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Predicting Presence Using Environment-Activated Motion in Immersive Virtual Reality

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ABSTRACT

Immersive virtual reality (IVR) has shown promise in being an effective platform method for a variety of interventions across a multitude of disciplines. Indeed, IVR allows researchers to place participants in realistic three-dimensional environments with a level of control that may not have been feasible in physical environments. Additionally, IVR elicits a higher sense of presence than computer-based interventions. Evidence suggests that presence, defined as the "sense of being there", is a key factor in the success of these interventions. The relationship between presence and hardware and software factors have been extensively investigated. Behavioral factors have comparatively received little attention. While these system factors are important to investigate, behavioral differences across users may preclude them from engaging in meaningful IVR interventions, regardless of the hardware and software solutions applied. Therefore, this study investigated how an individual's interaction with the virtual experience may influence their sense of presence. More specifically, we wanted to probe the relationship between environment-activated motion (EAM) and presence in IVR. EAM can be described as any motion within the experience initiated by the user or the environment. This is activated by user-activated motion (i.e., a user looks around) or environment-activated motion (i.e., a virtual dog moves within view). Eighty younger adults (22 male, 1 non-binary) completed a 10-minute IVR experience in Vesper Peak using the HTC Vive IVR system. The experience consisted of playing with a virtual robot dog (ex., petting and playing fetch) and teleporting to different areas of the mountain. The session was screen captured using OBS. EAM data were collected by analyzing the videos via OpenCV's implementation of Dense Optical Flow (DOF). Presence was collected via the IGroup Presence Questionnaire (IPQ, Cronbach's $\alpha = 0.87$). Five data were removed due to corruption, resulting in a final sample size of 75. A regression was conducted with EAM as the predictor and presence as the predictand. The overall model was non-significant ($R2 = 0.04$, $RSE = 5.87$, $F(1,73) = 3.83$, $p = 0.054$). These results suggest that environment-activated motion may not play a significant role in presence during IVR experiences. Future IVR-based interventions may not have to control for environment-activated motion and can focus more on user interaction and environment design. Further research is needed to look into how environment-activated motion and user-activated motion separately may affect presence in different ways.

Keywords: Virtual reality, Presence, Human factors, Motion, Individual differences

INTRODUCTION

Immersive virtual reality (IVR) has become increasingly available and popular as prices drop and accessibility rises. Consequently, investigations into this technology as an intervention and research medium have boomed. There is evidence for IVR to be an effective intervention medium across a variety of domains. IVR has been considered for use with a wide range of mental disorders (Freeman et al., 2017; Geraets et al., 2021). IVR has also been utilized with patients with physical pain from a range of causes including cancer (Pittara et al., 2021; Chow et al., 2021) and aging (Benham et al., 2019). Crucially, IVR has been used with community-dwelling older adults. This population has seen success with IVR interventions for general health outcomes (Dermody et al., 2020), some success with mobility and balance (Neri et al., 2017; Pacheco et al., 2020), and enrichment (Baker et al., 2020; Thach et al., 2020). With such a wide range of effects found in a diverse set of populations, it is important to consider the mechanisms behind these observed effects. For this, we look at the construct of presence in IVR experiences.

Presence, commonly defined as the "subjective sense of being in a virtual environment" (Schubert, 2003), is a vital aspect to IVR experiences. Indeed, in the cognitive psychology domain, evidence suggests that presence was a strong predictor of social and behavioral outcomes (Kalantari et al., 2022; Dilanchian et al., 2021; Yang & Zhang, 2022). Similarly, presence has been shown to predict the success of IVR-based exposure therapy (Gromer et al., 2019; Felnhofer et al., 2019). Even still, there is evidence for presence to affect neurophysiological arousal in IVR experiences (Uhm et al., 2019). Consequently, research into what may facilitate or inhibit presence during an IVR experience has been at the forefront of design-centered IVR research. When looking at design factors, visual realism (Hvass et al., 2017; Newman et al., 2022; Stefan et al., 2021; Gonçalves et al., 2022) and hardware (Kreimeir et al., 2019; Seltzer et al., 2019; Melo et al., 2022) have been found to influence presence. Human factors in IVR experiences have also garnered significant interest. Cybersickness is one of the most common correlates of presence, showing a negative relationship (Weech et al., 2019). Emotional responses, such as anxiety, have also consistently related to measures of presence across different VR paradigms (Riches et al., 2019; Diemer et al., 2015). Video game experience is another factor that has been investigated in the literature (Dilanchian et al., 2021).

Another design factor that has been investigated is *how* users interact with IVR environments. Different methods of locomotion have been studied as to their effect on presence with mixed results, though methods that required physical input (e.g., walking-in-place, real walking) tended to have higher reports of presence (Clifton & Palmisano, 2020; Freiwald et al., 2021; Soler-Domínguez et al., 2020). This last finding is particularly interesting to us, as it raises the question of how users are moving in IVR experiences and how this impacts various outcomes.

PROTOCOL

The current investigation focused on understanding how people interact within IVR experiences and how those interactions can affect presence. These individual behaviors may have significant implications for how human factors relate to design factors. Partly due to its existing relationship with presence and cybersickness (Ng et al., 2020; Caserman et al., 2021), we focused on motion within the IVR space. Specifically, we looked at environment-activated motion (EAM). We define EAM as visual change caused by the environment moving in the visual field. EAM may be elicited through user actions (ex., a user moving around the environment), motion caused by entities in the environment (ex., a dog crossing in front of the user), or a combination of the two. For the current study, our primary hypothesis was that higher measurements of EAM will result in higher levels of presence. That is, higher rates of EAM during the experience should elicit higher reported levels of presence after the experience. Additionally, we aim to explore the relationship between cybersickness and presence to confirm the negative relationship observed in current literature (see Weech et al., 2019 for a review).

Methods

Eighty younger adults were recruited to participate in the study (22 male, 1 non-binary). Participants consisted of undergraduate students at Florida State University taking general Psychology and upper-division Psychology courses. Before going into the IVR experience, participants were asked to fill out a brief demographics survey and virtual reality experience survey. Following that, participants were familiarized with IVR using the *SteamVR Home* software. In this, they were taught how to interact with objects (picking up, throwing, etc.) and how to teleport. After this brief training session, participants were asked to engage with *The Lab: Vesper Peak*, a low-intensity IVR experience. For ten minutes, participants were given no direct goal and were informed of the possible interactions within the IVR experience. This included playing with a robot dog and teleporting to different spots on the mountain face. During this time, we used *OBS*, a screen-capture software, to record videos of the participants within the experience. This resulted in one, ten-minute video per participant. After the experience ended, participants were asked to complete the IGroup Presence Questionnaire (IPQ, Schubert et al., 2001) as well as the Simulator Sickness Questionnaire (SSQ, Kennedy et al., 1993).

Analysis

In order to accurately quantify EAM, we turned toward Farneback's (2003) dense optical flow (DOF) algorithm. DOF computes an optical flow vector for every pixel in the frame. From this, we extracted the magnitude of change per pixel, summed the values in each magnitude vector, and calculated the mean of each composite vector across all pixels. This resulted in an average magnitude per frame of the screen capture (see Figure 1). This was further condensed into an average magnitude across all frames per participant. Presence was collected via the IGroup Presence Questionnaire ($\alpha = 0.87$). The

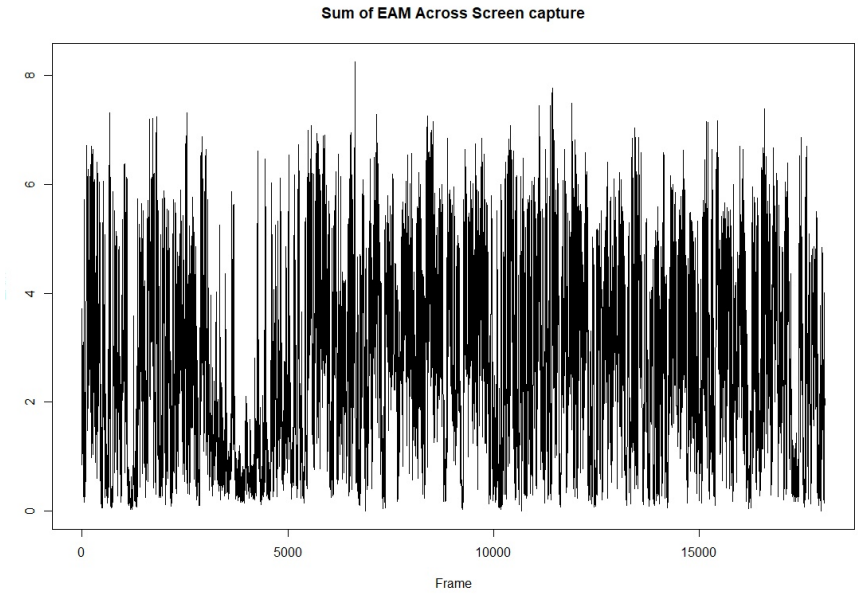

Figure 1: Sum of EAM magnitude per frame of the screen capture for one participant. Stronger movements are represented by higher peaks.

IPQ consists of three subscales: spatial presence, realism, and involvement along with a single general presence item. Scores across all subscales were summed into a composite score per participant. Five data were removed due to corruption, resulting in a final sample size of 75.

Results

In order to test our hypothesis that EAM will predict presence, we utilized a regression analysis. This was conducted with EAM as the predictor and presence as the predictand. The overall model was non-significant ($R^2 = 0.04$, $RSE = 5.87$, $F(1,73) = 3.83$, $p = 0.054$). That is, we were not able to predict the reported presence levels of participants using EAM. This finding suggests that motion induced by the environment has no impact on a user's feelings of presence. Toward adding to the VR literature, we also explored the correlation between cybersickness (recorded via the SSQ) and presence. We conducted a correlation analysis using cybersickness scores and presence scores. In contrast to the literature, we found no correlation between cybersickness and presence ($r = 0.097$). On average, participants reported low levels of cybersickness ($M = 21.12$) and high levels of presence ($M = 49.29$).

CONCLUSION

IVR has the potential to be utilized across a plethora of domains in a variety of ways. IVR-based interventions show promise in being an accessible and effective technology. Additionally, researchers have demonstrated the versatility of IVR as a medium for interventions. Indeed, IVR's ability to immerse

a user in a three-dimensional environment with a high amount of control allows researchers to test many different paradigms and interventions. Presence, a key factor of IVR, has proven to be a crucial determinant of the success of these IVR-based solutions. To be able to isolate and manipulate this factor may prove useful. Indeed, with its influence on the success of many IVR applications, it is important to maximize presence and minimize factors that would reduce it. While many studies have investigated potential design properties of presence (resolution, headset form-factor, real and abstract environments, etc.), less attention has been paid to the individual-factors of presence. This is a crucial aspect to investigate as designs have the potential to be generalizable if we can pinpoint the behavioural factors of presence. With that, this study aimed to investigate how EAM would influence presence. We predicted that EAM would be able to significantly predict reported levels of presence for participants. Instead, we found this relationship to be non-significant. Additionally, we aimed to explore the correlation between cybersickness and presence to bolster existing IVR literature. Surprisingly, we found no correlation between these two factors. This could be due to the low levels of reported cybersickness. Overall, these findings suggest that EAM does not play a role in the formation and maintenance of presence in low-intensity experiences. This may have implications when designing IVR experiences for those who experience higher degrees of cybersickness due to increased EAM, making IVR potentially more accessible. These findings may be specific to low-intensity IVR experiences. Further research is needed to generalize these results to higher intensity IVR interventions.

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