Design and Evaluation of First-/Third-Person Hybrid Locomotion Techniques in Virtual Reality for Enhanced Accessibility in Healthcare

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***Abstract*—This paper presents the design and evaluation of two novel locomotion techniques for virtual reality that address key challenges of accessibility and motion sickness by enabling continuous traversal around a scene from a seated position, with the ability to seamlessly switch between first-person and third-person perspectives. The techniques presented are ”static hybrid camera”, which uses fixed third-person camera angles designed for each scene, and ”dynamic hybrid camera”, where the third-person camera dynamically moves with the user's avatar. Both techniques aim to provide intuitive and comfortable movement without exacerbating motion sickness. The locomotion techniques were compared to teleportation in a 12-participant user study, demonstrating that these hybrid techniques successfully expand locomotion options in VR, improving accessibility and comfort especially for seated use.**

***Index Terms*—virtual reality, locomotion technique, virtual camera perspective, accessibility, healthcare**

I. Introduction

The immersiveness of virtual reality (VR) has revolutionized the way users engage with digital environments, offering an unparalleled sense of presence and interaction. Video games are among the most popular application domains of VR and there exists a growing number of VR serious games in the healthcare sector e.g. for rehabilitation, exposure therapy for psychological phobias, and pain relief [1]. A meta-analysis of virtual reality rehabilitation programs found that they are more effective than traditional rehabilitation programs for physical outcome development [2]. Examples of such solutions are upper-limb rehabilitation that uses hand gestures for virtual interaction [3] or a VR walking game aimed at aiding stroke recovery [4].

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The heightened level of immersion in VR stems from its ability to simulate three-dimensional spaces, providing users with a convincing perception of being physically present in a computer-generated world. However, this immersive experience is not without challenges, and one frequent side effect is motion sickness. The discrepancy between visual stimuli and vestibular feedback, particularly during rapid or continuous movements within the virtual environment, can cause motion sickness [5]. This phenomenon is a significant concern, as it can compromise the user experience and limit the broader adoption of VR applications that involve dynamic locomotion. Researchers must explore the intricate relationship between visual cues, vestibular input, and user expectations to develop locomotion techniques that maintain a high level of immersion while minimizing the risk of side effects. Conventional methods, such as continuous movement using analog sticks, often exacerbate motion sickness due to the perceptual incongruence between the user's visual perception and their physical state. As a result, researchers have explored a wide range of novel locomotion techniques, seeking to strike a balance between immersive experiences and minimizing adverse effects like motion sickness.

A common locomotion technique in VR is teleportation [6], [7], a standard choice for seated VR. However, teleportation has limitations, including the inability to facilitate true continuous movement, swift lateral or backward movements, and the absence of jumping capabilities. Alternative solutions exist such as redirected walking [8], walking in place [9], and arm swinging [10]. However, these techniques assume a standing position for VR use, which may not align with user preferences, and require ample room to move freely. Additionally, there is a critical concern regarding accessibility, as individuals with mobility challenges, such as wheelchair users, may not have the option to experience VR from an upright standing position.

Both motion sickness and motor impairment are considered primary sources of inaccessibility for VR [11] and VR technologies are at a point of maturation where it is crucial to integrate accessibility at a foundational level [12]. This paper endeavors to address these challenges by developing and evaluating new versatile, comfortable and immersive traversal techniques for VR scenes from a seated position, aiming to enhance the acceptance of VR and improve accessibility for all users, specifically within healthcare settings and beyond. The proposed techniques allow for a seamless transition between first-person and third-person view, enabling continuous movement without causing motion sickness from a seated position in order to maximize accessibility for all VR users.

II. Related Work

Challenges such as limited tracking space and motion sickness have led to the development of a large number of unique and varied VR locomotion techniques, as evidenced by Locomotion Vault [13], a database that contains more than 100 examples as of this writing. There have been various efforts to categorize these techniques. Boletsis et al. [14] divide these methods into four base categories: motion-based, roomscale-based, controller-based and teleportation-based. They later refined their taxonomy by splitting teleportation into motion-based teleportation and controller-based teleportation [15]. Cherni et al. [16] suggest an entirely different taxonomy of locomotion techniques after collecting a total of 22 locomotion technique examples. They split them into non-natural, semi-natural, walk simulation, and leaning-based, with the latter further divided into arm-based motion capture, head-based motion capture and trunk-based motion capture.

A number of first-/third-person hybrid VR locomotion techniques already exist: Pausch et al. [17] introduce the approach of picking up and moving around an avatar in a handheld miniature representation of a scene. Berger and Wolf [18] propose a similar approach, but with teleportation instead of flight for transitioning to the target location. Debarba et al. [19] focus on the feeling of embodiment in VR using a third-person perspective and the ability to switch to a first-person perspective. Movement was enabled by providing the user with a motion capture suit both in third- and first-person perspective and users could switch between perspectives at the press of a button. TPVR [20] implements a finger gesture-based traversal system from both a third-person miniature and first-person perspective based on Leap Motion hand-based tracking. When viewing the environment in miniature from above in third-person, a destination location can be picked by tapping on the environment with the index finger. Outstanding [21] allows the user to switch between a first- and third-person perspective with a smooth, gradual transition at any time. Users can explore their surroundings in first-person perspective by physical walking. In third-person perspective the environment is presented in miniature and the avatar can be directed through the environment from above. 3PP-R [22] fixes a miniature cutout of the scene in front of the user's face with a non-moving background displayed around the cutout environment. When the user rotates their head an avatar representation of the user standing in the middle of the cutout rotates with them so that it always faces in the same direction. The user can move through the scene using a combination of motion tracking in the 3D scene and analog stick controls, moving the cutout of the scene with the avatar. Griffin and Folmer [23] propose a technique that allows the user to switch between a first- and third-person perspective with locomotion limited to third-person view. The view's location in the third-person perspective stays static, only updating when switching back and forth from a first-person perspective. When the user breaks line of sight, the view is automatically updated to a first-person perspective.

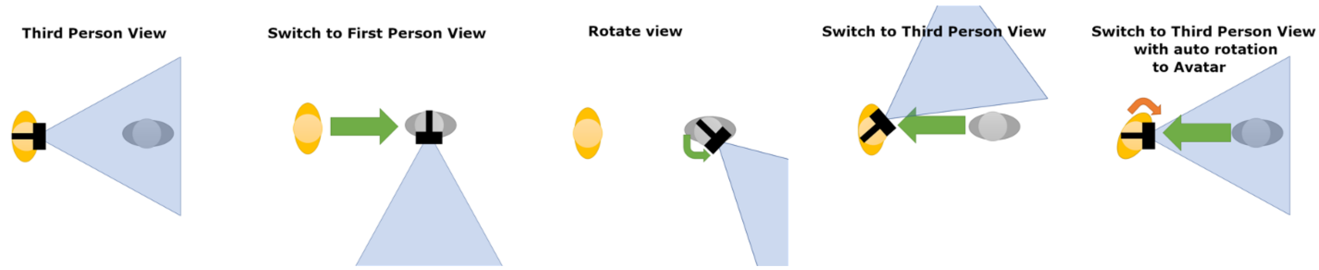
III. Design and Implementation

Based on a literature review of existing VR locomotion techniques, we designed and developed two novel locomotion techniques that combine first- and third-person perspectives to enable continuous movement, with the ability to quickly react and interact with the environment from a seated position (also see video demonstration [24]):

- Static hybrid camera: The third-person view is predetermined by the virtual scene's designer for each room or location. Users can switch to a first-person perspective at any time but can only move in third-person. The transition between perspectives is nearly instantaneous.
- Dynamic hybrid camera: The third-person view moves with the user's avatar during traversal, with only a small cutout of the environment visible, while the rest remains barely visible. Users can continuously rotate their view. The scene is visualized in a miniaturized form in third-person, with the ability to switch to a first-person perspective at any time. This transition is also presented in a cutout view to avoid excessive VR or motion-induced discomfort.

Static hybrid camera and dynamic hybrid camera can be considered improvements on both 3PP-R [22] and Outstanding [21], at least for seated use. Outstanding does not allow for camera rotation and requires manual button presses for the camera to catch up. 3PP-R meanwhile does not provide the ability to view a scene in first-person if needed, does not enable seated use as there is no way for the user to rotate the scene without rotating their head and lacks the ability to view a scene in its entirety.

In addition to the proposed novel locomotion techniques, a conventional teleportation locomotion technique was implemented as a control condition for evaluation. The design of the teleportation locomotion technique was kept as close as possible to common implementations in modern VR applications and games. Teleportation is initialized by moving the stick on the right controller forward, resulting in a colored arch at the tip of the motion controller that points forward and downward. Using an arch rather than a straight line allows users to teleport on top of elevated surfaces out of sight. If the



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

Fig. 1: Potential source of confusion (a - d) and solution (e) when switching between first- and third-person view. The grey figurine represents the third-person avatar, and the yellow figurine represents the view the user has when in third-person view. Fig. (e) illustrates that switching back to third-person view auto-rotates the user to look at the third-person avatar.

endpoint of the arch points to a valid location, a blue circle is displayed, denoting the target destination the user will reach upon teleportation. Letting go of the right analog stick triggers a fade-out animation, followed by the teleport, followed by a fade-in at the target destination. Moving the right stick left or right causes the user to snap-rotate by 45 degrees, allowing them to rotate on the spot without having to rotate their body, thus making seated play possible. All locomotion techniques presented in this paper were implemented in Unreal Engine 4.

A. Static Hybrid Camera

The static hybrid camera uses fixed camera perspectives so that the scene is viewed from a predetermined location and angle. An avatar allows the user to move around the scene. When the avatar reaches a predefined trigger area, the view transitions to a new camera angle and location to give a better view of the current avatar position. In enclosed spaces, one camera location per room is typically sufficient, but occasionally multiple camera locations are needed, e.g. in a hallway with doors on all sides or an L-shaped room.

Static hybrid camera demands bespoke level design and camera placement to work with minimal confusion. Originally inspired by video games such as Resident Evil, the static camera behavior of older video games cannot be mapped directly onto VR. While on a flat screen the camera is completely static, in VR the camera has to follow the user's head movement. While the initial view when entering a new scene can be predetermined for at least the yaw rotation (as rotating the user's view up or down would give the impression of a tilted scene), rotating the user's view must also consider the current rotation of the user's head. Consider the following scenario: A user moves their avatar from the left side of the room to the right side through a door. They follow the avatar with their head and end up looking to the right when they move the avatar to a new room. This triggers a camera transition to a new view location and rotation. If this location was not carefully chosen, the user might now end up staring at a wall or away from the avatar, forcing the user to look around the scene to find their avatar again. One solution to this problem as proposed by the developers of the video game Theseus [25] is the deliberate placement of cameras in such a way that on transition between scenes, when maintaining the head rotation, the user would end up looking at the avatar's location. This works reasonably well in enclosed spaces and when the whole environment can be designed around this technique. However, in open spaces finding the right angle can be challenging, since the user could approach a trigger area from any direction in an open environment.

Switching camera angles also poses a challenge to camera-relative movement controls when transitioning between scenes, as it causes the directional input to change relative to the camera. This can be a cause for confusion, especially when the change of view is sudden and unexpected. In the worst case, the user will end up running back the way they came, causing another camera change back to the initial view, thus compounding the confusion. To mitigate this issue, directional controls from the previous camera angle are retained when changing views and are only updated when the user points to a new direction or stops the avatar.

The ability to switch between first- and third-person introduces additional challenges. Consider the following scenario (see Figs. 1a - 1d): The user moves the avatar, from their perspective, to the right. They then switch to first-person perspective and then look left. Now, were they to switch back to a third-person perspective, they would end up looking away from the avatar, and would be forced to look around the scene to find the avatar again. To mitigate this issue, when transitioning from first-person to third-person, the view is automatically rotated to the avatar during the transition, thus making the avatar the first thing the user sees (see Fig. 1e).

Through preliminary user testing the animation duration for the transition between first- and third-person was set to 0.2 seconds. In addition, a slow motion effect was added when transitioning between first- and third-person positions, giving the user more time to reorient themselves in hectic situations requiring quick reaction time following a transition. Finally, controls to rotate the view in 15-degree steps were added to allow users to manually reorient themselves if necessary, and an arrow overlay pointing in the direction of the avatar when it is out of view was added to support orientation.

Fig. 2: Scene fully visible while standing still (top) and faded out with independent visual background while moving (bottom) when using dynamic hybrid camera.

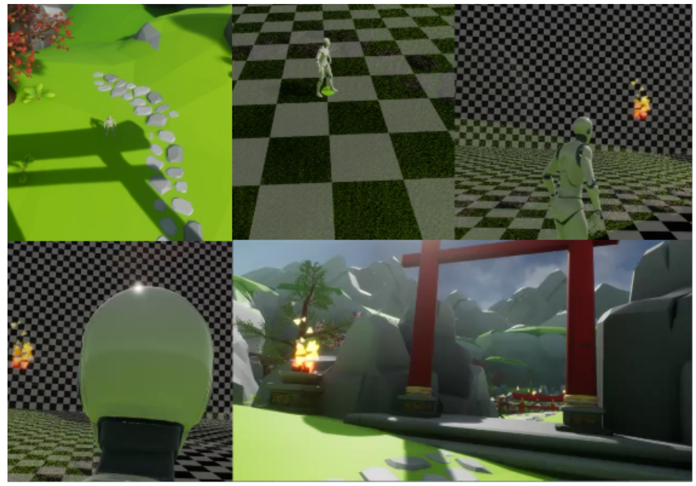


Fig. 3: Transition from third-person view to first-person view when using dynamic hybrid camera.

B. Dynamic Hybrid Camera

The dynamic hybrid camera control scheme provides a miniature overview of a scene and features a third-person camera with the ability to switch to a first-person perspective similar to Outstanding [21]. The scaled-down environment from a third-person perspective is presented with a scale of 1:10. Movement is controlled via analog stick similar to 3PP-R [22], but without mapping the avatar location to the HMD location in the tracking space.

The entire virtual environment is visible while standing still. When moving the avatar using analog stick controls or transitioning between first- and third-person perspectives, the environment is faded out except for a cutout radius around the avatar. Behind the transparent environment, an independent visual background in the form of a checkered plane is displayed beneath the cutout to ground the user's view on an unmoving background (see Fig. 2). Independent visual backgrounds have been shown to drastically reduce motion sickness when used in combination with independently moving scenes [26].

The opacity of the background can be adjusted per scene, and darker scenes anecdotally require a lower opacity to prevent motion sickness. An opacity between 0.1 and 0.15 was used in the prototypes presented in this paper, where a value of 1 corresponds to full opacity and a value of 0 corresponds to the environment being entirely invisible. Through preliminary internal testing, it was concluded that a visible radius of 35 cm around the avatar largely precluded motion sickness during movement. For transitioning from third-person to first-person and back (see Fig. 3), the radius had to be reduced further to only cover the floor under the avatar, since the perspective transition also changes the scale, thus, from the perspective of the user, growing the environment around them.

To quickly reorient the user towards their avatar in case they lose track of it, a dynamic "growing" animation unfolds during transitions from translucency to opacity. This animation involves a gradual expansion of the environment emanating from the avatar and spreading across the scene. By observing this effect, users can instinctively reconstruct the exact location of the avatar. In addition, similar to static hybrid camera, time is slowed down during the transition between perspectives to support users to reorient themselves in situations where quick reactions are required.

The transition from third-person to first-person is similar to the transition in Outstanding [21] with some adjustments: In Outstanding, the switch from third-person to first-person ignores the avatar's rotation, as rotating to the avatar's viewpoint would also require rotating the user's view, which could result in strong VR sickness. However, since our implementation hides most of the surrounding environment and allows the user to anchor themselves in the non-rotating independent visual background, we can gradually rotate the view to the avatar's viewpoint with a smooth transition (see Fig 3).

In the dynamic hybrid camera implementation, the avatar's location is anchored in front of the user's initial position, rather than being attached to the user's head as in 3PP-R [22], as moving and rotating a fully visible scene with the user's head could cause considerable motion sickness. Furthermore, anchoring the scene in a static position allows the user to peer away from the avatar and inspect the environment. In addition, a continuously rotatable camera controlled by the analog stick of the left controller (similar to modern third-person 3D video games) was implemented. Fading out the surrounding environment with an independent visual background (much like during avatar movement) enables the user to rotate their view without inducing significant motion sickness, despite rotation being one of the strongest causes of VR sickness compared to translational movement [5].

Initial testing revealed that maintaining constant visibility of certain elements, particularly those smaller than the avatar, during movement did not induce any discernible increase in motion sickness. This observation allowed for the visible retention of the avatar, objectives, and select obstacles, while rendering the remaining environment quasi-invisible by use of an independent visual background. The selective visibility of certain elements supports the user's orientation within the environment, as evidenced in preliminary testing.

To achieve the cutout effect (see Fig. 2), a material function was implemented and applied to every material in the scene. A material defines the visual look of an object in a scene and material functions define reusable functionality. By defining radius and location, the materials using the cutout shader can determine which parts are to be rendered fully, while areas outside the radius are rendered by applying the DitherTemporalAA function provided by Unreal Engine. This gives materials a dithered, semitransparent look when masked. The masked material allows for hiding certain parts of an object using a texture mask, which defines which areas are visible and which are not.

IV. Evaluation Methodology

A. Metrics and Measurements

Both quantitative and qualitative data were gathered for this study. In addition to recorded observations and comments, participants were asked to rate locomotion techniques in five rating categories (favorite, least favorite, competency, immersion, navigation). Completion times and number of hits by an obstacle were recorded and participants were asked to fill out the Presence Questionnaire [27] and the Simulator Sickness Questionnaire [28] for statistical analysis.

B. Participants

A total of 12 voluntary participants (five female) with a mean age of 30.2 years (SD = 1.5) were recruited for this study without material compensation provided. Participants were required to be at least 18 years old for participation. All participants had prior experience in playing video games. Three participants had no previous experience with virtual reality, and all others reported at least minimal prior experience. Six participants were persons wearing glasses.

C. Hardware and Software

The Oculus Quest 2 was used as the VR headset for this study. The Oculus Quest 2 enables full six degrees of freedom motion tracking of both the headset and two motion controllers, without the need for external markers or tracking devices, allowing for quick and easy setup. The Oculus Quest 2 features four cameras for tracking, a 1920 x 1832 per-eye resolution, up to 120hz refresh rate and 90° field of view. A high-end PC was used to run the VR application and the headset was connected to the PC using a USB 3.0 cable. Nvidia ShadowPlay was used for screen recording.

D. Trial Design

Three different trial maps were implemented to facilitate different kinds of interaction: a basic trials map in the style of an obstacle course, an interior navigation map set inside a building and an exterior navigation map set in an open outdoor environment. Each participant utilized all three locomotion techniques in all three trial maps (within subject design), resulting in nine trial runs for each participant. To avoid learning effects, the order of locomotion techniques was counterbalanced between participants with a Latin square design. Participants would start with one locomotion technique, complete the three trial maps, fill out the presence questionnaire and the simulation sickness questionnaire, and then continue with the next locomotion technique. After completing all nine trials, participants were asked to rate the locomotion techniques in five rating categories and provide feedback. During the trials, the facilitator took notes and the VR view of the participants was recorded for further analysis.

V. Evaluation Results

A. Quantitative Results

1) Performance Measurements: Repeated measures ANOVA was performed to compare the effect of the different locomotion techniques on time to complete a trial and times hit by obstacles. Time to completion was measured in all maps while times hit by obstacles was only measured in the basic trials map and the interior navigation map as there were no obstacles in the exterior navigation map.

There was a statistically significant difference in completion time in basic trials map ($F(2,22)=7.28$, $p=0.004$). Post-hoc tests using Holm correction showed a significant difference between dynamic hybrid camera (M=106, SD=24.4) and teleportation (M=144, SD=47.6) ($t=-3.20$, $p=0.025$) as well as static hybrid camera (M=106, SD=20.0) and teleportation ($t=-2.65$, $p=0.045$) for completion time. No significant differences were found between static hybrid camera and dynamic hybrid camera. There was a statistically significant difference in times hit by an obstacle in basic trials map ($F(2,22)=[4.67]$, $p=[0.020]$). Post-hoc tests using Holm correction showed a significant difference between static hybrid camera (M=0.92, SD=0.79) and teleportation (M=2.17, SD=1.03) for being hit ($t=-2.92$, $p=0.042$). No significant differences were found between dynamic hybrid camera (M=1.00, SD=1.04) and the others. There was no statistical effect of locomotion technique on completion time and times hit for the interior and exterior navigation maps.

2) Presence Questionnaire: For the presence questionnaire (PQ), there was no statistically significant difference for any category of the presence questionnaire between the three locomotion techniques.

3) Simulator Sickness Questionnaire: For the simulator sickness questionnaire (SSQ), while dynamic hybrid camera seemed to cause higher amounts of motion sickness for some participants, no significant differences were found for any subcategory or total score of the simulator sickness questionnaire between the three locomotion techniques.

B. Preference Ratings

After completing all trials with all control schemes, participants were asked to rate their favorite and least favorite locomotion technique, as well as which they felt most competent with, the most immersive and the best for navigation (see Fig. 4).

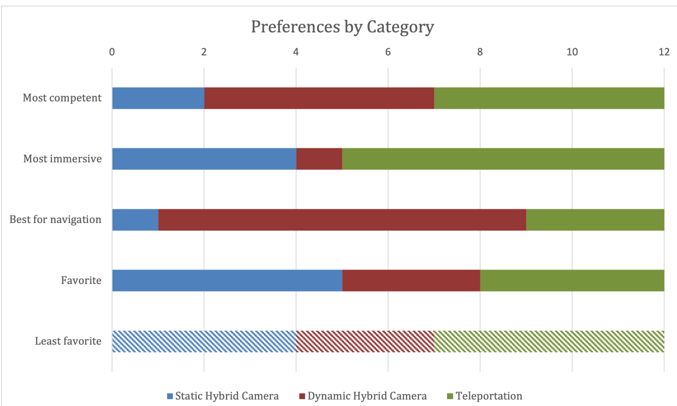


Fig. 4: Preferences by rating category.

Preferences regarding competency were split between teleportation and dynamic hybrid camera with each chosen by five participants. When considering immersion, seven participants preferred teleportation, while four participants chose static hybrid camera as the most immersive. When choosing the best locomotion technique for navigation, eight out of twelve participants chose dynamic hybrid camera, three chose teleportation and only one participant chose static hybrid camera.

Regarding favorite and least favorite locomotion techniques, preferences were divided: Five out of twelve participants chose static hybrid camera as their overall favorite, with four choosing teleportation and three choosing dynamic hybrid camera. Conversely, five participants chose teleportation to be their least favorite, followed by four participants choosing static hybrid camera and three choosing dynamic hybrid camera. Dynamic hybrid camera received the smallest number of ratings as both most and least favorite technique, suggesting that it is the least polarizing control scheme and a potentially safe choice.

Looking at individual preferences revealed that rarely does a user consider one control scheme universally preferable across all positive rating categories. Only one participant preferred teleportation over all the other locomotion techniques across all rating categories, while all other participants exhibited some degree of variation in their preferences depending on rating category.

C. Participant Feedback and Observations

Participants were observed and recorded during trials and asked for feedback after all trials were completed.

1) Static Hybrid Camera: In general, static hybrid camera provided high levels of immersion, but camera changes could result in confusion. Some participants considered it to feel more natural with a greater sense of presence and that it provided a better overview of the scene. Participants were more inclined to follow paths laid out in the environment because of an increased feeling of moving through the scene, as opposed to teleportation, where no feeling of movement was felt. Generally, the avatar representation in the scene resulted in higher immersion for scenarios requiring a lot of movement, e.g. collecting objects or fleeing from enemies. The ability to jump seemed to be a big contributing factor to the level of enjoyment when compared to teleportation and led to new behaviors compared to teleportation, such as constantly jumping everywhere to the point where participants occasionally forgot their objective. Participants also tried new techniques e.g. jumping over rooftops and fences in the exterior navigation map. The addition of an arrow that points to the location of the avatar when looking away was considered helpful by those who noticed it. One participant mentioned that they would be totally lost without the blue arrow pointing to the avatar. One participant observed the existence of the arrow but not the connection to the avatar location.

A common complaint was that camera changes were felt as too sudden and that there was no warning when they were to occur. Confusion increased when camera angles would rotate to large degrees when compared to a previous angle. Camera angle changes were felt as intense, particularly when switching for the first time. Interestingly, this feeling of intensity would change depending on the scene and distance to the avatar. One participant mentioned a higher level of discomfort when seeing the avatar from afar at the start of the interior navigation map, and then feeling at ease upon entering the building. Participants often struggled to adjust their movement direction after a camera change, especially when walking through doors, and sometimes interpreted camera changes as inverting the controls. Occasionally, there were attempts to move the camera closer to the character. Participants likened the confusion these camera changes cause to classic Resident Evil games. Switching between first- and third-person was also felt as intense, with fast zoom-in and -out animations.

Suggested improvements were to better design levels around the static hybrid camera control scheme, such as making rooms larger, and placing exits so that only one camera placement per room is needed to see all the exits. One participant suggested giving the user the ability to choose the location of the camera themselves, but could not explain how this could be achieved.

2) Dynamic Hybrid Camera: In general, dynamic hybrid camera was preferred for scenarios that required quick reactions and immediate movements. It was often considered to be the most intuitive control scheme, as it most closely resembled modern 3D video game controls. Having the view move with the avatar made participants seem more attached to it, and also gave them finer control. Participants had no trouble going through doorways, and since there were no sudden camera changes unlike static hybrid camera, participants always knew exactly where the avatar would move. The ability to smoothly rotate the view was hugely useful for participants and appreciated. One participant, who had little gaming experience, did complain about the relatively complicated controls, saying that they were way too complex for someone not already familiar with such control schemes. Once again, being able to jump at any time was appreciated, but used less frequently compared to static hybrid camera since participants had trouble looking ahead where they were going to land. Moreover, similarly to static hybrid camera, participants would follow the laid out paths more often, both because of a higher feeling of immersion and because it would help with the lack of visibility. Movement felt more natural compared to teleportation, but a common complaint was a lack of overview during movement, causing a feeling of running blind. Participants considered dynamic hybrid camera to provide a good overview, but only while standing still. Another common complaint was a lack of immersion and one participant even initially thought that the prototype was broken. The fade-out effect during avatar movement was met with confusion and participants often voiced their desire to always see the entire scene, as stopping to see the entire scene was seen as irritating. Generally, participants who experienced no motion sickness from using dynamic hybrid camera were eager to try it again, but with the entire scene visible.

Dynamic hybrid camera did cause more motion sickness compared to the other control schemes. Some participants felt motion sickness during movement, but interestingly not when transitioning between first- and third-person views. This motion-induced sickness might be scene-dependent, as one participant commented that the interior navigation scene caused no motion sickness. Another participant suggested concentrating on the circle of visible area around the avatar rather than the checkered background helped with motion sickness. One participant complained that the fade-in effect was too jarring depending on the scene, as it could result in rapid changes in light intensity. Another participant felt that this fade-in effect caused the feeling of sickness. Switching between first- and third-person seemingly caused little to no motion sickness as opposed to movement and rotation and generally allowed participants to quickly adjust to the switch.

A frequent suggestion was to make the visible area during movement larger when using the dynamic hybrid camera. One participant suggested providing the option to increase or decrease the size of the visible area to find the sweet spot between a good range of visibility and minimized VR sickness. Some participants even suggested providing an option to always show the entire scene when using dynamic hybrid camera for those who can handle it. A creative suggestion by one participant was to show the entire scene in a wireframe fashion rather than fading it out. Common improvement suggestions were made concerning the independent visual background. The checkered background was seen as quite immersion-breaking and considered a poor fit to the interior and exterior navigation maps, as they featured more realistic environments. While it was generally accepted as a necessary evil to avoid motion sickness, something more appropriate for a given scene was wished for.

VI. Discussion

Observations and feedback from the evaluation demonstrate that both proposed locomotion techniques successfully provide users with the ability to seamlessly move around a virtual reality environment while being able to quickly react and interact with the environment from a seated position without causing motion sickness. That being said, study results unsurprisingly also revealed that none of the three evaluated locomotion techniques was universally superior to the others and that each technique has its unique qualities, making each of them suitable for different purposes and usage scenarios. Looking at participant preferences, no singular VR control scheme was seen as superior in every way to others.

Dynamic hybrid camera was preferred for navigation by most participants over both static hybrid camera and teleportation. The significantly faster completion times of the basic trials map when using dynamic hybrid camera objectively support this subjective preference of participants. While the results of the SSQ did not show any significantly stronger aversion to dynamic hybrid camera than other control schemes, feelings of sickness were at least initially noticed during trial runs. Some participants reported these feelings subsiding in the darker interior exploration map, implying that lighting played a role regarding these feelings of sickness. Dynamic hybrid camera was also seen as the least immersive, pertaining mostly to the independent visual background. While finding a more thematically fitting background might heighten immersion, the miniature view and cutout effect during movement will probably not be able to rival the immersion of a purely first-person view. Having some parts of the environment permanently visible in front of the independent visual background had no effect on VR sickness in any measurable way, suggesting that future work might build on this quality e.g. by showing the environment in a wireframe fashion.

Static hybrid camera was selected as the favorite locomotion technique by the largest number of participants (5 out of 12), yet did not excel in any of the other rating categories. Analysis of user behavior indicates that camera changes should be kept to a minimum and that keeping users within a single scene for as long as possible is preferable. Using the static hybrid camera, participants had trouble with rapid and surprising camera position changes. Addressing this issue may involve implementing fixed rules, such as maintaining one camera position per room and allowing camera transitions only upon leaving a room. Participants also experienced disorientation and unintended backward movements, particularly when the camera position change resulted in a 180-degree view rotation. This was partially resolved by relative directional controls temporarily retaining the previous camera angle when changing views, but not entirely. A fade-to-black effect on camera transitions, akin to the teleportation fade effect, could alleviate user disorientation. This approach grants users a transitional period facilitating adjustment to the new camera angle and would give them time to let go of the controls and readjust to the new camera angle. It might also mitigate the sensation of dizziness experienced by some participants when transitioning between scenes with pronounced lighting differences.

Switching between first- and third-person was intuitive for participants and did not cause any motion sickness. Participants described their first-time experience of this view transition as intense and exciting, and usage became almost second nature over the course of the trials. Interestingly neither type of perspective switching, the fast zoom used with static hybrid camera and the slow rotational zoom used with dynamic hybrid camera, resulted in notable motion sickness. Since the rotational transition with dynamic hybrid camera requires the world to be faded out potentially resulting in a loss of immersion, the technique used with static hybrid camera might be preferable overall. One of the greatest perceived advantages of the hybrid locomotion techniques compared to teleportation was the ability to jump, bringing participants a great amount of joy. Certain challenges that were slow and cumbersome when using teleportation were perceived as fast, fluid and fun when participants had the ability to jump. The ability to jump entirely changed user behavior in larger scenes as participants jumped over obstacles and made their own path in a kinetic manner not possible with teleportation.

The study demonstrates that these hybrid techniques successfully expand locomotion options in VR, improving accessibility and comfort especially for seated users in the domain of healthcare and beyond.

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