Impact of Translation and Viewpoint Transition Methods in VR on Spatial Learning and Cybersickness

Virtual Translation and Viewpoint Transitions in Virtual Indoor Environments

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Virtual locomotion technique (VLT) is a fundamental component of virtual reality (VR) systems that translates physical and controller inputs into virtual translational movements and viewpoint transitions. Poorly designed VLTs can result in discomfort, nausea, and reductions in task performance. Understanding the effectiveness of VLTs across various levels of interaction fidelity is crucial to enhance user experience and spatial awareness. The current study addressed a significant gap in VR design research and practice, as few previous efforts have been made to comprehensively evaluate the effectiveness of controller-based VLTs in virtual indoor environments. We conducted a user study in which participants navigated through two complex virtual environments, one focusing on exploratory tasks and the other on goal-oriented navigation. The findings offer insights into the trade-offs among spatial knowledge acquisition, wayfinding performance, cybersickness, and sense of presence, and have design implications for future VR interfaces.

CCS CONCEPTS • Human-centered computing • Human computer interaction (HCI) • Mixed / augmented reality

Additional Keywords and Phrases: virtual reality, virtual locomotion, teleportation, view transitions, spatial learning, cybersickness

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1 INTRODUCTION

Virtual reality (VR) utilizes advanced head-mounted displays (HMDs) and interactive three-dimensional (3D) user interfaces that enable users to manipulate objects and navigate within virtual environments [46,56]. The virtual locomotion technique (VLT) is a fundamental component of VR systems that translates physical body movements (e.g., gestures or head-rotation) and inputs from digital devices (e.g., joysticks or treadmills) into virtual orientation, motion, and viewpoint transitions [41,50,52]. The design of VLTs can contribute to experiences of discomfort, disorientation, or

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nausea while performing tasks such as wayfinding, searching for objects, or inspecting scenes in VR [25,46,67,77]. Therefore, evaluating the effectiveness of VLTs across various levels of interactions is essential to improving user experience in virtual spaces.

Researchers have robustly demonstrated that different forms of VLTs can influence simulator sickness [82,88], navigational performance [48,74], and spatial cognitive abilities [8,34,54]. In general, locomotion techniques that support natural physical forms of interaction, such as translating real-world walking motions on a treadmill into virtual movement, are more beneficial for effective navigation in VR [15,58,77]. Similarly, controller-based steering methods, which enables users to control the direction and speed of continuous virtual motion, provide an uninterrupted optical flow that emulates aspects of real-world locomotion, thereby supporting spatial understanding and path integration [27,89]. However, such forms of motion have been associated with greater cybersickness, most likely due to sensory conflicts as the user's vestibular system processes visual cues without corresponding physical sensations (physical inertia etc.) [29,39]. Additionally, navigating large-scale interior environments such as hospitals or transportation hubs with realistic VLTs requires considerable time and physical effort, and users may become impatient with the need to traverse extended distances. In contrast, another locomotion technique that is frequently used in VR applications is teleportation, in which users select a destination and are instantly moved to that point. This type of VLT tends to reduce cybersickness by eliminating optical flow or acceleration cues, but the abrupt view changes may increase disorientation and negatively impact immersion and spatial awareness of the environment [21,22,48].

There is a growing trend in recently developed VLTs that seek to balance the benefits and drawbacks of teleportation and continuous movement, for example by integrating viewpoint transition scenes when teleporting, or by using a mixture of both strategies [8,43,48,52]. Some researchers have applied a joystick-based discrete rotational method that updates the user's orientation at fixed intervals, instead of continuously, and have found this effective for cybersickness reduction [13,19]. Yet another approach is to implement visual interventions such field-of-view (FOV) restrictions, peripheral blurring effects, and dynamic depth-of-field (DOF) blur to obscure distant non-focal cues during continuous locomotion [3,49,93]. VLT approaches that lean more toward teleportation may benefit from incorporating rotational self-motion cues, orientation indicators at landing points, and smooth viewpoint transitions to improve orientation and spatial knowledge acquisition [4,48,57]. Some studies have investigated the "HyperJump" approach, which seamlessly combines continuous and teleportation techniques by interspersing steady movement with regular-interval jumps to reach the destination more quickly. This approach may be particularly beneficial for balancing spatial orientation with usability in large-scale virtual settings [8].

These novel variations make VLT an exciting and rapidly evolving field. However, the pace of technological development can also mean that empirical research falls behind; at the current time there has not been a great deal of robust comparative study regarding the trade-offs among common VLT approaches. The purpose of the current study was to evaluate several popular controller-based VLTs to comparatively analyze their effects on cybersickness, perceived presence in the environment, and spatial learning in virtual indoor environments. The following two research questions directed the study's design:

RQ1. How do different VLTs influence spatial learning, cybersickness, and perceived presence in virtual indoor environments?

RQ2. Are there trade-offs between navigational performance, cybersickness, and perceived presence when using different VLTs in virtual indoor environments?

To address these questions, we designed the study around four locomotion techniques that combine various types of continuous and discrete movement and dynamic FOV restriction, as discussed in detail in Section 3. This research makes several notable contributions to the field. First, the empirical research provides a comparative evaluation of the effects of common controller-based VLTs, with a particular emphasis on spatial learning gains as well as user experience. Second, unlike previous studies that primarily focused on outdoor virtual spaces, we examined locomotion in complex virtual indoor environments, which are more representative of real-world design research applications in contexts such as healthcare and educational settings. The results can provide valuable insights for the development of future VR navigational interfaces tailored to various application scenarios.

2 RELATED WORK

2.1 Controller-based Travel Techniques

Researchers have explored a wide array of controller-based travel techniques in VR, including walking-based, steering-based, and selection-based methods [56]. While walking-based navigation closely resembles natural movement and rotation in the physical world, providing high interaction fidelity [75] and notable benefits in spatial orientation and feelings of presence [11,30,73], the practical constraints of workspace sizes and sensor-tracking ranges often restrict its use. Steering-based methods enable greater ease when traveling across extended virtual distances by allowing continuous directional control through physical inputs (i.e., controlled by steering devices) or gestures (i.e., controlled by gaze, hand, or body learning) without the need for actual walking [46]. For example, Sarupuri and colleagues [9] developed TriggerWalking, a technique that simulates bipedal locomotion by allowing users to alternate between the trigger buttons of one or both controllers while adjusting speed by changing the angles of the controllers. They evaluated TriggerWalking and found it was easy to learn, less physically demanding than walking-in-place, and induced less cybersickness compared to joystick locomotion. Kitson and colleagues [5] evaluated joystick-based control, head-directed steering, and three chair-based directional leaning interfaces. Their results revealed that joystick-steering was favored for comfort and precision, and provided better spatial orientation, accuracy, and ease-of-use, despite issues with controllability and stability. Xu and colleagues [62] compared between joystick and walking-in-place in a spatial knowledge acquisition task; these researchers found that both techniques resulted in a comparable average object placement error, indicating similar levels of spatial memory accuracy. Controller-based techniques offer a range of approaches to balance user comfort, spatial orientation, and task performance in virtual environments.

Teleportation is a common controller-based interface that involves discrete movement by automatically shifting viewpoint to a selected target destination [46]. Teleportation does not produce any optical flow during discrete jumps, thereby lowering the risk of cybersickness and offering higher usability and enjoyment compared to continuous steering-based navigation [47,66,76]. However, early research by Bowman and colleagues [21] indicated that the abrupt view changes in teleportation led to spatial disorientation during travel. Paris and colleagues [70] analyzed continuous and discrete locomotion techniques to determine their effectiveness in transmitting self-motion cues in an immersive virtual game environment; they did not find significant differences in simulator sickness or perceived presence, but their results indicated that teleportation tended to result in more path integration errors and spatial disorientation. Studies by Buttussi and Chittaro [32] and Kim and colleagues [36] also found that teleportation can negatively affect spatial understanding, resulting in poorer performance in spatial memory tasks compared to joystick-steering methods. Efforts to minimize disorientation in teleport-based VLTs generally focus on visualization technologies that display linear or curved trajectories from the current location to the destination prior to movement activation [31,57].

2.2 View Transition Techniques and Spatial Knowledge Acquisition

Several systematic taxonomy studies have characterized elements of 3D-travel techniques, including input conditions, direction/path control, rotation, and acceleration/velocity [20,21,55]. Prior researchers have emphasized how the interplay among such factors can lead to trade-offs between spatial knowledge acquisition and cybersickness [25,65]. In one notable study Bowman and colleagues [22] investigated the impact of four widely different teleportation speeds on spatial understanding during an object-locating task, and found no significant differences in spatial awareness across the different levels of velocity, indicating that this factor may not be very important to the impacts of teleportation. Bolte and colleagues [10] introduced the concept of "Jumper" VLTs, which allow users to walk naturally for short distances and make virtual jumps for longer distances, with smooth viewpoint transition animations. Results from a map-sketching task revealed that the Jumper technique only slightly diminished spatial memory performance compared to real-world walking, and was favored by users over standard teleportation for its less disruptive transitions. Weissker and colleagues [89] compared spatial awareness between continuous steering and jumping for repeated teleportation, and discovered that both methods achieved similar spatial updating accuracy while jumping caused much less simulator sickness.

Bhandari and colleagues [43] proposed the "Dash" VLT approach, which incorporates a small amount of optical-flow cues to enhance path integration and maintain orientation during teleportation. A subsequent study by Rahimi and colleagues [48] evaluated three automated viewpoint transition techniques— instant teleportation, animated interpolation, and pulsed interpolation with sequential intermediate views—on spatial awareness during outdoor scene transitions. They showed that animated interpolation allowed for best spatial awareness in terms of object-tracking tasks, but that it also induced more simulator sickness compared to the other methods. Building on these findings, Adhikari [8] developed the "HyperJump" technique, which was intended to seamlessly merge continuous short-distance travel with fast-paced jumps to facilitate more rapid navigation without compromising spatial memory.

Other studies have focused on viewpoint rotations rather than changes of position. Riecke and colleagues [12] and Klatzky and colleagues [72] demonstrated that participants could better maintain spatial updating during rotations if the VLT displayed landmark-rich visual motion cues. Cherep and colleagues [54] similarly emphasized the importance of rotational self-motion cues in spatial cognition, showing that a partially concordant teleportation interface (i.e., using a controller to translate but physically turning the body to rotate) resulted in fewer errors compared to a discordant interface (i.e., using a controller to both translate and rotate). This was further confirmed by Lim and colleagues [4], who found that the partially concordant method could significantly improve spatial knowledge acquisition in object-to-object pointing and sketch-map tasks. Zielasko and colleagues [19] systematically evaluated virtual rotation techniques and discovered that joystick-controlled methods excelled in search-task completion times, while joystick and body-based rotations showed similar performance in spatial learning for pointing and configurational tasks.

In summary, previous research suggests that the type of visual cues and motion-control used in VLTs may have a strong effect on spatial learning. However, this body of literature is limited and unsystematic (with different studies focused on different sets of VLTs and different outcome measures), and the vast majority of the research has been conducted in open outdoor virtual settings, where large distances are the norm and where spatial knowledge acquisition may develop differently compared to complex indoor environments.

2.3 Cybersickness during Virtual Travel

Cybersickness or simulator sickness refers to a range of symptoms experienced in virtual environments, including headache, eye strain, and nausea [45]. It often results from a sensory conflict caused by mismatch between visual and vestibular sensing (e.g., experiencing visual motion while being stationary), and can be influenced by intrinsic factors such as age and gender, or technical aspects such as optical flow rate and head-mounted display ergonomics [29,83,85]. A common strategy to reduce such sickness is FOV restriction that effectively narrow the horizontal edges or limit vertical visibility during movements and rotations [38,61,79]. For example, Fernandes and colleagues [3] developed a dynamic FOV restrictor that subtly reduces FOV when movement initiates and gradually expands it as movement stops. Their results demonstrated that such an approach could effectively mitigate motion sickness and allow participants to spend more time in virtual environments, with minimal awareness of the intervention. Similarly, Zhang and colleagues [95] designed "tunnel vision" smart-glasses that use switchable polymer dispersed liquid crystal (PDLC) film to dynamically alter peripheral vision in varying motion intensity scenarios. Carnegie and colleagues [49] proposed a foveated DOF method that employs gaze-contingent rendering to dynamically adjust blur effects based on the viewer's focus and the depth of the focal object to facilitate transitions between focal planes. Nie and colleagues [35] implemented a real-time saliency-based blurring technique that adjusts peripheral vision blur according to the relevancy of visual elements to the user's current task. Additional approaches include directly snap-rotating moving frames [92], adjusting the size of static blur windows [94], and using asymmetric FOV [33,37] to enhance comfort and subjective experience.

While these efforts have shown effectiveness in alleviating cybersickness, they come with compromises for screen manipulations, which can potentially affect presence levels, task performance, and spatial knowledge acquisition. A commonly reported finding is that cybersickness is negatively correlated with the sense of presence, influenced by factors such as sensory integration and system immersiveness [1,78]. For example, Lin and colleagues [94] identified a positive relationship between cybersickness and scores on the immersive tendency questionnaire (ITQ) administered after participants completed an anxiety-inducing task in VR. Additional studies, however, reported no correlations between the two when using FOV restriction techniques [3,94]. Teixiera and Palmisano [86] compared unrestricted and dynamic FOV restriction conditions in using an Oculus headset [63] and found that the sense of presence was not correlated with simulator sickness but was positively linked to vection (i.e., the illusion of perceived self-motion in VR). Again, however, this approach runs into issues with reduced spatial learning—Barhorst-Cates and colleagues [28] found that severe FOV restrictions of 4° or less significantly impaired spatial memory and required higher cognitive resources to complete a landmark pointing task. Given the increasing proliferation of continuous and discrete locomotion techniques with various view-control and transition methods, it is essential to take a broad comparative approach in understanding how these factors collectively influence spatial cognition, cybersickness, and perceived presence.

3 VIRTUAL TRANSLATION AND TRANSITION TECHNIQUE DESIGN

Different VR and gaming industries support a variety of VLTs for both developers and players. For example, Oculus, now part of Meta, supports Teleport Mode and Slide Mode (similar to CS) [64] in Meta Horizon games and offers techniques like "Blink" and "Snap Rotation" for developers creating new environments using game engines [53]. Similarly, Google VR supports Teleportation [87], Tunneling [90], and Chase Camera [16] techniques in its VR games. Moreover, current game engines, such as Unreal Engine and Unity, enable developers to adopt existing industry-standard locomotion techniques, make adjustments, or create custom solutions from scratch. However, the impact of different VLTs on spatial learning, presence, and cybersickness remains unclear. Therefore, this study compares the most frequently used techniques and investigates their effects.

Figure 1 illustrates the four locomotion techniques assessed in the study, featuring two movement types (Teleportation vs. Continuous Steering) and two transition effects (Blinking vs. Tunneling or restricted FOV). In all conditions, participants could rotate their view either by physically turning in place or by using the left joystick on the controller, which enabled 45-degree rotational increments.

In the Teleportation (TP) conditions (Conditions 1 and 2), participants used the forward joystick button on the right controller to point to their desired location within a 3-meter range. Movement was only possible if the teleportation ray was unobstructed by obstacles, such as walls, barriers, or other non-navigable areas. For transition effects, Condition 1 had no transition effect during teleportation, while in Condition 2, participants encountered a brief blink effect lasting 0.2 seconds, simulating a blink (fade-to-black) transition during each teleportation event.

In the Continuous Steering (CS) conditions (Conditions 3 and 4), participants moved forward by pressing the forward joystick button on the right controller at a constant speed of 1.2 m/s, provided the path was free of obstructions. The direction of movement was aligned with the participant's head orientation, mimicking a forward camera view. This movement style utilized a push-and-release mechanism, allowing participants to start and stop motion seamlessly. For transition effects, Condition 3 had no transition effect during movement, while in Condition 4, a Restricted Field of View, or "tunneling effect," was implemented for the entire duration of forward movement, reducing visual motion cues to enhance user comfort and mitigate cybersickness symptoms. Figure 2 shows the comparison of designed VLTs in VR.

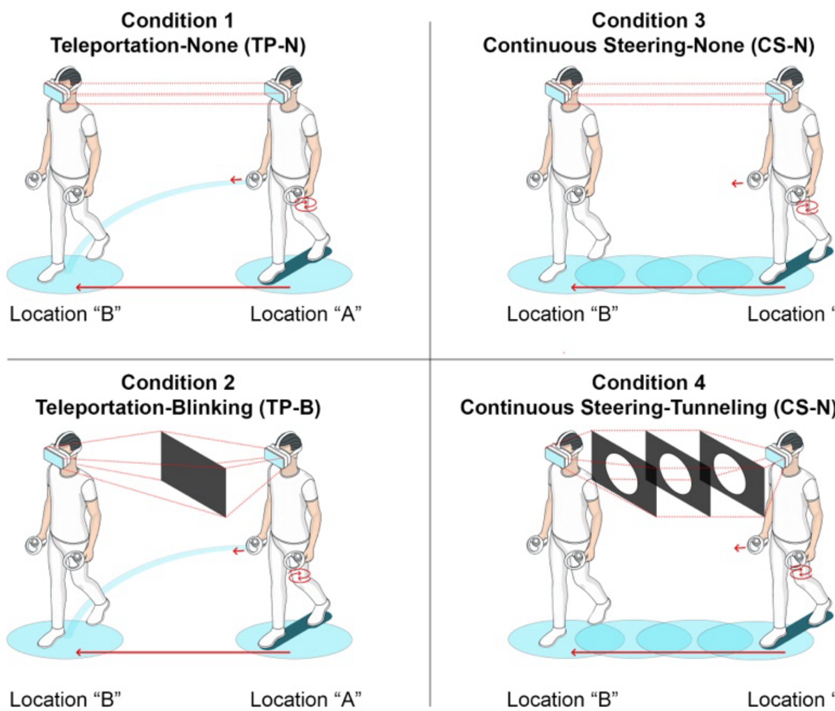

Figure 1: Overview of the four virtual locomotion techniques. Condition 1, Teleportation-None (TP-N); Condition 2, Teleportation-Blinking (TP-B); Condition 3, Continuous Steering-None (CS-N); Condition 4, Continuous Steering-Tunneling (CS-N)

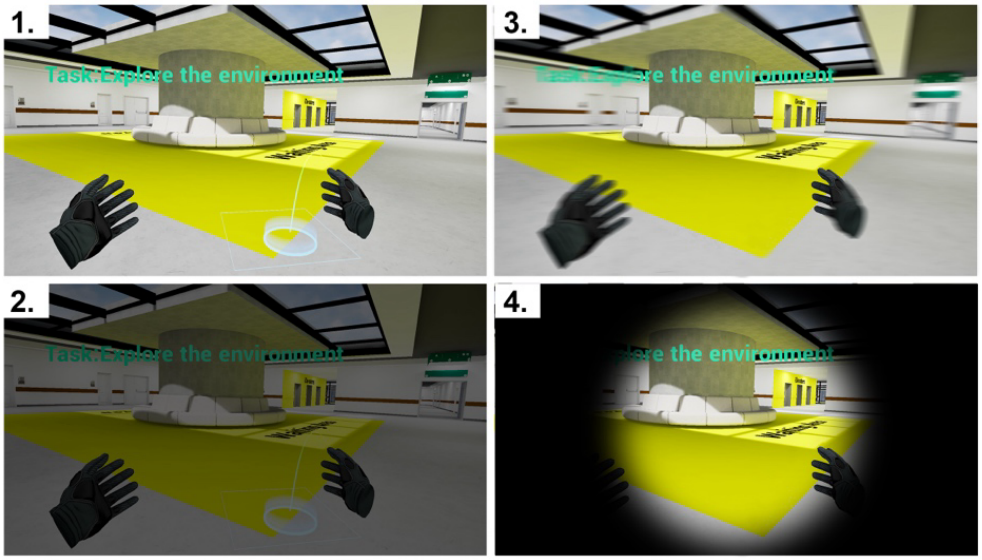

Figure 2. Screenshots of different conditions during navigation. 2.1 Condition 1 (TP-N) in the exploration level, 2.2 Condition 2 (TP-B) in the tutorial level, 2.3 Condition 3 (CS-N) in the Task-based level, and 2.4 Condition 4 (CS-T) in the Task-based level.

4 USER STUDY

After developing prototypes of the four different VLTs, we conducted an experiment to evaluate their effectiveness on spatial learning, wayfinding performance, cybersickness, presence, and usability. The experiment employed a between-group design to systematically understand the impacts within a simulated complex indoor environment.

4.1 Participants

We recruited 37 participants with diverse demographic backgrounds using a targeted convivence sampling method (world-of-mouth and university e-mail lists). Prior to any research activities, the study procedures were approved by the **[deleted for the purpose of blind review]**. All participants were informed about the study's objectives and requirements and provided written informed consent. The participants were primarily young adults, with the average age of 22.5 years (SD=4.35). The sample was relatively balanced by gender, with 51% reporting as "Female," but in regard to ethnicity it was skewed towards participants identifying as Asian (51%). The participants were well-educated, including 24 (64%) holding a bachelor's degree, 5 (14%) with a master's degree, and 3 (8%) with a doctoral degree. We asked the participants to complete the Spatial Anxiety Scale (SAS) (Lawton, 1994) and the Santa Barbara Sense of Direction Scale (SBSOD) (Hegarty, 2002). Both of these instruments have been linked with navigational performance and have been found to have good internal consistency. The average score on the Spatial Anxiety Scale was moderate at 22.3 (SD=5.83; possible range 8–40, with higher scores indicating greater anxiety). For the SBSOD, the average score was also moderate at 3.9 (SD=0.86, range 1–7, with higher scores indicating a better sense of direction). The full demographic information is summarized in Table 1.

Table 1: Participant information

Demographics	TP-N (N=9)	TP-B (N=9)	CS-N (N=10)	CS-T (N=9)	Overall (N=37)
Age	23.1 (6.39)	21.6 (2.70)	21.0 (2.62)	23.8 (4.99)	22.5 (4.35)
Gender					
Female	5 (56%)	4 (44%)	7 (70%)	4 (44%)	19 (51%)
Male	2 (22%)	4 (44%)	3 (30%)	5 (56%)	15 (41%)
Non-binary	2 (22%)	1 (12%)	0 (0%)	0 (0%)	3 (8%)
Ethnicity					
Asian	2 (22%)	6 (67%)	6 (60%)	3 (33%)	19 (51%)
White	4 (44%)	2 (22%)	2 (20%)	3 (33%)	9 (24%)
Multi-racial	1 (12%)	0 (0%)	1 (10%)	2 (23%)	4 (11%)
Others	2 (22%)	1 (11%)	1 (10%)	1 (11%)	5 (14%)
Education Level					
Bachelor's	7 (78%)	6 (67%)	7 (70%)	4 (45%)	24 (64%)
Master's	1 (11%)	1 (11%)	1 (10%)	1 (11%)	5 (14%)
Doctorate	0 (0%)	0 (0%)	1 (10%)	2 (22%)	3 (8%)
Others	0 (0%)	2 (22%)	1 (10%)	2 (22%)	5 (14%)
SBSOD	4.1 (0.67)	3.9 (0.66)	4.1 (1.00)	3.9 (1.09)	3.9 (0.86)
Spatial Anxiety	24.3 (6.46)	19.8 (5.78)	21.4 (5.36)	24.2 (7.01)	22.3 (5.83)

Notes: Self-reported gender, ethnicity, and education level are shown as n and (%). Other measures are shown as mean and (SD).

4.2 Environment

A hospital environment was chosen for this experiment because it reflects real-world scenarios where effective navigation is crucial where precise wayfinding can impact patient care and operational efficiency. Hospitals are inherently complex, featuring intricate layouts, numerous intersections, and distinct landmarks, making them an ideal setting for evaluating spatial learning and wayfinding performance. By simulating these environments, we can closely mimic the challenges faced in various real-world contexts, allowing us to assess how VLTs perform under conditions that require accurate navigation and decision-making. This choice provides valuable insights that can inform the design of VR applications used in medical training, planning, and patient education, ensuring they are realistic, effective, and applicable to real-world needs.

The experiment's design further supports this by including both an exploration phase and a task-based phase (Figure 3). The exploration phase offered a relaxed environment for spatial learning, allowing participants to familiarize themselves with the hospital layout at their own pace, which is essential for developing cognitive maps [7,18]. In contrast, the task-based phase replicated real-world healthcare scenarios, where wayfinding tasks are performed under time constraints and specific goals, simulating the pressures and demands of actual navigation. This combination allowed us to evaluate how participants learn and apply spatial knowledge in both low-pressure and high-pressure settings, reflecting the realities of navigating complex hospital environments [24,42].

The VR environment created for the study was designed to resemble a modern hospital interior, with dimensions of 40 m x 40 m x 3 m for the tutorial environment and 80 m x 80 m x 3 m for the Exploration and Task-based environments (Figure 3). Six key landmarks—Nursing Station, Relaxing Area, Four-Sided Patio, Elevators, Cafeteria, and Waiting Area—were clearly labeled with readable text and highlighted in distinct colors in the Exploration and Task-based environments (Figures 2 and 3). Each environment was divided into four zones (A to D), with appropriate directional signage and room numbers starting with the zone letter, such as room A109.

Modeling and UV mapping were primarily done using Autodesk 3ds Max, while Unreal Engine 5.4 (UE5) was used to program lighting, surface textures, and interactive features. Front-end interactions were developed using C++ and Blueprint visual scripting. The game was packaged for standalone use and presented to participants using a Meta Quest 3-HMD [63], providing a resolution of 2064 x 2208 pixels per eye. The Meta Quest 3 can be adjusted for users with different interpupillary distances and offers a horizontal field of view of 110° and a refresh rate of 72 Hz. Participants experienced the virtual environment from a standing position. They could freely look around and observe various parts of the hospital space and navigate based on assigned VLT. Participants' behaviors and interactions were recorded in a customized UE5 log file associated with the participant ID. This included timestamps (in milliseconds) for their trajectory and each behavioral event (i.e. start/end task), along with the gaze direction. Responses to questionnaire instruments were collected directly within the VR and were also included in the log file.

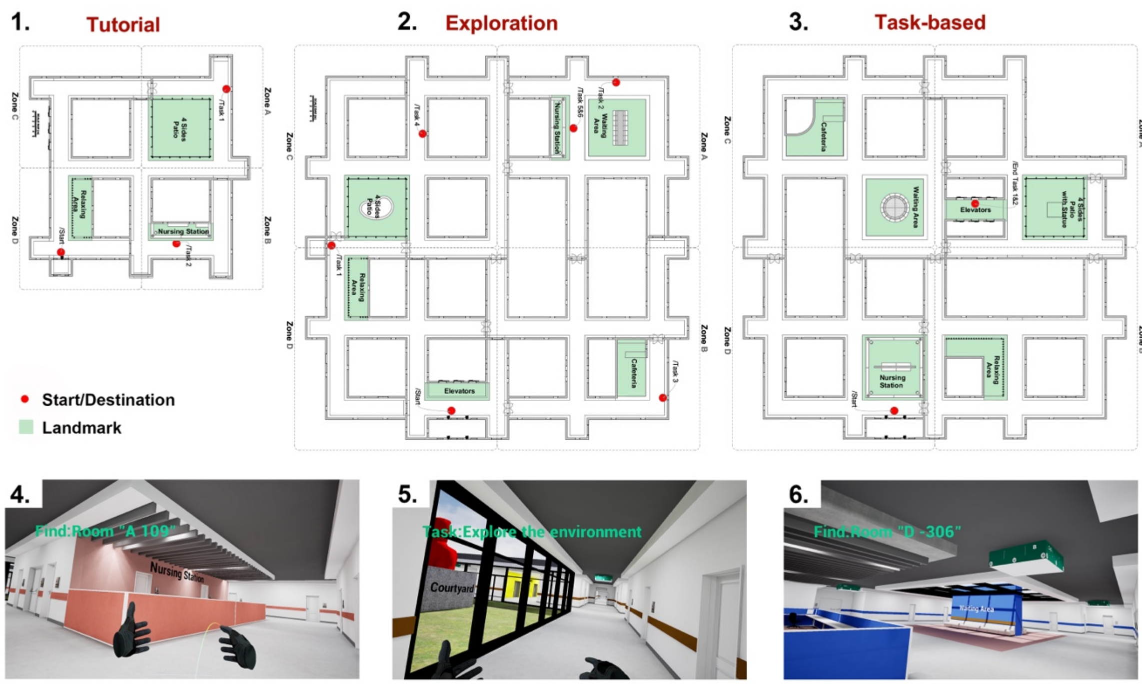

Figure 3. Plan and perspective view of participant. 1-3 Plan view of Tutorial, Exploration and Task-based environment with highlighted landmarks in green and start/end points in red, 4-6. Perspective views of a participant from Tutorial, Exploration and Task-based session.

4.3 Procedure

The detail procedure of this study is illustrated in Figure 4 and the corresponding task details are shown in table 2. The experiment followed a factorial design, with the independent variables being controller-based locomotion type (CS vs. TP) and viewpoint transition techniques (no effect vs. blinking or tunneling). Each participant was randomly assigned to a specific VLT that was consistently used throughout the entire experiment. The study was conducted in a controlled laboratory environment in a university campus building. Three environments were developed for this experiment

(Figures 3.1, 3.2, and 3.3). The first environment with relatively simple features was intended for tutorial session (Figure 3.4). The second and third environments, as detailed in Section 4.2, shared similar layout designs regarding the number of intersections, on-route environmental features, and overall navigation complexity, which allowed us to evaluate spatial learning and wayfinding effectiveness in comparable virtual environments. To independently assess participants' cognitive map development and navigation performance in relation to cybersickness and presence, without confounding factors such as intrinsic differing speeds associated with VLTs—where teleportation may allow for faster wayfinding compared to continuous locomotion which potentially leads to unequal environmental learning time—each participant completed two environments. Spatial learning was evaluated by having participants spend three minutes exploring the second environment (Figure 3.5), followed by an assessment of their wayfinding performance in the third environment (Figure 3.6). Sessions were conducted for one participant at a time, lasting about 45 minutes to an hour in total for each participant.

Before the start of the session, participants were briefed on the study's objectives and requirements and provided written informed consent. They also completed a brief survey regarding demographics, perceived sense of direction using SBSOD, and spatial anxiety using SAS. Following this, participants were guided through the Tutorial session where they used the assigned VLT to explore the tutorial environment for 5-10 minutes period to become familiar with Meta Quest 3 headset and navigational controls within the virtual environment while finding a room and landmark (Task 1 and 2). They also received a tutorial on the sketch map task conducted on a paper, and pointing and distance estimation tasks on a tablet (see Section 4.4).

Next, participants went through the learning phase in Exploration environment, were asked to freely explore the second hospital environment for up to three minutes (Task 0), beginning at the designated point, with the objective of covering as much of the environment as possible while paying close attention to the landmarks and the overall layout of the environment. This setup is commonly employed in prior research on cognitive map development [42]. At the end of the exploration, they were tasked for a wayfinding performance trial (Task 1 and 2) from a starting point to locate a specific landmark (Elevator), and then repeat their steps to the same destination to assess their spatial knowledge [40]. Participants were then asked to complete a sketch map task by placing the landmarks on a simplified map [51,80]. They also completed the pointing and distance estimation tasks related to previous landmarks and a self-report questionnaire to evaluate levels of cybersickness and presence, utilizing Simulator Sickness Questionnaire (SSQ) [71] and MEC Spatial Presence Questionnaire (MEC-SPQ) [69].

After the exploration environment, participants were directed to the Task-based environment where they are tasked with four wayfinding trials in a continuous loop (Task 1 to 4), with the subsequent task starting where the previous one ended. The routes varied in lengths from 185 to 345 feet (56.3 to 105.1 meters) and incorporated different levels of complexity in regard to the number of intersections and on-route environmental features, allowing for a comprehensive evaluation of the VLTs' effectiveness [23]. In the exploration learning phase, each participant was assigned to a starting task number and were instructed to find a particular room in the environment as quickly as possible for each trail. If participants were struggling or lost for more than ten minutes, or if they opted to abandon the task, then the researcher would promptly guide them to the end point. Once completing all tasks, they were again tested with an additional navigation and route-retracting tasks (Task 5 and 6), followed by the sketch map and questionnaire, identical to the procedure from the exploration phase. Finally, there were asked to evaluate the usability of VLTs through System Usability Scale [44].

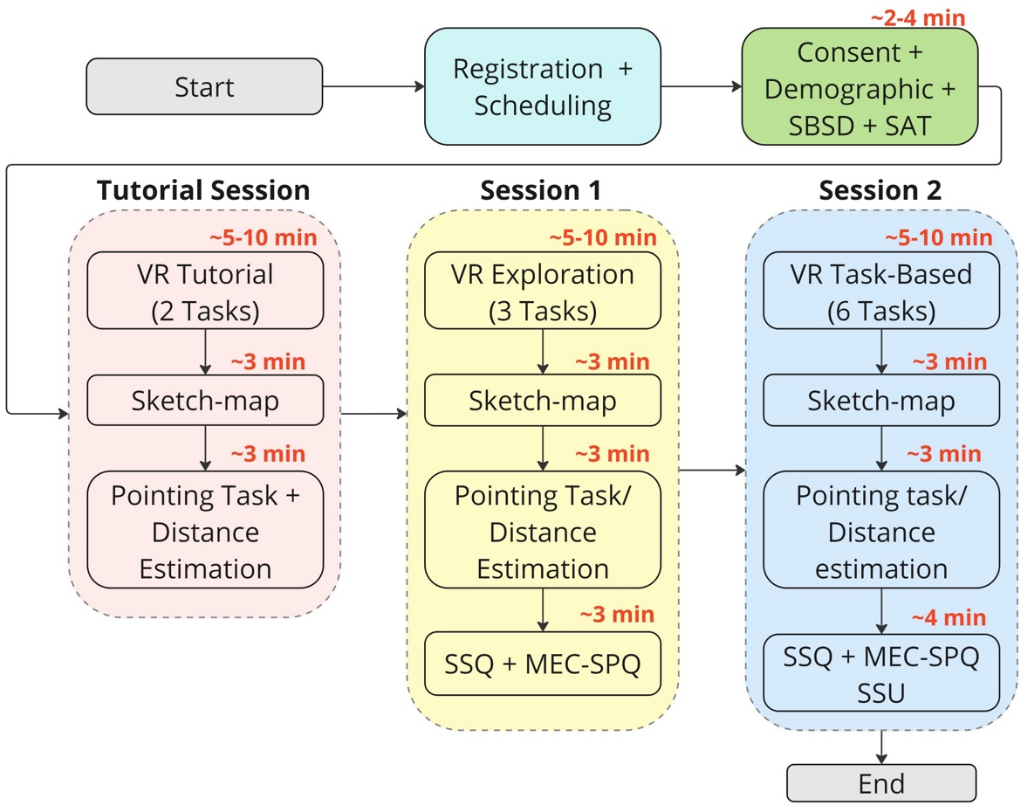

Figure 4. Experiment procedure.

Table 2: Conducted tasks for each environment

	Start	End	Notes
		Tutorial	
Task 1	Entrance	Room A109	
Task 2	Entrance	Nursing Station	
		Exploration	
Task 0	Entrance	Anywhere in the Environment	
Task 1	Entrance	Elevator	Performance task 1
Task 2	Entrance	Elevator	Performance task 2
		Task-based	
Task 1	Entrance	Room D-306	
Task 2	Room D-306	Room A-101	
Task 3	Room A-101	Room B-208	
Task 4	Room B-208	Room C-110	

Task 5	Entrance	Nursing Station	Performance Task 1
Task 6	Entrance	Nursing Station	Performance Task 2

4.4 Measures

We used two wayfinding performance metrics: the time required for task completion, and the distance traveled during each task. The time was automatically recorded from the moment participants began walking from the starting point until they reached the endpoint of each task. Participant trajectories on the floorplan were also captured using the established localization capabilities of the VR system. After each environment, participants completed a pointing task in which they were presented with two images on a screen. They were asked to imagine standing at the location shown in the left image, which is 0 degree to the north direction, and then point towards the straight-line direction where they perceived the location in the right image to be [17,91]. Participants responded using the mouse to control a slider on the screen to indicate the angles within the full 360-degree range. Angles from 270 to 90 degrees on the top half of the circle represented the participant pointing directly forward, while angles from 90 to 270 degrees on the bottom half indicated the participant pointing behind themselves. The errors were measured by the discrepancy between the actual angles from the left to the right image and the angles indicated by participants. For the distance estimation task, participants were asked to estimate the straight-line distance between the locations depicted in two images [68]. They also adjusted the slider on the screen to indicate the distance within a range of 0—1000 feet (304.8m). Distance estimation errors were determined as the discrepancy between the participant estimates and the actual straight-line distance. There were five pointing and distance estimation tasks after each environment, making a total of ten tasks for each measure.

For the map-completion task, participants were provided with a simplified map of the environment without landmarks on a letter-sized sheet of paper. The task involved recalling and placing all the six landmarks on the map, including their names, positions, and sizes. The sketch maps were graded for accuracy based on the correct identification of landmarks (6 possibles scores—1 point for correctly identified and 0 for not identified), placement (6 possibles scores—1 point for fully accurate placement, 0.5 for relatively accurate placement, and 0 for incorrect placement or not identified) , and their relative spatial configurations (6 possible scores—1 point for fully accurate configuration, 0.5 for relatively accurate configuration, and 0 for incorrect spatial configuration or not identified) [51,84]. The SSQ scores were calculated by summing across the scale's three components ("nausea", "oculomotor", and "disorientation"), and each weighted by specific coefficients using a ranking for a variety of sickness symptoms as none, slight, moderate, and severe (score range 0—235.62). The MEC-SPQ scores were averaged across its two dimensions ("self-location" and "possible actions") (score range 1—5). Scores on the SUS instrument, a 10-item, 5-point Likert scale, were normalized to a 0–100 range.

4.5 Statistical Analysis

We used R language for statistical analysis [88]. We first calculated descriptive results, then performed f-tests to examine the main effect of Translation, Transition, and their interaction effect on outcome measures including learning phase behavior (duration, distance), wayfinding performance (duration, distance), spatial learning (pointing error, distance estimation error, sketch-map score), and user experience (cybersickness, spatial presence). We then calculated effect sizes, partial η^2 and ω^2, with library "effectsize" [60]. For (marginal) significant effects, we estimated difference between conditions and confidence intervals, with library "emmeans", as suggested in [81]. Data from free exploration learning and task-based learning session were analyzed separately. We reported test results with p-values less than 0.05 as significant, 0.10 as marginally significant.

5 RESULTS

5.1 Descriptive Results

The overall descriptive and f-test results are summarized in Tables 3 and 4. In the Free Exploration portion of the study, participants spent an average of 39.62s (SD=18.50) and traveled an average distance of 77.86m (SD=29.09) during the wayfinding tasks. They had an average pointing error of 74.65 degrees (SD=22.37), a distance estimation error of 80.69ft (SD=61.41), and a sketch-map score of 10.61 (SD=4.12). They reported motion sickness levels of 55.90 (SD=49.26), and spatial presence of 3.18 (SD=0.72).

In the Task-based portion of the study, participants spent an average of 67.20s (SD=21.31) and traveled an average distance of 125.60m (SD=26.23) during the wayfinding tasks. In the subsequent performance tasks, they spent an average of 75.81s (SD=34.24) and traveled an average distance of 160.30m (SD=51.66). They had an average pointing error of 84.51 degrees (SD=24.09), a distance estimation error of 90.18ft (SD=56.34), and a sketch-map score of 7.14 (SD=3.40). They reported motion sickness levels of 64.39 (SD=54.72), and spatial presence of 3.04 (SD=0.83).

After finishing both learning environments, participants reported an average SUS score of 67.30 (SD= 15.39), indicating a moderate-good system usability [2].

Table 3. Descriptive Statistics, Main and Interaction Effects, Free Exploration Learning

	TP-N (n = 9)	TP-B (n = 9)	CS-N (n =10)	CS-T (n = 9)	Possible Range	Translation Main Effect	Transition Main Effect	Interaction Effect
Learning Phase Behavior								
Distance	404.83 (167.24)	491.74 (114.11)	331.02 (44.48)	357.83 (56.82)	(0, ∞)	**F=8.98 p=.005 η^2=0.21 ω^2=0.18**	F=2.58 p=.118 η^2=0.07 ω^2=0.04	F=0.74 p=.396 η^2=0.02 ω^2=0.00
Wayfinding Performance								
Duration	37.00 (14.56)	31.67 (13.24)	43.30 (11.84)	46.11 (29.18)	(0, ∞)	**F=2.90 p=.098 η^2=0.08 ω^2=0.05**	F=0.04 p=.850 η^2<0.01 ω^2<0.01	F=0.45 p=.506 η^2=0.01 ω^2<0.01
Distance	75.53 (19.76)	90.00 (30.98)	72.76 (25.32)	73.74 (38.89)	(0, ∞)	F=0.97 p=.332 η^2=0.03 ω^2<0.01	F=0.61 p=.441 η^2=0.02 ω^2<0.01	F=0.48 p=.492 η^2=0.01 ω^2<0.01
Spatial Learning								
Pointing Error	79.27 (23.99)	74.24 (13.19)	64.72 (28.20)	81.47 (20.22)	[0, 180]	F=0.31 p=.580 η^2=0.01 ω^2<0.01	F=0.70 p=.409 η^2=0.02 ω^2<0.01	F=2.20 p=.148 η^2=0.06 ω^2=0.03
Dist. Est. Error	83.15 (78.13)	62.52 (53.49)	77.71 (48.87)	99.70 (67.24)	[0, 1000]	F=0.55 p=.463 η^2=0.02 ω^2<0.01	F<0.01 p=.953 η^2<0.01 ω^2<0.01	F=1.07 p=.309 η^2=0.03 ω^2<0.01
Sketch Map	11.67 (2.78)	8.17 (3.54)	11.40 (4.25)	11.11 (5.16)	[0, 18]	F=1.03 p=.318 η^2=0.03 ω^2<0.01	F=1.94 p=.172 η^2=0.06 ω^2=0.02	F=1.46 p=.236 η^2=0.04 ω^2=0.01
User Experience								
Cybersickness	38.65 (34.33)	44.05 (22.58)	83.78 (70.13)	54.02 (47.24)	[0, 235.62]	**F=3.24 p=.081 η^2=0.09 ω^2=0.06**	F=0.64 p=.428 η^2=0.02 ω^2<0.01	F=1.24 p=.273 η^2=0.04 ω^2=0.01
Spatial Presence	3.07 (0.93)	3.11 (0.82)	3.42 (0.65)	3.11 (0.45)	[1, 5]	F=0.56 p=.461 η^2=0.02 ω^2<0.01	F=0.33 p=.568 η^2=0.01 ω^2<0.01	F=0.51 p=.482 η^2=0.02 ω^2<0.01

Note: Mean (SD) for descriptive results. F(1, 33) for main and interaction effects. Significant results are in bold. CS: Continuous. TP: Teleportation. Mean (SD). Dist. Est. Error: Distance Estimation Error, capped at 1000.

Table 4. Descriptive Statistics, Main and Interaction Effects, Task-based Learning

	TP-N (n = 9)	TP-B (n = 9)	CS-N (n =10)	CS-T (n = 9)	Possible Range	Translation Main Effect	Transition Main Effect	Interaction Effect
Learning Phase Behavior								
Duration	63.11 (17.62)	57.94 (23.99)	72.43 (16.14)	74.72 (25.53)	(0, ∞)	**F=3.51 p=.070 η^2=0.10 ω^2=0.06**	F=0.04 p=.848 η^2<0.01 ω^2<0.01	F=0.29 p=.594 η^2=0.01 ω^2<0.01
Distance	121.38 (20.41)	129.43 (23.30)	123.66 (23.21)	128.16 (38.49)	(0, ∞)	F<0.01 p=.966 η^2<0.01 ω^2<0.01	F=0.48 p=.491 η^2=0.01 ω^2<0.01	F=0.04 p=.844 η^2<0.01 ω^2<0.01
Wayfinding Performance								
Duration	71.39 (20.79)	42.11 (17.21)	85.25 (25.24)	103.44 (39.50)	(0, ∞)	**F=17.48 p<.001 η^2=0.35 ω^2=0.31**	F=0.31 p=.582 η^2=0.01 ω^2<0.01	**F= 7.14 p=.012 η^2=0.18 ω^2=0.14**
Distance	184.65 (78.00)	127.06 (15.40)	156.63 (38.09)	173.28 (44.03)	(0, ∞)	F=0.29 p=.594 η^2=0.01 ω^2<0.01	F=1.47 p=.234 η^2=0.04 ω^2=0.01	**F=5.30 p=.028 η^2=0.14 ω^2=0.10**
Spatial Learning								
Pointing Error	94.96 (20.60)	87.67 (28.33)	71.60 (23.66)	85.27 (20.32)	[0, 180]	**F=2.94 p=.096 η^2=0.08 ω^2=0.05**	F=0.20 p=.657 η^2=0.01 ω^2<0.01	F=1.84 p=.184 η^2=0.05 ω^2=0.02
Dist. Est. Error	100.55 (63.25)	78.20 (45.46)	103.43 (63.16)	77.07 (55.06)	[0, 1000]	F=0.01 p=.935 η^2<0.01 ω^2<0.01	F=1.67 p=.205 η^2=0.05 ω^2=0.02	F=0.01 p=.916 η^2<0.01 ω^2<0.01
Sketch Map	6.17 (2.25)	7.00 (3.50)	7.10 (3.76)	8.28 (4.06)	[0, 18]	F=0.89 p=.353 η^2=0.03 ω^2<0.01	F=0.78 p=.383 η^2=0.02 ω^2<0.01	F=0.02 p=.881 η^2<0.01 ω^2<0.01
User Experience								
Cybersickness	54.02 (52.36)	46.54 (33.82)	96.87 (65.95)	56.52 (53.17)	[0, 235.62]	F=2.48 p=.125 η^2=0.07 ω^2=0.04	F=1.94 p=.173 η^2=0.06 ω^2=0.02	F=0.89 p=.353 η^2=0.03 ω^2<0.01
Spatial Presence	3.08 (0.91)	2.96 (0.98)	3.14 (0.86)	2.96 (0.69)	[1, 5]	F=0.01 p=.906 η^2<0.01 ω^2<0.01	F=0.28 p=.602 η^2=0.01 ω^2<0.01	F=0.01 p=.919 η^2<0.01 ω^2<0.01

Note: Mean (SD) for descriptive results. F(1, 33) for main and interaction effects. Significant results are in bold. CS: Continuous. TP: Teleportation. Mean (SD). Dist. Est. Error: Distance Estimation Error, capped at 1000.

5.2 Exploration and Task-based Environment Learning Behavior

5.2.1 Task Duration.

In the Task-based environment, there was a marginally significant effect of Translation on time spent on wayfinding tasks, F(1, 33)=3.51, p=0.070, with a medium effect size, η^2=0.10, ω^2=0.06 (Table 4). The continuous-steering groups spent 13.0 (95% CI: [-1.1, 27.2]) more seconds on average than the teleportation groups. Descriptively, teleportation with effect had the lowest time, followed by teleportation with no effect, while both groups had lower time than the continuous movement conditions.

5.2.2 Distance Traveled.

In the Free Exploration environment, no significant differences were found between the groups in regard to Distance Traveled (Table 3). In the Task-based environment, there was a significant Translation by Transition interaction effect, F(1, 33)=5.30, p=0.028, with a medium-large effect size, η^2=0.14, ω^2=0.10 (Table 4). The continuous-steering groups traveled further than the teleportation groups, with transition effect by 46.2m (95% CI: [-0.8, 93.2]), but shorter without effect, by -28.0s (95% CI: [-73.8, 17.8]).

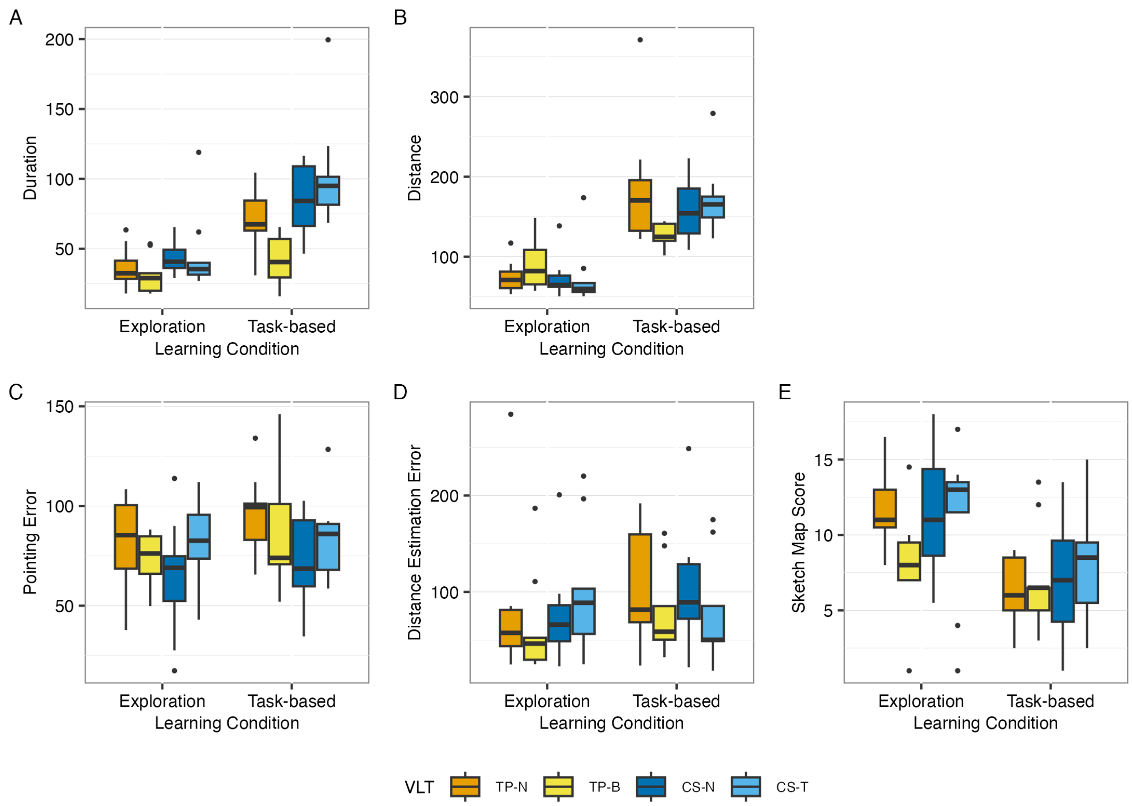

Figure 5. Distributions of Spatial Learning and Performance Measures per Condition.

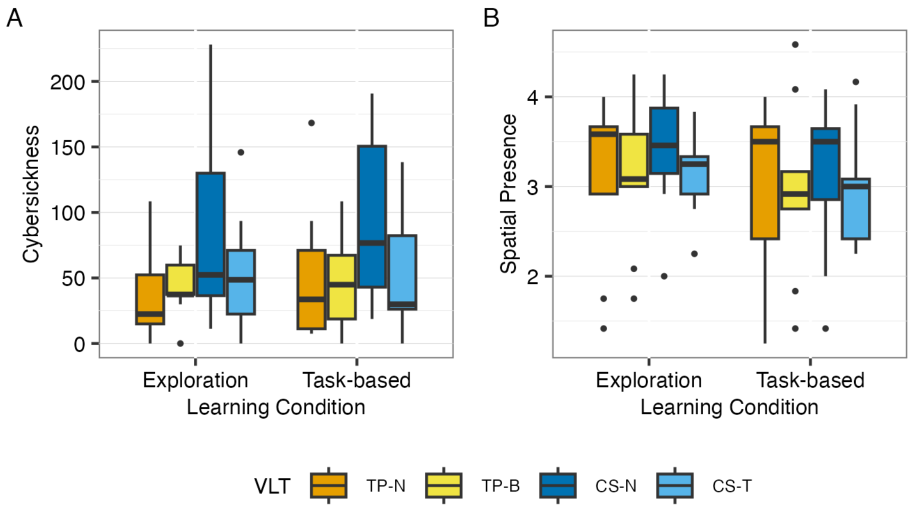

Figure 6. Distributions of User Experience Measures per Condition.

5.3 Spatial Learning

5.3.1 Pointing Error (Fig. 5C)

In the Free Exploration environment, no significant differences were found between the groups. Descriptively, continuous movement group with no effect tended to have lower error than other three groups.

In the Task-based environment, there was a marginally significant effect of Translation on pointing error, F(1, 33)=2.94 p=0.096, with a medium-small effect size, η^2=0.08, ω^2=0.05. The continuous-steering groups had a smaller deviation from the correct direction than the teleportation groups, by -12.9 degrees (95% CI: [-28.6, 2.83]).

5.3.2 Distance Estimation Error (Fig. 5D).

No significant differences were found between groups in regard to Distance Estimation. Descriptively, in free exploration learning environment, teleportation with effect tended to have lower error than the other conditions; continuous movement with effect had highest error in free exploration, but lowest in task-based learning.

5.3.3 Sketch Map Score (Fig. 5E)

No significant differences were found between groups in regard to Sketch Map Scores. Descriptively, teleportation with effect tended to have the lowest score in free exploration learning environment.

5.4 Wayfinding Performance

5.4.1 Task Duration (Fig. 5A)

In Free Exploration learning environment, there was a marginally significant effect of Translation on task duration, F(1, 33)=2.90, p=.098, with medium-small effect size, η^2=0.08 ω^2=0.05. The continuous group in general spent 10.4 (95% CI: [-2.0, 22.7]) more seconds than the teleportation group.

In Task-based learning environment, there was a significant Translation effect on task duration, F(1, 33)=17.48, p<.001, with large effect size, η^2=0.35, ω^2=0.31, and a significant Translation by Transition interaction effect on task duration, F(1, 33)= 7.14, p=.012, with large effect size, η^2=0.18, ω^2=0.14. The continuous group spent 61.3 (95% CI: [35.4, 87.2]) more seconds than the teleportation group with transition effect, but had a closer duration without transition effect, with a difference of 13.9s (95% CI: [-11.4, 39.1]).

5.4.2 Distance Traveled (Fig. 5B)

In Free Exploration learning environment, there was no significant difference in distance traveled between conditions. In Task-based learning environment, there was also a significant Translation by Transition interaction effect, F(1, 33)=5.30, p=.028, with medium-large effect size, η^2=0.14, ω^2=0.10. The continuous group traveled longer than the teleportation group with transition effect by 46.2m (95% CI: [-0.8, 93.2]), but shorter without effect, by -28.0s (95% CI: [-73.8, 17.8]).

5.5 User Experience

5.5.1 Cybersickness (Fig. 6A)

In the Free Exploration environment, there was a marginally significant effect of Translation on cybersickness, F(1, 33)=3.24 p=0.081, with a medium effect size, η^2=0.09, ω^2=0.06. The continuous-steering groups reported a greater extent of motion sickness than the teleportation groups, by 27.6 (95% CI: [-4.5, 59.6]). In the Task-based environment, no significant differences were found between groups in regard to cybersickness.

5.5.2 Spatial Presence (Fig. 6B)

No significant differences were found between groups in regard to spatial presence. Descriptively, continuous movement without effect reported highest motion sickness in both learning environments, while teleportation groups tended to report lower spatial presence.

6 DISCUSSION

6.1 RQ1. How do different VLTs influence spatial learning, cybersickness, and perceived presence in virtual indoor environments?

The study's overall results indicated that teleportation with a blinking technique was associated with stronger navigational performance compared to the continuous-steering groups (including lower error in estimating distances, less time required to complete wayfinding tasks, and improved route-based spatial knowledge outcomes). This finding is somewhat inconsistent with prior studies that have found teleportation to be associated with reduced spatial learning [32,36,70]. One possible explanation for this discrepancy is our use of the blinking effect, which may lead to reduced user awareness of the visual intervention and thus increased immersion and less environmental distraction [92,95]. However, it seems equally likely that this technique may provide less exposure to some environmental features such as prominent landmarks, which could result in poorer landmark-based spatial knowledge and retention of spatial configuration information, as evidenced in the lower scores on the Sketch Map task for the TP-B groups. Our comparison of TP-N vs. TP-B seems to support this, as the group without blinking effect had stronger performance in map-sketching task but weaker results in other spatial memory tasks. This suggests that retaining some optical flow during transitions—

similar to the "Jumper" and "Dash" techniques [10,43]—may be advisable if the goal is to improve spatial awareness when using teleportation.

In regard to continuous-steering methods, participants performed exceptionally well in the Pointing Task and Sketch Map tasks when there was no FOV restriction. They also reported a strong sense of presence within the environment in this condition. This suggests that continuous movement provides constant visual feedback that improves spatial understanding of the surroundings. However, this technique was associated with significantly higher levels of cybersickness, as well as with longer completion times for wayfinding tasks. Contrary to some previous studies [3], continuous movement with dynamic FOV restriction did not perform as well as the no-restriction group, though it did result in significant cybersickness reduction. This is likely because the FOV restriction limits constant visual feedback that contributes to spatial learning and environmental engagement. TP-B group was associated with better performance outcomes compared to continuous-steering with tunneling effect; both techniques reduce optical flow, but TP-B had less of a negative impact on wayfinding performance, while CS-T had a negative impact on both performance and spatial learning metrics. We suggest that blinking effect removes environmental distractions and diminishes cognitive load at the expense of landmark information learning, while FOV restriction narrows visual feedback for both landmark and route-based spatial references, making it less effective overall compared to teleportation-based techniques.

6.2 RQ2. Are there trade-offs between navigational performance, cybersickness, and perceived presence when using different VLTs in virtual indoor environments?

The results indicated that teleportation with the blinking effect (TP-B) was associated with significantly better task completion times, followed by basic teleportation. The two continuous-steering methods showed the worst completion times. This finding aligns with previous research suggesting that teleportation locomotion is more efficient in navigation [46]. Regarding the distance traversed, TP-B and CS-T groups resulted in significantly worse outcomes, whereas TB-N and CS-N were associated with better performance. Overall, this suggests a likely trade-off between efficiency in reaching destinations and precision in navigating. We speculate that the blinking effect may reduce distractions from surrounding environmental features in a way that allows users to quicky focus on target destination and move there at a rapid pace. However, as participants may overlook spatial details such as signs and landmarks that could serve as navigational cues, they traveled longer distances and had to adjust their routes more often to reach the destinations. This perspective is in accordance with the finding that TP-N was associated with higher spatial awareness and less traversed-distance, while still allowing participants to reach their destinations at a rapid pace. It suggests that allowing users to teleport while experiencing some transitional optical flow may lead to the most precise and efficient navigational performance.

The CS-N group resulted in the shortest travel distances despite requiring more time to reach destinations. This suggests that such an approach improves the ability to accurately process environmental information and navigate more effectively in indoor environments. However, the extended task-completion time may be attributable to elevated levels of cybersickness seen in this condition and the cognitive requirements of processing the more extensive visual information. Notably, the group who experienced CS-T completed the wayfinding tasks in a similar amount of time but traveled greater distances, suggesting that FOV restriction impaired participants' ability to perceive environmental details.

6.3 Implications for VLT Design

VLTs designs are important to many types of applications, ranging from gaming to virtual training and simulation, to therapeutic environments, among others. Thus, designers need to consider their particular goals when evaluating how to balance environmental detail, task efficiency, spatial learning, user comfort, and immersion. Given the tradeoff observed in our study and in the broader literature, we suggest that in many cases it will be useful to offer customizable interfaces that can cater to different user needs. For tasks requiring speed and direct navigation, such as target-finding or moving between fixed points, TP-B may be optimal. This technique minimizes distractions but potentially reduces broad environmental awareness—it may be suitable for environments such as airport interior simulations (finding one's departure gate), other large facility navigation, or some forms of search-and-rescue training. TP-N offers a more balanced solution for scenarios where users need quick movement but still want to gather some spatial information, such as medical emergency training. Continuous movement is best suited for broader exploration and immersive tasks that require detailed spatial learning, such as museum visits or other educational and aesthetic applications, though designers should consider the potential for increased cybersickness when using this approach.

For users who are focused on therapeutic or social applications, especially those such as older adults who are more susceptible to negative impacts, VR design should prioritize simplicity, comfort, and customization. Teleportation is likely to be the most suitable VLT approach in such contexts, as it minimizes physical exertion and disorientation. One exception is applications specifically targeted to navigational training, which may prefer a continuous-steering approach to better replicate the challenges of real-world environments. Customizable options such as adjustable speed and transition effects can help such audiences tailor their experience for better comfort. By integrating these considerations, VLT designs can better support diverse user groups, ensuring VR environments are accessible, engaging, and effective for a wide range of real-world and simulated scenarios.

7 LIMITATIONS AND FUTURE WORK

While this study provided valuable new knowledge about virtual locomotion techniques in indoor environments, it has some notable limitations. First, the participant sample was skewed toward young adult participants who were highly educated and identified as Asian. These demographic factors may have an influence on how individuals engage with VR technology and their navigational preferences and capabilities. Future studies can benefit from obtaining larger and more diverse participant samples, which will help to improve the generalizability of the findings. Second, the duration of participants' engagement with the VR environments in our study may have been insufficient to capture long-term effects of spatial learning, wayfinding performance, and simulator sickness. Future studies can benefit from examining the long-term use of continuous-steering and teleportation techniques especially in relation to spatial knowledge retention.

8 CONCLUSION

In this paper we presented a systematic evaluation of controller-based virtual indoor locomotion techniques, comparing continuous-steering and teleportation approaches, with and without viewpoint transitional effects during travel. We empirically examined participants' spatial knowledge acquisition, wayfinding performance, cybersickness, and perceived presence across each condition. The findings contribute to the field in three significant ways. First, our results demonstrated that the teleportation technique with a blinking effect is highly effective for acquiring route-based spatial knowledge and rapidly reaching destinations in indoor environments. In contrast, the continuous-steering method is more effective for achieving an immersive sense of presence and for acquiring broader landmark-based knowledge about spatial relationships in the environment, but it results in higher levels of cybersickness and slower information-processing times. Second, we found that greater incidences of cybersickness and greater perceived presence did not have much of an effect on wayfinding task duration, and that both of these factors were associated with less distance traveled. This indicates that when study participants are able to quickly reach a destination, researchers should not necessarily assume that they had a "positive" wayfinding experience or that they learned more about the environment. It is vital in navigational studies to examine a broad array of outcome factors, including spatial learning and cybersickness, to more fully evaluate the success of a design in accordance with its goals. Finally, this work led to multiple specific design recommendations for VR navigation interfaces in indoor environments, as summarized in Section 6.3. We anticipate that future research will continue to build upon this work and further advance our understanding of the rapidly changing field of VLT design in areas such as gaming, healthcare training simulations, and many other domains.

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