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Improving group navigation for VR-based entertainment applications

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A B S T R A C T

Various aspects of shared virtual environments have been explored to improve communication, collaboration, and entertainment among users. However, one crucial element, group navigation, remains in its early stages of development. The research gap suggests investigating different approaches to achieve suitable group navigation approaches within virtual reality environments. The employment of customized avatars that provide gestures and voice chat communication, along with controlled transitions between individual and group navigations, has not yet been fully studied. In this regard, this paper proposes a new approach for examining the aforementioned unexplored features of group navigation along with other modifications to current techniques. Moreover, features such as animated paths, transparent materials, switching between first-person view and third-person distant view, and preview avatars were incorporated into this approach. As the locomotion technique of the proposed solution varies noticeably with existing ones, the solution was evaluated in a user study comparing with teleportation and steering methods in terms of human behavior and psychology from usability, immersion, efficiency, safety, attention-guiding mechanism, and entertainment perspectives. The findings revealed that our approach outperformed teleportation and steering, providing promising insights into developing more interactive, entertaining, and socially immersive group navigation techniques in VR.

1. Introduction

Virtual reality (VR) is increasingly integrated into entertainment and collaborative platforms, enabling users to interact with digital environments in immersive and previously inaccessible ways [1–3]. VR provides immersive experiences that have been applied across various domains, including multiplayer gaming (e.g., Rec Room [4] and VRChat [5]), virtual field trips in education, and collaborative simulations for training scenarios such as emergency response or virtual museums [6–10]. Effective and intuitive navigation is essential for the functionality of these applications, directly influencing the user experience in collaborative virtual environments. For instance, social VR platforms such as Horizon Worlds demonstrate the potential of group interactions in virtual spaces, where navigation plays a central role in maintaining user engagement and collaboration [11].

The exploration of group navigation in VR is important due to several reasons. In this context, group navigation refers to the coordinated or shared movement of two or more users through a virtual environment, facilitated by specific system mechanics. First, VR offers shared environments in which users can share their experiences and collaborate with each other [12]. Group navigation can enhance such experiences and activities, particularly when teamwork, field trips, and other interactive applications are targeted. Moreover, group navigation in VR is beneficial for interpersonal engagement and communication. Users may experience enhanced interaction with avatars or digital characters owing to the feeling of presence and embodiment, which can be improved by incorporating group navigation in VR applications. In turn, this encourages social interaction, cooperation, and the sharing of common experiences.

Existing research highlights that while individual navigation methods are well-studied, their application to groups often leads to challenges such as group fragmentation, difficulty locating peers, and reduced spatial awareness [13,14]. Although some research on single-user navigation [15] has been presented, research on group navigation is still in its early stages, and further exploration is required in this field [16]. The current body of literature addresses various locomotion strategies, including teleportation, steering, and waypoint navigation, with an emphasis on reducing motion sickness and improving ease of use [15,16].

However, these methods expose critical flaws when applied to collaborative settings. Teleportation remains a popular approach due to its ability to minimize VR-induced symptoms, but it often disrupts spatial presence. Steering, while immersive, can cause cybersickness during prolonged use [17]. This leads to the central research problem for this

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study: current navigation paradigms prioritize individual movement at the expense of group cohesion, lacking the necessary mechanisms to maintain social presence and coordination during travel. This creates a clear gap in the literature. Specifically, few studies have explored navigation methods designed for groups, where maintaining social presence and coordination are critical. Existing research has yet to fully address how a holistic solution integrating features such as customizable avatars, communication methods, attention-guidance mechanisms, and dynamic transitions between navigation modes can enhance group navigation experiences. This gap represents a critical opportunity to develop and evaluate innovative solutions. Therefore, the novelty of this paper lies not in proposing group navigation as a concept, but in designing and evaluating a comprehensive solution that holistically integrates multiple features (e.g., dynamic view switching, preview avatars, animated paths) to directly address the known problems of group fragmentation and disjointed social presence.

This paper proposes a group navigation solution, focusing particularly on how these advancements can significantly enhance entertainment applications. As shown in Fig. 1, several aspects of group navigation and human behavior in virtual environments are investigated to achieve a suitable solution in terms of usability (user experience and system assistance), immersion (presence), efficiency, safety (VR-induced symptoms), and attention guidance mechanism. In order to make the findings more reliable, the authors compared the solution with two other locomotion techniques; teleportation and steering. As mentioned earlier, research in this field is still in its preliminary stages. Therefore, the literature review revealed a range of aspects and modifications that are unexplored in this field.

This paper makes the following unique contributions to the field of group navigation in VR:

- Proposed a novel group navigation solution that integrates distant third and first view during navigation, customizable and preview avatars, animated paths, and seamless transitions between group and individual navigation.
- Addressed limitations of existing techniques, such as disruptions in spatial presence and user fragmentation, by evaluating the benefits of a distant third-person view and f-formation adjustments during transitions.
- Provided insights into user behavior, engagement, and VR-induced symptoms by comparing the proposed approach with traditional locomotion techniques (teleportation and steering).
- Identified challenges for real-world applications, such as camera switching effects and discrepancies between VR and real-world interactions, while offering directions for further research.

To ensure that the research questions are grounded in the core problem identified in this study, we structured the evaluation to directly address the challenges associated with coordinating group navigation in shared virtual environments. Specifically, the evaluation focused on how the proposed method supports users in understanding navigation cues, maintaining group cohesion, and transitioning smoothly between group and individual movement—issues highlighted as limitations in prior work. First, we examined the adaptability and overall practicality of the approach to determine whether it can be effectively integrated into real-world group navigation scenarios. To address the problem of unclear or ambiguous wayfinding cues, we evaluated the clarity and interpretability of preview avatars and animated paths, assessing whether users could efficiently recognize intended routes and destinations. We further investigated how transitions between group and individual navigation modes influence spatial organization and user comfort, including whether an adjustment in f-formations is necessary. Because perspective and shared awareness are central to group coordination, we assessed the contribution of a distant third-person viewpoint to user orientation, group cohesion, and navigation experience. Additionally, we examined how incorporating customized avatars and voice communication supports social presence and collaborative interaction, both of which are vital for effective group movement. Finally, we evaluated potential VR-induced symptoms to determine whether the proposed approach introduces discomfort or usability barriers. These evaluation dimensions map directly onto the gaps identified in existing VR navigation research and collectively informed the formulation of the following research questions (which are also considered in comparison to teleportation and steering techniques):

- **RQ1**: How does the proposed group navigation approach perform in real-world scenarios in terms of usability, immersion, and efficiency?
- **RQ2**: To what extent do preview avatars and animated paths support user comprehension of navigation targets, as measured by perceived clarity and task accuracy?
- **RQ3**: How do transition dynamics between group and individual navigation modes influence spatial arrangement and user adaptability?
- **RQ4**: What is the effect of the distant third-person view on spatial awareness, group cohesion, and navigation comfort?
- **RQ5**: How do customized avatars and voice chat influence communication effectiveness, sense of presence, and perceived realism?
- **RQ6**: What types and levels of VR-induced symptoms (e.g., discomfort, nausea, disorientation) are reported when using the proposed approach?
- **RQ7**: How does the proposed group navigation method impact engagement, enjoyment, and fun, compared to traditional VR navigation methods?

The remainder of this paper is organized as follows. Section 2 reviews the literature, and Section 3 describes the methodology. The results and discussion are presented in Sections 4 and 5, respectively. Finally, the conclusions and areas for further study are outlined in Sections 6 and 7.

2. Literature review

2.1. Group navigation in VR entertainment systems

Group navigation in VR has several implications in diverse domains, including remote collaboration, education, and entertainment. For example, it can improve remote collaboration in collaborative work settings and allow geographically distant teams to collaborate virtually [18]. Matthes et al. [19] proposed a collaborative VR Neurorobotics Lab wherein local and remote users can participate in research in the neurorobotic field. Similarly, group navigation can facilitate interactive simulations and group-based learning in training and educational settings.

In the entertainment domain, group navigation plays a crucial role in immersive multiplayer gaming and social VR platforms. Effective group navigation enhances team coordination and strategy execution in games like *Among Us*, *Overwatch*, and *Escape From Tarkov*, where teamwork and communication are critical. While these examples showcase the importance of group navigation, existing research often lacks thorough evaluations on how different user experience factors, such as social presence, immersion, and satisfaction, are impacted during collaborative navigation [20]. For instance, current studies do not sufficiently address how players adapt to group navigation techniques or how such techniques influence the perceived enjoyment of gameplay.

Social VR platforms, including *VRChat*, *Rec Room*, and *Horizon Worlds*, also rely on effective group navigation to provide shared, immersive experiences [21]. These platforms enable users to socialize, participate in group activities, and explore virtual environments collaboratively. Deighan et al. [22] noted that the use of VRChat enabled individuals to engage in social interactions, diminish negative thoughts, and establish robust social connections and bonds with others. However, challenges persist, such as synchronizing movements between multiple users in real time and reducing the likelihood of disorientation in large virtual spaces [23]. Technical issues such as network latency, can disrupt the seamless execution of group movements, similar to [24] where the authors reported losing players' positions in a virtual environment due to the lack of stability stemming from technical glitches.

Virtual events, such as concerts, conferences, and trade shows, are another area where group navigation can have a significant impact [21]. Lo et al. [25] highlighted that navigation generated a stronger sense of presence among participants in a virtual concert. This enhancement led to higher satisfaction levels and a greater intention to attend concerts. In virtual events, users often navigate large and complex environments, and effective group navigation can help ensure that attendees stay together and have a cohesive experience. For instance, during a virtual concert, improved group navigation can allow friends to explore the venue together, find their seats, and enjoy the performance without getting separated. Similarly, in virtual conferences and trade shows, group navigation can facilitate networking and collaboration, enabling attendees to move between sessions and exhibits more efficiently.

2.2. Group navigation techniques in VR

Group navigation in VR can take different forms, depending on the specific application or scenario. Users in the same VR environment can physically move together in the virtual space. In some cases, group navigation entails teleportation, wherein individuals can immediately change their location in a virtual environment. This can help to overcome physical restrictions and successfully explore expansive areas. Users can maintain their relative locations and move in groups when they teleport together. Teleportation is a popular navigation technique in VR due to its ability to reduce motion sickness and allow for rapid traversal of large virtual spaces. However, it can pose difficulties related to spatial awareness and immersion [17]. Al Zayer et al. [15] stated that users may neglect spatial details and fail to recognize important contextual cues in teleportation-based systems. Weissker et al. [16] presented a solution based on the jumping approach for group navigation in distributed virtual environments, and assessed the solution in terms of comprehensibility, obstacle avoidance, and target formation adjustment. The proposed solution achieved promising results in terms of these metrics. However, as mentioned previously, other aspects and modifications must be explored in group navigation to investigate whether the proposed techniques can be enhanced (**RQs 3 and 4**). Weissker et al. [26] proposed a technique in which users can teleport together while holding their hands virtually. Although users who are close friends may appreciate this method, it can result in discomfort for people who are not acquainted with each other. Moreover, the requirement to press the grip button continuously to sustain the grouping could be another disadvantage.

Steering-based navigation techniques allow for more continuous movement through virtual environments. Martinez et al. [27] categorizes steering-based methods into several groups including head, hand, lean, and joy-stick directed, with the last group being the most commonly explored approach. The common issue with steering is that it seems to cause cybersickness more compared with other locomotion techniques [28]. This trade-off between continuous movement and comfort is a major limitation that needs further exploration, particularly in the context of group navigation where user comfort can significantly affect collaborative experiences.

The World-in-Miniature approach provides users with a scaled-down version of the virtual environment to aid in navigation and spatial awareness. Chheang et al. [29] proposed a world-in-miniature approach for group navigation in a VR environment. The proposed approach performed well in terms of task completion duration and usability. However, this approach was evaluated only in terms of usability with regard to the role of the guide. Other aspects, such as long-distance navigation and target formation, were not explored in this study. Berger et al. [30] stated that world-in-miniature-based navigation improves spatial comprehension and reduces motion sickness when traveling virtually. Moreover, Nam et al. [31] further explored WIM-based navigation, demonstrating that it can improve spatial comprehension and reduce motion sickness during virtual travel. Brument et al. [32] conducted a study comparing two group navigation techniques parabola-based group jump and WiM group teleport. They found that both techniques resulted in comparable spatial awareness scores, which increased over time.

Overall, group-navigation research is crucial because it advances the creation of more immersive, interactive, and socially engaging VR experiences. This allows users to move and engage in virtual environments, thereby promoting cooperation and communication [33]. Rasch et al. [34] highlighted the growing attention being paid to research in the field of group navigation, stating the need for further research in this field. In this regard, Jensen [35] mentioned the need for an investigation to facilitate participant navigation in virtual environments. Challenges such as network latency, real-time synchronization of group movements, and scalability have received little attention in existing studies. Additionally, current research lacks a comprehensive examination of user experience aspects, including efficiency, safety (**RQ6**), attention-guiding mechanism, and entertainment (**RQ7**). Future research could explore adaptive group navigation systems that respond to user behavior, preferences, and physiological states. For instance, AI-powered navigation systems could analyze group dynamics and automatically adjust navigation techniques to optimize user engagement. Similarly, integrating physiological sensings, such as eye-tracking and heart rate monitoring, could help detect discomfort and adjust navigation methods in real-time. Furthermore, stronger connections between group navigation techniques and entertainment applications, such as multiplayer games and social VR platforms, are needed. Existing studies often overlook the specific challenges and opportunities within these contexts, such as maintaining group cohesion during fast-paced gameplay or enabling seamless exploration in complex virtual environments. By addressing these gaps, researchers can better understand the role of group navigation in enhancing entertainment-focused VR experiences.

3. Methodology

Because the proposed approach covers several aspects, the methodology section is divided into different sections: locomotion technique, group representation, guidance elements, occluded areas, and the transition between individual and group navigations. Subsequently, the evaluation approach and experimental procedure are presented.

3.1. Locomotion technique

As the primary component of any navigation method, the locomotion technique developed in this study combined a steering method [36] with the use of an out-of-body camera [37]. Teleportation, the most common method of locomotion, was not chosen as this mode of motion does not exist in real life; moreover, studies have also debated that teleportation disrupts the sense of presence [38]. The absence of optical flow during viewpoint transitions also hinders path integration, a technique for estimating the distance traveled, thereby leading to potential spatial disorientation [39]. While we acknowledge that VR presents unique physiological challenges, continuous locomotion remains a familiar and intuitive navigation paradigm, widely used not only in real-world analogs but also across non-VR games. Although non-VR games do not face the same motion sickness constraints, their reliance on continuous motion mechanics has shaped user expectations for fluid movement and environmental continuity.

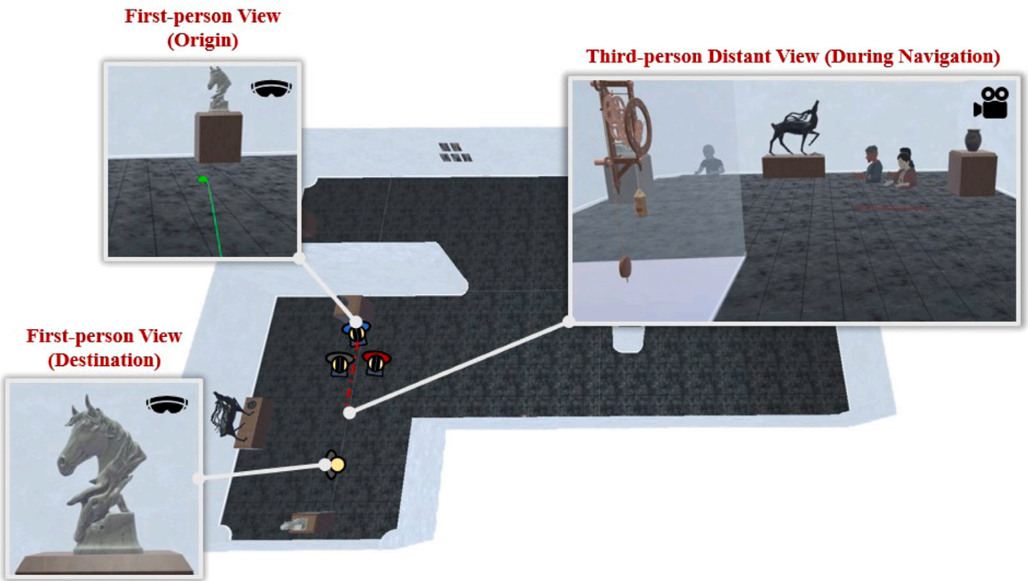

Fig. 1. Overview of the group navigation technique. The figure demonstrates the navigation process, beginning with the first-person view, switching to the third-person distant view (out-of-body) during navigation, and returning to the first-person view. Additional incorporated elements include customized avatars, preview avatars, and an animated path.

As a form of continuous locomotion, steering serves as a flexible analogy for performing virtual travel by consistently indicating the desired speed and direction of movement, resembling the operation of a real-world vehicle. However, steering introduces a sensory mismatch because the visual motion generates conflicts owing to the absence of a corresponding vestibular sensation. This discrepancy is considered to be a potential cause of motion sickness symptoms in VR [28]. In addition to the steering method, a distant third-person camera was also used. The distant third-person camera is a camera perspective or viewpoint within a VR environment, where the camera is positioned at a distance from the virtual avatar of the user. Unlike the first-person perspective, in which the camera is positioned to indicate the viewpoint of the user, a distant third-person camera provides an external or overhead view of the virtual scene. This perspective of the camera allows users to observe their avatars and the surrounding environment from different angles, providing a broader context and facilitating better spatial awareness and navigation within the virtual space. The out-of-body camera offers a continuous avatar representation, which helps reduce sickness symptoms induced by the steering method. Moreover, the distant third-person camera shows an animated trajectory to better visualize the travel between the origin and the destination. Thus, an animated trajectory is displayed through the camera whenever the users navigate the VR environment. There are trade-offs between steering and teleportation. In the context of group navigation — where spatial awareness, coordination, and social presence are crucial — continuous locomotion offers advantages that align better with the system's goals. Our design is informed by emerging trends in group VR research, which explore various modified locomotion strategies such as steering with virtual collision avoidance, scene transitions, and multi-ray jumping to balance realism, presence, and comfort [21].

In terms of defining the speed of animation, authors considered aspects namely realism, technical constraints, and iterative testing. Regarding realism, avatars' movement must be based on the human scale which defines the standard walking speed as 1.4 - 1.5 m/s [40]. Concerning the performance of the developed program and device capabilities, high speed may contribute to jittery animation, particularly for the steering locomotion technique. That said, switching the camera during navigation makes it less prone to face such phenomena. After iterative testing, a value of 2 m/s for speed showed an optimal balance between smoothness and efficiency. Fig. 2 illustrates the proposed locomotion technique by showing a first-person view before navigation, switching to a distant view during navigation, and finally switching back to the first-person view when the users are at the destination.

For the selection of a distant camera, the line of sight from the camera to the path to be traversed from the origin to the destination was checked, and the camera with the highest score was activated during navigation, using Cinemachine Unity Package. Fig. 3 indicates an example where camera 1 is selected as it achieves a higher score than camera 2, because, regardless of the presence of transparent materials, it offers a greater degree of line of sight for the path from A to B. This approach was employed in addition to the incorporation of transparent materials (refer to Section 3.4) to minimize the transparent objects and avoid potential confusion. In terms of the number of cameras used, two cameras were chosen as sample points in the current setup; however, this number can be adjusted based on the complexity of the scene. In simpler environments, fewer cameras may suffice, while larger or more intricate scenes may benefit from additional cameras to ensure optimal navigation support. These cameras are currently positioned at fixed points of interest, but they could be made dynamic in future iterations, adjusting their positions in real-time to maintain a clear line of sight as the group moves.

3.2. Group representation

To represent users within an environment, Weissker et al. [16] employed an abstract representation consisting of a virtual head, torso, and controllers. However, the impact of the level of avatar detail on the presence and effectiveness of group-navigation methods must also be investigated. Synchronized movements are associated with improved interpersonal trust [41] and enhanced collaboration [42]. Therefore, we employed high-fidelity avatars offered by the Meta Avatar SDK, Fig. 4. Avatars are virtual representations of users in a VR setting that have been created with attention to detail and realism. These avatars strive to replicate the visual characteristics, actions, and gestures of real people. By including facial expressions and bodily movements, higher-fidelity avatars compared to previous studies heighten the feelings of presence and immersion in a virtual environment. Customizations such as skin tone, hair style, face shape, and clothing were considered, supporting the social dynamics. This enhanced realism enables users

Fig. 2. The proposed locomotion technique. The figure illustrates the camera change between the first-person view and third-person distant view during locomotion.

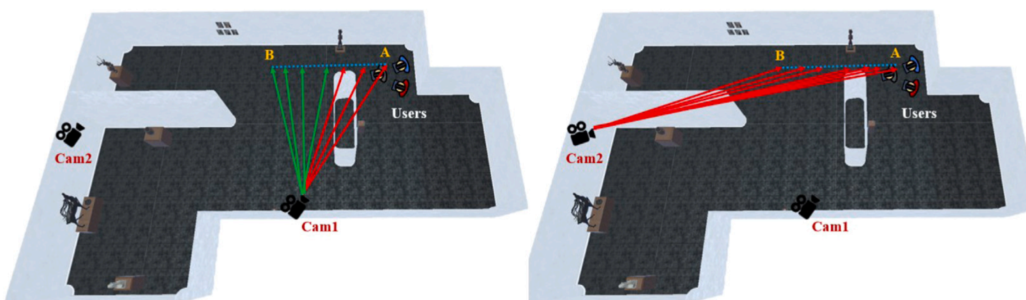

Fig. 3. Camera selection mechanism based on line-of-sight visibility. The system evaluates the traversal path from the origin (A) to the destination (B). In this example, Camera 1 is selected over Camera 2 as it maintains a clearer line of sight to the path, minimizing occlusion from environmental obstacles.

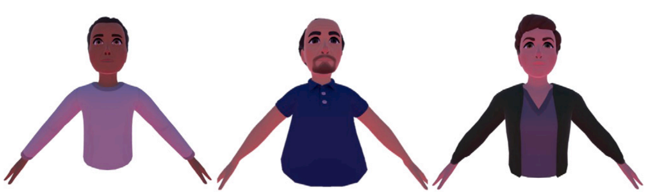

Fig. 4. Examples of the avatars provided by the Meta Avatar SDK.

to better recognize and interact with each other within the environment. Studies have shown that avatar customization enhances player enjoyment, engagement, and presence [43]. Moreover, customization enables users to express their unique personalities and preferences. Tarr et al. [44] conducted a user study to examine the effects of the synchronous and asynchronous movements of a small group of avatars in a virtual environment. Their findings revealed a higher level of social closeness during synchronous movements. Moreover, in [45], the authors stated that synchronizing bodily movement with the sounds of a virtual counterpart further boosts the likeability of a partner; consequently, voice chat was also incorporated into the technique using Photon networking asset. By employing avatars and communication features such as voice chat, users can interact in dynamic, immersive virtual environments, which helps in building realistic and cooperative virtual experiences [46].

3.3. Guidance elements

In accordance with the underlying goal of group navigation, which is to avoid missing opportunities and confusion, preview avatars and animated paths were added to the environment as acknowledging elements, as illustrated in Fig. 5. Guidance features are design elements or functionalities that aim to enhance the user understanding, awareness, and recognition of certain aspects of the VR experience. Among the attention-guidance methods, diegetic mechanisms refer to elements incorporated within the narrative or the environment itself. These mechanisms utilize the movements of characters or objects within the immersive environment [47]. Thus, preview avatars and animated paths can be related to diegetic mechanisms, even though they do not act independently and are dependent on the users.

Showing a preview avatar at a destination is a technique used to enhance user comprehension in VR environments. When users navigate a virtual space, they may encounter challenges in understanding their intended destinations. By providing a preview avatar at the destination for each user separately according to their current group formation, users can visually preview the appearance or position of their avatar before reaching a specific location. The reasons behind choosing a single avatar representation covered aspects of simplicity, clarity, and user experience, enabling users to focus on the destination without unnecessary visual information about other members of the group [48]. Rendering multiple avatars for each user may be resource-intensive as well. The preview avatar serves as a visual indicator that allows users to better understand their destination. It helps users comprehend where they are heading and provides them with a clear visual reference for navigation. The inclusion of a preview avatar contributes to the overall comprehensibility of the VR experience by reducing ambiguity and improving spatial awareness. It helps users develop a mental map of the virtual space and aids in navigation, particularly in complex or unfamiliar environments.

Animated paths serve as acknowledging features by directing users along predefined trajectories or routes. They help users comprehend the intended navigation paths, offer visual cues, and reduce potential confusion or disorientation in complex virtual environments.

Fig. 5 shows the two acknowledging elements when navigation is conducted. As shown, an avatar is spawned at the destination, providing information on the exact point to which the users must navigate. Meanwhile, an animated path is rendered from the origin to the destination as the avatars steer toward the destination.

3.4. Occluded areas

Switching between different camera views, which was discussed earlier, may not always be applicable, primarily because using several

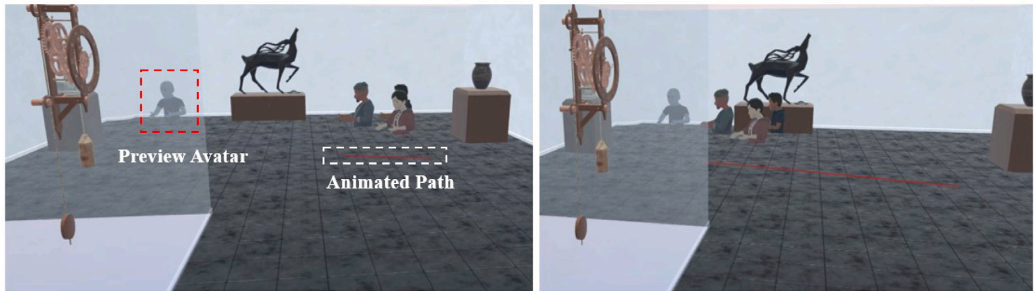

Fig. 5. Animated path feature and preview avatars. The animated path is depicted in red, while the preview avatars are displayed from the instantiation of the navigation until the end at the destination.

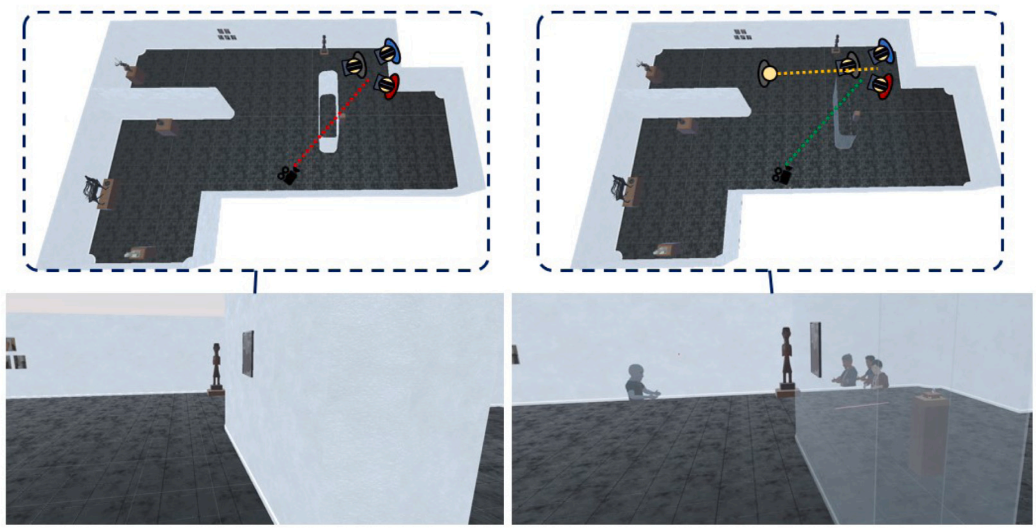

Fig. 6. Transparent Materials. When an object obstructs the line of sight of the distant third-person camera, the material is set to transparent, allowing users to see their animated avatars navigating toward the destination.

cameras in a scene may be computationally costly and the line of sight may still be completely or partially blocked by an object. Therefore, we decided to incorporate the conversion of materials into transparent materials when they block a part of the path. Previously, transparent materials were employed to avoid collisions between avatars and objects [16]; however, in our approach, they were used to provide a line of sight between the camera and the avatars. Transparent materials in VR are virtual objects or surfaces that allow light to pass through, thereby creating a see-through effect. These materials can be used to simulate glass, water, or other translucent substances in virtual environments. As shown in Fig. 6, after choosing camera 1 based on the line of sight, a section of the path is still blocked by walls. Therefore, the material of the blocking walls is changed to be transparent during navigation so that users can view the origin, resulting in an increase in the comprehensibility of the solution. The degree of transparency was set to 50% to ensure visibility while maintaining a sense of the object's presence and the transparency effect was activated from the beginning of the navigation until the end so that participants were informed about the origin and destination and the traversed path to get to the destination.

3.5. Transition between individual and group navigation

The benefits of group navigation have already been discussed. Wang et al. [49] stated that users prefer individual locomotion to movements controlled by others, with the exception of specific circumstances such as guided tours. Therefore, a transition feature was incorporated into the navigation technique so that users could perform both individual and group movements. This feature is studied in a previous study, however, it was offered as a feature to which users have access at any time, which may not be fully aligned with the idea of guided tours and may hinder coordinating the group for the guide. Thus, a proximity constraint is applied to this feature in our paper which activates the transition only if users are at a particular distance from a point of interest (POI). The proximity is calculated dynamically based on the size of each object, ensuring that the transition area is contextually appropriate. A collider detects when participants enter the proximity constraint of an object, triggering the transition and enabling limited individual locomotion.

Transitioning between group and individual navigations when visiting a POI in a VR environment allows users to switch seamlessly between collaborative exploration and individualized experiences. When users encounter a specific POI of interest, they can temporarily break away from the group navigation and explore it on their own. This transition offers several advantages. It provides users with the freedom to allocate time and attention based on their individual preferences. Furthermore, transitioning to individual navigation at a POI provides users with a more focused and immersive experience. To facilitate a transition, the guiding system can activate limited individual navigation near a POI after arriving at the destination. By controlled navigation, it is meant that the user has access to individual movements within a buffer of 2 to 3 Unity units around a POI. The range of the buffer varies according to the type and size of a POI. Clear communication and synchronization must also be ensured during the transition. The gestures offered by the high-fidelity avatars, along with voice chats, were effective in this case.

3.6. Evaluation

As navigation plays a crucial role in user interaction within virtual environments, a major objective of navigation techniques is to minimize adverse impacts on user well-being. When users do not have active control over their travel, an increase in the occurrence of sickness may be observed [50]; consequently, evaluating group-navigation techniques in terms of induced symptoms is of paramount importance. Moreover, the suitability of the proposed solution must be evaluated in several aspects such as immersion and efficiency [51] to verify the effectiveness of the incorporated features.

To evaluate all aspects of the proposed solution, a customized questionnaire and set of open questions were designed with some adaptations to current questionnaires by considering design notes provided in [52]. This may raise validity concerns, however, it is common practice to adapt existing questionnaires for new research purposes, especially when certain components from established questionnaires do not fit research components. In this regard, incorporating relevant aspects from available questionnaires into a new one allows researchers to maintain the validity and reliability of the questionnaire while ensuring that it aligns closely with the specific focus of the study. To ensure the validity of the questions and their alignment with the goals of the study, we employed a content validation process. We, with some expertise in the research field, first held regular meetings to critically review and refine the questionnaire. Following this, two experts in questionnaire construction in HCI and psychometrics were recruited to provide advanced modifications and guidance. Expert feedback was collected through structured forms that required each expert to rate the relevance and clarity of each item. Based on this input, a Content Validity Index was calculated and items with low agreement were revised or removed following further discussion. To ensure reliability, the questionnaire items were sourced from widely accepted standardized tests. All items in this customized questionnaire were presented as statements to be rated on a 5-point Likert scale. The questionnaire consisted of five main sections: usability, immersion, efficiency, safety, and attention-guiding mechanism. We tried to incorporate different metrics as the categorization of the locomotion metrics highlights aspects of travel performance, cognitive performance, biometrics, usability, user experience, discomfort, presence, effort, emotion, and preference by [27]. For transparency and replicability, the complete list of questionnaire items is provided in tables in the Results section.

Usability: The usability section comprises two parts, namely user experience and in-game assistance. The first part includes four questions from the user-experience section of the VR neuroscience questionnaire (VRNQ) and one question from the user-experience questionnaire (UEQ). The VRNQ was created to capture subjective feelings and sensations associated with experiencing VR environments from a neuroscientific perspective in four domains: user experience, game mechanics, in-game assistance, and VR-induced symptoms and effects [53]. The UEQ is commonly used to assess the overall user experience in a variety of interactive systems, including VR [54]. It measures the perceived usability and hedonic qualities of a system, and encompasses factors such as attractiveness, efficiency, novelty, and stimulation [55].

Immersion: This part consists of seven questions adopted from the presence questionnaire and one question from VRNQ. In this study, the revised version of the presence questionnaire by the Cyberpsychology Lab associated with the Université du Québec en Outaouais (2004) was employed to measure the sense of "presence" — relating to the human response to immersion [51] — experienced by users in a virtual environment.

Efficiency: To determine the efficiency, four questions were designed targeting high-fidelity avatars, voice chat, and individual locomotion. High-fidelity avatars and voice-chat-related questions were used to assess their performance from a communication perspective.

Safety: This section focuses on the induced symptoms caused by VR. To assess such aspects, the simulator sickness questionnaire is frequently used [56]. However, some assumptions have been made regarding the validity of the baseline assessment [57], which may not fully capture the unique factors that contribute to discomfort in VR. Therefore, we incorporated the symptoms section of the VRNQ into the customized questionnaire. It is important to note that the scores for the safety questions were reverse-coded to ensure accurate interpretation of the results.

Attention-guiding mechanism: This part examines the effectiveness of the attention-guiding mechanism, that is, preview avatars, in two subscales namely utility and affect, and the questions were adopted from [58]. Utility and affect provide information on the satisfaction and emotions resulting from experiencing a feature, respectively. Additionally, the scores for three questions related to the attention mechanism section were reverse-coded to maintain consistency in the data analysis.

Entertainment: To evaluate the entertainment aspects of the group navigation approach, engagement, enjoyment, and fun metrics were targeted each with a question.

Open questions: In addition to the scaled questionnaire, we considered three questions for further investigation. These were presented as open-ended questions that prompted participants to provide qualitative, free-text responses in their own words. To analyze the qualitative data from the open-ended questionnaire responses, initially, the authors conducted several meetings to review and cross-check the transcriptions of responses to ensure accuracy. Everyone independently read through the responses multiple times to gain a comprehensive understanding of the data and identify key patterns. During this stage, notable phrases or sentences were highlighted as initial codes. For instance, recurring ideas such as "individual locomotion being sufficient" or "adjusting f-formations for social integration" were identified. The authors then collaboratively organized these codes into themes by grouping similar responses. This iterative process allowed for the refinement and combination of themes, ensuring that they accurately represented participants' perspectives. For example, responses concerning "f-formation adjustments" emerged as a strong theme under the question regarding spatial arrangements (**RQ3**), while themes such as "engagement during individual exploration" were extracted under the question on the usefulness of individual locomotion. The identified themes and corresponding participant quotes were systematically reviewed and refined for clarity and coherence. This process enabled us to report general perspectives while preserving the diversity of individual responses.

3.7. Implementation

The core of the system was built using the Unity game engine V2021. Camera switching functionalities were implemented using the Cinemachine package V2.8. To create high-fidelity avatars and enhance user embodiment, the Meta Avatar SDK V24 was employed, enabling realistic and customizable character representations. For voice chat communication and multiplayer server functionalities, the Photon package was utilized. VR interactions, including locomotion and environmental engagement, were facilitated through the Meta Interaction SDK V69. The system was tested using the Quest 2 VR headset, offering 1832x1920 px per year resolution, 90 Hz native refresh rate, and 6 degrees of freedom.

3.8. Procedure

Twenty participants (ten females and ten males) aged between 23 and 34 years (M=26.1, SD=3.41) participated in the experiment, a sample size equal to or higher than similar studies (6 in [26], 12 in [16], and 20 participants in [29]) with a power of around 0.6 with an alpha level of 0.05 and effect size of 0.5. According to the self-report, participants had some experience (wearing VR headsets several times a week, and using multi-player VR apps several times a month) in the VR field, through either academic exposure or entertainment

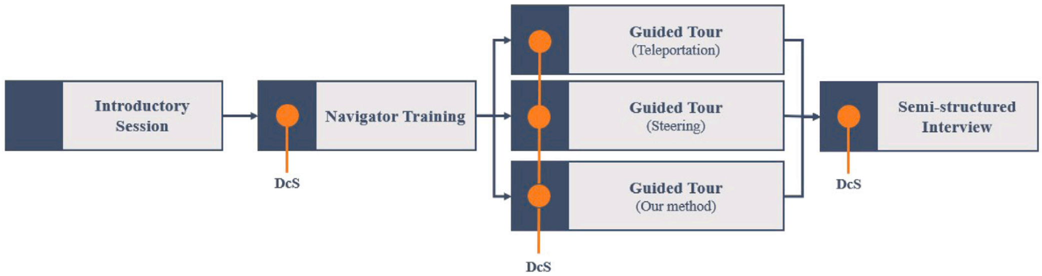

Fig. 7. Framework of the experimental procedure. The flowchart outlines the study phases: an introductory briefing and training session, followed by a counterbalanced evaluation of three locomotion techniques (Teleportation, Steering, and Group Navigation), concluding with semi-structured interviews.

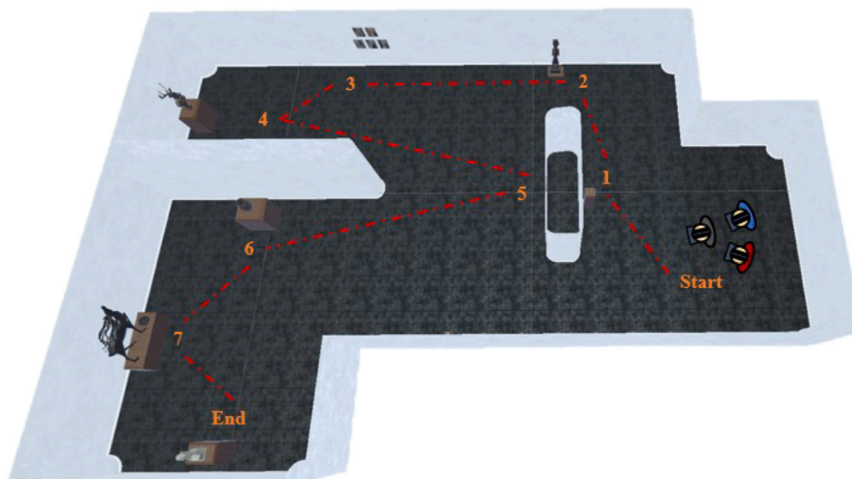

Fig. 8. Virtual museum environment and traversal path. The map displays the layout of the scene, including the location of Points of Interest (POIs) such as statues and art frames. The numbered markers indicate the specific order in which participants were required to visit these POIs.

purposes. Consequently, we expected a higher probability of obtaining reliable feedback from the participants after experiencing the system. Participants were informed of the experimental protocol via a consent form before beginning the experiment.

To evaluate our approach for VR-based entertainment applications, we set up a scene in Unity where users had to visit several Points of Interest (POIs) as if they were visiting a museum in the form of tourists. This scenario was chosen to simulate a real-world tourism experience, allowing us to assess how well our group navigation techniques enhance user engagement, enjoyment, and overall satisfaction in an entertainment context. Moreover, different gamification techniques are being applied in the field of tourism education [59] making this area worthy of exploring to evaluate group navigation for VR-based entertainment applications.

The overall framework of the experimental procedure including the data collection stage is illustrated in Fig. 7. The procedure begins with an introductory session to explain the idea of the experiment, followed by a training session to educate users on how to use the system. Subsequently, three separate experiment sessions were held, each targeting a specific locomotion technique (teleportation, steering, and the proposed group navigation approach). To minimize order effects and bias, the experiment employed a counterbalanced design. Participants were randomly assigned different orders of experiencing the three locomotion techniques. This ensured that the order of exposure did not systematically influence the results. The teleportation technique was implemented using the provided approach by Meta SDK. Regarding the steering method, the joystick-directed approach was incorporated into the system. Fig. 8 shows the order of visiting POIs as well as the designed environment. The scene was designed to represent a museum; therefore, several statues and art frames were added to the scene as

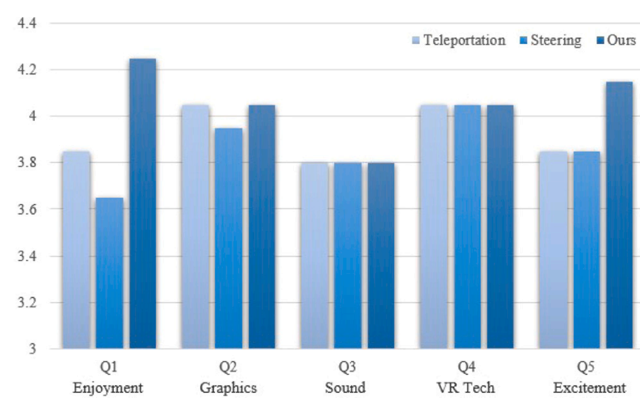

Fig. 9. Mean scores of usability questions in user experience. No statistically significant difference was found between the groups ($F(2,17) = 0.14$, $p = 0.87$, $\eta^2 = 0.02$).

POIs. Semi-structured interviews were conducted after the participants visited the environment. Notably, discomfort scores were measured at each stage by asking the participants the following question: "On a scale of 0 to 10, 0 being how you felt coming in, 10 being that you want to stop, where are you now?" as adopted from [16]. The term "discomfort score" refers to a metric used to determine how uncomfortable an experience was for users before, during, or after the VR experience. It seeks to measure the discomfort or unpleasant feelings that could result from several factors, such as motion sickness or any other type of discomfort connected to the VR system or the virtual environment itself.

Table 1
Statistical summary of the usability questions in user experience.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
What was your level of enjoyment of the VR experience?	3.85	0.72	3.65	0.72	**4.25**	0.76
How was the quality of the graphics?	**4.05**	0.38	3.95	0.49	**4.05**	0.38
How was the quality of the sound?	**3.80**	0.79	**3.80**	0.71	**3.80**	0.81
How was the quality of the VR technology overall (hardware & peripherals)?	**4.05**	0.21	**4.05**	0.30	**4.05**	0.21
How exciting/motivating was using the VR?	3.85	0.73	3.85	0.72	**4.15**	0.72

4. Results

In this section, the responses of the participants are illustrated and their general perspectives are reported. The data was analyzed using Python for statistical calculations, including one-way analysis of variance (ANOVA), post-hoc tests, effect size, and Cronbach's alpha. Before conducting inferential analyses, we tested for normality using the Shapiro–Wilk test. The results indicated no significant deviation from normality.

4.1. User experience

Table 1 shows the statistical summary of responses in the user-experience section for the usability questions. Cronbach's alphas were above 0.82 for all three settings which fall into the acceptable range of reliability according to [60–62]. In terms of our method, initially, the responses were considered to be predominantly positive (mean value of 4.06), see Fig. 9. Among the five questions, the question regarding the level of enjoyment gained the highest score, while the quality of sound exhibited the lowest score. This suggests that while the system was enjoyable, technical limitations such as audio quality may have hindered an otherwise seamless experience. The results of the user-experience sections in the customized questionnaire revealed acceptable satisfaction levels. In comparison with the teleportation technique, the level of enjoyment and subsequently the excitement of using VR were noticeably lower probably because of the disruption of the sense of presence [38] caused by the teleportation approach. A one-way ANOVA was conducted to compare the effect of the three navigation methods on user experience. The results indicated that there was not a statistically significant difference between the groups, $F(2,17) = 0.14$, $p = 0.87$, $\eta^2 = 0.02$. This small effect size confirms that the navigation method itself accounted for only 2% of the variance in user experience scores, reinforcing the lack of a strong, practical difference between the three conditions. Although not statistically significant, it seems the steering method outperforms teleportation slightly in terms of user experience, likely due to its continuous, natural movement, which resonates better with real-world navigation.

4.2. System assistance

Table 2 shows the statistical summary of responses recorded in the second section of the usability questions (system assistance). In general, the participants agreed on the helpfulness of the employed elements in our solution (the mean value of 4.35 was obtained - Cronbach's alpha was 0.78). Transparent materials and animated paths helped inform the users of their locations during navigation (**RQ2**). In addition to transparent materials, the results indicated that preview avatars were successful in making users aware of the process, which was in accordance with the results of Weissker et al. [16] (**RQ2**). In terms of the switch to third-person distant view, which was an unexplored element in group navigation, and the continuous camera view in steering, the participants responded that these camera views helped inform them of the destination (**RQ4**). Overall, in the assistance part of the proposed solution, preview avatars and third-person distant view achieved higher maximum scores than transparent materials and animated paths. The camera view in the teleportation technique was the least effective approach in terms of informing users of the destination because it lacks consistent visual continuity. These findings suggest that incorporating dynamic and multi-perspective views significantly enhances user awareness during group navigation.

4.3. Immersion

Cronbach's alpha values for immersion responses were 0.81 (our method), 0.75 (steering), and 0.76 (teleportation), indicating acceptable reliability. As shown in Table 3, our method obtained higher values in six out of seven questions entailing an acceptable level of immersion, which is also demonstrated by the results of the last question. However, the lowest scores were obtained when the participants were asked about the consistency between their VR and real-world experiences, see Fig. 10. The switching of the camera while navigating, which resulted in inconsistency with real-world experiences, could have caused this result. In this aspect, the steering took the lead whereas, as expected due to its continuous, real-world-like movement. The teleportation technique received the lowest score as it is not experienced in the real world, consistent with findings in [38], as the abrupt "jumping" between locations inherently disrupts immersion. The lowest score regarding the compelling level of the movement in the virtual environment is also another testimony that teleportation hinders the immersion aspect of experiencing virtual environments. Similarly, the questions regarding the effortless and natural feeling of the movement mechanism received lower scores than the other questions in all three approaches. Moreover, the difficulties in overcoming the current limitations of VR devices could be another factor influencing the immersion aspect of the solution. For the question on the ability to anticipate subsequent actions, the responses indicated an acceptable level that pertained to the acceptable comprehensibility level of the proposed approach while steering ranking second. Although the results illustrated an acceptable level of immersion, certain questions, when considered together, exhibit areas that require further investigation on this aspect of the group-navigation approach. To compare immersion scores across the three methods, a one-way ANOVA was performed. The results showed a statistically significant difference between the groups, $F(2,17) = 3.28$, $p = 0.041$, $\eta^2 = 0.28$. This difference was accompanied by a large effect size, suggesting that the choice of navigation method had a substantial and practically meaningful impact. Tukey's HSD post-hoc test revealed that our method was rated as significantly more immersive than the teleportation method ($p < 0.05$). No other significant differences between pairs were found. Further exploration of the reasons behind lower immersion scores revealed that participants found the combination of camera switching and VR limitations challenging. For future implementations, minimizing transitions and leveraging hardware advancements may address these issues and improve immersion levels.

4.4. Efficiency

When considering the efficiency of the proposed approach, similar to the aforementioned aspects, the participants provided positive feedback toward our approach (mean value of 4.23 - Cronbach's alphas were above 0.70 for all settings), see Fig. 11. As for efficiency, the perspective revealed that no noticeable difference was recognized

Table 2
Statistical summary of the usability questions in system assistance.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
How helpful was the animated path in informing you of the destination?	–	–	–	–	**4.15**	0.65
How helpful was the camera view in informing you of the destination?	3.3	0.95	**4.30**	0.71	**4.30**	0.78
How helpful was the preview avatar in informing you of the destination?	–	–	4.4	0.58	**4.50**	0.59
How helpful were transparent objects in informing you of the navigation?	–	–	–	–	**4.45**	0.49

Table 3
Statistical summary of the immersion questionnaire.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
What is the level of immersion you experienced?	3.80	0.70	4.35	0.47	**4.50**	0.50
How natural was the mechanism that controlled movement through the environment?	3.40	0.66	**3.95**	0.66	**3.95**	0.73
How much did your experiences in the virtual environment seem consistent with your real-world experiences?	3.05	0.38	**3.30**	0.55	3.25	0.45
Were you able to anticipate what would happen next in response to the actions that you performed?	3.30	0.53	3.75	0.53	**3.85**	0.47
How compelling was your sense of moving around inside the virtual environment?	3.20	0.48	3.75	0.43	**3.80**	0.40
How well could you examine objects from multiple viewpoints?	**4.05**	0.66	**4.05**	0.49	**4.05**	0.58
How quickly did you adjust to the virtual environment experience?	3.30	0.43	**3.95**	0.38	**3.95**	0.38

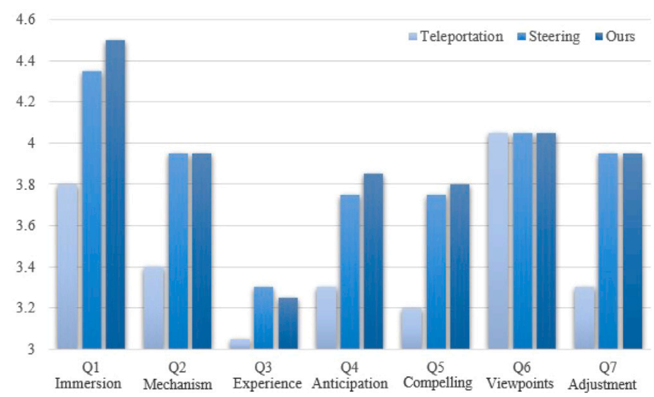

Fig. 10. Mean scores of immersion questionnaire. A one-way ANOVA confirmed a statistically significant difference between groups (F(2, 17) = 3.28, p = 0.041, $\eta^2 = 0.28$). Post-hoc tests revealed our method was significantly more immersive than teleportation.

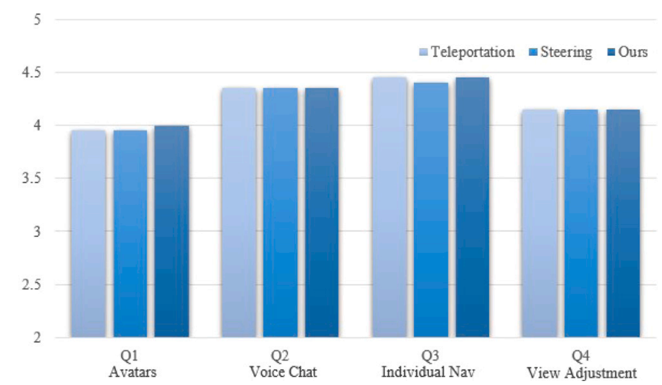

Fig. 11. Mean scores of the efficiency questionnaire. A one-way ANOVA indicated no statistically significant difference in scores among the navigation approaches (F = 0.02, p = 0.98, $\eta^2 = 0.002$).

between the three approaches which was expected as the locomotion technique may not be strongly correlated with aspects such as avatars and voice chat communication. For the efficiency metric, a one-way ANOVA showed no statistically significant difference in scores among the three navigation methods, F(2,17) = 0.02, p = 0.98, $\eta^2 = 0.002$. This negligible effect size confirms that the navigation method had virtually no impact on the perceived efficiency, which aligns with our expectation that these metrics were more related to avatar and voice chat features. As illustrated in Table 4, individual locomotion when visiting a POI exhibited the highest score in teleportation and our method, and the question regarding high-fidelity avatars received the lowest scores in teleportation and steering. Another general perspective highlighted the slight outperformance of teleportation compared with steering. The first two questions can be discussed together as the transition to individual locomotion when visiting a POI can enable users to adjust their views and visit the POI by themselves (**RQ3**). This type of transition offering limited movements when visiting a POI has not been previously explored; therefore, the results highlighted its effectiveness in group-navigation scenarios. For communication within the virtual environment, two questions were used to determine the efficiency of voice chat and high-fidelity avatars, primarily the offered gesture-synchronization features (**RQ5**). The responses indicated that both were efficient, although voice chat was considered more useful. Although the quality of the sound was not considered perfect according to the questions in the user-experience section, voice-enabled communication received positive feedback. Group navigation in VR often requires mechanisms for real-time communication and collaboration through voice chats, text-based messaging features, or even gestures. The results of this part of the evaluation also emphasized the fact that such features must be included in group navigation solutions for VR. In addition to voice communication, the high-fidelity avatars allowed users to observe and identify with each other within a virtual environment, fostering a sense of presence and social interaction. Customization allows users to create a personalized presence, making them feel more invested in the virtual experience [43]. Customized avatars can facilitate social interaction and collaboration among users. Therefore, the customizability features offered in our pipeline can probably positively influence communication by allowing users to better express themselves and engage more deeply with others in the virtual environment. The positive feedback of the efficiency questionnaire about communication through avatars can be a testimony to that. This enhanced emotional communication can lead to more effective collaboration and a stronger sense of social presence, which are crucial for successful group navigation in VR.

4.5. Safety

Table 5 reveals the summary of the ratings on the safety aspect of the three sessions in terms of VR-induced symptoms (**RQ6**). The responses of all three settings received Cronbach's alpha values above

Table 4
Statistical summary of the questions related to efficiency.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
How helpful was the high-fidelity avatar in communication with others?	3.95	0.86	3.95	0.73	**4.00**	0.77
How helpful was voice chat in communication with others?	**4.35**	0.57	**4.35**	0.47	**4.35**	0.47
How helpful was the individual locomotion while visiting a POI?	**4.45**	0.49	4.40	0.73	**4.45**	0.49
How helpful was adjusting the view while visiting a POI?	**4.15**	0.47	**4.15**	0.35	**4.15**	0.35

Table 5
Statistical summary of the questions related to safety.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Did you experience nausea?	**2.25**	1.21	2.95	1.38	**2.25**	1.29
Did you experience disorientation?	2.35	0.57	2.30	0.66	**1.95**	0.58
Did you experience dizziness?	2.55	0.97	2.95	0.74	**2.45**	0.97
Did you experience fatigue?	1.15	0.47	1.90	0.50	**1.10**	0.43
Did you experience instability?	2.05	0.92	2.95	0.76	**1.80**	0.87

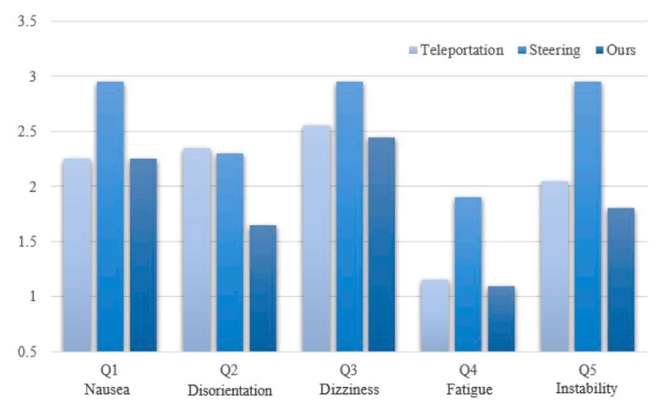

Fig. 12. Mean scores of the safety questionnaire (Lower is better). A one-way ANOVA revealed a statistically significant difference ($F(2, 17) = 3.31$, $p = 0.043$, $\eta^2 = 0.28$), and post-hoc tests confirmed our method was significantly safer than teleportation.

0.78. A one-way ANOVA was conducted to assess the safety ratings (VR-induced symptoms) across the three methods. The results showed a statistically significant difference between the groups, $F(2,17) = 3.31$, $p = 0.043$, with a large effect size $\eta^2 = 0.28$. Tukey's HSD post-hoc test revealed that our proposed approach was rated as significantly safer (fewer symptoms) than the teleportation method. Responses to these questions varied more when compared to those of previous sections, as indicated in standard deviation values. Moreover, no severe symptoms related to fatigue and disorientation were reported in our approach, see Fig. 12. However, three participants experienced the symptoms of dizziness and nausea in all approaches, steering being the most. This is in line with the findings of [28] indicating that teleportation generally induced less cybersickness than steering locomotion. In our solution, it is assumed that these included symptoms are caused by the switch between first-person and third-person distant view during navigation, and in terms of steering, the continuous movement may have resulted in such symptoms. Another reason could be the nature of VR technology, which contributes to such effects, and the minimization of these effects is being actively researched. Overall, the results highlighted that the proposed solution did not result in any adverse effects (mean value of 1.9), and only resulted in a significantly mild feeling of dizziness and nausea.

4.6. Attention-guiding mechanism

The attention-guidance mechanism focused on the suitability of the preview avatar. Cronbach's alpha values were 0.80 and 0.82 for steering and our method respectively. Overall, positive scores were obtained regarding the guidance mechanism provided by preview avatars (**RQ2**), Table 6. Specifically, the responses to the first two questions showed a high level of utility. The other questions targeted the likability aspect of the solution, and the results indicated that the preview avatar mechanism resulted in positive emotions among the participants. No noticeable difference in the suitability of the preview avatar was recognized between our approach and steering. That said, the slight outperformance of our approach may stem from the distant camera view which provides a better opportunity for the preview avatar to fulfill its responsibility to enhance the compressibility aspects of navigation.

4.7. Entertainment

The reliability of the entertainment questions was acceptable, scoring Cronbach's alpha values above 0.81. As shown in Table 7, participants reported being more engaged during the group navigation experience using the proposed approach, which outperformed both teleportation and steering (**RQ7**). The higher engagement in our method suggests that users felt more involved and immersed in the group navigation experience. In terms of enjoyment, our method also scored higher than both the other methods, see Fig. 13. Although the proposed method had the highest fun rating, the margin was smaller compared to teleportation. Steering was rated the least fun, likely due to its association with motion sickness, which might have affected users' overall experience. Finally, a one-way ANOVA was used to compare entertainment ratings. The analysis indicated a statistically significant effect of the navigation method on entertainment, $F(2,17) = 3.3$, $p = 0.041$, $\eta^2 = 0.28$, where the large effect size confirms that the navigation method had a strong, practically meaningful impact on participants' entertainment ratings. Post-hoc analysis with Tukey's HSD showed that our method was rated as significantly more entertaining than the steering method. The significant p-value for the comparison with steering, combined with a large effect size, suggests a robust and practically meaningful difference, with our method being rated as more entertaining.

4.8. Interview

In terms of the open-question section, the answers were almost identical in the three groups, therefore, we report the general perspectives here. For the first question in the open-question section (**RQ3**), *"Do you think the transition to the individual locomotion is satisfactory on its own? Do we need adjustments to f formations?"* 14 participants reported that their individual locomotion was sufficient. That said, others highlighted the priority of f-formation adjustments over individual locomotion or

Table 6
Statistical summary of the questions related to the attention-guiding mechanism.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
I found the presence of the preview avatar distractive.	–	–	1.40	0.58	**1.35**	0.57
I found the presence of the preview avatar disruptive.	–	–	**1.35**	0.57	**1.35**	0.57
I found the presence of a preview avatar to be annoying.	–	–	**1.20**	0.50	**1.20**	0.40
I found the presence of a preview avatar to be pleasing.	–	–	4.00	0.63	**4.05**	0.38

Table 7
Statistical summary of the questions related to entertainment.

Question	Teleportation		Steering		Ours	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
How engaged were you during the group navigation experience?	4.1	0.7	3.55	0.97	**4.55**	0.49
How much did you enjoy the group navigation experience?	3.7	0.64	3.25	0.76	**4.35**	0.47
How fun was the group navigation experience?	3.45	0.49	3.05	0.38	**3.75**	0.69

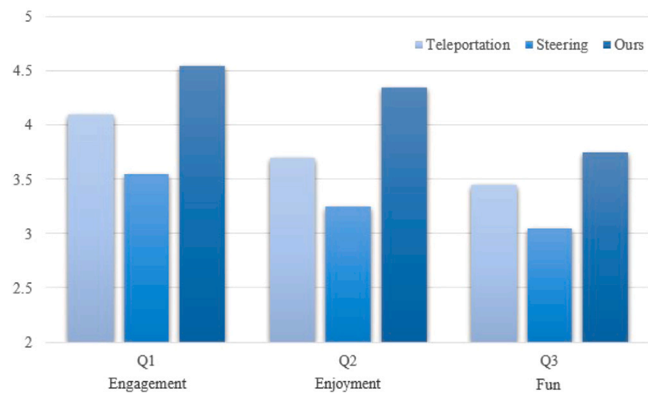

Fig. 13. Mean scores of the entertainment questionnaire. A one-way ANOVA showed a statistically significant difference (F(2, 17) = 3.3, p = 0.041, η^2 = 0.28). Post-hoc analysis confirmed our method was significantly more entertaining than steering.

at least the presence of both in the application by stating *"In some cases, adjusting the formation may be necessary. Therefore, both can be employed."*, *"Sometimes f-formation is required so that the guide can force users to follow a specific formation."*, and *"No, adjusting to f-formations is important for effective communication and social integration."* As stated in one answer, adjusting the spatial arrangement of group members promotes a sense of inclusion in the social group. This type of adjustment ensures efficient information exchange. This is achieved by having a clear line of sight and optimal auditory access to other members. Therefore, the incorporation of both options, individual locomotion, and f-formation adjustments, is preferable.

For the question *"How helpful was the controlled individual locomotion when visiting a POI?"* (**RQ3**), Almost all the participants agreed on the effectiveness of switching to individual locomotion when visiting a POI. Moreover, they considered the degree of freedom as a result of individual locomotion to be satisfying and engaging as proven by the following statements: *"a nice feature to visit the POI by our own tendency "*, *"very helpful. Giving users the ability to view the POI and enjoy a level of freedom while visiting"*, *"Moving independently through a POI allows you to engage more deeply with the surroundings."*, and *"enabling the user to enjoy individual locomotion seems satisfying."* The results indicate that individual locomotion offers personalized exploration of a POI such that the user can check the details of the surroundings and view the POI from different angles, thereby satisfying their interests and curiosity.

Mixed opinions were obtained regarding the attention-guiding mechanism (**RQ2**). According to the answers to *"Would you prefer having external cues such as an arrow instead of preview avatar?"*, 13 participants preferred preview avatars by stating that *"preview avatars, which are digital representations of individuals or guides, can provide a more interactive and immersive experience."*. However, some participants highlighted the need for external cues, such as arrows, for non-expert users. Five participants considered the arrows to be more comfortable and easier to follow. Therefore, we inferred that the performance of preview avatars when compared to external clues, such as arrows, depends on various factors, including user preferences and expertise. However, preview avatars exhibit benefits such as providing a more immersive approach to attention guidance. This can be achieved by offering a sense of companionship and social interaction. If preview avatars are also responsive, they can enhance the attention-guidance mechanism such that they can respond to the actions of users based on their behaviors.

4.9. Overall evaluation

Tables 8 and 9 present a summary of the scores received by our method along with the ANOVA test results. The scores for the safety questions and three questions related to the attention mechanism section were inversed to provide a better interpretation. We can observe that all factors except immersion received relatively good scores, indicating that the proposed method performed well in these aspects. Among the different aspects, the guidance mechanism and system assistance received the highest ratings. As discussed earlier, the switch to a distant view might have influenced the immersion aspect of the solution. In terms of standard deviation, all factors except safety achieved values below 0.65, which is significantly smaller than their mean values. This indicated that scores were clustered around the mean value. However, the safety factor exhibited a standard deviation of 1.05, which showed a marginal spread in scores, as mentioned previously, leaving room for further investigation in future work. When considering the overall scores, the solution received 2233 points out of 2900, which is another testimony to the suitability of the proposed approach.

Thus, a key finding of this study pertains to the transition between individual and group navigations. The inclusion of this feature in the proposed approach was appreciated by the participants as it assigned them a role when visiting a POI, which enhanced their sense of presence in the group. Another finding revealed the positive reception of high-fidelity avatars with voice chat communication, facilitating collaborative interactions that are crucial for effective communication and teamwork. Other features such as animated paths, transparent materials, switching between first- and third-person views, and preview avatars exhibit potential for enhancing group navigation. Overall, it can be concluded from the responses to all the questions that the proposed approach appears to be practical and suitable for real-world scenarios (**RQ1**).

The triangulation of quantitative metrics and qualitative interview data provided some insights. Regarding system assistance, the high

Table 8
Statistical summary of the questionnaires to evaluate our method.

	Usability		Immersion ↑	Efficiency ↑	Safety ↓	Attention-guiding Mechanism ↓
	User Experience ↑	System Assistance ↑				
Mean	4.06	4.35	3.91	4.23	1.91	1.46
STD Dev	0.64	0.65	0.61	0.57	1.00	0.56
Score	406(500)	348(400)	548(700)	339(400)	191(500)	117(400)

Table 9
Summary of one-way ANOVA results for usability, immersion, efficiency, safety, and entertainment ratings across navigation methods.

Questionnaire Measure	F(2, 17)	p-value	η^2 (Effect Size)
Usability	0.14	0.87	0.02
Immersion	3.28	0.041	0.28
Efficiency	0.02	0.98	0.00
Safety	3.31	0.043	0.28
Entertainment	3.30	0.041	0.28

quantitative ratings were clarified by interview findings which revealed a preference dichotomy: while the majority found preview avatars useful, a subset of users preferred the cognitive ease of external cues like arrows, a nuance lost in the aggregate mean. Second, while the quantitative results showed high satisfaction with the transition to individual locomotion (**RQ3**), participants specifically cited the degree of freedom and the ability to satisfy personal curiosity as the key factors, rather than just the functional mechanic itself. Moreover, although individual locomotion was rated highly, qualitative triangulation revealed that it is insufficient on its own; participants emphasized that F-formation adjustments are a necessary prerequisite for social inclusion, suggesting that quantitative metrics for locomotion must be interpreted alongside qualitative needs for formation. This mixed-method synthesis confirms that while the quantitative data validates the system's performance, the qualitative data is essential for understanding the specific design elements driving user satisfaction.

5. Discussion

RQ1: Suitability for Real-World Scenarios The user experience results indicated a high level of satisfaction. However, when compared to teleportation, the proposed method showed a lower level of enjoyment, suggesting a potential trade-off: while teleportation is often preferred for its comfort and minimal sickness [17], our method's continuous-style elements may have introduced discomfort that impacted enjoyment. This finding contrasts with [15] that teleportation-based systems may cause users to neglect spatial details and fail to recognize important contextual cues. Our approach appears to mitigate this limitation by incorporating continuous movement elements. Despite this, the lack of statistically significant differences between our approach and teleportation suggests that both methods may be suitable, albeit with room for improvement. Unlike the hand-holding teleportation technique [26], which may cause discomfort for users who are not acquainted with each other, our method does not require continuous physical interaction, potentially making it more suitable for diverse social contexts. The proposed method offers realistic navigation experiences, but factors like user immersion and the discrepancy between VR and real-world interactions (e.g., camera switching) still pose challenges for broader real-world adoption. We hypothesize that participant demographics, such as prior VR experience, may have influenced these responses, as more experienced participants might adapt more easily to such transitions. However, this was not formally tested in our study and remains an important area for future research. Further research on VR training sessions or user acclimatization techniques could help bridge this gap for less-experienced users.

RQ2: Comprehensibility of Preview Avatars and Animated Paths Participants found preview avatars and animated paths helpful in informing them of their destination. The statistical summary indicates that these elements are highly comprehensible. This finding corroborates previous research that highlights the importance of clear visual guidance in VR systems [16]. Preview avatars, in particular, were effective in making users aware of the navigation process, confirming the utility of this feature. However, some participants preferred external cues, like arrows, suggesting that the effectiveness of these avatars may vary based on user preferences and expertise. This finding has practical implications for future VR application design. Specifically, navigation systems could benefit from incorporating customizable guidance mechanisms that allow users to toggle between different cues (e.g., avatars, paths, arrows) depending on their familiarity and comfort with the VR environment. This adaptability ensures that both novice and experienced users can benefit equally.

RQ3: Dynamic Transition Between Group and Individual Navigation and F-Formation Adjustment The transition from group to individual locomotion when visiting a POI was well-received, with participants appreciating the personalized exploration it offers. Weissker et al.'s jumping approach [16] and Chheang et al.'s world-in-miniature approach [29] maintained consistent group structures without allowing individual exploration at destinations. Our approach addresses this gap by enabling users to break away for personalized interaction while preserving group cohesion for transit. The ability to adjust views and navigate individually added depth to the user experience, allowing for more engaging interaction with the environment. This feature proved to be beneficial for group navigation, as the freedom to explore while maintaining the group dynamic enhanced satisfaction. This hybrid model offers a novel integration not seen in prior systems, which tend to focus exclusively on either group or individual navigation. Our approach provides a novel integration of both and may be particularly suitable for applications that require collaborative exploration, such as educational simulations or virtual museums. While individual locomotion was satisfactory for most users, some participants highlighted the importance of f-formation adjustments for communication and social integration. By dynamically adjusting group formations, users were better able to maintain spatial relationships and visual connections, enhancing the overall social experience. This finding confirms and extends research in social psychology, which identifies spatial arrangements as a key factor for effective group interaction [13,14]. The inclusion of both individual navigation and f-formation adjustments would create a more flexible system, allowing for a more adaptable group dynamic.

RQ4: Benefit of Third-Person Distant View The distant third-person view was another well-received element, aiding users in navigating the virtual environment and providing clearer visual feedback about their destination. This agrees with prior work on World-in-Miniature techniques [30,31], which similarly found that an external perspective can improve spatial comprehension. This feature allowed participants to maintain awareness of their surroundings, contributing to better navigation. Furthermore, while Brument et al. [32] found comparable spatial awareness scores between WIM group teleport and parabola-based group jump techniques, our approach combines the spatial awareness benefits of distant views with continuous movement, potentially offering advantages in contexts requiring both orientation and smooth traversal. However, switching between first- and third-person views occasionally caused discomfort, suggesting that further refinement of these transitions may be needed to avoid disrupting the user experience. To mitigate these effects, strategies such as smoother interpolation during transitions, reduced transition speed, and optional comfort mode settings can be implemented [56]. Such refinements are essential for improving user comfort without compromising functionality.

RQ5: Impact of Customized Avatars and Voice Chat Customized avatars and voice chat contributed to the sense of presence and social interaction, which are critical in group navigation scenarios. Voice chat was particularly effective for facilitating clear communication, while avatars added an additional layer of interaction through gesture synchronization. These findings align with prior research that emphasizes the role of social presence in collaborative VR environments [44, 45]. Despite their benefits, participants rated voice chat higher than avatars, suggesting that verbal communication remains the dominant interaction method. Future research could explore advanced avatar behaviors, such as adaptive gestures or facial animations, to improve their effectiveness.

RQ6: VR-Induced Symptoms and Effects The proposed approach showed minimal VR-induced symptoms, with no severe cases of fatigue or disorientation reported. However, a small number of participants experienced dizziness and nausea, particularly during transitions between first- and third-person views. This specific finding aligns with a known body of research that identifies discontinuous camera movements as a primary contributor to VR sickness [56]. This suggests that while the approach is generally safe, some aspects, such as rapid view-switching, may need optimization to minimize discomfort. To address this, we recommend several mitigation strategies such as ensuring correct interpupillary distance to reduce visual discomfort, gradual exposure of users to build tolerance to VR through shorter sessions, and maintaining airflow and avoiding heavy meals before VR use [56].

RQ7: Entertainment in Group Navigation The evaluation of engagement, enjoyment, and fun provided valuable insights into the entertainment aspect of the proposed group navigation method. Participants rated engagement and enjoyment higher in the proposed method compared to both teleportation and steering, reflecting the interactive and immersive elements that contributed to a more entertaining experience. However, the fun ratings, while higher than steering, were closer to teleportation, suggesting that while the method is more engaging, it may not drastically alter the perceived fun factor. This aligns with **RQ1**, where the suitability for real-world scenarios could be limited by occasional disruptions in presence, which may also influence the entertainment aspect. The comprehensibility of preview avatars and animated paths (**RQ2**) likely played a role in maintaining engagement, while the smooth transition between group and individual navigation (**RQ3**) contributed to a sense of freedom and exploration, enhancing enjoyment. Additionally, the inclusion of third-person views (**RQ4**) and customized avatars (**RQ5**) helped create a socially immersive environment, adding to the entertainment value by enabling participants to navigate and communicate more naturally.

Theoretical Implications First, this study contributes to the literature on social spatial cognition by demonstrating that group cohesion in VR is not merely a function of proximity, but of synchronized transition. Contrary to models that treat navigation and social interaction as separate phases, our findings suggest a hybrid model where the transition between group travel and individual exploration is the critical moment for maintaining social presence. Second, we extend the understanding of perspective-taking in locomotion. While previous theory suggests third-person views distance the user from the experience, our data indicates that a distant view can actually enhance spatial presence by providing necessary context, provided the transition back to the first-person view is seamless.

Practical Implications This study provides actionable guidelines. Applications should not force a choice between group and individual movement. Systems should be designed to allow group travel for long distances, automatically releasing users into individual control upon reaching a POI. The success of preview avatars suggests that developers should prioritize diegetic visual cues (avatars, animated paths) over abstract UI to reduce cognitive load during collaborative tasks. Given the reports of discomfort during camera switching, developers must implement specific mitigation techniques, such as blinking (fading to black) or narrowing the field of view during the instant of transition between first- and third-person perspectives.

Limitations We acknowledge several threats to the validity of our findings. The study's findings revealed a lack of statistically significant differences between the proposed method and traditional navigation techniques in some metrics, a limitation and a threat to external validity. This could be attributed to the relatively small sample size or the variability in participant responses, factors that may have reduced the statistical power of the analysis. Furthermore, our participant pool was demographically constrained, with a narrow age range. This homogeneity restricts the generalizability (external validity) of our conclusions, as factors like age and prior technical experience can significantly influence VR tolerance, sickness susceptibility, and navigation preferences. While statistical significance was not always observed, the practical implications of the trends identified in the data remain important. For instance, participants consistently reported positive feedback regarding usability, intuitiveness, and overall satisfaction with the proposed approach. These findings suggest that the method may still hold substantial practical value, particularly in enhancing user engagement and collaboration in VR environments. The inconsistency between VR interactions and real-world experiences negatively impacted immersion. This gap needs to be bridged for the approach to be fully viable in real-world applications. While preview avatars were effective for most users, some participants, particularly non-experts, preferred external cues such as arrows. This highlights a potential threat to construct validity, as user expertise may be a confounding variable. We attempted to mitigate this threat by providing all participants with a uniform tutorial and practice session to establish a baseline level of familiarity. Although the symptoms were mild, the transitions between camera views (first-person to third-person) contributed to some discomfort. This presents a threat to internal validity, as the discomfort may have confounded the user experience ratings for the navigation method itself. This highlights the need for refining these transitions to minimize VR-induced effects. Lastly, the controlled experimental environment does not fully reflect real-world scenarios, where additional factors such as network latency and environmental distractions may influence user experience. This was a necessary trade-off to establish internal validity and isolate the effects of our specific navigation features.

6. Conclusion

This study offers a valuable contribution to the development of group navigation techniques for shared virtual environments, emphasizing both human behavior and entertainment aspects. By examining unexplored and modified features and incorporating customizable avatars, a controlled transition between individual and group navigations, and other navigation tools, the proposed approach provides promising insights for improving communication and collaboration among users compared to teleportation and steering. Theoretically, our findings contribute a hybrid model of group navigation that demonstrates the value of balancing group cohesion with individual agency, a concept that is underdeveloped in current literature. For practitioners and designers, this work provides a validated set of features — specifically preview avatars and dynamic group-to-individual transitions — that can be directly implemented to enhance user engagement and reduce group fragmentation in collaborative VR applications.

The controlled transition between group and individual locomotion at a POI was well-received, as it allowed users to experience personalized exploration while maintaining group cohesion. Similarly, animated paths and preview avatars were found to be effective in increasing users' comprehension of navigation processes. Customizable avatars played an important role in facilitating communication, particularly through voice chat and gesture synchronization, fostering a sense of social presence in group settings. Despite these promising findings, the study highlights areas requiring further refinement to ensure the system's practical applicability. For example, immersion was negatively affected by discrepancies between VR and real-world interactions, particularly during dynamic camera switching and viewpoint transitions. These inconsistencies challenge the broader adoption of the proposed technique for real-world applications. The practical implication is that designers must prioritize wearer comfort and seamless transitions to ensure broader adoption. Addressing such issues — through smoother transitions, adaptive comfort settings, and motion mitigation strategies — will be crucial for achieving a seamless user experience. Moreover, the findings were derived from a controlled experimental environment with a relatively small and homogeneous participant pool. This limitation implies that while our contributions are promising, future studies should validate the generalizability of the proposed navigation techniques across diverse user demographics, VR scenarios (e.g., multiplayer gaming, educational platforms, virtual conferences), and hardware configurations. Exploring these broader contexts will help determine the scalability and adaptability of the approach for real-world use cases.

7. Future work

The findings of the initial user study provided a foundation for further research and refinement, ultimately enhancing the immersive and interactive nature of shared virtual environments. Future research can build on these findings by conducting more extensive user studies (with full-scale construct or criterion validity assessments for questionnaires), including larger and more diverse participant pools. This will enable a more comprehensive evaluation of the effectiveness and usability of the proposed approach across different user demographics and cases. Moreover, future work could investigate deeper human psychology aspects such as cognitive load, user trust in avatars, and group behavioral dynamics in VR environments. Physiological metrics (e.g., heart rate, eye strain) could also be integrated to evaluate VR fatigue and comfort levels under extended usage. These analyses can help refine navigation mechanisms to mitigate VR sickness symptoms, as discussed in related works.

Additionally, spatial arrangements can be implemented along with individual locomotion to further investigate navigation approaches. The role of users in group navigation — such as leader–follower dynamics — can be examined to determine how roles influence the sequence of visiting POIs and navigation preferences. Additionally, haptic feedback can be explored to target the comprehensibility factor of the group navigation.

Given the mild symptoms of dizziness and nausea reported during view transitions, future research should focus on refining dynamic camera-switching techniques inspired by practices in the film industry. Smoother and adaptive transitions (similar to the film industry) can be tested to reduce motion discomfort while maintaining immersion.

While the present study focused on a museum simulation, the proposed system can be tested in other scenarios such as multiplayer gaming, virtual conferences, and educational simulations. These use cases will help validate the system's applicability to diverse VR applications.

Finally, given the variability in user preferences (e.g., preference for external cues like arrows over avatars), future research should focus on developing customizable navigation systems.

CRediT authorship contribution statement

Jalal Safari Bazargani: Writing – original draft, Visualization, Software, Methodology, Investigation, Conceptualization. **Jong-min Jeon:** Software, Methodology. **Abolghasem Sadeghi-Niaraki:** Writing – review & editing, Validation, Supervision. **Soo-Mi Choi:** Writing – review & editing, Validation, Supervision, Resources, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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