Usability in Virtual Reality: A Study of Locomotion & Visual Feedback

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Abstract

This study investigated the effects of interaction type and visual feedback in virtual reality (VR) to best determine optimal design considerations for the end-user. In this experiment, we studied three types of VR locomotion: walking-in-place, using a trackpad, and teleportation by the use of a point-and-click controller technique with or without visual feedback. Participants were assigned a locomotion style and participated in both visual feedback conditions. After initial familiarization, they entered an open-world game, in which they were asked to walk down a path using their locomotion style and either shoot their bow and arrow into a large rock, where they saw their arrows stick and dust particles on impact (feedback), or between two rocks where their arrows disappeared into the mist (no-feedback). The Simulator Sickness Questionnaire (SSQ) was administered after each session to gauge motion sickness levels. The Witmer Presence questionnaire was also administered after each feedback condition, in which participants rated their levels of presence in three categories: realism, immersion, and the possibility to act. Accuracy was recorded by the researcher, which was determined by how many virtual arrows landed in the correct target area for each condition. Ratings for realism and results for accuracy were significantly higher when participants used the walk-in-place locomotion method. The walk-in-place method was also found to be marginally more immersive and caused the least amount of simulator sickness when compared to the other two locomotion methods. When analyzing feedback conditions, no-feedback resulted in higher accuracy overall. However, feedback conditions did not seem to have an effect on other measures. This data suggests that the walk-in-place method may be the most effective locomotion style when it comes to usability in virtual reality.

Usability in Virtual Reality: A Study of Locomotion & Visual Feedback

Virtual reality (VR) has proven to be useful in various settings such as education, training, and entertainment. These systems provide a visual, auditory, and tactile experience similar to reality (Lee et al., 2017), which has the potential to drastically change and enhance human-computer interaction. However, in order to fully realize the potential benefits of VR the software needs to be designed for the end-user. Otherwise, users will not be able to properly take advantage of the software for their needs, and there can be potentially dangerous outcomes when VR is used for training purposes. For example, if a medical student that is practicing surgery in VR finds the software hard to use, they will learn less, which can be dangerous when they are assisting with surgery in the real world. Thus, research is needed to identify the design considerations that benefit users in virtual systems. This study explored the effects of interaction methods (walking-in-place, trackpad, and teleportation) and the presence of visual feedback on user performance and their sense of presence in VR applications.

When designing VR applications, two important criteria to achieve an exceptional user experience are immersion and presence. Immersion in VR is the degree to which the user's sensory information is engaged by the virtual system (Kim & Biocca, 2018). An immersive VR system allows the user to experience their environment, whom they are with, and what they are doing as if it were a real experience outside of the virtual environment. To achieve immersion within a VR system, the user must experience realistic interactions with the objects and backgrounds within their virtual environment. Changes in the virtual environment must be detected and reflect the user's behavior and motion to maximize immersion (Lee et al., 2017). However, presence is the human reaction to immersion. It is the subjective psychological response of a user who is experiencing VR (Slater, 2018). Presence can also be understood as the phenomenon of a user feeling as if they are "really there" within their virtual environment. VR systems are great for presence due to their ability to satisfy the user's visual sense through the implementation of three-dimensional visual information. The more immersed a user feels within the virtual environment, the more presence will be achieved. To foster immersion within VR, it is essential to develop realism within that environment.

The amount of realism a user feels within a virtual environment directly impacts the degree of immersion. Previous research has identified at least four main influences of achieving realism within virtual reality (VR). These include rendering, the field of view, 3D quality, and the level of interaction. The first three factors influence the quality of the visual image in the virtual environment. Rendering in VR is essential when creating realism because it is the process of generating the virtual environment. Low quality and/or slow rendering will result in an unrealistic environment. For example, low polygon density for objects or objects not appearing until the user is close can undermine the realism of the scene. Similarly, the field of view (FoV) within a VR system also plays a crucial role when influencing realism, because only content within a user's FoV is rendered in VR. So, when experiencing VR, the user must rotate their head to change their viewing orientation, which is described by the angles along the x, y, and z axes. If the user rotates their head and the scene is not fully rendered yet, it can cause that scene to look unrealistic (Lee et al., 2017). Three-dimensional (3D) visual quality also influences realism greatly. If the virtual environment has a low 3D quality, it won't appear like a real-life scene, which can cause the user to underperceive information. For example, Kelly et al. (2017) discovered that participants made more accurate judgments of size while in a high-quality 3D virtual environment compared to a low-quality 3D virtual environment. Another factor that is critical to one's sense of immersion is the level of direct interaction with the environment. The user needs to be able to move within the VR space and identify actionable objects that respond to the user's actions, or object affordances. For example, when a user sees a soccer ball in the virtual environment, they should know they are able to pick it up and throw it or walk over and kick it. These object affordances help increase immersion and realism within VR.

Research indicates the degree to which we experience realistic interactions within the virtual environment will influence the amount of experienced realism or one's sense of presence. When a person can directly interact with the virtual environment, such as through walking or reaching, there is a direct coupling between action and sensory input such as motion cues. For example, a study by Gerig et al. (2018) evaluated the accuracy of reaching a target within a virtual environment while varying visual quality. They discovered that high-quality 3D displays aided in reaching accuracy because participants were able to depend upon stereopsis and motion parallax not available in 2D displays. In terms of walking, previous research has indicated that direct walking interaction has been beneficial for making size and distance judgments within a virtual environment. Kelly et al. (2018) discovered that perceived size and distance judgments were more accurate after the participant performed direct walking interaction through a virtual environment in comparison to just visually previewing the virtual environment before performing the judgments. Direct walking interaction caused better performance on these tasks because walking interaction involves a continuous stream of visual feedback (Kelly et al. 2018). The constant flow of visual feedback improves the perception of space and may help perception-action calibration. Thus, direct interaction where there is nothing in-between the user and their environment to guide interaction (e.g. walking-in-place) should aid performance relative to indirect interaction which utilizes an object (ie. a controller) in-between the user and their environment to create artificial movement within a VR system.

According to Boletsis and Cedergren (2019), the three most well-established and common types of VR locomotion are the following:

- Walking-in-place: a type of motion-based locomotion that involves direct interaction. This type utilizes marching in place of continuous motion to control movement within the virtual environment.
- Controller: a type of controller-based locomotion that involves indirect continuous interaction by guiding artificial movement throughout a virtual environment with a physical controller. This depends on the VR system, but common controls for this type are trackpad and joystick.
- Teleportation: teleportation-based locomotion involves indirect interaction as the user utilizes the point-and-click feature on a controller to guide artificial movement within a virtual environment. This technique involves noncontinuous motion, as the user's viewpoint is teleported by visual "jumps" from scene to scene.

In the Boletsis and Cedergren (2019) study, they assessed levels of immersion between the three most well-established types of locomotion listed above. Their results indicated that the walk-in-place method had the highest ratings for immersion, with the trackpad method coming in second. Similarly, in the study by Lee et al. (2017), the researchers discovered that the walk-in-place method, compared to controller-based and hand-based movement styles, resulted in the highest ratings for immersion, satisfaction, presence, and realism. VR locomotion styles that utilize indirect walking interaction, such as trackpad and teleportation methods, have a greater conflict in motion cues between the visual system and other motion-sensing systems, and thus, less perception-action coupling as compared to direct walking interaction types, such as walking-in-place. This conflicting sensory information also places the user at risk for motion sickness.

In the Lee et al. (2017) study, they also found that the indirect locomotion styles of the gamepad controller and hand-based locomotion resulted in more symptoms of simulator sickness than the walking-in-place method. Simulator sickness develops when the brain receives conflicting signals, sent from the vestibular system, about where the user's body is in relation to the movement they are seeing within the virtual environment. This conflict between vestibular and visual motion cues can cause feelings such as headaches, dizziness, and nausea (Lee et al., 2017). A high degree of realism results in a very immersive environment, which then results in the user experiencing a high level of presence. However, if a high level of visual presence is achieved without other corresponding motion cues (vestibular), the user becomes at risk to the danger of simulator sickness. Boletsis and Cedergren (2019) found that the trackpad locomotion method produced the highest levels of simulator sickness out of the three total locomotion styles. Thus, the connection between physical movement in the virtual environment and the corresponding motion cues plays a crucial role in one's experience in VR, and the presence of visual feedback within the virtual environment may aid operators in using this motion-based information.

Previous research has indicated that the presence of visual feedback, the observable evidence of one's action on the world, increases performance on 3D motion tasks. Fulvio and

Rokers (2017) discovered that accuracy in a 3D Pong game was considerably better when visual feedback was present within the virtual environment. Specifically, they found that participants were better at using subtle visual information related to head movements, or "head jitter" when they could see where their ping pong ball hit the target. This "head-jitter" information was always present; however, when feedback was present, participants became more sensitive to the additional motion cues, and performance (hitting the target) improved relative to a condition where participants did not receive feedback from their actions. Moreover, these motion cues may be more prevalent when a person directly interacts with a VR system relative to indirect or artificial movement, such as with the VR controller methods.

The presence of feedback can also influence a user's level of overall presence. For example, when there is a delay in visual feedback it can negatively affect overall presence (Welch et al., 1996), reducing performance (accuracy of VR task) within a virtual system (Fulvio & Rokers, 2017). Welch et al (1996) studied the impact of delay and visual feedback in a driving simulator. Participants were assigned to either be a driver or a passenger in the study. The driver had direct visual feedback in response to their actions. For example, turning the wheel would directly result in the simulator screen moving in that direction. However, the passenger would experience a decoupling of the visual-action information due to its passive nature. Overall, this study found that the decoupling of visual feedback and action reduced the overall feelings of presence and that presence greatly depends on the perception of one's ability to move independently through the virtual environment. Thus, visual feedback coupled with the user's actions may lead to a greater sense of presence and better performance.

Hypotheses

The purpose of this study was to investigate walking interaction and feedback on a 3D motion task within a virtual reality system. Our particular interest was to compare direct and indirect interaction methods and the presence of visual feedback. Studying walking interaction methods and visual feedback together allowed us to investigate coupling action with feedback, extending the previous study performed by Fulvio and Rokers (2017). Altogether, given the Lee et al (2017) and Boletsis and Cedergren (2019) studies demonstrating that direct interaction (walking-in-place) produces higher ratings for immersion, satisfaction, presence, and realism, we hypothesized that direct interaction is better than indirect interaction for immersion, and consequently, the user's sense of presence should improve. Additionally, performance should increase and simulator sickness should decrease. Also, Fulvio and Roker's (2017) findings, in which they discovered visual feedback created by watching the ping pong ball hit the target helped participants use "head jitter" or visual information related to head movements help us hypothesize that the visual feedback from watching an arrow hit a target within a virtual environment will improve the use of visual motion cues, and consequently, accuracy with interacting with visible objects, and possibly the user's sense of presence. Moreover, we expected that feedback will be more effective in direct action (walking-in-place) than with the indirect controller methods because they lack sufficient perception-action coupling.

Method

Participants

The participants were students from Bradley University and members of the Peoria, IL community. Students were recruited from introductory classes in the Psychology Department at Bradley University and were offered extra credit in exchange for participating in the study.

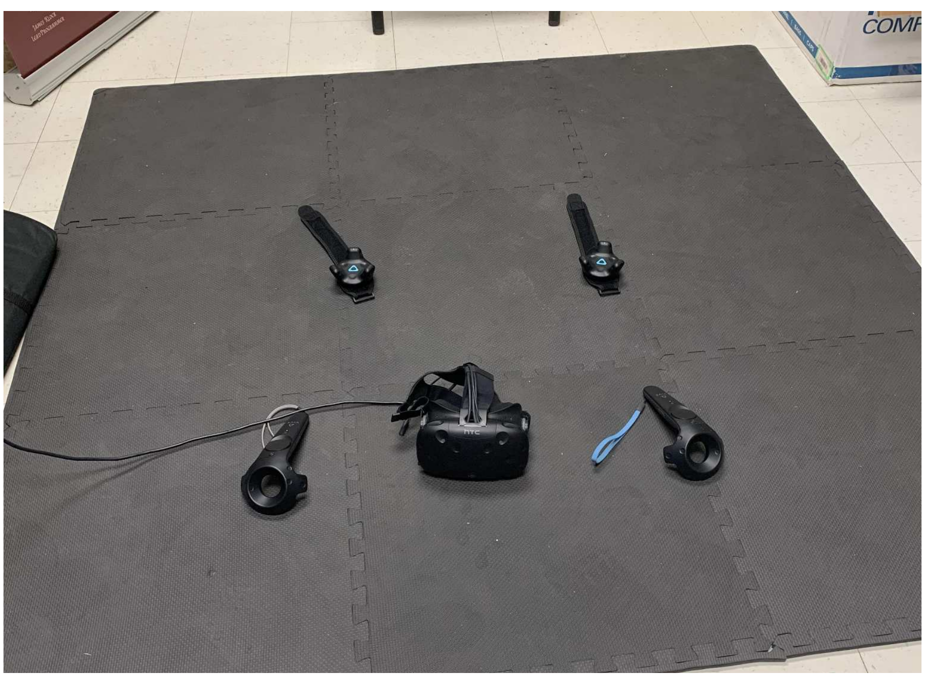
Members of the community volunteered their participation. Before the study began, demographic data were collected and informed consent was administered. All participants were under the age of 30, had varying levels of experience with virtual reality, and had corrected or normal vision.

Materials

In the study, we utilized the HTC Vive (https://www.vive.com/us/), a virtual reality system that consists of a head-mounted display (1080X1200 pixels per eye and 110° horizontal FoV) made by HTC Corporation (Xindian, New Taipei, Taiwan) and Valve Corporation (Bellevue, Washington, US). Trackpad and teleportation locomotion styles utilized the default Vive controllers for movement. The walk-in-place method used two Vive Trackers in combination with the "Natural Locomotion" (Myou Software, Miguelturra, Spain) software to help emulate walk-in-place interaction specifically for the selected VR game. Access to physical equipment (Figure 1) was provided by the Interactive Media department within the Global Communications and Fine Arts VR room. The selection of software for the research was an open-world VR game, titled "The Elder Scrolls V: Skyrim VR" (Bethesda Softworks, 2017). The software was displayed in the HTC Vive which was generated on a Windows 10 desktop computer using an Intel i7-5960X processor and NVIDIA GeForce GTX TITAN X graphics card. Head position and orientation were tracked using the Lighthouse tracking system sold with the HTC Vive. All participants used the HTC Vive display to interact with the software. Users were tasked with shooting a bow and arrow in both the feedback and no-feedback conditions. The feedback conditions were similar to the methods used in the Fulvio and Rokers (2017) study. They used a 3D pong game to test visual feedback. In their feedback condition, the participants would view the interception of the ping pong ball and the target if they hit it with the virtual paddle correctly. For their no visual feedback condition, participants would only hear a cowbell sound for hitting a target, or a “swoosh” sound when missed. However, in our feedback condition, users shot 3 arrows into a large rock and in the no-feedback condition, they shot 3 arrows in-between 2 rocks toward some mist in the game. In both conditions, they were asked to walk down a path until they reached a divot in the road. For the feedback condition, they were tasked to turn to their left and shoot 3 arrows into the shaded part of a large rock (Figure 2). If an arrow hit the rock, dust particles appeared and the participant visually saw their arrow stuck in the rock. In the no-visual feedback condition, the participant was tasked to turn to their right to shoot in-between two rocks over by the mist (Figure 3). The participant saw their arrow fly, but they did not see it land. Task accuracy was determined by the researcher's observation, in which the number of arrows that hit the correct target area was recorded (out of 3).

Figure 1

VR Equipment



Note. HTC Vive Headset, Controllers, and Trackers.

Figure 2

Feedback Target

Note. *The rock scene from "The Elder Scrolls V: Skyrim VR" (Bethesda Softworks, 2017) software depicts the target in the feedback condition. If hit, participants can visually see their arrow stick to the rock.*

Figure 3

No-Feedback Target

Note. The mist scene from "The Elder Scrolls V: Skyrim VR" (Bethesda Softworks, 2017) software depicts the target in the no-feedback condition. Participants do not see where their arrow lands.

Locomotion within the virtual environment seen through the HTC Vive display was completed by using the trackpad on the Vive controller, teleporting through the virtual environment with the controller, or by walking-in-place. For the controller method, a user simply moved their thumb on the trackpad in the direction they wanted to go while pressing with varying force to control the rate of motion. When using the teleportation method, the participant utilized the controller to point in the direction they wanted to go while holding the trackpad button down on the controller. When pushed, a ray appears to help guide the user in selecting where to teleport (Figure 4). To initiate the teleport, the user releases the button. To walk in place, participants wore 2 Vive trackers, in which each tracker was strapped around the participant's ankle. In this locomotion method, the user still holds onto the controllers with their hands, but to move, they march in place and the Vive trackers translate the movement.

Following each feedback task, presence was measured with Witmer's presence questionnaire (Witmer et al., 2005) and simulator sickness was assessed using the simulator sickness questionnaire (SSQ) after the task (Kennedy et al., 1993, as cited in Walter et al., 2019). Witmer's presence questionnaire involves 24 questions that gauge a user's overall sense of presence within a virtual environment. Participants marked an "X" in the appropriate box of the 7-point scale for their response *(1 = not at all, 7 = very much so)*. The presence questionnaire was analyzed in three subscales: realism, immersion, and possibility to act. For realism, questions such as "How compelling was your sense of moving around inside the virtual environment?" and "How natural did your interactions with the environment seem?" were asked. Ratings for immersion included questions such as "How easily did you adjust to the control devices used to interact with the virtual environment?" and "Was the information provided through different senses in the virtual environment consistent?" When measuring the possibility to act, questions such as "Were you able to anticipate what would happen next in response to the actions that you performed?" and "How responsive was the environment to actions that you initiated (or performed)?" was presented. The SSQ lists symptoms that are commonly experienced with simulator sickness. It measures symptoms such as feelings of dizziness, nausea, fatigue, general discomfort, and eye strain. In total, the questionnaire has 16 different symptoms listed, which a participant must rate on a scale from none, slight, moderate to severe. The total SSQ score is calculated by adding the symptom scores *(0 = none, 1 = slight, 2 = moderate, 3 = severe)*.

Figure 4

Teleportation Locomotion Style

Note. Starting path scene from"The Elder Scrolls V: Skyrim VR" (Bethesda Softworks, 2017) software depicts the teleportation locomotion style, which displays a ray to help guide the movement jump.

Procedures

Participants were randomly assigned to one of three interaction methods: walk-in-place, trackpad, or teleportation. All participants were first given a maximum of 10 minutes to practice shooting their bow and arrow, along with practicing their locomotion style. Once participants were familiar with the software and their interaction method, they performed a walking and bow and arrow task under two feedback conditions. In both conditions, participants were instructed to walk down a path until they reached a divot in the road. In the feedback condition, they were instructed to turn to their left and shoot 3 arrows into the lower shaded part of the large rock. In the no-feedback condition, participants were tasked to turn to their right and shoot their 3 arrows between two rocks toward the mist. Before starting each condition, participants were shown an image of the upcoming target area and confirmed their comprehension. The visual feedback conditions were counterbalanced and accuracy was observed and noted by the researcher while the participant completed the bow and arrow task. The number of arrows that landed in the correct target area (out of 3) was recorded for each participant in each condition. To focus on the effects of visual feedback, all participants went through the experiment with no in-game sound.

Results

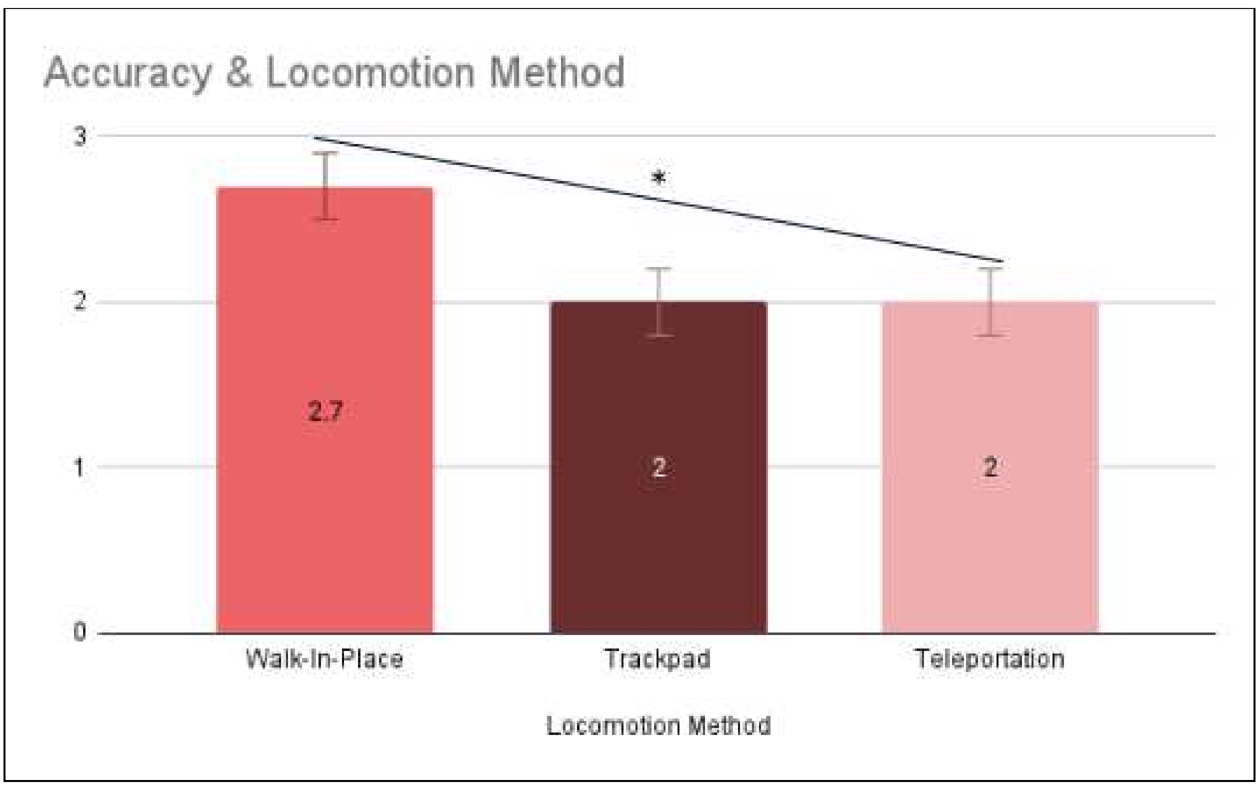
Results were analyzed in a 2 x 3 mixed ANOVA with visual feedback (feedback vs no feedback) as a repeated-measures factor and walking interaction (walk-in-place, teleport, and trackpad) a between-subjects factor. Analyses were performed on accuracy, presence, and simulator sickness data.

Accuracy

Accuracy results indicated a significant main effect of method $F(2,27) = 6.211$, $p = 0.006$. As it was originally predicted, the walk-in-place method (M = 2.5, SE = 1.97) displayed the highest amount of accuracy when compared to the teleport (M = 1.75, SE = 0.23) and trackpad (M = 1.75, SE = 0.17 locomotion methods (Figure 5). There was also a significant main effect of Feedback $F(1,27) = 7.043$, $p = 0.013$ (Figure 6). However, contrary to our expectations, there was higher performance in the no feedback condition (M = 2.133, SE = 0.16) than in the feedback condition (M = 1.86, SE = 0.12).

Figure 5

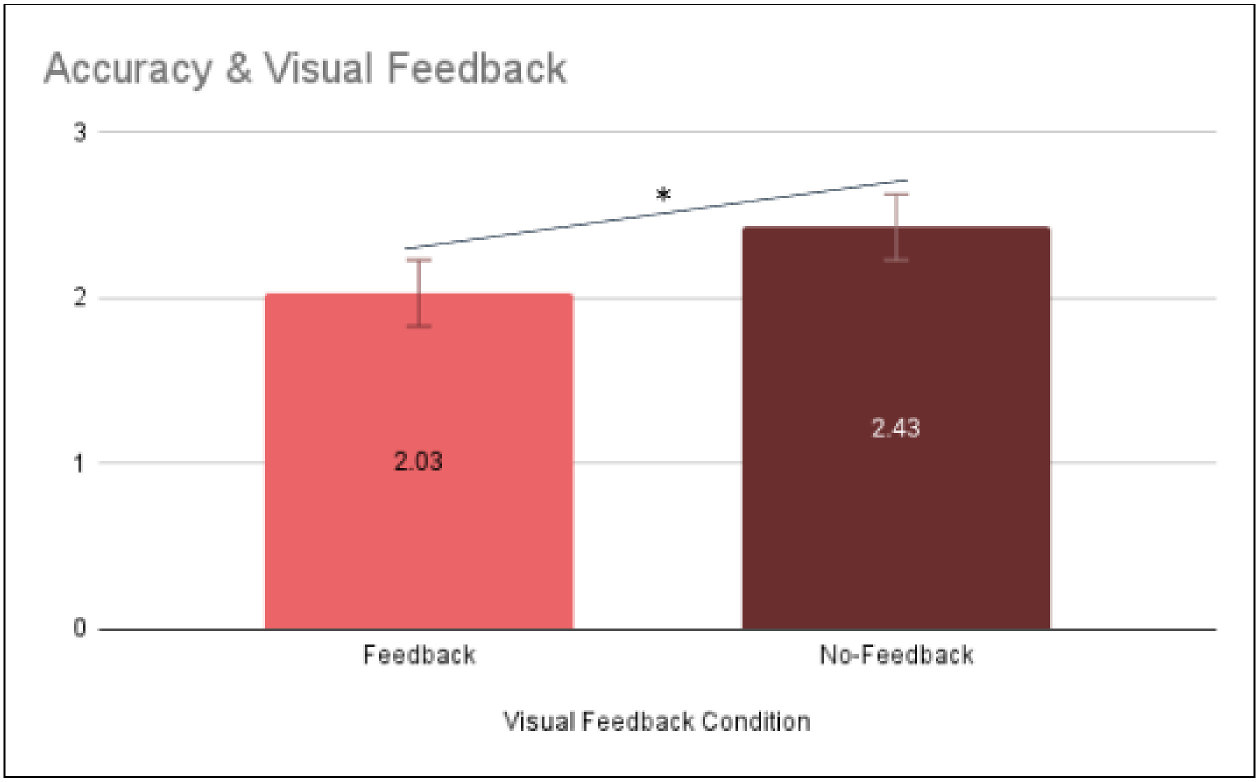
Accuracy & Locomotion Method Results



Note. Accuracy results for each locomotion method.

Figure 6

Accuracy & Visual Feedback Results



Note. Accuracy results for each visual feedback condition.

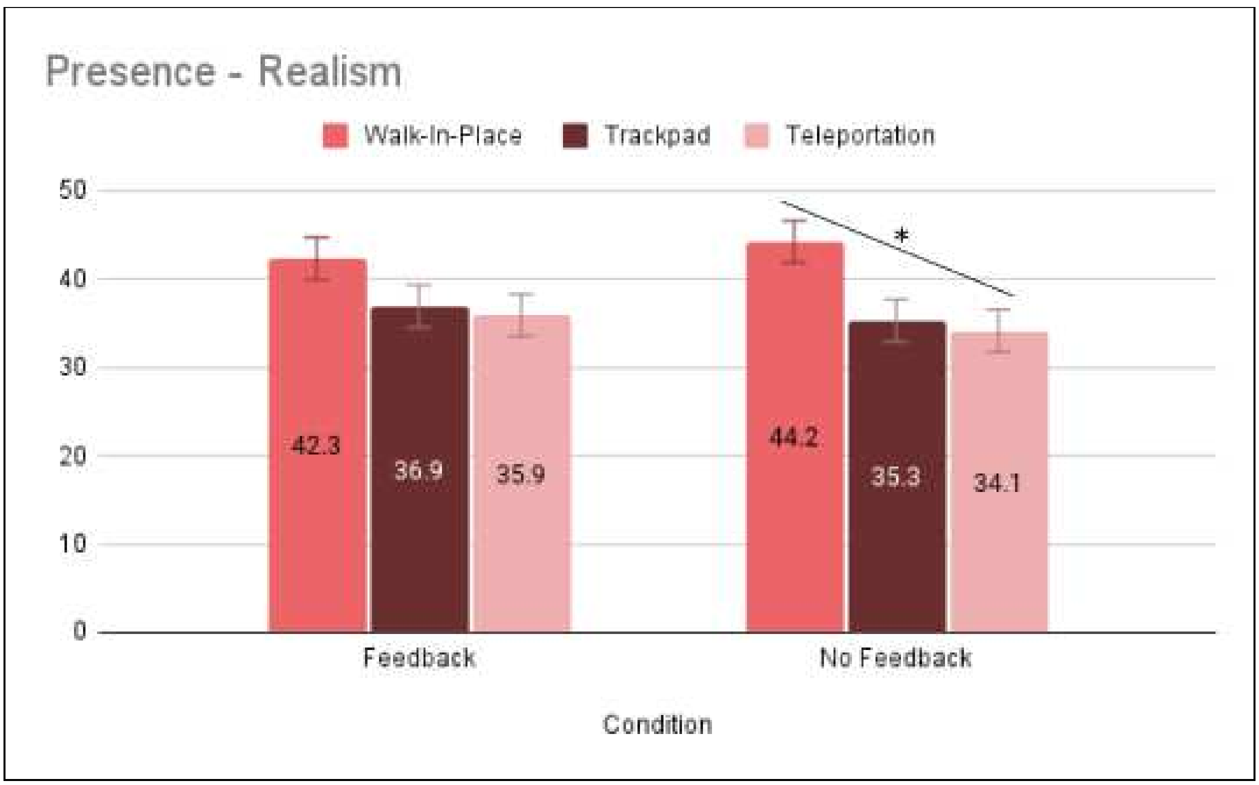
Presence

Presence levels were assessed using Witmer's Presence Scale, in which we analyzed three different sub-measures: realism (Figure 7), immersion (Figure 8), and the possibility to act (Figure 9). Across all presence sub-scales, the walk-in-place locomotion method consistently produced the highest scores, and the feedback conditions did not display consistent differences.

Realism displayed a significant main effect of method $F(2,27) = 3.666$, $p = 0.039$. The walk-in-place locomotion method displayed higher levels of realism ($M = 43.25$, $SE = 1.78$) when compared to trackpad ($M = 36.1$, $SE = 2.43$) or teleportation ($M = 35.0$, $SE = 2.97$). The levels of realism for each method were consistent with our hypothesis. There was also a significant interaction between feedback and method of locomotion, $F(2,27) = 3.66$, $p = 0.039$. Analysis of simple effects indicated that the locomotion method was not statistically significant under the feedback condition. However, there was a significant effect for the method of interaction under the no-feedback condition, $F(2,27) = 5.066$, $p = 0.014$. Tukey post hoc tests indicated that realism was rated significantly higher under the walk-in-place method compared to the other two locomotion methods ($p < 0.05$).

Figure 7

Realism Results

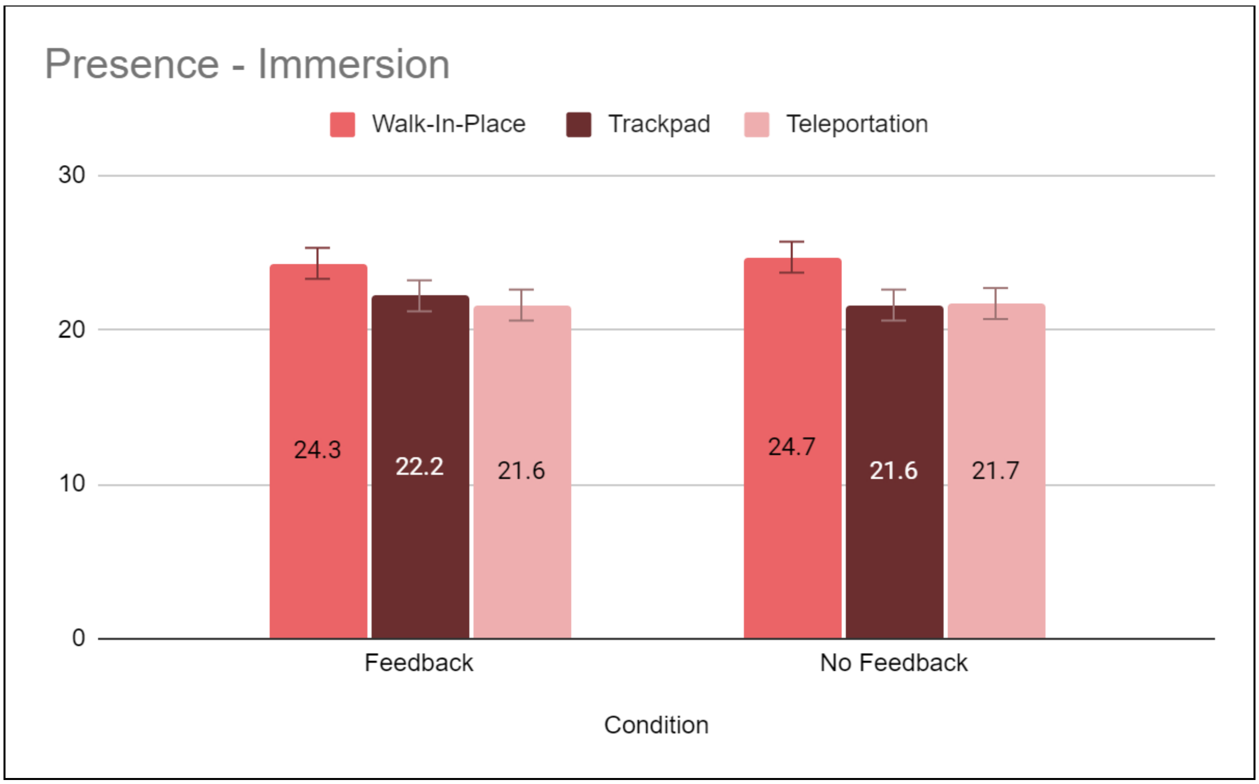


Note. Realism results for each feedback condition and each locomotion method.

Immersion results indicated that there was a marginally significant main effect on method $F(2,27) = 2.558$, $p = 0.096$. The walk-in-place locomotion style produced higher ratings for immersion ($M = 24.5$, $SE = 0.68$) across both feedback conditions, relative to the teleportation ($M = 21.65$, $SE = 1.14$) and trackpad ($M = 21.9$, $SE = 1.19$). These results (Figure 8) were consistent with our hypothesis.

Figure 8

Immersion Results

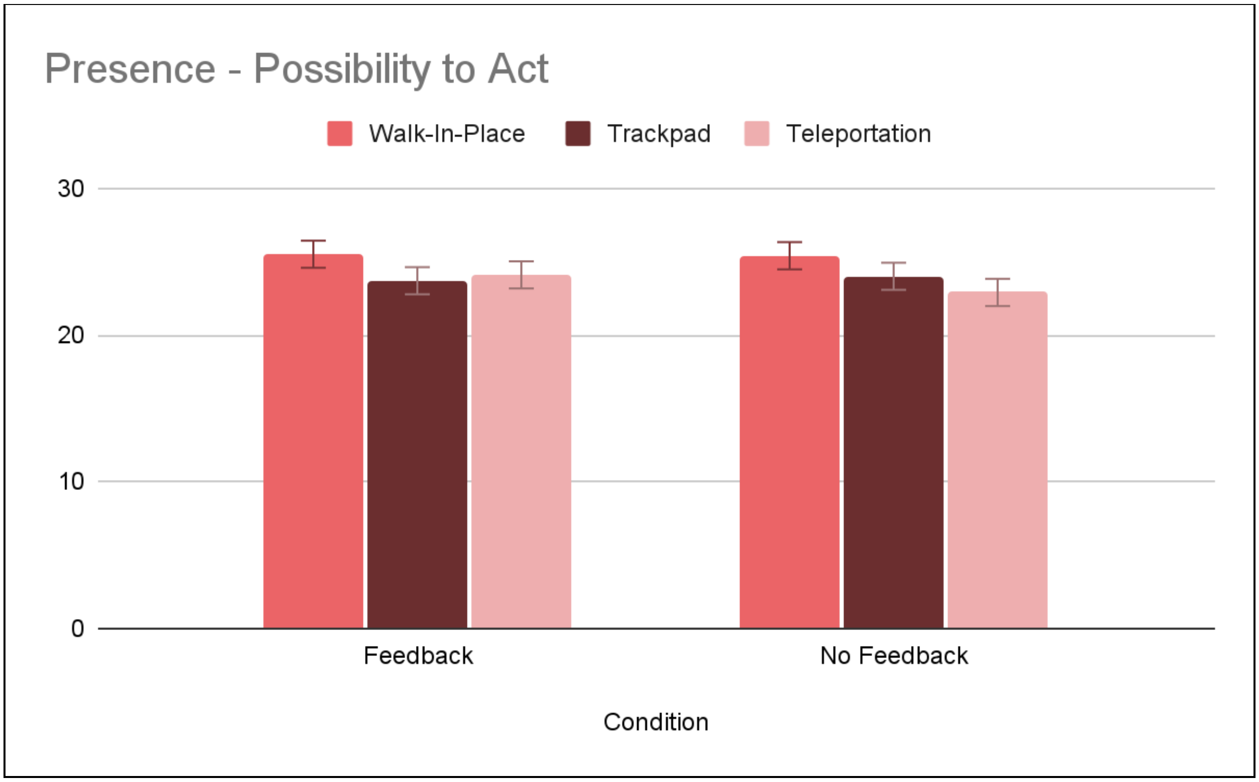


Note. *Immersion results for each feedback condition and each locomotion method.*

The possibility to act results did not produce any significant main effects or interaction. However, the walk-in-place method ($M = 25.45$, $SE = 0.69$) again tended to yield the highest score compared to the other two locomotion styles (Figure 9).

Figure 9

Possibility to Act Results



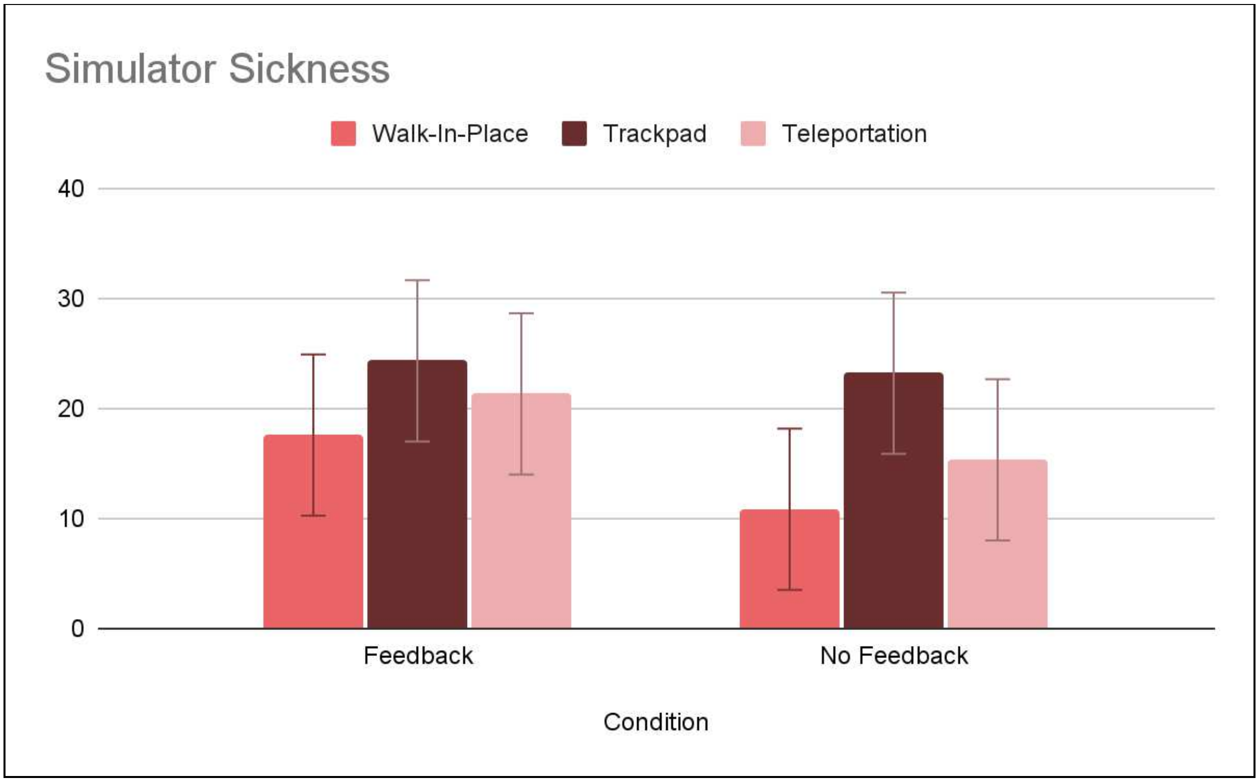
Note. Possibility to Act results for each feedback condition and each locomotion method.

Simulator Sickness

Simulator sickness levels did not display any significant effects. However, the walk-in-place method had the lowest overall scores (M = 14.21, SE = 7.41) when compared to teleportation (M = 18.32, SE = 9.57) and trackpad (M = 23.76 , SE = 4.99) in both feedback conditions. It was originally hypothesized that the walk-in-place method would result in the least amount of simulator sickness and that the trackpad method would have the highest amount. These levels are displayed in figure 10.

Figure 10

Simulator Sickness Results



Note. Simulator Sickness results for each feedback condition and each locomotion method.

Discussion

There are several key findings from this study. First, the walk-in-place locomotion style was significantly more accurate and realistic. It was also marginally more immersive and caused the least amount of simulator sickness when compared to the other locomotion styles. Secondly, the no-feedback condition resulted in higher accuracy overall. However, other measures did not display a significant difference between the feedback and no-feedback conditions.

To achieve immersion within a VR system, the user must experience realistic interactions within their virtual environment. Consistent with the results from the Lee et al. (2017) study, the walk-in-place method produced the highest ratings for realism when compared to other locomotion styles. These results were expected because the walk-in-place method is a form of direct walking interaction, which has direct coupling between action and sensory input. The other indirect locomotion methods were less realistic due to the artificial movement. This will directly impact the degree of immersion, or the degree to which the user's sensory information is engaged by the virtual system (Kim & Biocca, 2018), and thus, the level of realism. Although the measure of immersion yielded only marginally significant results, the trend was in the correct direction. Similar to the findings in both the Lee et al. (2017) and the Boletsis and Cedergren's (2019) studies, the walk-in-place method displayed the highest immersion ratings.

Although the effects of the locomotion methods on the levels of immersion and realism were consistent with previous results, the effects on simulator sickness were not present. In a study by Lee et al. (2017), it was discovered that the indirect locomotion styles also resulted in more simulator sickness than the direct locomotion style (walk-in-place). The locomotion methods did not produce significantly different levels of simulator sickness, however, the walk-in-place method did produce the lowest feelings of simulator sickness when compared to trackpad and teleportation styles. This finding may be due to the amount of time spent in the virtual environment, though. Tasks in each feedback condition did not take very long to complete, so there might not have been enough time for feelings of simulator sickness to develop, and therefore, a significant result to emerge.

Furthermore, the increased realism with the direct interaction method may have aided participants in accurately hitting the target. Kelly et al. (2018) discovered that perceived size and distance judgments were more accurate after the participant performed direct walking interaction through a virtual environment in comparison to just visually previewing the virtual environment before performing the judgments. In their study, direct walking interaction caused better performance on their 3D judgment task. In our study, the walk-in-place method (direct interaction) had the highest scores for our task accuracy measure when compared to the trackpad and teleportation (indirect interaction) locomotion styles.

Although the walk-in-place method seems to be improving accuracy, visual feedback did not seem to help performance. Fulvio and Rokers (2017) discovered that performance was better when visual feedback was present. However, our study had the highest accuracy in the no-feedback condition, not supporting our original hypothesis. Although participants practiced to the point of proficiency and conditions were counterbalanced, our feedback condition did not produce the expected results. The opposite pattern in the results may be related to the selected targets for the feedback and no feedback condition or due to limited trial numbers. The visual feedback condition could have been a more difficult task for the participant, possibly due to contrast differences between the arrow and the target. In the feedback condition, the arrow has a similar luminance as the target. Consequently, there is lower contrast relative to the no-feedback target, where the arrow had a lower luminance relative to the higher luminance mist surrounding the target location. It would be easier to judge the movement of the arrow toward the target location. Similarly, due to these contrast differences, judging where the participant’s arrow landed on the feedback target could also be considered a more difficult task for the researcher. Greater control over the target stimulus would allow for better control of the visual feedback provided to participants along with the ability to assess the accuracy of the participant's actions in the environment. For example, if software constraints were not present, one consistent target could be used and visual feedback could be turned on or off for each condition (arrow sticking vs disappear). Additionally, unlike the Fulvio and Rokers (2017) study, the level of head jitter was not measured in this study. Thus, it is possible there was greater use of head jitter in the no-feedback condition. Finally, due to time restraints, we were only able to gather data from 10 participants in each locomotion method. Our results would have greater power if we had more time to collect additional data.

For future research, a few modifications may help. First, changing the targets to reduce possible contrast differences may help, as well as using software that offers more visual feedback customization. Additionally, it would be beneficial to keep track of participant improvement in performance. This could be completed by recording which arrows hit the target. For example, if participants consistently miss the first 2 arrows, but always hit the third, it would display improvement. Thus, it would be easier to judge improvement that may be related to feedback. Another potential modification would involve recording response time in terms of accuracy. For example, recording the timestamp of arriving at the destination and when the arrow is fired at the target. This would explore which locomotion style allows for the quickest orientation to the target.

Altogether, the results from this study suggest that the walk-in-place method may be the most effective locomotion style when it comes to usability in virtual reality. However, more research on visual feedback may be necessary. Nevertheless, software developers can use this research when designing locomotion interactions for VR applications to ensure the best user experience in terms of realism, immersion, simulator sickness, and task performance. For example, this research can be utilized when deciding on a locomotion style to incorporate into a new VR training software.

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