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Eye fixations and electrodermal activity during low-budget virtual reality embodiment

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Summary

As motion-sensing devices become more accessible to consumers, it is important to understand how users experience embodiment when using these devices. In our 3 × 2 between-groups study, we explored eye fixations and electrodermal activity (EDA) in order to more objectively understand potential interaction effects between the self-avatar body, and the presence of a mirror within the context of low-budget embodiment. We developed six experimental conditions concerning *Body* (human, mannequin, and zombie self-avatars) and *Mirror* (mirror and no mirror) factors, and presented participants with a virtual environment in which they could control their self-avatars by using HTC Vive controllers and trackers. In addition to eye fixations and EDA, we assessed self-reported data concerning body ownership, agency, self-location, as well as enjoyment of the experience. Our results suggest that the *Body* may have been more influential in eliciting body ownership than the *Mirror*, and that an interaction effect between *Gender* and *Body* may influence eye gaze behavior. Additionally, female participants reported significantly higher agency than males. We consider logical next steps for similar research which might elaborate upon our findings.

KEYWORDS

body ownership, electrodermal activity, embodiment, eye fixations, low-budget, mirror, self-avatar, virtual reality

1 | INTRODUCTION

Virtual reality research investigating embodiment, the sense of having and perceiving a virtual body as one's own body, often involves the use of a mirror within the virtual environment for the purposes of eliciting a sense of embodiment.[1-5] In addition to including a mirror in the virtual environment, another important factor in eliciting a sense of embodiment is the appearance of the self-avatar: the virtual body one receives in virtual reality. While numerous studies have examined the importance of the appearance of self-avatar bodies or body parts for embodiment,[4,6-9] less research exists concerning potential interaction effects between *Body* and *Mirror* factors (see Figure 1).

Considering that consumers may not have access to expensive software and technologies necessary for the creation of personalized avatars, we investigate self-avatar body types which may not be similar in appearance, but are instead readily available to consumers. In our 3 × 2 study, we presented participants with a virtual room in which they either saw a mirror, or no mirror in front of them within the environment. All participants received one of three self-avatar body types which included a human, mannequin, or zombie character (see Figure 2), and could control their self-avatar with

FIGURE 1 Top: mirror; human, mannequin, zombie. Bottom: no mirror; human, mannequin, zombie

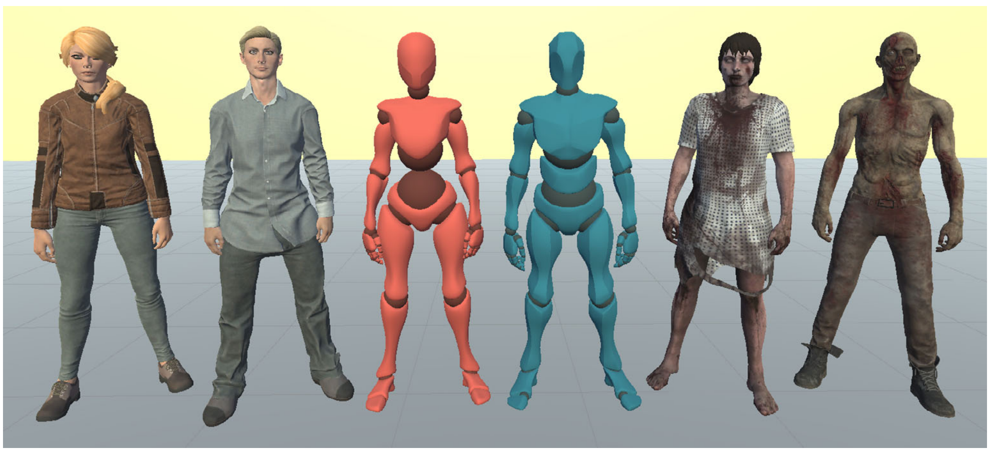

FIGURE 2 Self-avatars used in the experiment: human, mannequin, and zombie

HTC Vive trackers and controllers. Participants were able to move their limbs as they liked, and experienced the virtual environment for two minutes before filling out a short questionnaire.

In addition to the self-reported data collected from the questionnaire, participants' eye fixations and arousal levels were captured in order to explore sense of embodiment as it might relate to physiology. We investigated the influence of gender within several analyses as well, and determined three primary hypotheses in our exploration of eye fixations, electrodermal activity (EDA), and embodiment, listed below.

- **RH1:** Self-avatar body type will be more influential than the presence of a mirror for eliciting body ownership.
- **RH2:** Increased sense of embodiment will be consistent with increased arousal, as well as decreased eye gaze toward the self-avatar.
- **RH3:** Females will look significantly more often and longer at their self-avatar than males.

2 RELATED WORK

Placing a mirror in front of the user within the virtual environment is thought to elicit a sense of embodiment as well as increase a user's sense of agency.[10] Studies have explored variations in the amount of time needed to display the mirror,[1] as well as placement of the mirror within the user's peripersonal space[3] in order to better understand ways in which virtual mirrors influence embodiment. It has also been shown that the appearance of self-avatar bodies or body parts may influence embodiment.[4,6,7]

While it is known that personalized, self-similar avatars can increase feelings of body ownership,[11] obtaining such self-similar avatars is not yet possible for most consumers, as the necessary equipment for the development of personalized avatars, such as specialized software and photogrammetry scanner systems, is expensive. Considering that the low-cost motion-sensing devices such as the HTC Vive trackers used in this study are becoming more available to consumers, it is important to understand how different-looking self-avatars may detract or enhance feelings of embodiment within low-budget virtual reality applications. In the current study, we consider potential interaction effects between *Body* and *Mirror* factors, in order to understand how these factors may influence a consumer's sense of embodiment outside of the laboratory.

In addition to self-reported data, past virtual reality experiments have captured physiological data by using EDA,[12-15] which can be indicative of high levels of arousal or stress,[16] as well as eye gaze behavior such as eye fixations,[17-19] which can be indicative of not only attention,[18] but anxiety,[17] engagement,[20] as well as social functioning.[19] Virtual reality studies capturing EDA have explored public speaking anxiety,[17] and posttraumatic stress disorder[21] among other interests. Concerning sense of embodiment in virtual reality, studies have previously captured EDA in response to threat to a virtual body part,[9,12] and in order to measure the influence of stress on body ownership.[22] Studies capturing eye fixations have investigated social deficits in individuals with autism spectrum disorder,[13] and used eye fixations to understand reward learning.[18] However, it appears less research has captured eye fixations in order to better understand sense of embodiment.

Within virtual reality embodiment, the influence of both avatar gender and participant gender on body ownership have been explored. Slater et al.[4] showed that male participants can feel body ownership of a female virtual body, while Schulze et al.[23] similarly found that participants were able to feel body ownership even if avatar gender did not match their gender. Lopez et al.[24] determined that male participants who were embodied as female avatars had significantly higher implicit gender bias than participants embodied as male avatars. In our study, we hope to not only contribute more objective knowledge concerning *Body* and *Mirror* factors by capturing eye fixations and EDA, but by additionally examining potential main or interactions effects of participant gender within low-budget virtual reality applications.

3 | METHODS

In this section, we discuss the participants, experimental procedure, data collection as well as the virtual environment used in the study.

3.1 | Participants

As this study was part of a larger experiment investigating *Body* and *Mirror* interactions, we had previously determined that 72 participants (12 in each experimental condition) would suffice. In reading the consent form, participants had a general awareness of our study goals, but had no prior knowledge which *Body* they would be given in the virtual environment. Our participants (41 male, 31 female) consisted of undergraduate and graduate students (49 undergraduates, 23 graduates; ages 18–32) from Purdue University, who were recruited through e-mails, posters, and word of mouth. The participants gave informed consent, and received monetary compensation for their time. This study was approved by our Institutional Review Board.

3.2 | Experimental conditions

Six experimental groups were determined for this study, based on the factors *Body* and *Mirror*. These groups were: human, mirror; human, no mirror; mannequin, mirror; mannequin, no mirror; zombie, mirror; and zombie, no mirror. We employed a 3×2 between-groups design in order to explore interaction effects between *Body* and *Mirror* (Figure 1).

3.3 | Virtual environment implementation

The virtual room used in the experiment was created with the Unity3D game engine, and is shown in Figure 3. The room was relatively plain, so as not to distract attention away from the self-avatar body, only including a few pieces of artwork,

FIGURE 3 Three different perspectives of the virtual environment with the mirror

and plants around the edges of the room. We did not collect eye fixations from these background objects, instead including them in an effort to create a more believable environment, which would likely not be empty of any surrounding objects. All assets were downloaded from the Unity asset store. The mirror was placed directly in front of participants, so that the full self-avatar body could be seen. For participants in the no mirror dimension, a generic painting of the same size stood in place of the mirror. The characters used for self-avatars were downloaded from Adobe Mixamo and Adobe Fuse. We used FinalIK with HTC Vive trackers and controllers in order to allow participants the ability to control their limbs.

3.4 | Measurements

We collected participants' eye fixations and EDA data to more objectively understand how participants experienced the virtual environment. Our questionnaire provided self-reported data concerning sense of embodiment, and enjoyment. Our data collection is discussed in more detail below.

3.4.1 | Questionnaire

Sense of embodiment encompasses many concepts,[25] three of which are sense of self-location: the perceived location of the virtual body relative to the physical self;[26] agency: the perceived ability to control the virtual body's actions;[27] and body ownership: the sense of owning the virtual body as one owns their physical body.[28] In our 7-point Likert scale questionnaire, we included two items for body ownership, four items for agency, and two items for self-location.[29] Lastly, we included three items to measure enjoyment of the experience.[30] We additionally provided a space for participants to express their comments at the end of the questionnaire. Each questionnaire variable was averaged for our statistical analyses, with reverse-coded questions being reverse scored. Our questionnaire was administered on screen immediately after the virtual experience had finished.

3.4.2 | Eye fixations

Using the Cognitive3D spatial analytics platform, we captured three measurements concerning eye fixation data. Eye fixations data included fixation count (the number of different instances of fixations on a specified object), fixation length (the total duration time for each fixation object), and time to fixation (the time at which a fixation first appeared on an object). We assigned the self-avatar bodies and the mirror as objects from which we would like to collect fixation data. For the no mirror dimension, we collected fixation data from the painting which stood in place of the mirror.

3.4.3 | Electrodermal activity

In order to investigate participant's arousal level, EDA peak quantity was captured during the experience. Our EDA peak count is a sum of all arousal responses throughout the 2-min virtual experience. Because participants moved their limbs

FIGURE 4 A participant given the human self-avatar, in the mirror dimension

in order to explore their self-avatar, we understand that the EDA signal may have been significantly altered by movement artifacts. However, because all participants were moving in order to examine their self-avatars, we decided to do an exploratory assessment of EDA across groups, under the assumption that each group was equally prone to motion artifacts.

3.5 | Procedure

Participants first completed a demographics survey and signed a consent form upon arriving at the lab. Next, a Shimmer3 GSR+ sensor was attached to their non-dominant hand. Two HTC Vive trackers were placed on the participant's feet, and one HTC Vive tracker was positioned at the center of the back. Participants were given the HTC Vive controllers to use for hand tracking, and wore the head-mounted display (HMD) for head tracking. Eye tracking calibration was completed using the HTC Vive Pro Eye HMD before the virtual experience was started. The researcher informed participants that they could move the self-avatar body how they would like to do so within the virtual environment. Participant were made aware that there were no tasks within the virtual environment, and that they only needed to experience the environment, which would last two minutes.

Participants were instructed to stand in the center of the room, without walking within the virtual space (see Figure 4). In this way, all participants experienced the virtual environment within the same position in the room. Once participants indicated that they were ready to begin, the researcher began the EDA recording and started the virtual reality application, which automatically began eye fixation data collection. After 2 min, the researcher ended the virtual reality application and terminated the EDA recording. The participant removed the HMD and completed the questionnaire on Qualtrics, an online survey tool.

4 | RESULTS

We used two-way Analysis of Variance (ANOVA) to explore main and interaction effects between *Body* and *Mirror* factors, and used three-way ANOVAs to explore interaction effects between *Body*, *Mirror*, and *Gender*. Post hoc comparisons were conducted with Bonferroni corrections. Normality tests were evaluated graphically using Q-Q plots of the residuals. Pearson bivariate correlations were used to assess correlations between our eye fixation data and our self-reported data, as well as to explore correlations between EDA and self-reported data.

4.1 | Eye fixations and EDA

In this section, we report eye fixation data as well as EDA data. Our eye fixation data includes fixation count, fixation length, and time to fixation, while our EDA data includes the total EDA responses during the virtual experience, here referred to as EDA peak count.

4.1.1 | Self-fixations

We used a two-way ANOVA to explore interaction effects of *Body* and *Mirror* factors on **self-fixation count**. While we found no interaction between *Body* and *Mirror* ($F(2,66) = .438$, $p = .647$), or main effect of *Body* ($F(2,66) = 1.085$, $p = .344$), we found a significant main effect of *Mirror* on self fixation count ($F(1,66) = 7.932$, $p < .01$). Post hoc comparisons showed that participants who experienced the mirror dimension looked significantly less times at their self-avatars ($M = 106.78$, $SD = 25.05$) than participants who did not experience the mirror ($M = 206.56$, $SD = 25.05$). Consistent with these results, we also found a significant main effect of *Mirror* on **self-fixation length** ($F(1,66) = 6.584$, $p < .05$). Post hoc comparisons showed that participants who experienced the mirror ($M = 11.91$, $SD = 2.80$) looked significantly less at their self-avatars than participants who did not experience the mirror ($M = 22.06$, $SD = 2.80$). We determined no main effect of *Body* ($F(2,66) = .967$, $p = .386$), or interaction effect between *Body* and *Mirror* ($F(2,66) = .392$, $p = .678$) on self fixation length. We also investigated **time to self-fixation** and found a significant main effect of *Body* ($F(2,66) = 4.214$, $p < .05$). Post hoc comparisons revealed that participants who were given a zombie self-avatar ($M = 8.18$, $SD = 4.47$) looked significantly sooner at the self-avatar than participants who were given a mannequin self-avatar ($M = 26.50$, $SD = 4.47$). We found no main effect of *Mirror* ($F(1,66) = 2.443$, $p = .123$), or interaction between *Body* and *Mirror* ($F(2,66) = .804$, $p = .452$) on time to self fixation.

4.1.2 | Object fixations

We wanted to confirm that the mirror, in the mirror dimension, was looked at significantly more so than the painting, which would indicate that participants in the mirror dimension did in fact look at the mirror, rather than simply look forward. With our *Body* × *Mirror* two-way ANOVA, we assessed differences in object fixation length, object fixation count and time to object fixation. In the mirror dimension, the object refers to the mirror in the virtual environment, and in the no mirror dimension, the object refers to the painting. We determined no two-way interaction between *Body* and *Object* ($F(2,66) = .495$, $p = .612$), or main effect of *Body* ($F(2,66) = 1.058$, $p = .353$), but found a main effect of *Object* ($F(1,66) = 75.635$, $p < .001$) on **object fixation length**. Post hoc comparisons showed that the mirror ($M = 49.52$, $SD = 2.85$) was looked at significantly longer than the painting ($M = 14.48$, $SD = 2.85$).

We found no two-way interaction ($F(2,66) = .084$, $p = .919$), or main effect of *Body* ($F(2,66) = .899$, $p = .412$) on **object fixation count**. We determined a main effect of *Object* on **object fixation count** ($F(1,66) = 17.566$, $p < .001$), with post hoc comparisons revealing that the mirror ($M = 156.53$, $SD = 10.18$) was looked at significantly more times than the painting ($M = 96.17$, $SD = 10.18$). Lastly, we investigated **time to object fixation**, and determined no two-way interaction ($F(2,66) = .757$, $p = .473$), or main effect of *Body* ($F(2,66) = .091$, $p = .913$), but discovered a significant main effect of *Object* ($F(1,66) = 11.213$, $p < .001$) on time to object fixation. Post hoc comparisons revealed that participants who experienced the mirror ($M = 1.78$, $SD = 1.10$) looked significantly sooner at the mirror, than participants looked at the painting ($M = 7.00$, $SD = 1.10$).

4.1.3 | Electrodermal activity

While we found no two-way interaction using our *Body* × *Mirror* two-way ANOVA with **EDA peak count** ($F(2,66) = .450$, $p = .640$), we determined a significant main effect of *Body* on EDA peak count ($F(2,66) = 3.655$, $p < .05$). Post hoc comparisons showed that participants with the zombie self-avatar ($M = 14.13$, $SD = 1.21$) had significantly more EDA peaks than participants with the mannequin self-avatar ($M = 9.50$, $SD = 1.21$).

4.2 | Self-reported data

We evaluated body ownership, agency and self-location aspects of embodiment as well as enjoyment of the experience in our self-reported data.

4.2.1 | Body ownership

We neither found interaction between *Body* and *Mirror* concerning **body ownership** ($F(2,66) = .176$, $p = .839$), nor a main effect of *Body* on body ownership ($F(2,66) = 1.862$, $p = .163$). Interestingly, we also found no main effect of *Mirror* ($F(1,66) = 2.477$, $p = .120$) on body ownership.

4.2.2 | Agency

No interaction effect between *Body* and *Mirror* ($F(2,66) = .625$, $p = .539$), main effect of *Body* ($F(2,66) = .818$, $p = .446$), or main effect of *Mirror* ($F(1,66) = .647, p = .424$) were found concerning **agency**.

4.2.3 | Self-location

Exploring **self-location**, we found no interaction between *Body* and *Mirror* ($F(2,66) = .048$, $p = .953$), main effect of *Body* ($F(2,66) = 2.896, p = .062$), or main effect of *Mirror* ($F(1,66) = .185$, $p = .668$).

4.2.4 | Enjoyment

We also investigated **enjoyment**, finding no significant interaction between *Body* and *Mirror* ($F(2,66) = .435$, $p = .649$), main effect of *Body* ($F(2,66) = .098$, $p = .906$), or main effect of *Mirror* ($F(1,66) = .012$, $p = .914$).

4.3 | Gender differences

We used a three-way ANOVA in order to explore the influence of *Gender* on eye fixations, EDA peak count, and sense of embodiment. While we did not find any interaction effect between *Body*, *Mirror*, and *Gender* on **agency** ($F(2,60) = 1.022$, $p = .366$), we determined a main effect of *Gender* on agency ($F(1,60) = 4.607$, $p < .05$), with females ($M = 5.36$, $SD = 0.15$) reporting significantly higher agency than males ($M = 4.94$, $SD = 0.13$) as shown with post hoc comparisons. We found no significant three-way interaction between *Body*, *Mirror* and *Gender* ($F(2,60) = .524$, $p = .595$) concerning **body ownership**, nor main effect of *Gender* ($F(1,60) = 3.595$, $p = .063$) on body ownership. We also found no three-way interaction ($F(2,60) = .531$, $p = .591$), or main effect of *Gender* ($F(1,60) = .267$, $p = .607$) on **self-location**. While we found no three-way interaction effect ($F(2,60) = 1.482$, $p = .235$) on **self-fixation length**, we discovered a two-way interaction effect between *Body* and *Gender* ($F(2,60) = 4.995$, $p < .01$) on self-fixation length (see Figure 5a). Post hoc comparisons showed that male participants given zombie self-avatars ($M = 29.31$, $SD = 4.46$) looked significantly longer at their self-avatars than male participants given mannequin self-avatars ($M = 10.57$, $SD = 4.18$). We determined no main effect of *Gender* ($F(1,60) = 3.439$, $p = .069$) on self fixation length.

Looking at **self-fixation count**, we similarly found no three-way interaction effect ($F(2,60) = 1.327$, $p = .273$), but again found a two-way interaction effect between *Body* and *Gender* ($F(2,60) = 3.371, p < .05$) concerning self-fixation count (see Figure 5b), with post hoc comparisons revealing that male participants with the zombie self-avatar ($M = 259.81$, $SD = 40.81$) looked significantly more times at their self-avatar than male participants given the mannequin self-avatar

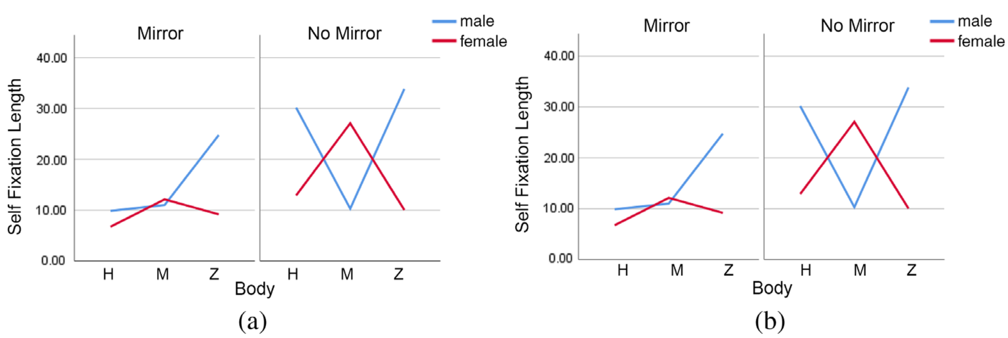

FIGURE 5 *Gender* × *Body* interaction effect on (a) **self-fixation length**: males with zombie self-avatars had significantly higher self fixation length than males with mannequin self-avatars, and (b) **self-fixation count**: males with zombie self-avatars had significantly higher self fixation count than males with mannequin self-avatars. H = human, M = Mannequin, Z = Zombie. Vertical axis: (a) 0–40 seconds for **self-fixation length**, (b) 0–400 for **self-fixation count**. Blue lines denote males and red lines denote females

($M = 110.50$, $SD = 38.24$), but no main effect of *Gender* ($F(1,60) = 3.355$, $p = .072$) on self-fixation count. We determined no three-way interaction effect ($F(2,60) = 1.710$, $p = .189$), two-way interaction effect between *Body* and *Gender* ($F(2,60) = 1.619$, $p = .207$), two-way interaction effect between *Mirror* and *Gender* ($F(1,60) = .071$, $p = .790$) or main effect of *Gender* ($F(1,60) = .170$, $p = .682$) on **time to self-fixation**.

Lastly, we explored the potential influence of *Gender* on **EDA peak count** and determined no significant interaction effect between *Body*, *Mirror,* and *Gender* ($F(2,60) = .524, p = .595$), nor interaction between both *Body* and *Gender* ($F(2,60) = .648$, $p = .527$), and *Mirror* and *Gender* ($F(1,60) = .483, p = .490$). We determined no main effect of *Gender* ($F(1,60) = 3.595, p = .063$) on EDA peak count.

4.4 | Correlations

We assessed correlations between our eye fixations, EDA and self-reported data, and determined one weak negative correlation between **self-fixation count** and **self-location** ($r = -.233$, $n = 72$, $p < .049$), as well as a weak negative correlation between **time to self-fixation** and **body ownership** ($r = -.263$, $n = 72$, $p = .025$).

5 | DISCUSSION

In our 3×2 between-groups study, we explored the presence of a *Mirror* and the influence of the self-avatar *Body* type on low-budget virtual reality embodiment. We collected eye fixations and EDA data in addition to self-reported data from the questionnaire. In this section, we mention how our physiological data may relate to our self-reported data, and discuss partial evidence or lack thereof for our **RH1**, **RH2**, and **RH3**.

Our **RH1** stated that the self-avatar body type would be more influential than the presence of a mirror for eliciting body ownership. However, our results revealed that neither the self-avatar body type nor the presence of a mirror in the virtual environment influenced body ownership. It is possible that because the mirror was outside of the participant's peripersonal space, it was too far away to make any impact on body ownership.[3] Our results are similar to those of Lugrin et al.[31] who reported no significant differences in self-reported body ownership between all three avatars when examining a human, robot, and block-man avatars. Jo et al.[32] also investigated three self-avatar body types for inducing body ownership, finding that the cartoon-like semblance of the actual participant elicited the most body ownership, when compared to a realistic self-avatar and a cartoon-like character in a different outfit. Considering their results, it is possible that none of our self-avatars elicited body ownership, as none bore any semblance to any participants. However, previous works[5,6] have shown that it is possible to elicit body ownership when self-avatars differ from participants. It is possible that by including a *Customization* factor, we may better understand the role of customization versus similarity in body ownership within future work. Additionally, our study was limited in that we only collected eye fixations from the mirror as an entire object, and therefore do not know if participants looked more at their self-avatar reflection in the mirror, or at the reflections of environmental objects.

It is possible that issues in our body ownership items on the questionnaire may have obscured potential differences reported in body ownership. Unfortunately, issues in the phrasing of our body ownership questions forced us to throw out two items, which left us with only two questions for body ownership. Gonzalez-Franco et al.[29] suggest both reverse-scored and normally scored questions for assessing aspects of embodiment, and therefore it is possible that our two final questions were not effective in determining participant feelings of body ownership. Considering these findings, our results do not support our **RH1**.

Although we could not determine an influence of *Body* on body ownership in analyzing our self-reported data, we found significantly higher arousal for participants given the zombie self-avatar compared to participants given the mannequin self-avatar, as seen through our EDA data. Perhaps the increased arousal found for participants given zombie self-avatars was indicative of stress or anxiety, considering that participants may prefer interacting with avatars that are attractive.[33] Therefore, participants may have been anxious or stressed by controlling the zombie self-avatar, as it was unattractive with its ripped clothing and bloodied skin. Lin et al.[8] found that zombie hands were perceived as more realistic than robot-like hands, and so perhaps arousal due to unattractiveness may have even been amplified by increased realism of the zombie self-avatar. Tieri et al.[34] found that physical continuity of virtual limbs was important for inducing an electrodermal response. Although they explored body ownership within the context of perceived threat to a virtual limb, their results showed that a virtual hand which was physically continuous with the wrist increased body ownership as opposed to virtual hands which were disconnected from the wrist. Considering that our mannequin self-avatar's hands were connected to the wrist via a ball-like joint, unlike a real hand-wrist connection, it is possible that EDA was significantly lower for mannequins for this reason.

We also determined that participants with zombie self-avatars looked at their self-avatars significantly sooner than participants with mannequin self-avatars, suggesting a relationship between time to self fixation and arousal, however these two variables were not correlated. Our results further suggest that the sooner a participant looked at their self-avatar during the virtual experience, the more body ownership they reported, which suggests the potential importance for timing of self-avatar fixations in eliciting body ownership. If we consider both that looking sooner at one's self-avatar is correlated with increased body ownership, and that participants given zombie self-avatars looked sooner at their bodies than participant given mannequin self-avatars, we could consider perhaps zombie self-avatars felt higher body ownership, which would partially support our **RH1**. In order to better understand if the *Body* factor may influence self-reported body ownership, we suggest future studies more deeply examine the influence of distance from participant to the mirror, as well as continue to explore relationships between self-avatar realism and arousal, and how this relationship may impact body ownership.

Considering self fixation count, we found that the more times participants looked at their self-avatar, the less self-location with the self-avatar body they reported. Perhaps more eye fixations toward the self-avatar decreases the self-location aspect of embodiment, as low-budget embodiment systems may introduce motion artifacts and cause the participant to feel taken out of the experience, and therefore less embodied. Similarly, perhaps as participants look sooner at the self-avatar body, they may report higher body ownership because they have had more time between first viewing the body and the end of the virtual experience, and therefore may have had time to focus on other aspects of the experience besides issues with motion artifacts.

We were able to confirm issues with motion artifacts in our embodiment set-up based on participant commentary. For example, one participant mentioned *"The movements picked up seemed to be slightly delayed and were less than my movements,ε* suggesting problems in motion-sensing. Another participant said, *"I felt as if the virtual body was a second skin on top of my own. But I didn't think it was my body more like a huge costume I was wearing,ε* demonstrating another reason for the lack of body ownership reported. Perhaps due to low-budget embodiment, we can conclude that as self-location increased, self-avatar fixations decreased, which partially supports our **RH2**. Based on these findings, we suggest future studies consider having participants look at their self-avatars for a predetermined length of time, and/or at a specific time during the experience, in order to better understand the role that eye fixation count, duration, and timing may play in determining embodiment, and if a specific eye fixation behavior might also be best suited for embodiment.

For our **RH3**, we explored the potential influence of *Gender*, and determined a significant main effect of *Gender* on agency, with females reporting significantly higher agency than males. We did not expect to find differences in agency, as our virtual environment involved no defined tasks or goals required of participants. It is possible that an increased exploration of the self-avatar's capabilities led to a decreased sense of agency, as more self-avatar movement would reveal more motion artifacts. During the experiment, males appeared to experiment with different positions and rotations of the self-avatar more so than females. In future studies, it would be important to capture movement data in order to determine if agency was influenced by participant movement. Considering the proteus effect, which suggests that individuals may behave as their self-representation would be expected to behave,[35] perhaps females felt that their behaviors matched their self-avatars bodies better than males, and therefore reported higher agency.

Our results further suggest that male participants given zombie self-avatars looked significantly longer and significantly more times at their self-avatars than male participants given mannequin self-avatars. This finding additionally emphasizes differences between zombie and mannequin self-avatars, as well as an influence of gender. However, our results cannot fully determine whether or not these differences may be due to participant or self-avatar gender, as we matched our participants self-reported gender with the self-avatar gender. Here, we might suggest that future studies replicate our study in order to determine if participant gender or avatar gender was more impactful. Schrammel et al.[36] found that, regardless of participant gender, fixations were longer on male virtual characters than female virtual characters, perhaps due to differences in social status or expected interactions between genders. Although their study explored interactions with virtual characters rather than viewing a self-avatar, if we were to consider that low body ownership may have contributed to perceiving the self-avatar as one might perceive an unrelated virtual character, our results are in line with those of Schrammel et al.[36] in that male zombie self-avatars were looked at significantly longer than male mannequin self-avatars.

An additional reason for the difference in fixations between the zombie and mannequin self-avatar may be due to an incongruency of actions. Marschner et al.[37] found that incongruent signals may increase attentional demands of the observer, therefore, because the zombie may have been significantly more likely to be involved in aggressive actions as often seen in zombie-filled entertainment, perhaps more attention was paid to the zombie as it made less sense with participant expectations for movement, with no participants implementing zombie-specific movements themselves. Future research could better inform our results by providing congruent and incongruent tasks for participants, which might help to determine if the differences found in agency were related to self-avatar task-related congruency. It may have also been important to collect specific game experience data from participants prior to the study, as it is possible that participants with significant experience with zombies in entertainment may have reacted differently than those not as familiar with zombies. Lastly, if zombie self-avatars were perceived as threatening, our results would again be similar to those of Schrammel et al.,[36] who found longer fixations in response to virtual character expressions that may have been perceived as threatening. Although participant gender did not influence self-fixations, providing no support for our **RH3**, our results indicate interesting interactions between *Body* and *Gender*, which we hope to continue to explore in future studies.

6 | CONCLUSION

In this study, we collected both physiological data and self-reported data in order to understand potential interactions between *Body* and *Mirror* within a low-budget virtual reality embodiment application. We developed six experimental conditions concerning *Body* (human, mannequin, and zombie) and *Mirror* (mirror and no mirror) factors, and presented participants with a virtual environment in which they could control their self-avatar with HTC Vive controllers and trackers. We discovered differences in arousal as well as eye fixations between zombie and mannequin self-avatars, however determined no differences in self-reported body ownership. We determined that as self-fixations increased, less self-location with the self-avatar was reported, suggesting a potential relationship between eye fixations and aspects of embodiment using low-budget motion sensing devices. Lastly, we determined that females reported significantly higher agency than males, suggesting that a more complex relationship between gender and agency in low-budget embodiment applications may exist.

In summary, next steps for future research include a deeper investigation of the influence of both mirror-participant proximity and self-avatar realism on body ownership, and experiments designed to disentangle the uses and effects of self fixation count, duration, and timing. Additionally, studies that pursue congruent and incongruent tasks may better inform relationships between agency and gender. Our study provided objective data from EDA and eye fixations to better understand how consumers experience virtual reality embodiment using the low-budget motion-sensing equipment and different-looking self-avatars available to them. It is our hope that our findings and suggestions for similar future research may allow for the enhanced development of low-budget virtual reality embodiment applications for consumers.

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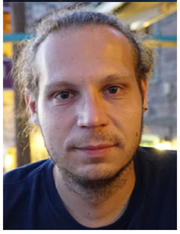

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