Evidence for a Relationship Between Self-Avatar Fixations and Perceived Avatar Similarity within Low-Cost Virtual Reality Embodiment

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Abstract

In this study, we investigate potential relationships between avatar appearance and viewpoint within the context of low-cost motion tracking using *Body* and *Mirror* factors. Six experimental conditions were developed that combined *Body* and *Mirror* factors. In this between-groups design, participants were able to control their self-avatar by using HTC Vive controllers and trackers. Our results suggest a relationship between perceived similarity with the self-avatar and looking at the self-avatar.

Index Terms: Human-Centered Computing—Human Computer Interaction (HCI)—Interaction Paradigms—Virtual Reality

1 Introduction

The virtual embodiment experience [4,32,41,44,45,52]—that is, the sense of having a virtual body and perceiving it as one's own—has been one of the most examined areas in virtual reality (VR) research. Embodiment has been examined in the presence of body morphological differences [6,62], additional body parts [27,29,37], rubber-hand illusions [28,50], as well as with haptic and tactile stimuli [35,58]. Studies have shown visuomotor as well as visuotactile stimulation to be vital in eliciting a sense of embodiment [19,29,34,58].

To achieve a visuomotor embodied experience, one needs to use a motion tracking system that transfers the user's physical movement to the self-avatar: the character that represents the user within the virtual environment. In embodiment studies, participants are often asked to move and observe their self-avatar from a first-person perspective [3,12,60]. Synchronous visuomotor feedback can also be achieved through the use of a mirror in which the participant sees a third-person view of their self-avatar and its movements. Mirrors have been used extensively [6,24,29,37,62] in order to guide the user to observe their self-avatar from a first or third-person perspective, or a combination of these two perspectives.

Numerous consumer-grade devices have been developed and can be used to transfer human movements and actions to the self-avatar at a much lower cost than the high-end motion tracking devices often used in many research labs and production studies. Consequently, embodied virtual reality experiences have become accessible for consumers, who may now experience embodiment through the use of commercial consumer-grade motion-sensing devices (e.g., HTC Vive controllers and inverse kinematics solvers that can control the arms of self-avatars).

This study aimed at exploring embodiment through two important factors—namely, the *Body* and the *Mirror*, in order to inform best practices within low-cost embodiment virtual reality (VR) paradigms. We employed a 3×2 between-groups design to determine if embodiment was affected by different types of *Body* (human, mannequin, and zombie) and *Mirror* (no mirror and mirror) factors by developing six experimental conditions (human, no mirror; human, mirror; mannequin, no mirror; mannequin, mirror; zombie, no mirror; and zombie, mirror). We provided a preliminary scene in which participants could view the self-avatar and explore its movements. Next, participants experienced a secondary virtual scene in which they were asked to observe a multi-character scenario within an outdoor park environment. We will call virtual characters "environmental characters" in order to distinguish them from the self-avatar character. With the secondary virtual environment, we wanted to shift participant's attention towards the environmental characters, and therefore did not provide a mirror in this environment. This scene consisted of human, mannequin, and zombie environmental characters within the park environment. Environmental characters walked, sat on benches, stood, or danced while the participant observed, standing at the center of the environment. Throughout this multi-character scenario, the participants' eye gaze was collected. Immediately following the VR experience, a questionnaire was administered to collect self-reported data. Our primary hypotheses are as follows:

- **RH1:** There will be an interaction effect between *Body* and *Mirror* factors concerning body ownership.
- **RH2:** Self-avatar body type will influence participant responses in the environment, and towards environmental characters with the same body type.
- **RH3:** Higher self fixations will correlate with less perceived similarity with the self-avatar.

We chose to examine embodiment within the context of low-cost motion tracking in order to best inform virtual reality design for users experiencing VR embodiment on their own, outside a research environment. Investigating *Body* and *Mirror* interactions in the context of low-cost motion tracking may contribute to a better understanding of user perceptions during commercial VR embodiment experiences.

In this paper, we present our results collected from eye gaze behavior and self-reported data, the investigation of *Body* and *Mirror* factors, as well as our study's limitations. We also provide results-driven design considerations which may enable researchers to create better low-cost motion tracking VR embodiment experiences, as well as list future research directions suggested by our data, which are the main contributions of this paper.

2 Related Work

The sense of having one's own body has often been described as a non-conceptual, somatic form of knowledge, different in kind from other types of knowledge [8,30]. In this study, we consider the sense of having one's own body as the sense of embodiment (SoE), as explained by Kilteni et al. [32], which describes embodiment as the sense of being inside, controlling, and having a virtual body. According to this interpretation, SoE can be broken down into three individual components: the sense of self-location, the sense of agency, and the sense of ownership. When combined, these three components can provide a strong SoE. Considering that a notable number of studies have been published so far concerning embodiment in virtual environments, in this section, we present and discuss

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978-0-7381-1367-8/21/$31.00 ©2021 IEEE
DOI 10.1109/VRW52623.2021.00031

related work on avatar appearance (embodiment through the use of morphologically different self-avatars compared to the user's appearance), embodiment through self-avatar control, and embodiment through self-observation (the use of virtual mirrors to allow users to easily observe their virtual appearance).

The impact of having a virtual body, also called a self-avatar (an avatar that represents the user within a virtual environment [9, 60]), has been examined extensively. One important factor proven to affect SoE is the appearance of the self-avatar [3, 39], which is broken down into three main factors: the structure of the virtual body, the shape and dimension of body parts, and the rendering style. It has been found that these factors characterize the realism, anthropomorphism, and fidelity of the self-avatar towards the user's real body, and that the combination of these factors contributes to different degrees of the sense of body ownership, and consequently, toward SoE [39, 43].

Previous studies in VR have examined either partial embodiment [11, 54, 68] or whole-body embodiment [6, 20, 31]. Considering partial embodiment, it has been found that the sense of body ownership is stronger when VR users control a realistic hand model compared to a non-anthropomorphic hand model [39]. Studies using 3D technologies that create replicas of the user for the self-avatar have also been conducted. These studies have shown that virtual replicas of the user for the self-avatar can positively affect the user's sense of body ownership [26, 66]. Additionally, a number of studies have explored the use of self-avatars that differ from the user in terms of body structure [36], gender [59], height [40], and age [6, 62], and have indicated that it is feasible to induce a sense of body ownership with self-avatars that are dissimilar to users in a variety of ways.

In order to allow the user to experience the body of a self-avatar as their own body, previous studies have given users in a virtual environment the freedom to control their own avatars, which allows the user to become embodied via control of the avatar [60, 68]. It is known that the freedom to control a self-avatar using motion tracking can provide a positive impact on SoE [16] in virtual environments. Thus, the use of motion tracking systems [46] and inverse kinematics solvers [51] have been used in most previous studies. A number of commercial low-cost systems have been used to allow either whole-body or partial-body motion tracking for VR purposes [13].

Considering whole-body embodiment, various studies have investigated the influence of the virtual mirror for the SoE. In previous studies [6, 31, 59], participants were able to observe their self-avatar from a first-person viewpoint as well as view their self-avatar's reflection by looking in a mirror. Considering that the sense of body ownership in these studies was affected by a first-person viewpoint of the body, the actual impact of the mirror for the SoE was unclear. Additionally, in a study by Ito et al. [29], it was found that both constant interruption of virtual mirror presentation and only presenting the mirror during the first half of the virtual environment did not significantly change body ownership of a virtual tail compared to continuous mirror presentation throughout the entire duration of the virtual environment. While the appearance of the self-avatar and the viewpoint with which one can observe it can easily be combined with low-cost motion tracking to allow for self-avatar control, the combined impact of self-avatar and viewpoint on embodiment was assumed to be more complex. Therefore, in our study, we explored relationships between *Body* and *Mirror* factors in the hope that our results might inform future low-cost motion tracking VR embodiment applications which make use of virtual mirrors and/or use morphologically different self-avatars.

3 Materials and Methods

This section provides background information and implementation details for the development of our VR application.

3.1 Participants

An *a priori* power analysis was conducted to determine the sample size for our study using the G*Power software version 3.1.9.3 [14]. Our calculations were based on 85% power, a large-effect size $f = .40$ [17], six (3×2) groups, and an $a = .05$. The analysis resulted in a recommended sample size of 12 participants per group (72 participants in total). In this study, the participant group consisted of 72 undergraduate and graduate students (41 male, 31 female). Ages ranged from 18 to 32 ($M = 21.72$, $SD = 3.11$). Participants were recruited through posters placed on various notice boards in our department's building and e-mails sent to students from several departments on campus. Participants provided informed consent that was approved by the Institutional Review Board of Anonymous University. All participants received a small gift card as compensation for their time.

3.2 Experimental Conditions

We chose a 3×2 between-groups study design in order to compare the different experiences of participants across the examined conditions of this study. The six conditions were formed by combining *Body* (humans versus mannequin versus zombie self-avatar), and *Mirror* (no mirror versus mirror in the preliminary scene) factors; therefore the six conditions were: human, no mirror; human, mirror; mannequin, no mirror; mannequin, mirror; zombie, no mirror; and zombie, mirror.

For the *Body* factor, participants were given either a human, mannequin, or zombie self-avatar, which remained the same in both the first and second virtual environments. The virtual avatars were the same size for all participants. While many studies have involved creating self-avatars for participants through the use of actual photos of the participants [5, 63, 66, 67], fewer studies have assessed embodiment with pre-made, general-looking self-avatars. Previous studies examining differences in self-avatar realism have used humans as the basis for the most realistic character or body part, cartoon-like characters to represent a lesser element of realism [65], and zombie-like characters or body parts to represent the lowest level of realism [39, 69]. Therefore, we selected human self-avatars for higher realism, mannequin self-avatars for lesser realism, and zombie self-avatars for the least realism. The three different self-avatars body types can be seen below in Figure 1.

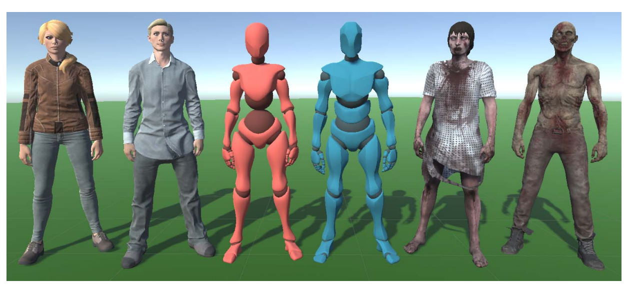

Figure 1: The three self-avatars body types for female and male participants.

For the *Mirror* factor, participants experienced the first virtual environment with or without a mirror. In the mirror condition, participants experienced a plain room with a mirror placed on a wall about three meters in front of them, as this was the distance necessary to ensure that the participant could view the entire self-avatar. In the no mirror condition, participants experienced a plain room with a painting in place of the mirror. Previous studies have examined using a mirror only in a preceding scene, before the primary scene of the virtual experience [57], as well as placing a mirror on one side of the participant, while the action in the scene took place in front of the participant [47]. We decided to include the virtual mirror in the first virtual environment which preceded the second, primary virtual environment. In this way, the participant would be able to fully explore the self-avatar in a virtual environment separated from the multi-character park environment, with no distractions.

3.3 Virtual Environment Implementation

Both the preliminary and primary virtual environments were developed in the Unity3D game engine, and are shown in Figure 2. The plain room was a four-sided room which included a few plants and generic pieces of artwork around the edges of the room, which were downloaded from the Unity asset store. The self-avatars were downloaded from Adobe Mixamo and Adobe Fuse. FinalIK was used in combination with HTC Vive trackers in order to allow the participant to move the self-avatar. A large mirror or painting of the same size faced participants, depending on their condition. In the preliminary virtual environment, participants observed their virtual body either via first and/or third person perspective, depending on their condition.

Figure 2: The two different virtual environments that were used in our study from a user point of view. Top: the plain room during the zombie, mirror condition (left) and the plain room during the no mirror conditions of the study (right). Bottom: the primary virtual park environment.

One multi-character virtual park environment was developed which all participants experienced following the plain room environment. The multi-character environment was designed to be an outdoor park area, which included trees that surrounded a square courtyard-like area with flowers and tiled pathways. The animations for the environmental characters were downloaded from Adobe Mixamo, and programmed in the Unity game engine. A soundtrack which matched the outdoor environment was included for this environment. An equal proportion of environmental characters were included and evenly spaced throughout the courtyard; this totaled to eleven of each environmental character (eleven humans, eleven mannequins, and eleven zombies). Environmental characters walked around the outer pathway of the courtyard, stood together in groups, sat at benches, and danced in the grass, again with an equal proportion of environmental characters per activity as well as per distance from the participant, allowing many different actions for the participant to look at during the otherwise passive experience.

3.4 Measurements

We collected both eye fixations and self-reported data in this experiment. The following subsections describe the measurements and ratings in detail.

3.4.1 Questionnaire

Our 12-item questionnaire explored the following four concepts: body ownership, perceived similarity, plausibility illusion, and mutual awareness. Our question concerning body ownership is based on work by Slater et al. [18], while our questions concerning perceived similarity with an avatar were taken from Wrzesien et al.'s [67] work with self similar avatars. Mutual awareness items came from the Networked Minds Subscale [10], and questions concerning Plausibility Illusion were taken from work by Skarbez et al. [55]. Mutual awareness in the context of our questions refers to how much the participants noticed and were aware of environmental characters, as well as how much they perceived these characters as noticing and being aware of themselves. Plausibility in this case refers to how consistent with expectations participants found the environment to be. Perceived similarity refers to how similar participants determined their own physical body to be with their self-avatar body. The self-reported data from our questionnaire were analyzed as separate variables. Our 7-Point Likert scale questionnaire was administered through the anonymous university's Qualtrics system immediately following the VR experience, and is provided in supplementary materials.

3.4.2 Eye Fixations

We collected eye fixation data in the form of three measurements using Cognitive3D spatial analytics platform: fixation count, fixation length, and time to fixation. Fixation count refers to the total number of different times there was a fixation recorded on an object. A fixation count of three, for example, would mean that the participant looked at that object three separate times. Fixation length refers to how long each fixation lasted. A fixation length of 14, for example, would mean that the participant spent 14 seconds looking at that object in total, perhaps over three separate instances if we are referring to the same object within this example. Time to fixation refers to the time elapsed before the specified object was fixated upon. For example, if an object has a time to fixation of 30, then that object was not fixated upon until 30 seconds into the VR experience.

We assigned fixation objects for which fixation data should be collected, which included the self-avatar and environmental characters. From the self-avatar, we collected fixation count, fixation length and time to fixation. For the environmental characters, we collected fixation count totals and fixation length totals, which included all environmental characters within each type.

3.5 Procedure

Upon arriving at the lab, participants were provided written consent as dictated by the Institutional Review Board of our university. Participants then completed a demographics questionnaire. Next, the researcher set up our low-cost motion tracking system. This entailed placing the HTC Vive trackers around both the participant's feet, as well as one tracker around the participant's waist which sat in the middle of their back. The participant held the two Vive controllers in order to allow for hand tracking. In total, we had six motion-sensing devices for motion tracking: the three trackers, two controllers (see Figure 1), and the head-mounted display. Next, the researcher helped the participant put on the HTC Vive Pro Eye head-mounted display (HMD), and walked the participant through the Vive Eye Pro eye tracking calibration. The participant was instructed to observe the scene and move their virtual limbs and body as they would like within the environment. The plain room environment lasted two minutes. Next, the participant removed the HMD, and filled out a brief questionnaire on Qualtrics, the results of which are not included in this analysis. The participant then put the HMD back on, completed the eye calibration, and experienced the multi-character virtual environment, which also lasted two minutes. After this virtual environment terminated, the participant removed the HMD and filled out our primary questionnaire on Qualtrics. Trackers were removed and the participant was then debriefed.

4 Results

To analyze our data, we used two-way ANOVAs to explore main and interaction effects. We also used three-way ANOVAs to assess potential influences of gender as an additional variable. Before analyzing the data, we determined that the data was normally distributed using Q-Q plots of the residuals. Post hoc comparisons were performed using Bonferroni corrected estimates for multiple comparisons. We used Pearson bivariate correlations to explore correlations between our self-reported and eye fixation data. Finally, the items that belonged to the examined scales were tested for reliability by computing Cronbach's alpha coefficient. Due to sufficient correlations ($.71 \leq \alpha \leq .94$), we used a cumulative score of all examined variables as the final result, and treated them as continuous scales. Removal of items would not enhance the reliability measures. Please see our supplementary file for our descriptive statistics.

4.1 Self-Avatar Embodiment

A two-way ANOVA was conducted that examined the effect of *Body* and *Mirror* on **body ownership**. No significant interaction effects of *Body* and *Mirror* regarding **body ownership** [$F(2,66) = 2.071$, $p = .134$], nor main effects of *Body* [$F(2,66) = 2.421$, $p = .097$] or *Mirror* [$F(1,66) = .329$, $p = .568$] were found.

A two-way ANOVA was conducted that examined the effect of *Body* and *Mirror* on **perceived similarity** concerning the participant's own body with the self-avatar body. There was no statistically significant interaction between *Body* and *Mirror* on perceived similarity [$F(2,66) = 2.436$, $p = .095$]. However, we found a significant main effect for the *Body* factor [$F(2,66) = 5.972$, $p < .005$]. Post hoc comparisons showed that perceived similarity was significantly higher for those in the mannequin condition ($M = 4.58$, $SD = .27$) than the zombie condition ($M = 3.23$, $SD = .27$). No main effect for *Mirror* was found [$F(1,66) = .663$, $p = .418$].

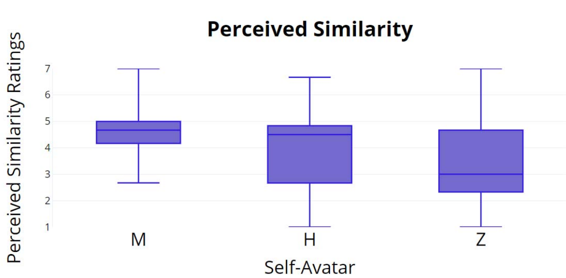

Figure 3: Perceived similarity ratings between the three self-avatar conditions. M = Mannequin, H = Human, Z = Zombie.

Similarly the effect of *Body* and *Mirror* on **plausibility** revealed no statistically significant interaction [$F(2,66) = .014$, $p = .986$], but we found a significant main effect for the *Body* factor on plausibility [$F(2,66) = 5.863$, $p = .005$]. Post hoc comparisons showed that plausibility was significantly higher for those in the mannequin condition ($M = 3.84$, $SD = .12$) than the zombie condition ($M = 3.27$, $SD = .12$). We did not find a significant main effect for the *Mirror* factor [$F(1,66) = .135$, $p = .715$].

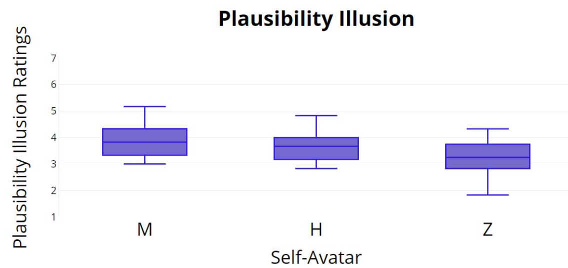

Figure 4: Plausibility illusion ratings between the three self-avatar conditions. M = Mannequin, H = Human, Z = Zombie.

4.1.1 The Influence of a Mirror

Regarding **mutual awareness**, while there was no statistically significant interaction between *Body* and *Mirror* [$F(2,66) = .635$, $p = .533$] as well as no significant main effect for *Body* [$F(2,66) = .817$, $p = .446$], we found a significant main effect for the *Mirror* factor [$F(1,66) = 6.809$, $p < .011$]. Post hoc comparisons showed that participants in the mirror condition ($M = 4.41$, $SD = .11$) reported significantly lower mutual awareness than participants in the no mirror condition ($M = 4.83$, $SD = .11$).

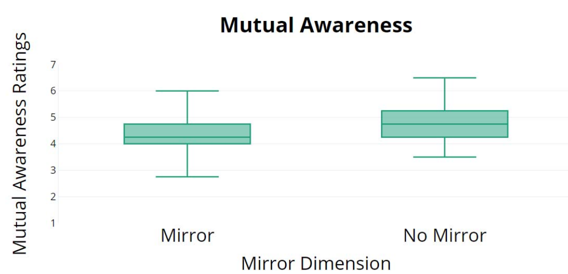

Figure 5: Mutual awareness ratings between *Mirror* and *No Mirror* conditions

4.2 Eye Fixations

In order to determine if self-avatar body type influenced eye fixations towards environmental characters, we employed two-way ANOVAs to investigate both eye fixations towards environmental characters, and eye fixations towards the self-avatar.

4.2.1 Environmental Characters

We determined no statistically significant interactions between *Body* and *Mirror* for **human fixation length** [$F(2,66) = .646$, $p = .528$], **mannequin fixation length** [$F(2,66) = 1.078$, $p = .346$], or **zombie fixation length** [$F(2,66) = .155$, $p = .857$]. We also examined fixation counts, and determined no significant interactions between *Body* and *Mirror* for **human fixation count** [$F(2,66) = 1.121$, $p = .332$], or **zombie fixation count** [$F(2,66) = .231$, $p = .794$]. We determined a significant interaction effect between *Body* and *Mirror* for **mannequin fixation count** [$F(2,66) = 3.310$, $p = .043$]. Because post hoc comparisons showed no significant differences between conditions, we can only consider this result as a trending interaction effect. No main effects for *Body* and *Mirror* factors were found concerning human, mannequin and zombie fixations lengths, as well as for fixation counts.

4.2.2 Self Fixations

We determined no significant interactions between *Body* and *Mirror* for **self fixation length** [$F(2,66) = .772$, $p = .466$], or for **self fixation count** [$F(2,66) = .911$, $p = .407$]. We determined no main effects for *Body* and *Mirror* factors concerning self fixation count and self fixation length.

4.3 Gender

We explored gender differences using three-way ANOVAs with the three body conditions, two mirror conditions, and the two gender conditions. However not statistically significant, we determined a trending main effect of *Gender* [$F(1,60) = 3.937$, $p = .052$] on **body ownership**, with females ($M = 4.863$, $SD = .301$) reporting higher body ownership than males ($M = 4.072$, $SD = .261$). Concerning **self fixation length**, we found a trending main effect of *Gender* [$F(1,60) = 3.752$, $p = .057$], with males showing a longer self fixation length ($M = 9.49$, $SD = 1.31$) than females ($M = 6.74$, $SD = 1.29$); however, this did not reach statistical significance.

4.4 Correlations

We explored correlations between eye fixation data and self-reported responses using a Pearson product-moment correlation coefficient. Below is a table (see Table 1) presenting our correlation data.

We determined a negative correlation between **self fixation length** and **perceived similarity** [$r = -.302$, $n = 72$, $p = .010$], as well as between **self fixation count** and **perceived similarity** [$r = -.259$, $n = 72$, $p = .028$].We found a positive correlation between **time to self fixation** and **perceived similarity** [$r = .236$, $n = 72$, $p = .046$]. Lastly, we determined a negative correlation between **zombie fixation count** and **perceived similarity** [$r = -.273$, $n = 72$, $p = .020$].

5 Discussion

In this 3 (*Body*; human, mannequin, and zombie) × 2 (*Mirror*; no mirror and mirror) study, we examined self-reported concepts concerning embodiment, and explored eye fixations within the context of our low-cost motion tracking VR embodiment application. A two-scene virtual experience was developed, involving a plain room (mirror or no mirror) environment, followed by the multi-character virtual environment. While our results do not support our **RH1**, our results support our **RH3**, and provide partial evidence for our **RH2**.

Our **RH1** stated that we would see an interaction between *Body* and *Mirror* factors concerning body ownership; however, our results determined no significant interaction or main effects of *Body* or *Mirror* for body ownership. Although we could not determine a interaction effect between *Body* and *Mirror* factors, our results showed a main effect of *Mirror* on mutual awareness, indicating that participants who did not experience a mirror reported higher mutual awareness. Because participants who did not have a mirror were given only a first-person perspective, it is logical to conclude that they may have been more aware of other virtual characters without the third-person perspective of their self-avatar to capture their attention. While we determined no other main effects of the *Mirror*, our mutual awareness results show that the *Mirror* was, at the least, a factor which drew attention away from environmental characters when presented previously. Concerning self-avatar *Body*, body ownership did not differ across self-avatar body conditions. These results are similar to those of Lugrin et al. [42], who found that varying levels of avatar visibility did not influence body ownership.

Previous work in embodiment suggests that the addition of a mirror in the virtual environment would enhance SoE [24]. Here, we suggest three main reasons why we may have found limited results concerning *Mirror* and *Body* factors. Firstly, because our virtual mirror was placed outside of the participant's peripersonal space, it is possible that the mirror did not elicit significantly higher body ownership in the mirror condition [49]. Second, including a mirror in a virtual environment in which there are significant self-avatar flaws may be detrimental for body ownership. For example, Gao et al. [21] examined avatar visibility and mirror versus no mirror feedback with a self-avatar, and determined that embodiment was possible only in their no mirror condition. Additionally, work by Gorisse et al. [25] found that the first person perspective was more important for body ownership than their third person perspective in their virtual environment, suggesting a lower impact of the mirror on body ownership. However, Debarba et al. [15] found no differences in first person and third person perspective concerning body ownership. Therefore, thirdly, it is possible our measurements of embodiment were not sensitive enough to differences in SoE. Our lack of a disembodied *Body* condition (using asynchronous visumotor feedback, for example) may have contributed to the lack of differences between body types, especially considering it has been shown that even within the same condition, individual differences play a role in how embodied a user may feel [22]. Using additional psychometric tests, such as memory or spatial tasks as in [61], or including a full embodiment questionnaire such as [23] would have been informative for our results.

Our **RH2** proposed that the participant's self-avatar *Body* would influence responses in the environment and responses towards environmental characters with the same *Body*. While we found no differences in eye fixations towards environmental characters concerning *Body* × *Mirror* interactions, our hypothesis was partially supported by several other analyses. Both self-reported perceived similarity as well as plausibility were higher for participants given the mannequin self-avatar than for participants given the zombie self-avatar. Not only did our results indicate that participants found the mannequin body significantly more similar to their own body than participants with the zombie self-avatar, but participants with the mannequin self-avatar found events in the virtual environment significantly more plausible than participants given the zombie self-avatar.

Considering that zombie characters in VR have been shown to induce fear [38], it is possible that fear related to the zombie self-avatar or zombie environmental characters contributed to decreased believability. Previous research has suggested that users prefer to have attractive self-avatars [2, 33], and so it is also possible that the unattractive zombie self-avatar, with ripped clothing and blood stains may have distracted from the experience.

Our **RH3** proposed that higher self fixations would correlate with lower ratings of perceived self-avatar similarity. Our results support this hypothesis, suggesting that as time spent looking at the self-avatar increased, perceived avatar similarity decreased, and vice versa. This is in line with research by Skarbez et al., which determined that having an accurate depiction of the self-avatar was the most influential factor concerning plausibility of the virtual environment [56]. Our results suggest that increased self avatar fixations may be detrimental to believability of the avatar, but it is unclear if this would be the case for higher fidelity motion tracking systems.

Numerous studies have evaluated the influence of environmental characters' eye fixations towards users [7, 53, 64], but to the best of our knowledge, less research has explored eye fixations towards environmental characters or towards the self-avatar.

In addition to our primary hypotheses, we also examined *Gender* concerning body ownership. While our data did not reach statistical significance, we found trending results ($p = .052$) which showed that females reported higher body ownership than males, while males spent more time looking at their self-avatar than females ($p = .057$). Women and men evaluate their appearance in different ways [48], and perform different methods of body checking [1] which may have contributed to the trending difference in body ownership. We acknowledge that our study did not have the appropriate statistical power for our additional three-way ANOVA exploration of *Gender*;

Table 1: Correlations between eye fixations and self-reported data.

	Mannequin Fixation Count	Human Fixation Count	Zombie Fixation Count	Mannequin Fixation Length	Human Fixation Length	Zombie Fixation Length	Self Fixation Count	Self Fixation Length	Time to Self Fixation
Body Ownership	.100	.230	-.177	.054	.085	-.44	-.110	-.027	-.025
Perceived Similarity	.054	-.192	-.273*	.122	-.22	-.173	-.259*	-.302**	.236*
Mutual Awareness	.048	-.029	.096	.125	.096	.153	-.064	.002	.159
Plausibility	-.075	.153	.018	-.063	.076	-.003	.003	.008	.143

* Correlation is significant at the .05 level (2-tailed).
** Correlation is significant at the .01 level (2-tailed).

however, our trending results indicate additional directions for future research concerning *Gender* and self-avatar fixations.

6 Design Considerations

We have determined several themes which could be informative in the design of future low-cost motion tracking VR embodiment applications. In this section we provide design considerations suggested by our results.

Considering our results, the mannequin self-avatar may allow for increased plausibility of virtual events and increased perceived similarity with the mannequin self-avatar. Therefore, designers may choose to *select a mannequin self-avatar in order to increase believability of the experience*. Based on our results concerning mutual awareness, designers may choose to *include a mirror in a previous scene, when decreased mutual awareness in a multi-character environment is desired*. If increased mutual awareness towards environmental characters is needed, designers may choose to *remove the mirror from the previous scene*.

Designers may want to consider participant's gender when examining body ownership; it may be beneficial to *consider the different ways in which males and females look at their self-avatars* and how this may impact body ownership. Our results suggest that it may be useful to *include a mirror in a prior virtual environment for the purposes of inducing an increased awareness of self*.

7 Future Research Directions

In this section, we present future research directions suggested by our findings. Firstly, research examining parameters such as how soon, how long, and how often one looks at the self-avatar may be informative in understanding the influence of self-avatar fixations in virtual environments. For example, it may be useful to consider the most appropriate time frame in which participants should first look at the self-avatar, in order to increase body ownership.

Considering our trending results with *Gender*, it is possible that additional means of inducing body ownership may be necessary with specific individuals. Future research might explore how preliminary self fixation analyses could be used in order to prepare the same target body ownership for each participant. We did not collect movement data from participants, and so can make no conclusions concerning relationships between participant movement behavior and body ownership. Future research might seek to explore effects of eye fixations and movements on body ownership.

8 Limitations

While every participant experienced a correctly aligned virtual body, our VR application needed to be restarted for several participants in order to adjust the tracking alignment. Additionally, participants had to stand in the center of the testing room, in order for the virtual body to behave correctly. This is a notable limitation in that participants were only able to move a few steps on all sides of the starting point, rather than walk throughout the entire virtual space. Concerning our trending results with *Gender*, we did not have enough statistical power to make certain conclusions about our additional analyses. We would like to include an equal proportion of females to males in our studies, and these results further motivate us to seek new ways in which to ensure this happens.

Because the eye tracking software used in the study did not provide us with a way in which to measure which body parts of the self-avatar, or which body parts of the environmental characters were fixated upon, we cannot make generalizations about our data concerning *where* specifically participants may have looked at, concerning both the self-avatar and environmental characters. For example, we do not know if participants spent more time looking at the face of the environmental characters or at their torsos. Additionally, interview analysis with participants would have been informative in better interpreting results concerning body ownership.

9 Conclusions

In this 3×2 study, we developed six experimental conditions (human, no mirror; human, mirror; mannequin, no mirror; mannequin, mirror; zombie, no mirror; and zombie, mirror) with which we explored potential interaction effects from *Body* $\times$ *Mirror*. Self-reported and eye fixation data were collected and analyzed. Participants were given one of three self-avatars, and first observed a room with or without a mirror, then experienced a multi-character environment. Participants were able to control their self-avatars with the HTC Vive trackers and controllers. Our results determined no significant interaction or main effects of *Body* or *Mirror* for body ownership, rejecting our **RH1**. Our results provide partial evidence in support of our **RH2** in that the self-avatar body may influence responses in the virtual environment and towards environmental characters with the same *Body*; however, which was observed through plausibility of virtual events and perceived similarity with the self-avatar. Our **RH3** was supported in that we found a negative correlation between self fixation length and perceived similarity. We determined trending effects of *Gender* on body ownership, with females reporting higher body ownership than males, and found that participants who viewed a mirror in a previous environment exhibited decreased mutual awareness.

Our primary findings provide evidence for the use of mannequin/generic self-avatars for body ownership, and suggest a relationship between self-fixations and perceived self-avatar similarity. Additional research is needed to better understand the way in which self-fixations may impact avatar perception more generally. We provided design considerations and future research directions stemming from our results in the hope that they may be helpful in creating VR applications which seek to better understand how self-avatars are looked at and perceived in low-cost motion tracking VR environments.

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