Comparison of Calculation Modes for Virtual Co-embodiment: Movement Average and Vector Summation

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Abstract

When two individuals control a virtual avatar simultaneously (virtual co-embodiment), their movement performance can, somewhat surprisingly, improve compared to when they control an avatar alone. This study investigated whether movement performance is affected by how individuals' movements embody into an avatar: by averaging the positions of individual's body parts or by summing the movement vector of each individual's body parts. The experiment, in which participants reached a target with the avatar's hand in these two types of co-embodiment, showed that the vector summation was more efficient in improving body movements than the position average.

Index Terms: Virtual co-embodiment, Vector summation, Averaging position of body parts.

1 Introduction

Virtual co-embodiment allows multiple individuals to share and control a VR avatar simultaneously [1]. This co-embodiment is typically achieved by averaging the positions of individuals' body parts and reflecting the averaged positions into the positions of the avatar's body parts [1][2][3]. Previous studies reported that, when two individuals co-embody an avatar, their performance in bodily movement [2] and motor skill learning [3] improved compared to when they manipulate an avatar alone.

This improvement in movement performance may be related to our ability to engage in joint action–"any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment" [4]. In daily life, we often interact with each other to achieve a joint goal, such as carrying a table across a room. Virtual co-embodiment would arouse our ability of joint action, resulting in improved movement performance and improved motor learning. If this were the case, in a situation more like joint action, the virtual co-embodiment would induce a larger improvement in movement performance. This study investigated whether movement performance can improve in a joint action-like virtual co-embodiment situation.

Most previous studies on virtual co-embodiment controlled a virtual avatar based on the average of two individuals' movements. However, the movement average is not likely to represent joint action between them. In joint action in the real world, such as moving a table across a room, the physical load of each individual is halved when two individuals carry a table together compared to carrying it alone. Action load per person is reduced as the number of contributors increases. To represent joint action in virtual co-embodiment, controlling an avatar based on the summation of

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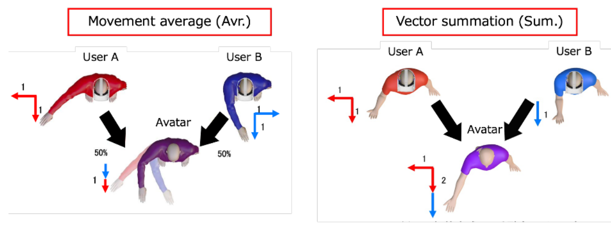

Figure 1: The schematic diagram of calculation modes for virtual co-embodiment

movement vectors of individuals would be more appropriate, as the physical load decreases according to the number of users. In this study, we investigate whether the co-embodiment modes (movement average vs. vector summation) affect the movement performance of individuals. If the representation of joint action facilitates performance during co-embodiment, individuals' performance will improve when they co-embody in the vector summation than when they co-embody in the movement average.

2 Method

Participants. Twenty-two participants participated in pairs (eighteen males and four females, eleven pairs, 21–24 years of age) in the experiment. All participants had normal or corrected-to-normal vision and no difficulty with right-hand movements. All experiments were approved by the Research Ethics Committee of Ritsumeikan University.

Apparatus. The experimental unit for each participant consisted of a computer, a Meta Quest 2 head-mounted display (HMD), and a pair of Meta Quest 2 controllers. The virtual co-embodiment system was constructed with these two units. We controlled the experiments and rendered the three-dimensional virtual environments by Unity (2020.3.2f1) on the two computers (PC1: GALLERIA XA7C-R37; PC2: GALLERIA XF). The controllers measured the three-dimensional positions and rotation of each participant's hands. The sampling rate for measuring the hand movement was 90 Hz.

Movement conditions. We conducted four movement conditions, combining two co-embodiments (co-embodying vs. solo) and two calculation modes (movement average vs. vector summation). In co-embodying in the movement average, we presented the avatar's wrist with a position that averaged between each controller held by each participant. In solo in the movement average, we presented the avatar's wrist with the same position as the controller position held by each participant. In co-embodying in the vector summation, we presented the avatar's wrist in a position that summed up the movement vector of each participant. In solo in the vector summation, we presented the avatar's wrist in a position twice as far as the movement vector of each participant so that the movement distance was matched with that in the co-embodying condition. We calculated each participant's vector between a current frame and one frame before.

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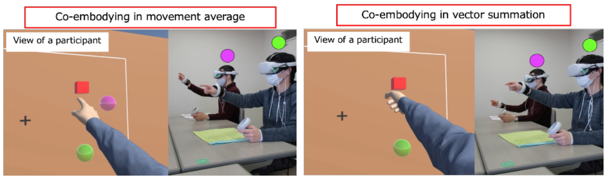

Figure 2: Example scene of experiment. The spheres indicate each participant's controller positions, which were not shown during the experiment.

Procedure. Participants were seated on chairs wearing HMDs and holding the controllers in both hands. Their hands were placed on a table in the real world. We conducted four trials in each of the four conditions, with a total of twelve trials per participant. Trials of our movement conditions were conducted in a random order.

In each trial of the reaching task, participants were asked to reach a target by using the right hand of the avatar. A target (a red cube) was presented at a random position, and it disappeared when the avatar's hand touched it. A target appeared at a depth of 50 to 60 cm away from the frontal plane of an avatar's body in all movement conditions. After the reaching task, participants were asked to evaluate their sense of agency ("How much did you feel as if you actually controlled the avatar's hand?") and body ownership ("How much did your avatar's body feel like your own?") during the task. Participants were asked to respond on a 7-point scale for each questionnaire (1: Strongly disagree, 7: Strongly agree).

3 Results

The three-dimensional right-hand positions of each participant were analyzed. We conducted 2 (co-embodiments) x 2 (calculation modes) ANOVA with aligned rank transformation.

Straightness is the difference between the length of an individual's hand trajectory and the straight line joining the hand's start and endpoint (target) during the reaching task (smaller values indicate straighter trajectories). We found the main effects of co-embodiments and modes were significant ($ps < .01$), with no significant interaction between them ($p = .95$). The post-hoc analysis showed that movement trajectories were significantly straighter in co-embodying in the vector summation than in the movement average ($ps < .01$). Jerk is the average rate of acceleration changes during a reach, indicating how smoothly participants move their hands. We found the significant main effects of co-embodiments and modes, and their interaction ($ps < .05$). The post-hoc analysis revealed that there were no significant differences between solo and co-embodiment in vector summation ($p = .35$). However, there were significant differences between solo and co-embodying in the movement average ($ps < .001$). These results indicate that the hand movements of individuals become smoother under the vector summation regardless of whether they co-embodied or not.

For sense of agency, we found significant main effects of co-embodiments and modes, and significant their interaction ($ps <$ .005). The post-hoc analysis revealed that there were significant differences between solo and co-embodying in both methods ($ps <$ .01). There were no significant differences between co-embodying in the movement average and that in the vector summation ($p = .36$). For sense of body ownership, we found that the main effects of co-embodiments and methods, and their interaction were significant ($ps < .005$). The post hoc analysis showed no significant differences between co-embodying in the movement average, co-embodying in the vector summation, and solo in the vector summation.

4 Discussion and Conclusion

Our results showed that individuals moved their hands straighter and smoother when they were co-embodying in the vector summation than the movement average. These results suggest that movement performance became more efficient when joint action occurs between co-embodying individuals. Virtual co-embodiment could be applied to investigate the mechanism of joint action in future studies.

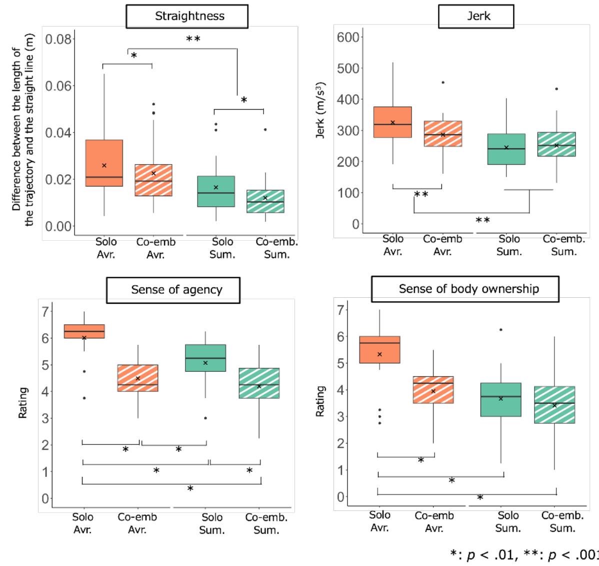

Figure 3: Results of straightness, jerk, sense of agency, and sense of body ownership.

The sense of agency and body ownership decreased when individuals were co-embodying with others. However, there is no difference between calculation modes. These results suggest that the difference in calculation modes does not affect the subjective perception of action and embodiment during virtual co-embodiment. The sense of body ownership in solo in the vector summation also decreased, in the same way as both co-embodiment conditions. In solo in the vector summation, the avatar's hand was presented far away from the position of the individual physical hand. The spatial discrepancy between these hands could occur in the lower sense of body ownership in solo in the vector summation.

In this study, the distances to targets were the same in three movement conditions. Therefore, the avatar's arm did not stretch when individuals reached the target in the vector summation. Individuals also moved their hands less in the vector summation than in the average movement. In future work, it is necessary to control the amount of hand movement in each calculation mode. We also need to examine whether the vector summation has a benefit in other types of movement and learning tasks.

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