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Effects of Walking Together in a Co-Located Virtual Reality Game

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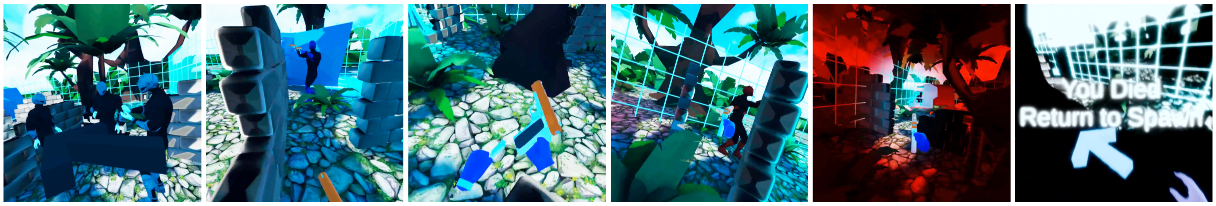

(a) (b) (c) (d) (e) (f)

Figure 1: Screenshots from the point of view of a player who is (a) with three other players before being assigned to a team, (b) hiding behind cover with the other member of the blue team, (c) reloading his laser gun, (d) ambushing a player from the red team, (e) being hit by an opponent, and (f) being guided back to the starting area after being eliminated.

Abstract

This paper details a within-subjects study exploring how two locomotion techniques affect players' experiences while playing a co-located virtual reality (VR) game. The participants played a two-versus-two game, reminiscent of laser tag, in a 14m × 14m arena, and they moved around in the arena either by physically walking or by using VR controller while standing. When walking, participants reported significantly higher social presence directed at their teammates and significantly lower simulator sickness. Moreover, they found walking significantly more natural, they were significantly more likely to forget that they were using controllers, and they were significantly more concerned with keeping distance to other players.

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

1 Introduction

Locomotion, or travel, is one of the most ubiquitous forms of interaction in virtual reality (VR) and it is central to many VR games. Although numerous locomotion techniques have been proposed, it is ultimately the goal of the VR application that dictates what technique is best suited [21]. Magical locomotion techniques that imbue users with superhuman abilities (e.g., teleporation or flight) make it possible to traverse great distances efficiently and effortlessly. However, many applications demand techniques that adhere to real-world constraints (e.g., training scenarios and games set in the real world). Moreover, other applications may deliberately include physical movements to make interaction effortful (e.g., VR exergames). Thus, immersed users are often asked to navigate virtual environments (VEs) on foot [15].

Natural walking in VR have been studied extensively [15]. However, much of this work has focused on scenarios involving a single walking user, and research on the effects of physical walking on users' experiences of social interactions in VR remains scarce. Moreover, research on walking in VR often involves tasks that are not necessarily representative of those encountered when using commercially available VR applications. Specifically, VR games may involve multiple users engaged in scenarios encouraging unpredictable behavior. VR users can enjoy a range of multiplayer games at home, but the experience of physically walking together is rarely possible outside of large VR arcades. However, does physically walking together positively influence players' experiences, compared to modes of locomotion that can easily be deployed at home?

To explore this question, we performed a preliminary study comparing physical walking to stationary locomotion using VR controllers during a two-versus-two VR game. Our findings suggest that physical walking elicited higher social presence, lower simulator sickness, it was perceived as more natural, it made participants less attentive to the controllers, and made them more worried about keeping distance to other players.

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2 Related Work

Effects of walking in VR: A large body of work has explored the effects of different locomotion techniques, including the effects of physical walking on users' experiences and behavior (for recent surveys see [1, 2, 9, 15]). Physical walking has been shown to positively influence factors such as presence [22], spatial knowledge [4], accuracy [13], collision avoidance [21] and navigation speed [21], compared to locomotion techniques offering lower interaction fidelity. Notably, findings vary with respect to the effects of physical walking on simulator sickness, with some work suggesting reduced simulator sickness [4], while other work found no difference [23] or increased simulators sickness [21]. Even though single-user scenarios are most common, some research has studied the behavior and experiences of co-located walking users.

Co-located and separated users: Collisions are a major concern when multiple immersed users share the same physical space, and prior work has explored different types of feedback for preventing such harmful interactions [18, 20]. Other work has explored the experiences and behaviors of walking users that are either physically co-located (they share the same tracking space) or physically separated (they are in separate tracking spaces). Podkosova and Kaufmann [19] explored how physical walking trajectories changed during three different two-user scenarios: (1) two immersed users were virtually and physically co-located; (2) two immersed users were virtually co-located, but physically separated; and (3) two non-immersed users were physically co-located (i.e., they performed the task while able to see the shared physical space). The results indicate that physical and virtual co-location led to increased clearance distances, increased path curves, and lower walking speeds.

Furthermore, the immersed users reported higher co-presence (i.e., the feeling of being together in the VE) and more concern about collisions, when exposed to physical co-location, compared to physical separation. Born, Sykownik, and Masuch [3] present a study comparing physical co-location and separation during exposure to a cooperative two-player, room-scale VR game. Based on the results, the authors conclude that co-located players tended to neglect the cooperative task. Moreover, they found that physical separation may positively influence self-reported team cohesion, team involvement, communication quality and in-game performance. The two conditions did not yield statistically significant differences with respect to presence, and no differences were found with respect to players' wish to deliberately avoid contact with teammates.

Physical events and virtual experiences: When walking users share the same physical space, real and virtual events will be spatial connected. Notably, work involving interaction between a single human user and virtual characters provides some indication that closer ties between real and virtual events may affect social presence and co-presence. Lee et al. [12] asked participants to play a tabletop game with a virtual human, presented using an optical see-through head-mounted display (HMD), and compared conditions where the virtual opponent was able to move either a virtual token or a physical token. When the opponent was able to move the physical token, participants reported higher co-presence and found the opponent more physical. Moreover, Pimentel and Vinkers [17] found that co-presence directed at a virtual human may be higher when the virtual human responds non-verbally to physical events occurring outside the VE. Krum, Kang, and Phan [7] examined how proxemic behavior toward a virtual human is affected by locomotion technique (joystick or physical walking) and haptic priming (in the beginning of the experience, a confederate touched the user when the virtual human did). The results indicated that locomotion technique affected stopping distance and step back distance. Haptic priming did not affect such proxemic behaviors, but positively influenced self-reported measures related to whether the virtual human was perceived as a sympathetic and reliable partner.

3 Methods and Materials

The aim of the study was to explore how physical walking compared to a locomotion technique, frequently used in commercial VR games, in terms of the players' sense of social presence toward teammates, simulator sickness, and the general player experience. The study relied on a within-subjects design and compared two conditions that were identical, except from the locomotion technique:

- *Walking:* The users were able to physically walk and run around the play space (i.e., there was a one-to-one mapping between their real and virtual movements).

- *Standing:* The users remained physically stationary, and virtual movement in the horizontal plane was controlled using the thumbsticks on the VR controllers. The users were standing and virtual rotations were mapped to their physical rotation.

3.1 Participants

Twenty participants (14 males and 6 females), aged between 20 and 25 years (M=20.0, SD=1.5), were recruited among the students at Aalborg University. When asked about prior VR experience, 10 reported having no experience, 7 reported having moderate experience, and 3 reported being very experienced. Out of the 10 participants who had tried VR before, 5 reported that they rarely experienced simulator sickness, 4 experienced it sometimes, and 1 experienced it frequently. They participated in groups of four, and all knew each other before participating.

Figure 2: Top: Overview of the VE showing the starting areas for blue team (left) and the red team (right), as well as the walls and vegetation serving as obstacles. Bottom: Three players in the physical environment.

3.2 Game Play and Virtual Environment

The game used for the study was a two-versus-two first-person shooter, reminiscent of laser tag. We chose this genre because it encourages collaboration with one's teammate and movement around the VE, and it involves simple mechanics that require little or no prior knowledge. The game was set in a bright stylized VE, the players embodied humanoid avatars, and the avatars were not visibly damaged when hit. This was done to create a fun and playful experience, reminiscent of laser tag rather than a realistic combat scenario. Figure 1 shows a series of screenshots of the VE, avatars, and interactions from the point of view of a player. A video showing a playthrough of the game from the perspective of one player is available online[1].

The game took place in a 14m $\times$ 14m arena, and the borders were delineated using a grid (Figure 2). The arena was designed to encourage players to move, crouch, and sneak around. At the beginning of each match, the two teams were located in opposite corners of the arena, and the VE was populated with obstacles that offered cover and limited the ability to hit the opposing team from the starting area. Four laser pistols with eight rounds were located in the starting area and users had to relocate to acquire additional ammunition scattered throughout the arena. To further encourage movement, more powerful weaponry was placed outside the starting area (i.e., two rifles were placed in the two other corners).

The game consisted of rounds, and the overall victory was decided through a best-of-three playoff (i.e., each game involved two to three rounds). Each round was won by eliminating the two players on the opposing team by hitting them with the laser weapons. When a player was eliminated, their view of the VE changed and they were guided back to the starting area where they waited until the round ended. The duration of each round was limited to three minutes, and if one team had more players remaining than the other when the time expired, they were declared winners of the round.

[1] `https://youtu.be/YUiYr12PZJw`

3.3 Equipment and Setting

The game was developed using the Unity game engine and Normcore was used for networking. It was presented using four Oculus Quest 2s, and the controllers were used for all interaction with objects in the VE (i.e., picking up, firing, and reloading weaponry). All tracking was performed using the native tracking of the Quest 2s, and no notable tracking drift was observed.

The avatars' upper bodies were animated using inverse kinematics driven by the movement of the HMDs and controllers. The virtual legs were controlled using animated walk and run cycles. This meant that the players' real and virtual leg movements were decoupled, which may reduce self-reported presence [10]. Thus, we only rendered the virtual hands when players looked at their own bodies. The players' heads, forearms, and lower legs were colored either red or blue to differentiate between teams.

The study was run in a classroom at Aalborg University, which allowed for a play space matching the size of the virtual arena (i.e., 14m × 14m). During exposure to *walking*, participants could freely move in the play space, and during *standing* they would be distributed in the space with approximately the same distance to the center and edges of the play space.

3.4 Procedure:

Participation occurred in groups of four (two on each team), and condition order was counterbalanced between groups. After filling out a questionnaire asking about demographic information, participants were introduced to the locomotion techniques, gameplay, and mechanics. Then they were exposed to the first condition. Both conditions began with a practice round designed to familiarize participants with the current locomotion technique. Afterwards, they played a full best-of-three game. After each condition, the participants completed a questionnaire about their experience.

3.5 Measures

The post-exposure questionnaire aimed to gauge the participants experiences of social presence, simulator sickness, as well as other aspects of the player experience.

Social presence: Inspired by previous work on social presence in VEs [11], we administered Harms and Biocca's Social Presence Questionnaire (SPQ) [5] to evaluate participants' sense of social presence directed at their teammate. The SPQ is based on the view that social presence can be considered a person's sense of being socially connected with another agent, and it is conceptualized in terms of six dimensions that make up the sub-scales of the SPQ:

1. *Co-presence (CoP):* The degree to which a person feels like being in the presence of someone.

2. *Attentional allocation (Att):* The amount of attention a person allocates to and receives from someone else.

3. *Perceived message understanding (Msg):* The degree to which a person feels that they and someone else understand the messages communicated to each other.

4. *Perceived affective understanding (Aff):* The degree to which a person feels that they and someone else understand the emotional and attitudinal states of each other.

5. *Perceived affective interdependence (Emo):* The degree to which a person feels affected by and is able to affect someone's emotional and attitudinal states.

6. *Perceived behavioral interdependence (Bhv):* The degree to which a person's behavior is affected by, and can affect, someone's behavior.

The SPQ includes 36 items (six per sub-scale) rated on 7-point scales, ranging from 1 to 7. Participants were explicitly asked to focus on social presence relative to their teammate when answer providing their answers. Like Lee et al. [11], we derived scores for each of the six by averaging the items corresponding to each sub-scale, and we derived a *total SPQ* score by averaging the ratings of all items.

Simulator sickness: To measure the participants' experience of *simulator sickness* after exposure to each condition, we administered the Kennedy-Lane Simulator Sickness Questionnaires (SSQ) [6]. The SSQ asks participants to evaluate the severity of 16 symptoms of simulator sickness (e.g., eyestrain, dizziness, and stomach awareness) on 4-point scales, including the options 'none', 'slight', 'moderate' and 'severe', corresponding to the symptom variable scores 0, 1, 2 and 3. The ratings form the basis for three diagnostic sub-scales (*Nausea*, *Oculomotor discomfort*, and *Disorientation*) and a *total SSQ* score reflecting the general severity of simulator sickness.

Player experience: Finally, the post-exposure questionnaire included five custom-made items related to specific aspects of the *player experience*:

1. *Perceived competence:* The degree to which players felt competent while playing.

2. *Movement naturalness:* The degree to which players felt that the mechanism that controlled movement was natural (i.e., like walking in real life).

3. *Controller disregard:* The degree to which players forgot that they were using controllers.

4. *Distance keeping:* The degree to which players wanted to keep distance to other players.

5. *Outcome importance:* The degree to which players were invested in the outcome of the game.

The five items were answered using 7-point rating scales, ranging from 1 to 7, where a high rating indicated strong agreement with the statements presented.

4 Results

4.1 Social Presence

The assumption of normality was not violated in case of the six sub-scales or the total SPQ score, as assessed by Shapiro-Wilk's tests (*CoP*, p = .475; *Att*, p = .496; *Msg*, p = .540; *Aff*, p = .953; *Emo*, p = .508; *Bhv*, p = .140; and *total SPQ*, p = .484), and no significant outliers were identified from inspection of boxplots of difference scores. Paired-sample t-tests were used to identify statistically significant mean differences between the two locomotion techniques for the six sub-scales and the total SPQ score. Figure 3a visualizes the corresponding results.

Co-presence: The mean *CoP* score was higher for *walking* (M = 5.85, SD = 0.87) than *standing* (M = 4.71, SD = 1.68); a statistically significant difference of 1.14 (95% CI, 0.42 to 1.86), t(19) = 3.309, p = .004, d = 0.74.

Attentional allocation: The mean *Att* score was higher for *walking* (M = 4.16, SD = 0.82) than *standing* (M = 3.78, SD = 0.88), but the difference of 0.38 (95% CI, -0.06 to 0.84) was not statistically significant, t(19) = 1.772, p = .092, d = 0.40.

Perceived message understanding: The mean *Msg* score was higher for *walking* (M = 3.95, SD = 0.66) than *standing* (M=3.04, SD=0.93); a statistically significant difference of 0.91 (95% CI, 0.36 to 1.45), t(19) = 3.493, p = .002, d = 0.78.

Perceived affective understanding: The mean *Aff* score was higher for *walking* (M = 3.45, SD = 0.90) than *standing* (M=2.98, SD = 1.20), but the difference of 0.48 (95% CI, -0.05 to 1.00) was not statistically significant, t(19) = 1.898, p = .073, d = 0.42.

Perceived affective interdependence: The mean *Emo* score was higher for *walking* (M = 3.21, SD = 1.50) than *standing* (M = 2.73, SD = 1.78), but the difference of 0.48 (95% CI, -0.35 to 0.99) was not statistically significant, t(19) = 1.949, p = .066, d = 0.44.

Perceived behavioral interdependence: The mean *Bhv* score was higher for *walking* (M = 3.43, SD = 1.61) than *standing* (M = 2.49, SD = 1.36); a statistically significant difference of 0.93 (95% CI, 0.29 to 1.57), t(19) = 1.949, p = .007, d = 0.68.

Total SPQ: Finally, the mean *total SPQ* score was higher for *walking* (M = 4.01, SD = 0.63) than *standing* (M = 3.29, SD = 0.90); a statistically significant difference of 24.93 (0.71 (95% CI, 0.38 to 1.05)), t(19) = 4.507, p $<$ 0.001, d = 1.01.

4.2 Simulator Sickness

Two participants provided incomplete responses to the SSQ (i.e., they both failed to respond to all items). Thus, their responses were excluded from the analysis (n=18). The assumption of normality was not violated in relation to the three sub-scales or the total SSQ score, as assessed by Shapiro-Wilk's tests (*nausea*, p = .062; *oculomotor*, p = .431; *disorientation*, p = .202; and *total SSQ*, p = .101), and no significant outliers were identified from inspection of boxplots of difference scores. Paired-sample t-tests were used to identify statistically significant mean differences between the two locomotion techniques for the three sub-scales and the total SSQ score. Figure 3b visualizes the corresponding results.

Nausea: The mean *nausea* score was higher for *standing* (M = 36.57, SD = 27.81) than *walking* (M = 21.71, SD = 19.30); a statistically significant difference of 14.84 (95% CI, 4.02 to 25.66), t(17) = 2.893, p = .010, d = 0.68.

Oculomotor: The mean *oculomotor* score was higher for *standing* (M = 30.71, SD = 23.03) than *walking* (M = 16.42, SD = 12.54); a statistically significant difference of 14.32 (95% CI, 4.41 to 23.63), t(17) = 4.244, p = .005, d = 0.76.

Disorientation: The mean *disorientation* score was higher for *standing* (M = 64.19, SD = 46.08) than for *walking* (M = 19.34, SD = 25.77); a statistically significant difference of 44.85 (95% CI, 24.91 to 64.80), t(17) = 4.745, p $<$ .001, d = 1.12.

Total SSQ: Finally, the mean *total SSQ* score was higher for *standing* (M = 46.75, SD = 31.64) than *walking* (M = 21.82, SD = 16.64); a statistically significant difference of 24.93 (95% CI, 12.10 to 37.79), t(17) = 4.093, p = .001, d = 0.96.

4.3 Player Experience

Wilcoxon signed-rank tests were used to compare the data from the five items between conditions. Figure 3c visualizes the corresponding results.

Perceived competence: When asked about *perceived confidence* 10 participants rated *walking* highest, whereas 6 rated *standing* highest. The median scores were higher for *walking* (Mdn = 5.5) than *standing* (Mdn = 5.0), but this difference was not statistically significant, z = 1.073, p = .283.

Movement naturalness: When asked about *movement naturalness*, 16 participants rated *walking* highest and 3 rated *standing* highest. The median scores were statistically significantly higher for *walking* (Mdn = 6.0) compared to *standing* (Mdn = 2.5), z = 3.355, p = .001.

Controller disregard: When asked about *controller disregard*, 17 participants rated *walking* highest and 3 rated *standing* highest. The median scores were statistically significantly higher for *walking* (Mdn = 5.0) compared to *standing* (Mdn = 2.0), z = 3.314, p = .001.

Distance keeping: When asked about *distance keeping*, 14 participants rated *walking* highest and 4 rated *standing* highest. The median scores were statistically significantly higher for *walking* (Mdn = 4.5) compared to *standing* (Mdn = 3.0), z = 2.239, p = .025.

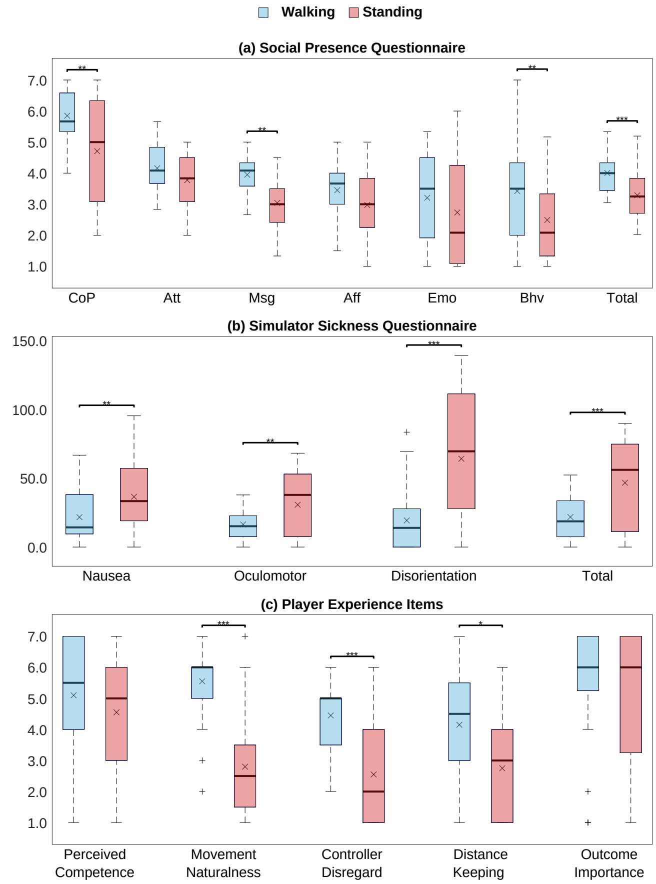

Figure 3: Boxplots showing results related to the social presence questionnaire (a), simulator sickness questionnaire (b), and player experience items (c), in terms of medians (-), means (x), interquartile ranges, minimum and maximum ratings, and outliers (+). $*$: $p < .05$; $**$: $p < .01$; $***$: $p < .001$.

Outcome importance: Finally, one participant did not respond to the question about *outcome importance* after exposure to *standing*. Of the remaining 19 participants, 7 rated *walking* highest and 5 rated *standing* highest. The median scores were the same for *walking* (Mdn = 6.0) and *standing* (Mdn = 6.0), z = 0.974, p = .330.

5 Discussion

Below we discuss the findings related to the three measures of social presence, simulator sickness, and the general player experience in turn, as well as some of the main limitations of the current study that suggest the need for future work.

Walking elicited stronger social presence: The SPQ was administered to measure participants' sense of social presence toward their teammates. Walking elicited significantly higher mean scores on three sub-scales (*co-presence*, *perceived message understanding*, and *perceived behavioral independence*) and the *total SPQ* score. This may suggest that when walking, participants felt more as if they were in the presence of someone else in the VE (*co-presence*); they felt that they better understood messages exchanged with their teammate (*perceived message understanding*); and to a greater extent they felt that their behavior affected, and was affected by, the teammate. Walking also yielded higher mean scores with respect to the three sub-scales *attentional allocation*, *perceived affective understanding*, and *perceived affective interdependence*. However, none of these differences were statistically significant. Taken together, we believe these results to suggest that walking may yield stronger social presence toward teammates than stationary locomotion in the context of games such as ours.

Walking elicited less simulator sickness: The mean scores pertaining to all three sub-scales (*nausea*, *oculomotor discomfort*, and *disorientation*) and the *total SSQ* score were significantly higher after exposure to the condition involving stationary locomotion. These results are in line with previous work suggesting that walking may elicit less simulator sickness than stationary locomotion [4] and can be explained by sensory conflict theory of motion sickness, which stipulates that the sickness arises as a consequence of discrepant information about self-motion from different senses [8]. In case of stationary locomotion, the visuals suggest self-motion whereas the vestibular and kinesthetic senses suggest that the user is not moving. Walking does not involve such a conflict.

Other effects of walking together: Out of the five custom-made questionnaire items, significant differences were found with respect to *movement naturalness*, *controller disregard*, and *distance keeping*. That is, participants reported that they found the walking experience more natural, which is consistent with previous work suggesting that physical walking is perceived as more natural than locomotion techniques with lower interaction fidelity [22]. Moreover, the participants were significantly more likely to forget that they were interacting using controllers when walking, which was to be expected given that the controllers mainly were used as a proxy for the virtual laser weapons during that condition. Finally, the participants reported a significantly higher desire to keep distance to other players when walking. This is consistent with previous work suggesting that physically co-located users exhibit more cautious movement behavior when collisions are likely, compared to distributed users [19]. However, it is worth noting that this result seemingly contradicts previous work by Born, Sykownik, and Masuch [3] that found no difference between physically co-located and separated players in terms of their desire to avoid mutual contact. A possible explanation is that the current study involved gameplay that encouraged fast walking or running, which made physical contact between players more dangerous.

Limitations and future work: Contrary to previous studies that compare physically co-located and separated users, we deliberately ran both conditions in the same room to avoid confounding locomotion technique and physical co-location. However, physical walking and stationary locomotion differ not only in terms of the actions performed to move. The two techniques also differ in terms of physical mobility. Thus, in case of walking, the players real and virtual positions were always aligned, whereas the stationary technique introduced a misalignment between the two. This difference may have influenced the participants' sense of social presence and their concern about collisions. Thus, the study only allows us to conclude that the two locomotion techniques yielded differences in terms of the participants' experiences, but we are unable to conclude whether the observed effects should be attributed to the mode of locomotion, the misalignment, or both. We do not consider this to be a major limitation because the two techniques by design are different with respect to both mode of interaction and avatar-user alignment. However, it would be relevant for future studies to explore if the effects of walking persists when users are physically separated (e.g., using a 2×2 factorial design crossing locomotion technique and co-location). It would also be relevant to explore the effects of other stationary locomotion techniques that seek to provide a more natural walking experience, such as walking-in-place techniques [14].

Because all players participating in a match relied on the same locomotion technique, we cannot conclude whether the observed effects were caused by the player walking, the other players walking, or both. We attempted to mitigate this by using the same leg animations for both conditions, but locomotion technique also affect movement in space. Thus, it is relevant for future studies relying on more complex study designs to explore the effects of different players relying on different locomotion techniques. Furthermore, we did not collect data pertaining to the users' performance and behavior (e.g., real and virtual movement in space), and it is relevant for future studies to include such measures.

Finally, the generalizability of our findings is limited by the specific scenario and the lack of a diverse sample. Thus, future work needs to explore if the observed effects extend to other types of games and genres, and future studies should rely on more diverse and representative samples [16].

6 Conclusion

This paper detailed a preliminary user study comparing physical walking to a common locomotion technique (navigation using a controller while standing) during a two-versus-two VR game. The results indicate that the participants experienced significantly higher social presence and lower simulator sickness when walking together; and walking was experienced as significantly more natural, it made the participants less aware of the controllers, and it made the participants more concerned with keeping distance from other players. Taken together, the results suggest that it may be useful to host similar multi-user VR games in larger play spaces, such as the ones featured in some VR arcades, to enable physical walking rather than stationary locomotion.

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