**Figure 9: Result of Subjective Ratings: The sense of body ownership**

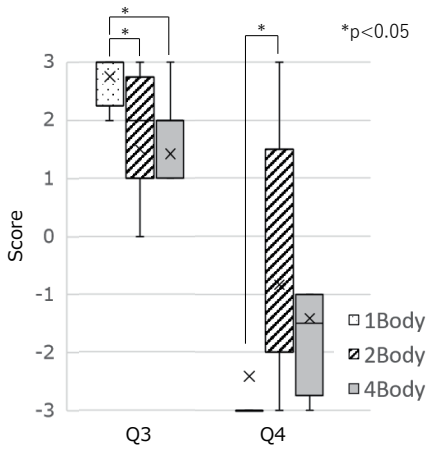



**Figure 10: Result of Subjective Ratings: The sense of agency**

Figure 11 shows the result of the comparison among the conditions regarding the question about efficiency and difficulty. The score of the feeling of difficulty was lower in the one-body condition than in the two-body condition ($p < 0.05$) and four-body condition ($p < 0.05$). We also used a Steel-Dwass test for the statistical test.

There was no significant difference on the sense of body ownership for all bodies (Q1 and Q2) in between the one-body and four-body conditions. Also, there was no significant difference in between the one-body and four-body conditions on a question for the sense of agency (Q4). This result suggests that the participants kept the sense of embodiment close to the one-body condition even in the four-body condition.

From the results of the comparison among conditions, the sense of agency (Q3) decreased as the number of bodies increased, even though it was preserved in between the one-body and four-body conditions in the other questions (Q1, Q2 and Q4). This is similar to the sense of presence in a study of bi-location by Wissmath et al.[24]. In that study, the self-localization of two environments converged to 50%. In the same way, the sense of agency in each body is considered diminished due to the participant becoming the object of an action multiplied by distributed embodiment.

In the two-body condition, the two bodies faced each other by 180 degrees of rotation so the participants could see both the bodies' movements from a single perspective. Also, in the participants' free responses (Q7), there were several comments that the task "could be completed by using only one of the two perspectives in the two-body condition." These facts suggest that the perception of one body as "my body" and the other as "another body synchronized to me" in the two-body condition may have reduced the sense of body ownership. It can be said that the sense of body ownership may be retained in conditions where the two bodies are not visible to each other, even in the two-body condition. At the same time, these facts support the possibility of spatial perspectives by taking perspectives other than one's own, which has been proposed in several studies [2, 9, 10, 17].

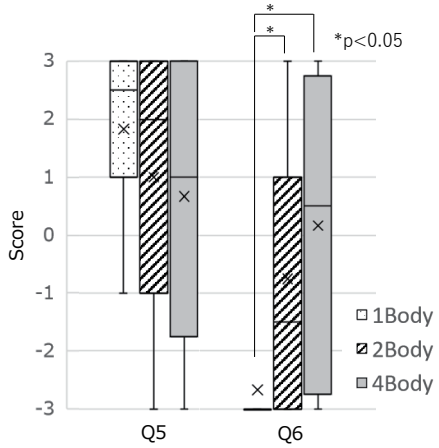



**Figure 11: Result of Subjective Ratings: The feeling of efficiency and difficulty**

Figure 12 shows the result of comparing the manipulation of bodies in parallel (Q9) and the switching of attention(Q10). In the four-body condition, the score of Q10 was higher than that of Q9 ($p < 0.01$).We used Mann-Whitney U test for the statistical test.

When embodiment is distributed in multiple bodies, we can set up the two hypotheses that the operations of multiple bodies are performed in parallel or by switching the attention. From the comparison between Q9 and Q10 in each condition, it can be said that the manipulation of the four bodies is not parallel but is performed by switching the body of attention in the consciousness. Even in the case of two bodies, this body switching is expected to occur in conditions in which the bodies are not visible to each other in light of the earlier discussion.

The switching the body of attention was done actively by each participant's decisions in Experiment 1. In Experiment 2, we investigated the case where requests of body-switching were generated by external factors due to the task.

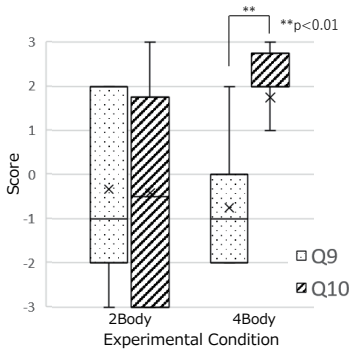



**Figure 12: Result of Subjective Ratings: Comparison between manipulating the multiple bodies in parallel and switching**

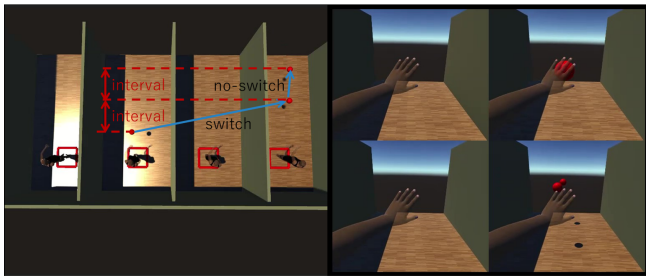



**Figure 13: The Flow Task. Left: A view of the task from above. Right: The participant's view**

## 6 EXPERIMENT 2

In Experiment 2, to explore the limits of operating multiple bodies directly under the condition of synchronizing with four bodies in different places, we gave the participants a flow task that generated body-switching requests by the balls flying one after another. We found that when a participant is synchronized with multiple bodies, the switching of attention to sensory information from the distributed bodies was reported in Experiment 1. The switching of attention was caused by active behaviors to complete the reaching task. Thus, in this experiment, we tried to explore behavior and cognition on passive behavior by having a flow stimulus in a dynamic environment.

### 6.1 Method

*6.1.1 Participants.* The same 12 participants participated in Experiment 2 after they performed Experiment1.

*6.1.2 Flow Task.* We set up a flow task with a ball flying continuously into each body under the conditions of synchronization with the four bodies (Figure 13). The balls flew to a range of 0.3m on each side from the center of the target's body and 1.3m to 1.6m in height. The participants were asked to touch the flying balls with their dominant hand. We induced body switching to occur by flying the next ball to a different body target than the previous ball. To observe switching performance when the body switching was requested faster, the intervals between the appearance of the ball could be changed. There were 12 patterns of switching from one body to another in the four bodies. In addition, to randomize the timing of the body switching, we prepared cases where the switching frequency was once per one trial, once per two trials, and once per three trials in each switching pattern. They were randomly combined for 72 trials (36 switches, 36 no-switches) (12 patterns × (1 trial + 2 trials + 3 trials)). The participants were prevented from occlusion by having their hands made translucent and were informed whether the reaching was a success or a failure by sound. We measured the ball touch success rate in body switching and no-switching trials.

*6.1.3 Procedure.* Participants wore the HMD and the tracking suits. The skeleton tracking was calibrated. After the experiment was explained, the participants performed the flow task. The flow task was given six times (one practice phase and five performance phases) with varying intervals between ball appearances (0.6s, 0.5s, 0.4s, 0.3s, 0.2s, 0.1s). Then, the participants were asked to answer the questionnaire on a 7-level Likert scale of -3 (very strongly disagree) to 3 (very strongly agree). The questions asked were mainly about the following:

- Q1. It felt like a ball was coming at me.
- Q2. It felt like the ball was flying at me from four directions.
- Q3. It felt as if a ball was flying to each of the four distributed me.
- Q4. What did you think about when you performed the task? (Free Answer)
- Q5. What were your thoughts on the task? (Free Answer)

### 6.2 Result

*6.2.1 Task Performance.* We measured the success rate of touching the flying balls in body switching and no-switching under each interval. The result is shown in Figure 13. We performed a paired t-test to compare the task performances between the body switching and no-switching conditions in each interval. When the intervals were 0.4s, the success rate of the switching trials was higher than that of the no-switching trials ($p < 0.05$).

The task performance decreased as the intervals became shorter. This is natural because the needed body switches faster as the interval gets shorter. It was confirmed that multiple bodies were operated by the body-switch, as seen in the questionnaire of Experiment 1. There was no significant difference in the other intervals. Only when the intervals were 0.4s was the success rate of the switching trials higher than that of the no-switching trials. The occlusion between the balls in the no-switch trials due to the experimental design may influenced the fact that switching trials had better performance.

*6.2.2 Subjective ratings.* Figure 15 shows the subjective ratings for the feeling of balls flying toward oneself(Q1), convergence into one body (Q2), and the feeling of distribution into four bodies (Q3). The result of Q1 was answered by all participants as 3 (very strongly agree). We performed a Mann–Whitney U test between Q2 and Q3. The score of Q3 was higher than that of Q2 ($p < 0.05$).

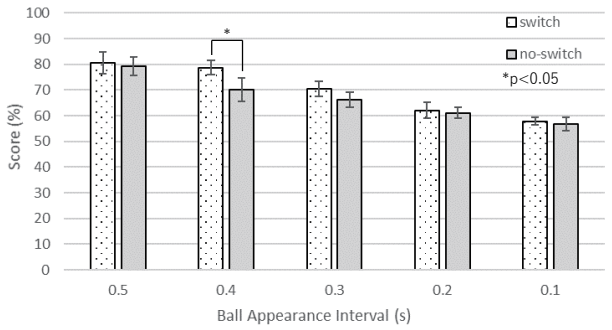



**Figure 14: Result of Task Performances: The ball touch success rate in switching and no-switching**

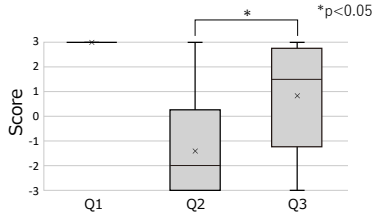



**Figure 15: Result of Subjective Ratings: The feeling of balls flying toward oneself(Q1), convergence into one body(Q2), and distribution into four bodies(Q3)**

By looking at the result of Q1, it was observed that participants experienced a strong sensation of a ball coming at them. This suggests that humans can perceive all the presented sensory information from the distributed embodiments as their own.

From the comparison between Q2 and Q3, the sense of being distributed into four bodies was stronger among participants than the sense of being converged in one body. This indicates that motion synchronization and view sharing with multiple bodies induce the distribution of the sense of presence.

Next, we turn our attention to the open-ended questions. Regarding the participants' strategies for the task (Q4), some of them said, "I focused on the field of view where there were more balls and gave up on the ones that were not in time" and "I thought about which order to move the view." This confirms again that the operation in consciousness is done by switching. In addition, multiple bodies have the potential to improve the efficiency of the task through speculative execution. In the feedback for the task (Q5), there were comments like "Even if I could recognize which field of view the ball was coming, my hand couldn't catch up" and "I felt a big gap between the position of my virtual hand and my actual hand when I switched the field of attention". These comments confirmed that there is a time lag from the switching of the attention view to the spatial grasp of that view. In addition, it is possible that the body switching may be caused by a passive request, which leads to the perception of a large gap between the body position and the actual hand.

## 6.3 Discussion

To summarize the results of Experiments 1 and 2, under the condition of synchronizing with four bodies, the manipulation of the bodies by switching the attention body was performed in both the reaching task and the flow task. This suggests that the switching of attention to sensory information among multiple distributed bodies is caused by an active transition to the most appropriate body to complete a task in a static environment and a passive transition to correspond to stimuli for each body in a dynamic environment.

The participants manipulated the four bodies by switching the attention to the sensory information among these bodies while feeling the sense of presence, body ownership, and agency in parallel to the four bodies. This is a very interesting fact. The sense of embodiment can be retained in parallel, but a switch may be needed to perform an intentional behavior. Further investigation is required to verify this.

# 7 LIMITATION AND FUTURE WORK

In the statistical analysis, it must be cared low the amount of participants and experimental design.

The sense of embodiment is partly due to the internal forward model and partly due to the reasoning process[3]. The results of questionnaire for participants' reflection include the sense from the reasoning process. Thus, further studies are needed to investigate body sensations close to the internal forward model, for example, using sensory decay by an efference copy of the motor command.

To unify each body, we did not provide any differences for the multiple bodies and things around them in this study. However, adding some differences may help in gaining perceptions of positional relationships with each other. Also, the induction of attention may make the switch more efficient.

We tested a case where all the bodies were similarly synchronized with the participants, but in adapting to multiple bodies, there are other possible synchronization methods, such as mirrored methods and methods involving different body shapes, such as a long arm[16]. There are also other possible operating methods that can be used to switch the body a user is moving by using gaze information.

In this study, there were two types of body sensations: those that could hold four bodies in parallel and those that were switched. We discussed the possibility that the user's intention may influence the difference.

We examined user behavior and cognition on distributed embodiment up to four bodies in the experimental setup. As a future study, we would like to explore the maximum limit for body cognition by increasing the number of bodies beyond the current configuration.

# 8 CONCLUSION

In this study, we examined participants' body cognition when experiencing synchronized movements and shared views with multiple bodies through the VE. We set up two tasks and evaluated them by the task performances and the subjective ratings. We found that people can have the sense of embodiment for each body even with the four-body condition when synchronized with multiple bodies. Also, we observed that the moving distance in the reaching task decreased by choosing the proper body in Experiment 1. Our




**Figure 16: By using MultiSoma, the user can synchronize movement and vision with one, two, or four bodies.**

experiment demonstrated that participants are able to manipulate multiple virtual bodies to complete the task. Also, we observed that body switching is caused by passive triggers with stimulus for each distributed body (Experiment 2).

We believe that distributed embodiment has a potential to bring various extensions such as cooperative work, parallel work, and group behavior by one person for future studies.

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