Co-located Immersive Gaming: A Comparison between Augmented and Virtual Reality

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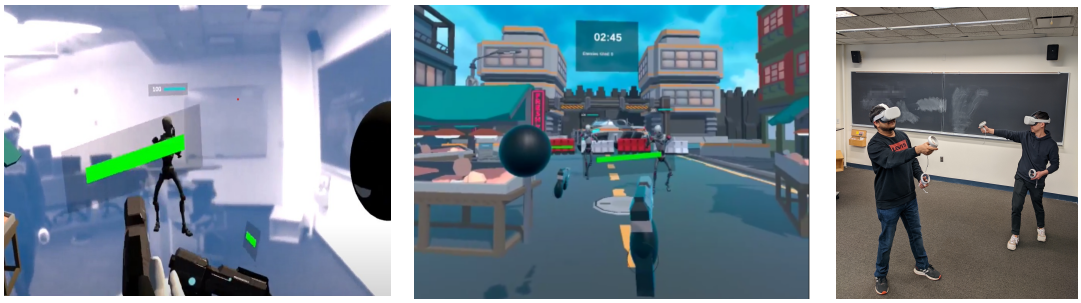


Fig. 1: *Escape from Kyle-Earth*: (*Left*) AR version; (*Middle*) VR version; (*Right*) Users in action while playing the game.

***Abstract*—Despite the surge in commercially available multi-player mixed reality (XR) devices and applications, few studies have focused on the player experience during co-located, multi-player gameplay in XR environments. To address this gap, we designed and developed *Escape from Kyle-Earth*, a co-located, multiplayer XR game that can be played in both AR and VR using a head-mounted display. We then conducted a user study with 26 participants, in which each participant played both versions of the game. Our results indicate that VR evoked a stronger sense of presence while its AR counterpart increased co-presence between players. However, there was no significant difference in game enjoyment between the two platforms. Our work contributes to the burgeoning literature on co-located immersive gaming.**

***Index Terms*—co-located immersive gaming, XR gaming, AR gaming, VR gaming, player experience**

I. Introduction

The increasing availability of mixed reality (XR) headsets and applications in recent years has greatly impacted the landscape of modern gaming [1]–[3]. These applications utilize both physical and computer-generated visual, auditory, and haptic elements. There are many configurations of XR that exist today, though it is usually considered as a spectrum, with virtual reality (VR) sitting on one end and our physical reality on the other [9]. VR involves the user engaging with a completely synthetic environment; VR applications are designed to engulf the user in a reality that is completely disconnected from the real world. Along that same spectrum is augmented reality (AR), which augments the physical world with virtual elements. AR involves viewing and interacting with computer-generated perceptual information overlaid onto the physical environment through some type of display.

Given the inherent differences between VR and AR experiences, it is presumable that gaming experience would be different when a game is played in VR and in AR. Despite the increasing availability of AR and VR headsets, how AR and VR gaming might differ remains an underexplored question. Another aspect of such immersive games is communication and synchronization between players. Though prior studies have been done on collaborative user experience in VR [6], [7], [14], research on collaborative AR experience is sparse in comparison. Therefore, another question that remains unanswered is: how do VR and AR compare when there are multiple users playing the same game simultaneously?

Bearing these open questions in mind, the purpose of this work was to compare player experience between AR gaming and VR gaming during a co-located, collaborative game. Specifically, we were interested in examining how AR and VR platforms would affect players' presence, co-presence with teammates, and game enjoyment. For this purpose, we developed a multiplayer shooting game, where participants collaborate to defeat robots within a time limit. Results from our user study show that VR gaming led to a greater sense of presence than AR gaming and that players felt more co-present when playing the game in AR than in VR. However, the two did not differ in game enjoyment.

II. Related Work

A. Co-Location

Player location can have a large influence on multiplayer AR/VR gameplay. In [16], Sykownik et al. define two ways in which players of the same virtual reality game can be physically placed: the players can be co-located, meaning that they are physically in the same room, or they can be remote, meaning that they have no way of interacting with each other outside of the game and the gaming system.

Born et al. in [5] investigated the effects of physical player locations by having participants play a two-player game that was heavily reliant on coordination. The study used the same two configurations that were used in [16], and primarily

focused on how the teammate's physical locations affected how often the players collaborated on in-game maneuvers, overall game performance, and the amount of communication. Remote placement led to a significantly higher number of enemies killed between the teammates, as well as a significantly greater amount of conversation. However, there has not been much work focusing on the effect of multi-user interaction in a co-located AR application, specifically, head-mounted AR applications.

B. Presence

Sense of presence involves players identifying with a virtual character and actively perceiving and experiencing their surroundings in a virtual environment. Increased immersiveness attenuates input from the physical environment and amplifies the virtual sensory input, which increases focus and involvement within the virtual world [17]. This is a primary concern for our experiment as increased involvement engenders a greater enjoyment of video games [11].

According to Lee et al. [8], advanced head-mounted displays (HMDs), such as Oculus Rift, provide users with basic presence. However, there are additional factors to consider for an immersive virtual environment, such as realistic interaction with objects and smooth movement within the computer generated world [8]. In order to improve the sense of immersiveness, immersive game designers and developers often incorporate smooth continuous locomotion and viewpoint changes using joysticks in the controller. They also provide appropriate haptic and auditory feedback whenever a player grabs an object in the virtual world. The careful design of an XR environment often plays a big role in increasing immersiveness. For example, in 3D role-playing XR games, designers often cover the surroundings of the game with appropriate buildings and obstacles and insert relevant music to engender a sense of presence. However, since AR allows the user to see both physical and virtual objects, one cannot assume that it offers the same level of presence, and this metric should be compared between the two environments.

C. Co-Presence

Co-presence is another factor that plays a key role in a multiplayer game. According to Slater and Steed, co-presence refers to the subjective feeling of another player's presence and ease of interaction in a computer-generated world [15].

Several factors affect co-presence in the VR environment. In [6], Freiwald et al. compared avatar appearance and locomotion techniques in a competitive snowball fighting game and concluded that locomotion has a significant effect on co-presence while a realistic avatar appearance had a weak positive effect. Specifically, continuous locomotion via the controller joystick improved the players' sense of co-presence, but it came with certain trade-offs; most notably, higher levels of cybersickness. While co-presence is an important aspect for collaboration and task completion, there needs to be a balance between other aspects of VR games, such as cybersickness and game enjoyment. The potential of co-presence in co-located AR could be high due to the fact that users will be able to see both in-game avatars and physical players. However, this has yet to be been examined empirically.

D. Hypotheses

Based on our review of related literature, we came up with the following set of hypotheses:

Hypothesis 1 (H1): The VR environment would yield a greater sense of presence. In general, an HMD system masks a player's vision and hearing capabilities and exposes them to a synthetic world. If the 3D game is well designed, the player has the sensation of being completely isolated from their physical world and starts adapting to the virtual world as their reality. However, the same is not true for an AR game, where the physical cues and clear visibility of the other players around them makes the environment less immersive.

Hypothesis 2 (H2): The AR environment would evoke a better sense of co-presence. During VR gaming in which the players' view is occluded, the only way they can recognize other co-located players is through the in-game virtual avatars. While virtual avatars show the positions of players within the synthetic environment, there is a disparity in the avatar position and the physical position of the other player [10]. This could lead to a decrease in overall co-presence since there is no true face-to-face contact between the players. On the other hand, AR overlays virtual objects over the real world, which means that users can view both the physical selves and virtual representation of their partners. Although the disparity of avatar and physical locations in the AR version still exists, the physical view of their partners may evoke a strong sensation that they are playing the game together in the same room.

Hypothesis 3 (H3): Compared to AR gaming, VR gaming will lead to greater game enjoyment. Freiwald et al. in [6] and Nacke et al. in [11] demonstrated that higher sense of presence has a positive correlation with the game enjoyment. We hypothesize that, because of the increased sense of presence it affords, VR gaming will lead to greater game enjoyment.

III. User Study

A. Design

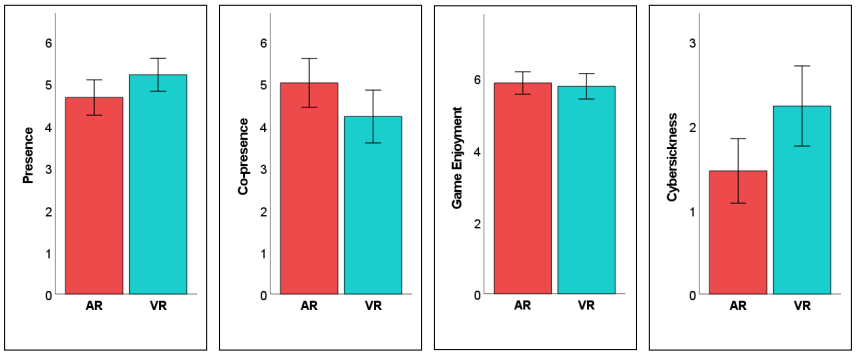
We conducted a within-subjects experiment with participants playing the game in AR and VR at different times. We compared three metrics for an AR version and a VR version of the same game, as described below:

Sense of Presence: Sense of presence was measured using the eight items from the corresponding questionnaire in [12]. All items were rated using a 7-point Likert scale.

Co-Presence: Co-presence was measured using the four items in the social presence questionnaire by [4], rated on a 7-point Likert scale.

Game Enjoyment: Game enjoyment was measured using the Game Enjoyment Scale from [13]. The scale has five items rated using a 7-point Likert scale.

Cybersickness: Cybersickness was measured using a single item that involved participants rating the severity of cybersickness they experienced on a 7-point Likert scale.



(a) Presence (b) Co-Presence (c) Game enjoyment (d) Cybersickness

Fig. 2: Bar graphs for study measures. Error bars represent 95% confidence intervals.

B. Participants

We recruited 26 participants (7 females, 18 males) and divided them into groups of two, leading us to conduct our study with 13 pairs of participants. The median age of the participants was 25 years (21-31), and all but one were right-handed. No participants experienced severe cybersickness symptoms during gameplay, and all participants completed the study without any cybersickness-related disruptions.

C. Apparatus

For our user study, we developed two versions of a co-located multiplayer XR game called *Escape from Kyle-Earth*: (a) a VR version and (b) an AR version. Both versions were played on Meta Quest 2 (the AR version used the passthrough feature providing access to the built-in camera feed.) The gameplay was largely the same between the two. The main difference between these versions was the environment in which game elements were rendered. Representative game scenes from the two versions of the game are shown in Fig. 1. We developed the game in Unity and used the XR Interaction Toolkit and the Oculus Integration package to implement the game mechanics in the VR and AR versions. We also utilized Normcore, a Unity plugin, to enable the multiplayer capabilities.

Escape from Kyle-Earth is a cooperative two-player game, where the players are on a futuristic planet that has been invaded by robots named "Kyles". These robots are driven by artificial intelligence (AI) with a finite state machine controlling their state (chase or attack) based on their distance to the players. The enemy AI implemented for Kyles seeks to shoot either player in the game. The players, on the other hand, have to protect themselves from the robots by dodging their attacks, taking cover, and shooting back at the robots using guns that are spawned at the start of the game. Players can perceive the presence of another player through an in-game virtual avatar represented by a ball-like head holding a gun.

In addition to normal bullets being shot at Kyles, the players have an option of a collaborative attack. The players can hold their respective guns together within a very small distance and shoot from that position. Auditory and haptic feedback is provided when the guns are close enough to perform such an attack. This bullet is marked by a different color and sound and inflicts higher damage to the Kyles.

Each game session has a timeout of 3 minutes within which the players are expected to destroy ten Kyles, which results in players winning the game. If one of the player's health reaches zero or the timer expires, the game is considered to be lost for both the players. Before gameplay, players were provided with a tutorial scene. The tutorial described the motive of the game and had the players practice the different game controls before entering the actual game.

D. Procedure

We performed the experiment in a large classroom on a university campus. Participants played both versions of the the game in the same pairs. Each pair, on a particular day, played either the AR version or the VR version of the game. The second trial, which involved the pair playing the other version of the game, took place at least 24 hours after the completion of the first trial. We purposefully spaced out the trials in this manner to avoid any bias in our data collection. Half of the pairs completed their first session in AR, while the other half did theirs in VR. We conducted the sessions for one group at a time so that the players could fully concentrate on the game and their teammate without any outside distractions. During all the sessions, an experimenter was present in the room to help the participants with any assistance they required. After completing their first gameplay session, participants scheduled their second session, which was completed in an identical manner.

IV. Results

To examine the effect of gaming environment (AR vs. VR) on our study measures, we conducted paired samples t tests. Fig. 2 shows the results of the user study for both the AR and VR versions.

1) Presence: Results revealed that the participants felt a greater sense of presence in the game when they played the VR version of the game (M = 5.20, SE = 0.19) than the AR version (M = 4.66, SE = 0.20), $t(25) = 2.81$, $p = 0.10$. This supports our hypothesis, H1, that the players would feel more present in the VR environment. This is likely due to the fact

that players' views are completely occluded by the VR headset, eliminating environmental distractions.

2) Co-presence: Results also showed that compared to VR gaming (M = 4.21, SE = 0.30), AR gaming (M = 5.01, SE = 0.28) led to a greater level of co-presence with the other player, $t(25) = 2.7$, $p = 0.012$. We conjecture that the participants, though probably distracted by the view of the real-world environment in which they could see their physical teammate, used it to their advantage to establish a better medium of communication. The result confirms hypothesis H2, which states that the AR environment would yield a greater sense of co-presence.

3) Game Enjoyment: In relation to game enjoyment levels, there was no significant differences between AR (M = 5.86, SE = 0.15) and VR (M = 5.77, SE = 0.17), $t(25) = 0.62$, p = 0.543. Hence, our hypothesis, H3 is falsified by these results.

4) Cybersickness: Results indicated that participants experienced more severe cybersickness in the VR version (M = 2.23, SE = 0.23) than in the AR version (M = 1.46, SE = 0.19), $t(25) = 2.87$, $p = 0.008$.

V. Discussion

Our results indicate that the choice of XR environment depends heavily on the context of the co-located application. Due to a greater sense of presence, players who seek immersion inside the game environment may opt in for VR gaming. In the case where feeling physically present with a teammate is important, our results point to taking advantage of the co-presence that an AR environment offers. However, in a scenario where game enjoyment and/or optimizing team performance is the priority, our results indicate that neither environment offers a significant advantage. The choice would then come down to the preference of the players. It should be noted, however, that our results show that compared to AR gaming, VR gaming leads to greater cybersickness, which could be part of the reason for nonsignificant differences in game enjoyment levels, as cybersickness during VR gaming hinders game enjoyment [18]. It is also possible that our game may not lead to different enjoyment levels on different platforms (VR/AR), underscoring the importance of replicating our study with other games.

Despite the rigor of our experiment, we acknowledge several shortcomings in this study, particularly with respect to the design of the game. For example, different locomotion setups between the two game environments may have impacted user performance metrics, since in-game navigation is significantly quicker and less tiring when joystick movement is available, as was the case in the VR version of the game. Additionally, several trials involved players losing the game very quickly, due to the enemy attacks. A reiteration of this study could include a more in-depth tutorial or even a multiplayer tutorial. This would allow the players to acclimatize themselves more with the game environment and mechanics. Future studies should also consider recruiting a larger sample with a wider age range.

VI. Conclusion

Co-located immersive gaming is an emerging area of research. We developed an innovative co-located, multiplayer XR game for head-mounted displays that can be played in both VR and AR environments. We conducted a user study and observed that the two environments impact multiplayer experience differently. Making the choice between these environments for an XR game will ultimately come down to the game's purpose and player preference, as each offers its own advantages and disadvantages.

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