A Cardboard-Based Virtual Reality Study on Self-Avatar Appearance and Breathing

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ABSTRACT

Cardboard-based virtual reality is an affordable solution for experiencing virtual reality content. Particularly during the COVID-19 pandemic, several studies used cardboard-based virtual reality remotely to minimize viral spread. We conducted a study to explore the potentials of low-cost virtual reality on participants' sense of presence and body ownership illusion in our research lab, thereby providing a controlled research setting. Our 2 (Avatar: realistic vs. mannequin self-avatar) $\times$ 2 (Breathing; breathing vs. no breathing motion) study investigated presence and body ownership when participants were instructed to observe a virtual environment passively through a cardboard-based virtual reality application while being embodied as a self-avatar. Our study's results indicated that: (1) the mannequin self-avatar exerted a stronger effect on participants' presence; (2) younger participants who experienced the mannequin avatar reported stronger body ownership compared with older participants; and (3) while experiencing a mannequin avatar with no breathing motion, participants with prior VR experience reported higher body ownership illusion compared with participants with no prior VR experience. In this paper, we discuss our findings, as well as the study's limitations and future research directions.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality

1 INTRODUCTION

Cardboard virtual reality (VR), a mobile VR tool, was developed in 2011 and has become popular among those who want an immersive experience [29]. It also has demonstrated value in various areas and is used widely in research studies [15,21]. Moreover, compared with traditional head-mounted displays (HMDs), such as Oculus Quest and HTC VIVE, cardboard VR is easy to set up and use, requiring only a smartphone [1].

With cardboard VR, virtual reality research is done more simplistically. Previous research projects [2, 21] using cardboard VR focused mainly on asking study participants to observe virtual content while minimal interaction was taking place. It is easy to imagine that such passive experiences potentially could be annoying, particularly when the participant is embodied in a self-avatar that the user does not control at all. As a result, the participants might not feel embodied at all in such a self-avatar.

Previous studies found cardboard VR to be more effective than a traditional HMD [14,44]. Moreover, considering that both presence and embodiment are essential elements in VR, and that providing an immersive experience to users through low-cost HMDs, such as cardboard VR, is necessary, we conducted a 2 (Avatar: realistic vs. mannequin self-avatar) $\times$ 2 (Breathing: breathing vs. no breathing motion) study using cardboard VR to investigate whether the appearance of the self-avatar and breathing motion assigned to the self-avatar's body potentially could impact participants' presence and body ownership using a low-cost virtual reality HMD. It should be noted that previous studies [8, 17, 23, 35] considered the appearance of the self-avatar body on body ownership illusion, but considering that no full-body motion tracking could be applied due to cardboard VR's limitations, we realized that it would be interesting to explore whether breathing motion assigned to the self-avatar's body would exert an additional effect on participants' sense of presence and body ownership illusion.

We think that such a study could help us understand whether it is possible to develop a simplistic application that potentially could impact how participants perceive themselves in a virtual environment. To do this, we aim to answer the following research questions:

- **RQ1:** How do different self-avatars impact participants' sense of presence and body ownership?
- **RQ2:** Does breathing motion assigned to the self-avatar impact participants' sense of presence and body ownership?
- **RQ3:** Do demographic factors (age and prior VR experience) impact participants' sense of presence and body ownership?

This paper is organized into the following sections. Section 2 presents literature related to our study. Section 3 provides details on the methodology followed. Section 4 presents the obtained results. In Section 5, we discuss our study's results and limitations. Finally, conclusions and potential directions for further research are presented in Section 6.

2 RELATED WORKS

The sense of presence is viewed as an essential factor when examining how users experience virtual reality because it increases felt experience, sense and sensibility, and agency and autonomy within the virtual environment [42]. Lombard and Ditton [22] conceptualized *presence* as concerning the degree to which a medium could produce realistic representations. Previous research indicated that realistic virtual environments and degrees of immersion can affect presence [12]. The understanding of presence will provide usefulness and profitability to new technologies, such as HDTV, video games, the web, etc. [22]. For VR, understanding participants' sense of presence is essential because it provides direct feedback regarding the fidelity of virtual representations [12].

However, "embodiment" is the feeling of experiencing the avatar in an immersive virtual environment. It has been studied in different contexts, such as self-motion artifacts [16], visuomotor calibration [17], serious game learning [7, 17], tactile sensation [8, 35], and external appearance [3,32,35]. One important factor that contributes to embodiment is body ownership [12,16], which is the experience of perceiving a virtual body as one's own body. Different studies used virtual avatars to explore their effect on embodiment. Krogmeier and Mousas [18] found observation on self-avatar's body through a mirror induced arousal, which increases embodiment. Pan and Steed [19] confirmed that using self-avatars exerts important effects on embodiment. More studies have begun to focus on reactions toward virtual avatars. Mousas et al. [25] found that assigning users

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self-avatars would make them more aware of the virtual environment. Later studies further explored avatar appearances' effects and found that they affect emotional reactivity [24, 26], emotional contagion, and virtual character unpleasantness [26, 27].

Aside from the traditional VR study using PC-based HMDs (e.g., Oculus Rift or HTC VIVE), an increasing number of cardboard-based HMDs have been used in recent studies [1, 2, 15, 21, 31, 37, 40, 41]. Cardboard-based HMDs now are applied widely in various contexts, such as medical science [15, 31], education [21, 41], and business [21]. Because of low-cost application development and hardware production, cardboard-based HMDs have become a convenient tool on both Android and iOS platforms. Amin et al. [2] compared the use of cardboard VR and Oculus HMDs in a clinical study and concluded that cardboard VR allows patients to experience mobile VR at home, while Oculus HMDs can be expensive and difficult to use [1]. Amin et al. [2] also mentioned combining the simplicity of cardboard-based HMDs and a carefully designed pain management game to ensure ease of use for chronic pain patients. Finally, Snelson and Hsu [37] also praised cardboard VR's cost and benefits in their 360-degree video study on education.

This paper utilizes previous studies' results and expands on them by investigating the effects of self-avatar appearance and breathing motion on participants' sense of presence and body ownership illusion. We conducted a study using a cardboard-based HMD to explore whether our experimental dimensions (Avatar and Breathing) could be viewed as methods to improve virtual reality users' sense of presence and body ownership.

3 Methodology

The methodology followed in this paper is presented in the subsections below.

3.1 Participants

For this between-group study, we recruited 80 participants from our department via emails, class announcements, and posters placed on notice boards in our building. The sample comprised 40 males (age: $M = 23.80$, $SD = 5.99$) and 40 females (age: $M = 25.8$, $SD = 8.01$). Out of our sample, 53 had experienced VR at least once before. All participants volunteered for and completed the entire experiment and responded to all questions.

3.2 Application

We developed our virtual reality experience using the Unity game engine and exported it as an Android application. We used the Samsung Galaxy S9 as our projection medium in the cardboard. We chose the Funsparks[1] VR cardboard (price < \$7.00) to host the smartphone (see Figure 1). Among several different low-cost cardboard cases, we chose Funsparks due to the head strap provided, which allowed users to move their hands freely.

The developed virtual reality experience was set in a forest (see Figure 2), with the user's self-avatar sited in the middle of that forest. While sitting in the forest, users of our application could rotate their heads to observe the environment while also listening to bird sounds, rustling leaves, and breathing sounds from the self-avatar. Whether the breathing motion was assigned depended on the examined condition. It should be noted that aside from head rotation, no other body movements were supported due to restrictions in our low-cost HMD and experimental setup.

3.3 Experimental Conditions

Based on our 2 (Avatar: realistic vs. mannequin self-avatar) × 2 (Breathing: breathing vs. no breathing motion) framework, we developed four experimental conditions: **realistic self-avatar with breathing motion** (participants embodied in a realistic virtual character with breathing motion assigned); **realistic self-avatar with no breathing motion** (participants embodied in a realistic virtual character with no breathing motion assigned); **mannequin self-avatar with breathing motion** (participants embodied in a mannequin virtual character with breathing motion assigned); and **mannequin self-avatar with no breathing motion** (participants embodied in a mannequin virtual character with no breathing motion assigned). It should be noted that we prepared both female and male self-avatars to fit participants' gender self-identification (see Figure 3).

[1]https://www.amazon.com/gp/product/B01N0TZJXV/ref=ppx_yo_dt_b_asin_title_o03_s00?ie=UTF8&psc=1

Figure 1: The cardboard case and smartphone used in our study.

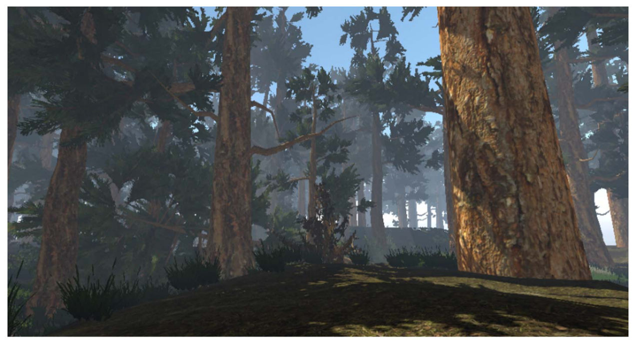

Figure 2: The application's virtual environment that our participants observed.

Figure 3: The different self-avatar characters used in our study (from left to right: mannequin character; realistic male character assigned to male participants; and realistic female character assigned to female participants).

3.4 Measurements

We collected data using a 10-item questionnaire comprising two measurements: presence (Q1-Q4) and body ownership illusion (Q5-Q10). For the presence questions, we referred to [36], while the body ownership questions originated in [4] and were altered to suit virtual environments in [34]. Each question was answered using seven-point Likert scales. The questionnaire is provided in Table 1.

Table 1: The presence and body ownership illusion questionnaire used in our study.

No	Measurements	Questionnaire
Q1	*Presence*	Please rate your sense of being in the forest on the following scale, from 1 to 7, in which 7 represents your normal experience being in a place.
Q2		To what extent were there times during the experience when the virtual reality became the "reality" for you, and you almost forgot about the "real world" in which the whole experience was really taking place (1 indicates not all; 7 indicates all the time)?
Q3		During the experience, which was strongest on the whole: your sense of being in a virtual forest or of being in the real world (1 being in the real world; 7 being in the virtual forest)?
Q4		During the experience, did you often think to yourself that you actually were just sitting in a room wearing a helmet, or did the virtual reality overwhelm you (1 being not at all; 7 being very much)?
Q5	*Body ownership*	During the experience, did it feel as if your hand disappeared (1 being not at all; 7 being very much)?
Q6		How strong was the feeling that the body you saw was your own (1 being not at all; 7 being very much)?
Q7		How much did you feel like you were looking at your own body (1 being not at all; 7 being very much)?
Q8		How much did you feel like your real body was becoming virtual (1 being not at all; 7 being very much)?
Q9		How much did you feel like you had two bodies (1 being not at all; 7 being very much)?
Q10		How much did you feel like the virtual body began to look like your real body (1 being not at all; 7 being very much)?

3.5 Study Procedure

After scheduling a day and time, each participant who arrived at our research laboratory first read and signed a consent form that the university's Institutional Review Board (IRB) approved. Participants then filled out a questionnaire to obtain demographic data. Following that, we put the smartphone inside the cardboard case and gave it to the participants, instructing them on how to wear the cardboard properly. Once set up, the research team let the participants sit and hold the cardboard while opening the application. Participants were asked to try sitting as the virtual character and adjusting their breathing speed as heard in the application. The participants observed the forest scene for one minute, then the application stopped, and participants were given another questionnaire (see Table 1). The research team then answered any questions the participants may have had. The participants then were thanked for their time and excused. None of the participants spent more than 20 minutes in the lab.

4 Results

All results obtained from the study are summarized in this section. We performed all analyses using IBM SPSS (version 26.0) statistical analysis software. The normality assumption of the objective measurements and subjective ratings was evaluated with Shapiro-Wilk Tests at the 5% level and graphically using Q-Q plots of the residuals. The measured items from presence and body ownership were tested for reliability (Cronbach's alpha: $\alpha > .70$ for all measurements), and due to sufficient correlation, we used a cumulative score of all items in each scale as the final result and treated each measurement as a continuous scale, as is typical. We used a two-way analysis of variance (ANOVA) to analyze the obtained data with Avatar (realistic vs. mannequin) and Breathing (breathing vs. no breathing motion) as the independent variables, and presence and body ownership measurements as the dependent variables. Three-way ANOVA was used to explore potential differences in age and prior VR experiences. Individual differences were assessed using a Fisher's LSD post hoc test with corrected estimates if the ANOVA was significant. For all statistical tests, $p < .05$ was deemed statistically significant.

4.1 Presence

We did not find a statistically significant Avatar $\times$ Breathing two-way interaction effect on presence [$F(1,76) = 1.610$, $p = .208$, $\eta_p^2 = .021$]. Furthermore, no statistically significant main effect on the Breathing dimension was found [$F(1,76) = .685$, $p = .411$, $\eta_p^2 = .009$]. However, the analysis revealed a statistically significant main effect for the Avatar [$F(1,76) = 8.763$, $p = .004$, $\eta_p^2 = .103$]. A post hoc comparison using Fisher's LSD revealed that participants embodied in a realistic ($M = 3.48$, $SD = 1.30$) self-avatar reported significantly lower presence value than those who embodied the mannequin ($M = 4.49$, $SD = 1.71$) self-avatar.

4.2 Body Ownership

Our analysis did not reveal a statistically significant Avatar $\times$ Breathing two-way interaction effect on body ownership [$F(1,76) = 1.036$, $p = .312$, $\eta_p^2 = .013$]. Moreover, neither main effect was found for Breathing [$F(1,76) = .642$, $p = .425$, $\eta_p^2 = .008$] nor for Avatar [$F(1,76) = 1.745$, $p = .190$, $\eta_p^2 = .022$].

4.3 Age Differences

We explored age differences' effects on both presence and body ownership measurements. For the analyses, we split our participants into two groups [younger (18-24 years old) and older (25+ years old)] and conducted a three-way ANOVA (Avatar $\times$ Breathing $\times$ Age). The reason for splitting the participants into these age groups was to keep roughly the same number of participants in each group.

We did not find a Avatar $\times$ Breathing $\times$ Age three-way statistically significant interaction effect on presence [$F(1,72) = .014$, $p = .905$, $\eta_p^2 = .001$], nor a Breathing $\times$ Age two-way interaction effect [$F(1,72) = .260$, $p = .612$, $\eta_p^2 = .004$] or a Avatar $\times$ Age two-way interaction effect [$F(1,72) = .939$, $p = .336$, $\eta_p^2 = .013$]. Similarly, no statistically significant main effect for Age was found [$F(1,72) = 1.971$, $p = .165$, $\eta_p^2 = .027$].

As for body ownership, we did not find a statistically significant Avatar $\times$ Breathing $\times$ Age three-way interaction effect [$F(1,72) = 1.180$, $p = .281$, $\eta_p^2 = .016$], nor a Breathing $\times$ Age two-way interaction effect [$F(1,72) = .951$, $p = .333$, $\eta_p^2 = .013$]. However, our analysis did reveal a Avatar $\times$ Age two-way statistically significant interaction effect [$F(1,72) = 4.518$, $p = .037$, $\eta_p^2 = .059$]. A post hoc comparison using Fisher's LSD revealed that younger participants who experienced the mannequin self-avatar reported higher body ownership illusion ($M = 5.11$, $SD = 1.64$) than older participants ($M = 2.97$, $SD = 1.43$). Furthermore, we found a statistically significant main effect for Age [$F(1,80) = 6.042$,

$p = .016$, $\eta_p^2 = .077$] on body ownership, indicating that younger participants reported higher body ownership ($M = 3.64$, $SD = 1.63$) than older participants ($M = 3.06$, $SD = 1.76$).

4.4 Prior VR Experience Differences

A three-way ANOVA (Avatar × Breathing × Prior VR Experience) was conducted to explore the potential effects of prior VR experience (prior VR experience vs. no prior VR experience).

For presence, we did not find a Avatar × Breathing × VR Experience three-way statistically significant interaction effect [$F(1,72) = 2.140$, $p = .148$, $\eta_p^2 = .029$]. Moreover, neither Avatar × VR Experience two-way interaction effects [$F(1,72) = .022$, $p = .883$, $\eta_p^2 = .001$] nor Breathing × VR Experience two-way interaction effects [$F(1,72) = 3.503$, $p = .065$, $\eta_p^2 = .046$] were found. Finally, no main effect of VR Experience was found [$F(1,72) = .075$, $p = .786$, $\eta_p^2 = .001$].

As for body ownership, a statistically significant Avatar × Breathing × VR Experience three-way interaction effect was found [$F(1,72) = 13.496$, $p = .029$, $\eta_p^2 = .065$]. Fisher's LSD post hoc analysis revealed that in the presence of a mannequin avatar with no breathing motion, participants with prior VR experience reported higher body ownership illusion ($M = 4.47$, $SD = 2.20$) than those with no prior VR experience ($M = 2.23$, $SD = 1.69$). Moreover, a Breathing × VR Experience two-way statistically significant interaction effect was found [$F(1,72) = 11.41$, $p = .04$, $\eta_p^2 = .06$]. A Fisher's LSD post hoc analysis revealed that participants with prior VR experience rated their body ownership illusion higher when no breathing motion was assigned to the self-avatar ($M = 3.66$, $SD = 1.91$) than with breathing motion ($M = 2.76$, $SD = 1.42$). We did not find a Avatar × VR Experience two-way significant interaction effect [$F(1,76) = .742$, $p = .742$, $\eta_p^2 = .010$] or main effect on VR Experience [$F(1,79) = .030$, $p = .862$, $\eta_p^2 = .001$].

5 Discussion and Limitations

We conducted a VR study to explore the potential effects of self-avatar appearance and breathing motion assigned to the self-avatar on participants' sense of presence and body ownership when using a low-cost virtual reality headset. In this section, we discuss our findings and the study's limitations.

We found a significant main effect of Avatar on presence. Participants' ratings on presence were higher when embodied in a mannequin avatar than in a realistic avatar. Previous studies support this result. Jo et al. [13] found that cartoon-like characters generated a stronger sense of presence in their research. Gisbergen et al. [10] also mentioned that stronger character resemblance can cause stress in VR users and potentially can affect sense of presence. In our case, we think the reason for the higher rating on presence in the mannequin avatar is related to the uncanny valley effect. In their study, Brenton and Chatting [6] argued that the uncanny valley is related to the sense of presence. Furthermore, Pyasik et al. [33] also mentioned that detailed body appearance could be an essential contributing factor to presence. Because our realistic avatar did not achieve full similarity with participants' appearance, they decided to provide higher ratings to their sense of presence when embodied in a self-avatar with a less-realistic appearance. However, we did not find any significant effect of Avatar or Breathing on body ownership. We view this as a somewhat-novel finding because it opposes previously published results. Past studies indicated that in immersive environments, realistic avatars tend to induce stronger virtual body ownership illusions [20, 23, 43]. We think the reason behind this result was the lack of agency and motor control over the self-avatar [38].

We then found a significant effect on age. In our study, younger participants who experienced the mannequin avatar rated the body ownership illusion higher when compared with older participants. Past studies indicated [30, 39] that age is an essential factor affecting body ownership, perception, and adaptation in immersive environments. Older people take more time to adapt to the VR system and the virtual world. Because our experiment lasted only a minute, we think that younger participants had a better chance of getting accustomed to the application. By comparison, older participants might need more time to perceive the content thoroughly. As for the Avatar, according to Lurgin et al. [23], a realistic human appearance could lead to an uncanny valley effect because less-realistic avatars (robot and block-man) generated a stronger sense of body ownership. We think the avatars' appearance in this study caused the same effect as in Lurgin's study.

Finally, we studied the effect of VR experience and found that participants with prior VR experience rated their sense of body ownership higher than those who had no prior VR experience. On a similar note, Freeman et al. [9] found a relationship between previous experience and presence, indicating that previous experience would lead to more robust judgment and sense of presence. Studies also asserted that prior experience could result in stronger and faster human cognition [5, 11]. Based on the previous findings, we think that participants who had previous VR experience adapted to the virtual body faster within the time limit than those who had no prior VR experience. Moreover, we found that participants with prior VR experience rated their sense of body ownership higher when no breathing motion was assigned to the self-avatar compared with participants with no prior VR experience. Based on this finding, we conclude that participants with prior VR experience never had been embodied in avatars with breathing motion assigned to them before and, thus, were more accustomed to static bodies. However, we argue that further studies should be conducted to explore the potential effect of VR experience and motion assigned to self-avatars.

Aside from our findings, the study has several limitations that should be considered in future studies. First, the hardware was limited. We used the Samsung Galaxy S9, which has less computational power than most computers used for running virtual reality applications. Moreover, we did not optimize the graphics pipeline for the smartphone in Unity. As a result, many participants reported lag and fps drop during the experiment, which could cause potential frustration. Second, there was no eye tracking. In this case, we could not detect whether the participants were paying attention to either the virtual environment or their bodies. Pseudo-eye tracking has been used widely in mobile devices [28] and has been proven effective in detecting eye gaze. In our future studies, we should consider implementing such a feature. Third, there was no way to adjust body height and size automatically because cardboard VR does not support that feature. We think that finding ways to perform such adjustments could benefit future studies. Forth, we think that investigating participants' previous traditional computer gaming experience can also be an indicator of body ownership, which we should consider in our future studies. Finally, there was a lack of motion tracking in the application, possibly eliciting a less-realistic experience than traditional VR.

6 Conclusion and Future Works

We conducted a cardboard-based VR study that explored the effects of self-avatar appearance and breathing motion on presence and body ownership. As a result, Avatar made a greater impact on presence, and Age significantly affected body ownership. These results can offer essential design considerations for future cardboard-based VR applications.

Based on the reported results and limitations, we would like to mention some potential future research directions. We think that including an eye-tracking system within the application and the cardboard using sensors could be interesting to explore in the future because it would let us understand participants' attention and focus during the experiment. We also think that understanding body ownership by assigning different motions to the self-avatar body would be another interesting research direction that is worth exploring. Finally, we think that comparisons between high-end and low-cost devices also should be conducted.

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