Embodiment in Recorded VR Training: Effects of Avatar Appearance

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Abstract

Virtual reality (VR)–based training often integrates After Action Review (AAR) to enhance learning, where recognizing one's own actions is critical for performance improvement. A key mechanism underlying this recognition is the sense of embodiment (SoE), the perception of a virtual body as one's own. While SoE has been studied mainly in synchronous contexts, little is known about its persistence during non-interactive replay of past actions. This pilot study (N = 5) investigated how avatar appearance influences SoE when participants observed recordings of their own VR performance under temporal asynchrony. Using a within-subjects design, participants performed an object placement task with three avatar conditions—Mannequin (MA), Resemblance (RA), and Customized (CA) and then viewed replays of their actions. SoE was measured across body ownership, agency, self-identification, self-attribution, and spatial presence. Results showed a trend in the order of RA > CA > MA for self-identification and spatial presence. These findings indicate that SoE can be sustained even in non-interactive replay conditions, highlighting avatar appearance as an important factor in designing effective VR-based AAR systems.

Keywords

Virtual Reality, Sense of Embodiment, Avatar Appearance, Non-interactive replay

1. Introduction

Virtual reality (VR) is widely used for simulation-based training in healthcare, the military, and industry. In addition to simple training procedures, these programs also incorporate learning methods such as After Action Review (AAR) to enhance training effectiveness. AAR is a method that enables learners to objectively review their actions and mistakes after completing a training simulation [1]. Research has shown that AAR based on a learner's own performance video yields stronger learning effects compared to videos of others' performances. This effect is particularly pronounced among learners with high self-efficacy [2]. These findings suggest that AAR enhances training effectiveness and that recognizing one's own performance is a crucial factor in both learning transfer and performance improvement.

In VR, this recognition of one's own actions is closely tied to the sense of embodiment (SoE), a core experiential mechanism through which users come to perceive a virtual body as their own. SoE is defined as perceiving the features of a virtual body as if they were part of one's own body. [3]. SoE has been associated with benefits such as enhanced cognitive performance [4], stronger tactile perception [5], and improved learning effectiveness [6].

Among the various factors that shape SoE, the visual appearance of avatars has been shown to play a particularly important role. Previous studies have found that perceived similarity body shape, identity match, scan-based realism, and personalization/customization all influence the formation of SoE [7, 8, 9, 10]. However, most research has focused on SoE in real-time settings where time is synchronized. Much less is known about whether SoE can also occur or persist when people watch recordings of their own past performance under time-asynchronous conditions.

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This study investigates how avatar appearance affects SoE when learners observe recordings of their own performance under temporal asynchrony. To this end, we pose the following research questions:

- **RQ1**: Do people experience SoE when watching recorded 3D VR scenes?
- **RQ2**: Does SoE differ depending on the avatar's visual appearance?

To answer these questions, participants completed a simple shape-matching task using avatars with three different visual appearances. Afterwards, they watched recordings of their own performance. This allowed us to examine whether participants experienced SoE in recorded 3D VR scenes and whether avatar appearance influenced the level of SoE.

2. Related Work

2.1. Sense of Embodiment in VR

In head-mounted display (HMD)-based VR, the sense of embodiment can be conveyed to the user through a virtual body, or avatar [11]. SoE generally consisted of three components: agency, body ownership, and self-location [3]. Agency refers to the feeling that the movements of the virtual body originate from and are controlled by oneself [12]. Body ownership refers to experiencing and attributing the perceived virtual body as one's own body [13]. Self-location is the sense that oneself is located at a specific body or spatial position within the virtual environment [14].

SoE in virtual environments influences users' cognition, perception, and behavior, and is related to user experience and performance in multiple ways. For example, in a memory task involving paired letters, participants demonstrated significantly higher recall performance under high-SoE conditions [4]. In tactile experiments, stronger tactile illusions were observed when SoE was heightened [5]. Furthermore, when presenting a virtual body that differed in appearance from the physical body, users' behavioral patterns were altered according to the characteristics of the virtual body [6].

2.2. Avatar Appearance and Customization

Although various factors can elicit a SoE, avatar appearance and the process of directly customizing avatars can also play a significant role in inducing it. When users viewed their avatars through a full-body virtual mirror, realistic avatars elicited higher SoE and task performance compared to non-realistic avatars or the absence of avatars [7]. SoE was further enhanced when avatar appearance matched users' identity traits such as gender and ethnicity [8]. Personalized avatars resembling the user's own appearance also increased SoE, while the use of HMDs, compared to CAVE-based VR, provided stronger immersion and thus greater SoE [9].

Creating one's own avatar has also been shown to enhance both SoE and self-identification. Customized avatars were often perceived as highly similar to oneself, as they reflected aspects of one's self-image [15]. This self-identification effect was stronger for user-customized avatars and was accompanied by higher perceived self-similarity, self-expression, and willingness to self-disclose [16]. Moreover, when user-customized avatars were employed in a running game, SoE was significantly increased [10].

2.3. Embodiment under Non-interactive Replay

Previous experiments on the temporal asynchrony condition employed pre-recorded first-person actions not performed by the participants. These actions were replayed in real time and mismatched the users' actual movements. Under such conditions, SoE was found to decrease [17, 18, 19]. However, these studies created a mismatch by showing pre-recorded actions not performed by the participant. In contrast, the present study has participants observe recordings of their own performances from a third-person perspective. This design enables us to investigate whether SoE can emerge under non-interactive replay conditions and whether avatar appearance affects the degree of SoE.

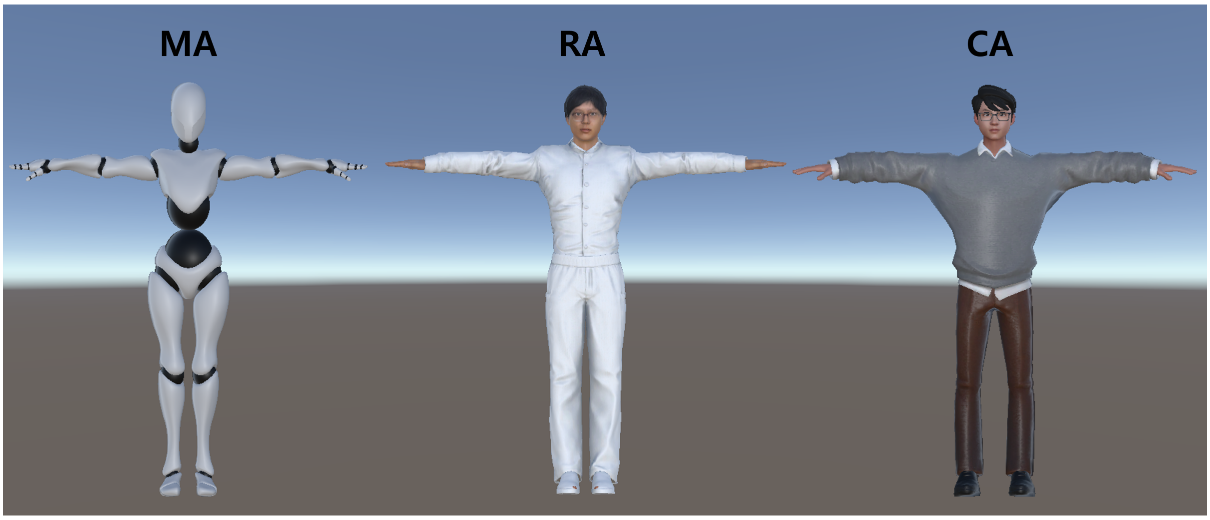

Figure 1: The avatars with different appearances were used in the experiments. From left to right: MA, RA, CA.

3. Preliminary Study

3.1. Method

This study employed a one-factor within-subjects design to examine the effect of avatar appearance. The independent variable, avatar appearance, consisted of three levels, as illustrated in Figure 1:

- **Mannequin Avatar (MA)**: A basic avatar with a generic form, provided identically to all participants.
- **Resemblance Avatar (RA)**: An avatar generated based on the participant's actual appearance.
- **Customized Avatar (CA)**: An avatar created directly by the participant using a provided customization tool.

To control for potential learning and order effects arising from the experimental sequence, a counterbalanced Latin square design was employed, ensuring that the order of avatar presentations was evenly distributed across participants.

3.2. Materials

The experiment was conducted using a Meta Quest 3 HMD, with hand movements tracked through the Quest 3's native hand-tracking system. The virtual environment was developed in Unity 2022.3.47f1. The avatars shown in Figure 1 were generated as follows:

- **MA**: This avatar was based on the *X-Bot*[1] model from Adobe Mixamo and was designed to have a non-individualized appearance.
- **RA**: The face was generated from a frontal photograph of the participant using the Headshot plug-in in *Character Creator 3(CC3, Reallusion)*[2], and clothing was standardized in white.
- **CA**: Participants used the *Ready Player Me*[3] platform to design and customize their avatars according to their personal preferences.

The experimental task was conducted within the virtual environment illustrated in Figure 2.

[1]https://www.mixamo.com/
[2]https://www.reallusion.com/character-creator/
[3]https://readyplayer.me/

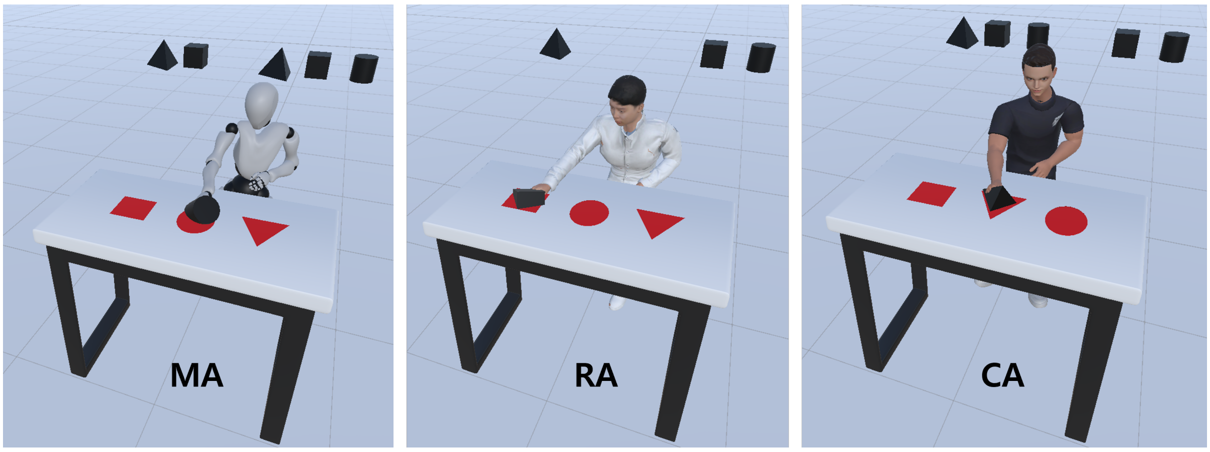

Figure 2: Non-Interactive replay. The tasks performed by the participants are replayed. Geometric objects are placed behind the avatars, and the symbols displayed on the table are used for placement.

3.3. Procedure

The overall procedure is illustrated in Figure 3. The experiment consisted of a preparation phase followed by three main sessions, each corresponding to one of the three avatar conditions (MA, RA, CA).

Prior to the experiment, frontal photographs of each participant were collected to generate the RA. Participants also created their own CA in advance. They used the Ready Player Me platform, reflecting their personal preferences.

In each session, participants performed a simple object placement task. As shown in Figure 2, six geometric objects (a prism, a cube, and a cylinder, arranged in sequence) were floated behind the participant. On the desk in front of the participant, symbols corresponding to these objects (square, triangle, and circle) were presented in a randomized order for each session.

Participants were instructed to pick up the objects one by one and place them on the corresponding symbols on the desk. They were free to move within the virtual environment and could use either hand. The task ended once all six objects had been correctly placed, at which point the recording of the participant's task was also stopped.

After completing the task, participants took a 5-minute break. They then observed a replay of their own performance. The replay began from a third person perspective located 1 meter behind the avatar's starting position, but participants were free to adjust their viewpoint and angle as desired. The replay lasted for the same duration as the original task. Immediately after the replay, participants completed a questionnaire to evaluate their experience. This procedure was repeated for all three avatar conditions.

3.4. Measures

To evaluate participants' experiences, we administered the 12-item questionnaire shown in Table 1. All items were rated on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The questionnaire

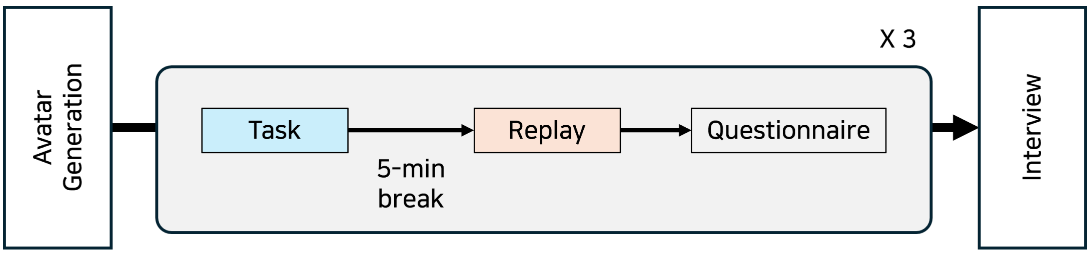

Figure 3: Procedure of experiment.

Table 1
Questionnaire items for Non-interactive replay.

No	Question
Q1	It felt like the observed virtual human was my body. [20]
Q2	It felt as if the observed virtual human was someone else's body. [21]
Q3	I felt like I was causing the movements of the observed virtual human. [20]
Q4	I felt like the actions of the observed virtual human were my own actions.
Q5	Sometimes, I had the feeling that I was looking at myself. [23]
Q6	I felt like the virtual human was me. [22]
Q7	I could identify myself with the virtual human. [22]
Q8	I had the feeling the virtual human was behaving as I would behave. [22]
Q9	I felt like the virtual human had the same attributes as I have. [22]
Q10	I had the feeling that I was in the middle of the action rather than merely observing. [22]
Q11	It seemed as though I actually took part in the presented environment. [23]
Q12	I felt like the observed virtual human was reenacting the actions I had performed in the past.

items were adapted from the Virtual Embodiment Questionnaire (VEQ) [20], the Avatar Embodiment Questionnaire (AEQ) [21], the extended VEQ [22], and the Conscious Bodily Self-Perception scale [23], along with additional items developed specifically for this study to evaluate participants' recognition of their own actions.

The questionnaire was categorized into five sub-factors as follows:

- **Body Ownership (BO)**: The extent to which the virtual body is experienced as one's own body (Q1, Q2) [20, 21].
- **Agency (AG)**: The sense of controlling the movements of the virtual body (Q3, Q4) [20].
- **Self-Identification (SI)**: The degree to which participants identified themselves with the avatar (Q5, Q12) [23].
- **Self-Attribution (SA)**: The extent to which participants attributed the avatar's physical or psychological characteristics to themselves (Q6, Q7, Q8, Q9) [22].
- **Spatial-Presence (SP)**: The feeling that one's body physically exists in the virtual environment (Q10, Q11) [23].

3.5. Participants

A pilot test was conducted with five participants who had substantial experience with VR (4 male, 1 female; mean age = 26.8).

4. Results and Discussion

Data analysis was conducted on five participants. A Friedman test was applied to the overall average (AVG) of the questionnaire scores as well as to the mean values of BO, AG, SI, SA, and SP. Additionally, Kendall's W was reported as a non-parametric effect size to quantify the degree of agreement across repeated measures.

No significant effect of the avatar appearance conditions was found on AVG, $\chi^2(2) = 1.2$, $p = 0.5488$, $W = 0.12$. Similarly, the experimental conditions did not significantly influence BO, $\chi^2(2) = 0$, $p = 1$, $W = 0$. The analysis also revealed no effect on AG, $\chi^2(2) = 1.625$, $p = 0.443$, $W = 0.1625$. Effects on SI were likewise nonsignificant, $\chi^2(2) = 2.47$, $p = 0.29$, $W = 0.247$. In addition, no significant differences were observed for SA, $\chi^2(2) = 1.368$, $p = 0.504$, $W = 0.136$, nor for SP, $\chi^2(2) = 2.941$, $p = 0.229$, $W = 0.294$. See Figure 4.

This study investigated how avatar appearance influences the SoE when learners observe recordings of their own performance under temporal asynchrony. Participants performed a simple object placement

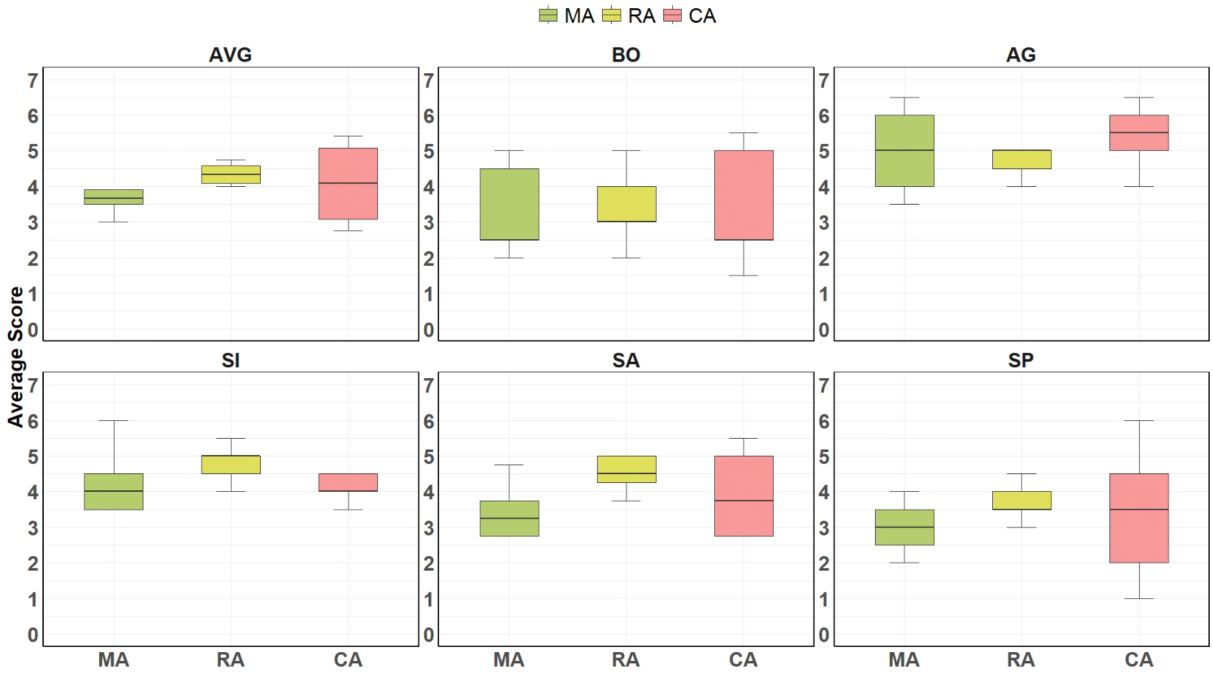

Figure 4: Summary of SoE measurement results. The boxplots illustrate the overall average and sub-factors (BO, AG, SI, SA and SP). Conditions are color-coded: MA (green), RA (yellow) and CA (red).

task using three avatar appearance conditions (MA, RA, CA) and subsequently observed replays of their performance. The sense of embodiment was then analyzed across the dimensions of BO, AG, SI, SA, and SP.

The analysis indicated that SI, SA, and SP scores followed the order RA > CA > MA, confirming that participants were more likely to identify with avatars resembling themselves. This is consistent with previous research showing that greater resemblance between an avatar and the user leads to higher levels of self-identification [7, 8, 9]. Although the CA condition did not perfectly replicate participants' actual appearance, the possibility of self-expression and the process of creating the avatar itself may have facilitated self-identification [10, 15, 16]. A noteworthy finding is that, for CA, the variance was considerably higher than that of the other conditions, particularly in SA and SP. This may be interpreted as reflecting differences in participants' attachment to avatars as suggested by prior studies on varying levels of incorporation of avatars as self-representatives [24], and individual differences in self-identification would vary depending on customization strategies (self-similarity oriented vs. ideal-self oriented) [25].

For BO, no significant differences were observed across the three conditions, while AG was highest for the CA condition. This may have been influenced by visual inconsistencies in the avatar's body caused by mismatches between participants' motion-tracking data and the avatar's skeletal structure.

Post-experiment interviews revealed additional insights. Some participants reported experiencing discomfort in the RA condition, describing the avatar as both similar and dissimilar to their own appearance. Others indicated that the replay observation time was too short to adequately reflect on their actions. In addition, some participants expressed dissatisfaction with the limited customization options provided for creating the CA, which they felt restricted their ability to fully represent themselves.

5. Conclusion

This study investigated whether a sense of embodiment can emerge when learners observe recordings of their own VR performance under temporal asynchrony, and how avatar appearance affects this experience. To this end, a within-subjects design was employed, manipulating avatar appearance across three conditions (MA, RA, CA) and analyzing multiple dimensions of SoE.

The findings indicate that SoE can be sustained even under non-interactive replay conditions, extending prior research that has primarily focused on synchronous, real-time environments. Moreover, avatar appearance was found to play a critical role in shaping SoE, particularly with respect to self-identification (SI, SA) and spatial presence (SP). These results are consistent with prior literature emphasizing the importance of visual similarity and personalization in embodiment, while also highlighting the additional significance of user-created avatars as a medium for self-expression.

Although this work was conducted as a pilot study (N = 5) and thus has limited generalizability, it provides valuable insight into the mechanisms by which avatar design influences embodied experiences. Future studies should increase the sample size, refine avatar rigging, and systematically vary replay conditions to further clarify the relationship between temporal asynchrony, avatar appearance, and SoE. Such efforts will not only advance theoretical understanding of embodiment in VR but also contribute to the design of training systems, educational platforms, and personalized virtual experiences for After Action Review (AAR).

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Declaration on Generative AI

During the preparation of this work, the author(s) used X-GPT-5 in order to: Grammar and spelling check.

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