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Comparative Evaluation of Different following Mechanisms in VR Guided Tour: A Preliminary Study

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Abstract: Given virtual reality (VR)'s popularity, VR already impacts various applications such as education and tourism. In the above applications, users usually need to follow a specific target, such as a teacher or a tour guide, to explore and learn from the environment. However, because of the constraint with visual senses and unintuitive locomotion, following a target in VR is not as easy as doing it in real life. As a result, the user may not concentrate on the audio narration or the surroundings. Therefore, finding a following mechanism that can help the user concentrate and learn in VR is important. In this paper, we focus on the following techniques in VR. We propose four types of following mechanisms: limited (which restricts the user's ability to move), semi-limited (which constrains the user's range of activity), improved semi-limited (with visual assistance), and not limited (user's movement is not constrained). This study consisted of 29 participants divided into four groups and aimed to evaluate how the following mechanisms affect user experience and make users more concentrated in the virtual world. The experiment shows that the semi-limited following mechanism with visual assistance is superior to the other three types in the performance of the touring experience and helping users pay attention to the tour content.

Keywords: virtual environment; following techniques; VR-guided tour

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1. Introduction

Given virtual reality's (VR) popularity, VR already impacts various applications such as education [1–3] and tourism [4]. Nowadays, due to the COVID-19 pandemic, tourism has temporarily halted, and traveling around the world is nearly impossible [5,6]. In such difficult times, the VR tour is not only a useful tool to maintain the attractiveness of destinations [7] but also a substitute [8,9] and rehearsal for real-world tourism. However, experience in VR is quite different from in real life [10]. A common situation in education and tourism is that the user might have to follow a specific target such as the teacher or the tour guide and listen to audio narrations about the environment. While touring in real life, it is easy to follow the tour guide without strain. We can use all our human senses to observe a tour guide's movement, listen to sounds to judge position, or look at where the crowds are heading. However, while touring in virtual reality, we do not have all the clues from our sense organs. The visual system is the primary means of interaction in a virtual world. Thus, it is much more challenging to concentrate on the tour guide's movement while looking around in the virtual environment.

Furthermore, the experience in VR-guided tours is also related to the locomotion allowed in the VR environment. Zanbaka et al. [11] discovered that giving users a larger space to walk around offers benefits over general virtual travel techniques. However, current consumer-level VR solutions are usually space-limited, and the available physical spaces may contain several obstacles. Thus, users may experience spatial discontinuity or dangers while using VR devices. Generally, a video-based virtual tour is a pre-recorded video following a fixed guide path. The video content may be captured by 360 degree videos recorded in the real world [10] or pre-computing from synthetic virtual 3D scenes. In this case, the viewers do not have to move or make an effort to follow the tour guide; they can only slightly change their head orientation but cannot freely change their positions. On the other hand, 3D virtual tours create a complete 3D environment and give users more freedom to explore the virtual world; viewers can go to any place they want in the virtual world and observe the scene they are interested in. However, it is easy to get lost from tracking the tour guide. As mentioned earlier, while experiencing a virtual tour, we usually have limited space, so the users have to use different locomotion techniques to move around [12]. Meanwhile, users need to make much more effort to follow the virtual tour guide, which results in missing points of interest, decreasing immersion, and frustrated users. Therefore, it is crucial to balance how much freedom users can have regarding locomotion and movement when following a virtual tour guide.

In this paper, we focus on the learning effect of different following mechanisms in VR-guided tours and try to find the best one that helps users pay attention to their surroundings and the audio narrations. In a virtual scene replicated from Barcelona, we compare the performance of three following mechanisms: limited (which restricts the user's ability to move), semi-limited (which constrains the user's range of activity), and not-limited (user's movement is not constrained). Our hypothesis is that: in a VR-guided tour, the following mechanisms may affect the participants' learning efficiency and user experience. We evaluated the effect with questionnaires including user experience in VR, gaming experience, and how many details the user remembered in the VR tour. We found that the semi-limited mechanism is superior to the others. As the experiment shows, the semi-limited mechanism minimizes the frustration from the physical space limitation and lets users concentrate on the guided tour and the virtual environment.

2. Related Work

In this chapter, we introduce the related studies on the user's behavior and experience in virtual reality tourism. Tourism in VR should have a certain degree of freedom. Therefore, we first introduce some research focusing on locomotion in virtual worlds. In addition to head rotation, locomotion gives the user the ability to explore and navigate the virtual world. Next, we briefly talk about human behavior. To compare the effect of different following mechanisms, we need to consider the navigational effect on learning. Last but not least, when following and tracking the tour guide, attention guidance techniques may be important to help the participants find it easy to focus.

2.1. Locomotion

Locomotion is a classic problem [13] regarding how people move in the virtual worlds. There are two core types of virtual locomotion: physical and artificial locomotion. Physical locomotion means that movement in the virtual world occurs according to movement in the physical world. Because of the tracking technique, physical locomotion with a consumer-level VR device cannot apply to a large space; thus, different techniques such as the treadmill have been developed to simulate an infinite virtual space in a narrow physical space [14]. Furthermore, artificial locomotion means the movement in the virtual world is not related to the movement in the physical world; users use controllers or other devices to drive the movement in the virtual world. However, artificial locomotion may cause sickness or loss of spatial awareness. Rahimi et al. [15] evaluated the effect of spatial awareness with different scene transitions and teleportation techniques. Generally, a VR system usually provides those two locomotion implementations for the user to travel in the virtual environment.

In general VR applications, the user needs to choose proper locomotions according to surroundings in real life and the moving distance in the virtual environment. In a VR-guided tour, this problem is more complex. Users must put much more effort into following the virtual tour guide. Hence, finding a proper following technique related to locomotion techniques and the space size is important.

2.2. Following Behavior in Virtual Reality

Human following behavior in VR [16] examines users' walking behaviors in the presence of a virtual tour guide. The authors of this study designed a virtual art museum where a virtual agent guided subjects. The results show that users tend to adapt their walking speed and match the virtual tour guide's path. Another result shows that whether users were explicitly told to follow the virtual tour guide or not, it did not significantly affect the result. Humans are observed to move collectively. Humans often walk together in groups and in crowds. In [17], the authors examined how a pedestrian controls speed when following a leader. The results also demonstrate that followers follow at the same pace as the leaders. In this study, we designed our limited following mechanisms according to the above research.

2.3. Navigational Effect on Learning in 3D Virtual Environments

Navigational techniques navigate the user to the target position and impact the user experience in virtual environments. Furthermore, navigation methods may improve the learning efficiency of the user. Ragan et al. [18] compared the learning performance of two groups of people: automated navigation and manual-control navigation. Their experiment showed that when users interact more with the environment, they perform better in an exploratory form of learning but may still have adverse effects in other aspects. Tobu and Goktas [19] found that participants with guidance have higher cognitive engagement and perform better on knowledge acquisition. Burigat and Chittaro [20] compared navigation methods in virtual environments with traditional maps. They found that navigation in a virtual environment gives participants more spatial knowledge. The research also shows that active navigation, which means letting people control their movement, is more effective than making them experience a passive tour in the virtual environment. In this study, we involved active and passive navigation methods in following the tour guide. We compare the learning effect of different following mechanisms through a virtual tour. Moreover, we purpose a hybrid following mechanism combining the advantages of passive and active navigation methods.

2.4. Attention Guidance

Attention guidance guides the user's attention to a certain point of interest, such as using color change on texts or an object in the image [21]. Danieau et al. [22] implemented some visual effects such as blur, desaturation, and fade to emphasize the point of interest to the users. Grogorick et al. [23] investigated the efficiency of five different gaze guidance techniques, and their results showed that local luminance modulation is the most effective technique. In addition to adjusting the rendered images, Lin et al. [24] compared two different pilot methods: automatically changing the view and adding an arrow as visual guidance. Experiments showed that adding an arrow is suitable in tour applications. Nielsen et al. [25] added a firefly to implicitly direct their attention. They also tried to guide the users by controlling their body's orientation. Further research has considered guiding participants with different styles of avatars [26] or dynamically adjusting the image color [27] to guide the user's attention. Although some of the research did not show a positive influence, attention guidance is still an important issue in VR research. In this study, we utilize some attention guidance techniques mentioned above, such as guiding arrows and blur, to guide the user's attention.

3. Material and Methods

In this chapter, we first briefly introduce the different following mechanisms we designed and how we implemented them. Next, we introduce the synthetic VR scene. Last, we conduct a small user study to evaluate the learning efficiency.

3.1. Following Mechanisms

We first propose three types of following mechanisms, limited (L), semi-limited (SL), and not-limited (NL) (Figure 1). After a prior study, we add one more mechanism named improved semi-limited (ISL). We stated all as follows.

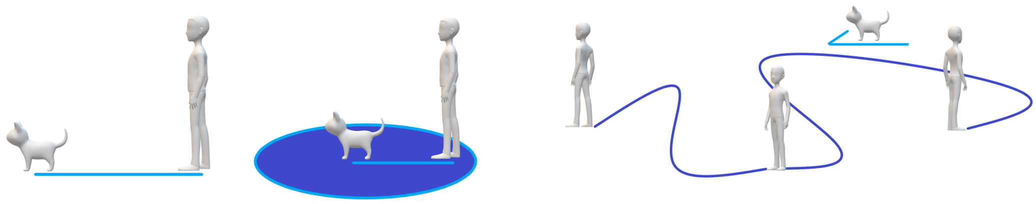

Figure 1. The different following mechanisms. **Left**: Limited. The user's position is limited behind the guide (the cat in the figure). **Middle**: Semi-limited. The user is allowed to walk around the guide (in the blue circle) but will be automatically moved to the near-guide position if the user is far from the guide. **Right**: Not limited. The user can freely move anywhere in the virtual environment.

- **Limited (L)**: Inspired by the pre-recorded 360 degree virtual tours, the virtual tour guide is always in front of the user at a fixed distance. This means the speed of the guide and the user are the same. The user can only rotate their head to change the orientation of the viewpoint; other movements, such as walking and teleporting, are not allowed in the environment.
- **Not limited (NL)**: Distance between the user and virtual tour guide is not limited. This means that the user can move anywhere to explore the world, even ignoring the tour guide. If the user wants to follow the tour guide, he/she has to move by using the controller manually.
- **Semi-limited (SL)** and **Improved semi-limited (ISL)**: There are two versions of the semi-limited mechanism. Both have the same concept: users can only move within a specific range around the virtual tour guide. The only difference is in the repositioning phase. In the original version, when the user moves out of the range (eight meters in the experiment), the user will be immediately transmitted to a new position behind the tour guide within the range without transition animation. To keep the user's spatial continuity, we hope the user's point of view is kept after the transition. Thus, after the transition, the new position is adjusted according to their heading direction such that the tour guide will always be in front of them. Hence, it is much easier for the user to find the guide. However, the prior experiment shows that the original version gives adverse experiences to most participants. They felt annoyed while experiencing the guided tour. Some of the users said they were dizzying. Furthermore, the result underperforms compared to the other two mechanisms. See Sections 4 and 5 for detailed experiment results.

In order to improve the user experience, we adjusted the timing and the transition animation when the repositioning occurs. First, to reduce the frequency of repositioning, we set a ten-second interval between each reposition, which means even though if the user keeps walking away from the tourist guide, the repositioning will not be triggered consecutively, making users less annoyed. Second, we add some visual clues and animation to reduce the space discontinuity when repositioning users, as in Figure 2. The visual clues consist of a count-down timer telling users when the reposition will happen and an arrow pointing to the tour guide's position, similar to the off-screen enemy indicator in shooting games. For the transition animation, we add a gradual blur effect when the countdown starts. We also move users in a time-lapse mode instead of directly setting their new position. The progressive transition animation gives the user better spatial awareness.

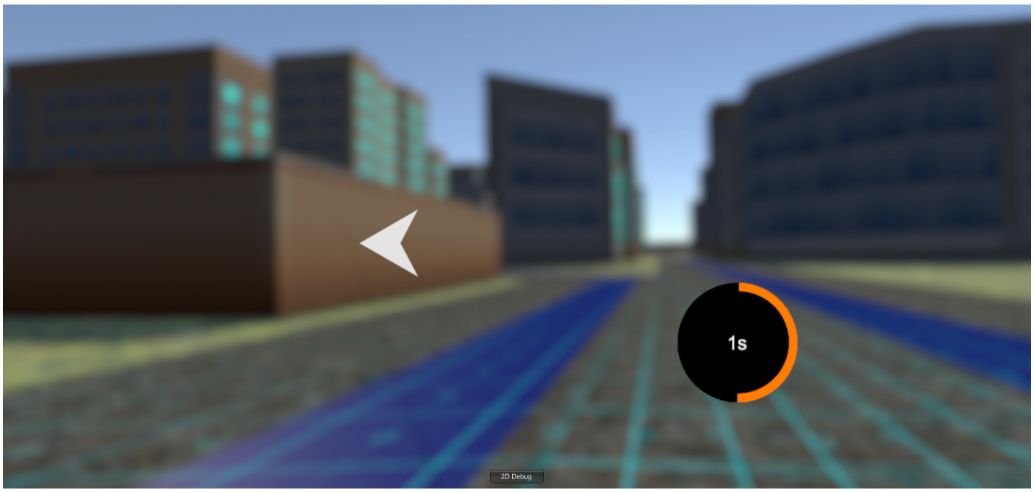

Figure 2. The visual cues we used in the ISL to improve the user experience of the semi-Limited mechanism. A blur animation, a countdown icon, and an arrow indicating the moving direction are added.

3.2. Description of the Virtual Environment

To evaluate the efficiency of the following mechanisms, we built a virtual guided tour and analyzed the learning efficiency of how the user explores the virtual environment. The guided VR tour is based on a real-world tour. We built a virtual world in Unity, which is replicated from real-world surroundings but only rendered with some rough textures; then, we added multiple virtual objects and events into the scene to enrich our VR tour (Figure 3).

3.2.1. Tour Content

We started our virtual tour in the Eixample district of Barcelona, Catalonia, Spain. In the Eixample district, there are three major attractions, La Sagrada Familia, La Monumental, and Plaça de les Glòries Catalanes. We choose the street in Spain as the evaluation environment because we wanted to find a place where our subjects have never been. The user was guided through these three attractions by our virtual tour guide with audio narration. It described the history and the architectural design of the attractions to give the user a better understanding. The audio narration was fulfilled by the Google Cloud Text-to-Speech Service [28]; using the WaveNet [29] voice gives us a more natural-sounding voice. The guided tour starts from La Sagrada Familia and ends in Plaça de les Glòries Catalanes. The size of the touring area is about 1 km $\times$ 1 km and the tour takes about 25 min.

3.2.2. 3D Models

To build the surroundings in our virtual world, we used Google Maps Platform Gaming Services [30] for Unity to fetch 3D models of the buildings, streets, parks, etc. With Google Maps Gaming Services for Unity, we can duplicate real-world surroundings while minimizing the amount of system performance needed in the VR environment. Additionally, our synthetic VR environment has a low level of detail and no virtual people around. We wanted to make the scene as simple as possible so the evaluation difference only comes from the following mechanism but not from personal preferences. However, in order to increase the content of the guided tour, in addition to the actual tourist spots, we imported some models from Sketchfab [31] and added related narrations. For example, we put a dragon statue into the scene and made up some stories to satisfy the user's curiosity. We wanted these special attractions to enrich our virtual environment and enhance the user's interest.

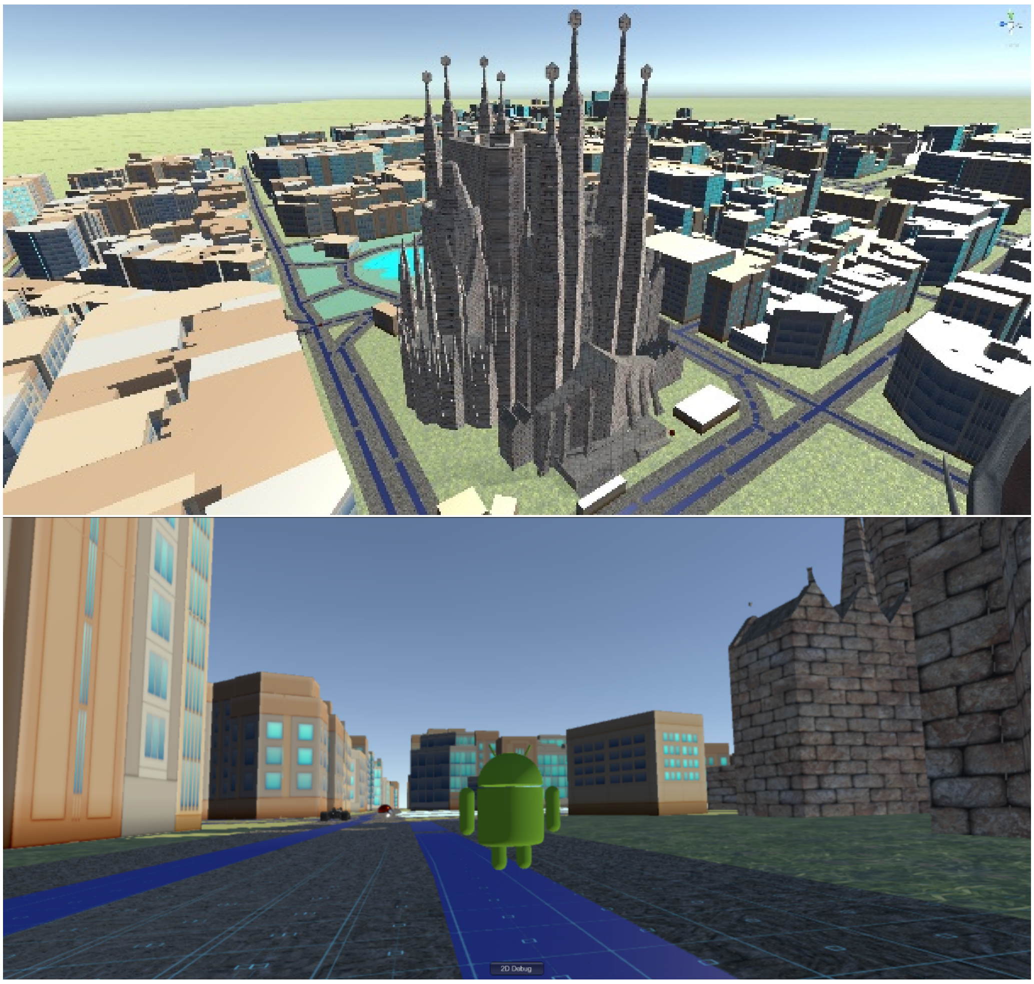

Figure 3. The experiment's virtual environment and attractions. **Up**: The La Sagrada Familia in the virtual guided tour. **Down**: The user's view during the guided tour.

3.3. User Study

In the experiment, participants begin the tour in the virtual world we built based on the street view in Barcelona, Spain. The tour guide will lead them along the prerecorded route, past three of the landmarks discussed earlier. As soon as the tour guide reaches each historical site, the guide will stop moving and present the surroundings and history, which is also prerecorded. Participants can resume the tour by pressing a button. In addition, the tour includes some unique objects and events to explore; the guide will also introduce them. The tour takes about 25 min to complete. In the limited following mechanism, participants are always located eight meters behind the tour guide. Participants cannot move around on their own; they can only change the orientation of the viewpoint by rotating their heads. In the semi-limited mechanism, the participants can move freely only in a range of eight meters centered at the tour guide. Whenever the participants move away from the tour guide by more than eight meters and the time after the last reposition is more than 10 s, they will be transmitted to a new position behind the tour guide, and the distance is half the range. To minimize the possibility of feeling disoriented, the participant's viewing orientation will be kept after the repositioning. Last, in the not-limited mechanism, the participants can move anywhere and even ignore the guide completely.

A total of 29 participants (18 male, 11 female) recruited from our campus consented and were paid for participating in a one-hour experiment. All of them had no or less (have played only one or two times before) VR experience. Most of them were undergraduates, and only six participants were graduate students. Their ages ranged from 19 to 22. The participants were divided into four groups randomly, as shown in Table 1.

Table 1. The number of participants in different guided mechanisms.

	Number of Participants
Limited	6
Semi-Limited	9
Semi-Limited (revised)	7
Non-Limited	7

The setup for the VR tour experience consisted of an HTC VIVE headset and an in-ear headphone. The HTC VIVE's two screens each have a 110 degrees field of view, and each screen's resolution is 1080×1200 with a 90 Hz refresh rate. Because of a safety perspective, we asked the user to sit on an office chair with wheels. The free space he/she can move is around 3 m $\times$ 1.5 m. However, in most cases, users use the controller and teleport to move in the virtual environment. The experiment consisted of the following steps, as seen in Figure 4:

1. Participants were randomly assigned to one of the following mechanisms initially.
2. (5 min) Participants were given a general introduction telling them what they would experience in the guided tour in VR, followed by instructions on using the controller to move around and interact with the virtual environment.
3. (5 min) After a short break, they put on the VR headset and roamed around to become familiar with the environment.
4. (25 min) Afterwards, they started the main guided tour with prerecorded narration. The whole tour takes about 20–25 min to finish.
5. Finally, participants filled out a 4-part questionnaire.

The experiment took roughly 50 min in total.

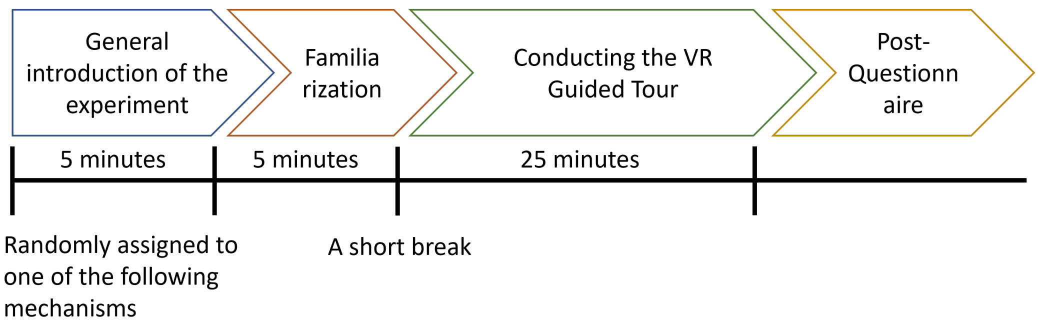

Figure 4. The experimental protocol.

As mentioned before, we used questionnaires to measure the opinions and attitudes of the users. All questionnaire questions were Likert-scale questions or open-ended questions; for the Likert-scale questions, we used a scale from 1 to 5. Precisely, the questionnaire can be divided into four sub-questionnaires:

- Game Experience: The Game Experience Questionnaire (GEQ) [32] is a questionnaire widely applied in games research, assessing the experience on seven aspects: immersion, flow, competence, positive and negative affect, tension, and challenge. GEQ provides a measure of the gaming experience for the virtual guided tour. In this paper, we applied a concise version called the in-game GEQ. It consists of 14 Likert questions. By applying GEQ, we can assess how much the virtual tour entertains the users.
- Cognitive awareness in the VR tour: This questionnaire consists of four Likert-scale questions about the experience in the virtual environment, such as how immersive the environment is and how many details the user can remember after the experiment. Inspired by [1,11], we also ask the users to draw the path they went through in the VR

tour and point out the landmarks mentioned in the narration. This questionnaire is designed to determine the level of cognitive awareness the users have regarding the tour environment.
- Usability of ths following mechanism: Additionally, we needed to evaluate the usability of different following mechanisms. Following the classic System Usability Scale questionnaires [33], another eight Likert-scale questions were added, asking questions about the usability of the mechanisms. By applying the questionnaire, we can evaluate how participants feel and their willingness to use this mechanism. For example, "Comfortable working with the mechanism." can show how the participant feels about the mechanism. "Easy to learn and use." can show us if there is a steep learning curve on the mechanism.
- Open-ended questions: Finally, three open-ended questions asked the participants the difference between being in a real-world guided tour and a virtual tour, what is the thing that impressed them most, and any suggestions for improvements. All the questionnaires are listed in Table 2.

Table 2. The 29 evaluation questionnaires.

Questionnaire Types	Questions
Game Experience Question(GEQ)	1. I was interested in the game's story.
Game Experience Question(GEQ)	2. I felt successful.
Game Experience Question(GEQ)	3. I felt bored.
Game Experience Question(GEQ)	4. I found it impressive.
Game Experience Question(GEQ)	5. I forgot everything around me.
Game Experience Question(GEQ)	6. I felt frustrated.
Game Experience Question(GEQ)	7. I found it tiresome.
Game Experience Question(GEQ)	8. I felt irritable.
Game Experience Question(GEQ)	9. I felt skillful.
Game Experience Question(GEQ)	10. I felt completely absorbed.
Game Experience Question(GEQ)	11. I felt content.
Game Experience Question(GEQ)	12. I felt challenged.
Game Experience Question(GEQ)	13. I had to put a lot of effort into it.
Game Experience Question(GEQ)	14. I felt good.
Cognitive awareness in the VR tour	15. I am interested in the environment.
Cognitive awareness in the VR tour	16. I felt immersion.
Cognitive awareness in the VR tour	17. Given a map with start and end point, I can draw the guiding path.
Cognitive awareness in the VR tour	18. Given a map, I can point out the landmarks mentioned in the guiding tour.
Usability of ths following mechanism	19. The mechanism is easy to learn and use.
Usability of ths following mechanism	20. The mechanism is annoying.
Usability of ths following mechanism	21. I felt the mechanism is free and with enough degree of freedom.
Usability of ths following mechanism	22. I miss the narration.
Usability of ths following mechanism following mechanism.	23. I divided my attention between the narration and the following mechanism.
Usability of ths following mechanism	24. The mechanism helped me pay attention.
Usability of ths following mechanism	25. I was comfortable working with the mechanism.
Usability of ths following mechanism	26. The mechanism was distracting.
Open questions	27. Describe the things that impressed you during the virtual tour.
Open questions	28. Any suggestion for improvements or comments?
Open questions	29. Compared with a real-world guided tour, what's the difference?

4. Results

We performed a Jarque–Bera test [34] to test the normality, and the *p*-value on most of the data distribution (94/104 classes) is >0.05, indicating that the data follows a normal distribution. For the case where a *p*-value < 0.05, we found that the collected data in such questions are all or almost the same, with an extreme value such as zero or five. For example, all participants gave the ISL five grade in the question "I forgot everything around me". Those cases are obviously shown in Figures 5 and 6. Meanwhile, we used Student's t-test [35] to determine if there is a significant difference between different mechanisms in different questionnaires and how they are related. We applied the t-test to each pair mechanism in each question. In one question, there were six possible mechanism pairs, and if there existed more than one pair in which the *p*-value is < 0.05, we said that the question has a significant difference. In other words, we think the different following mechanisms give different responses to the question, so this question is meaningful. The experiments show that statistics in questions Q2, Q5, Q9, Q10, Q12, Q13, Q15, Q18, Q20, Q21, and Q22 have significant differences ($p < 0.05$) in different mechanisms. Although the number of participants is a bit less, we can only apply a small amount of data with the normality test and the significant difference analysis. However, we still think the quantitative result is reasonable.

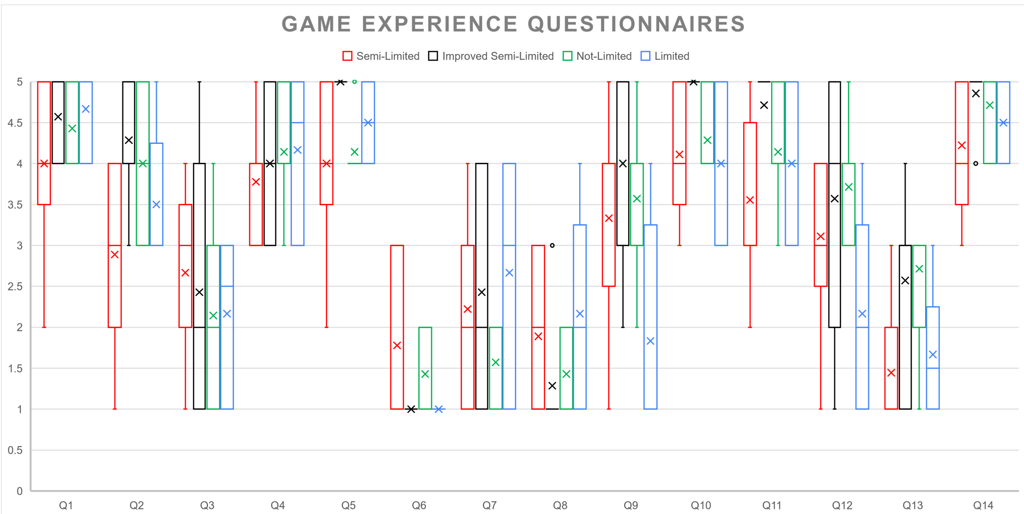

Figure 5. The box plot of the GEQ results.

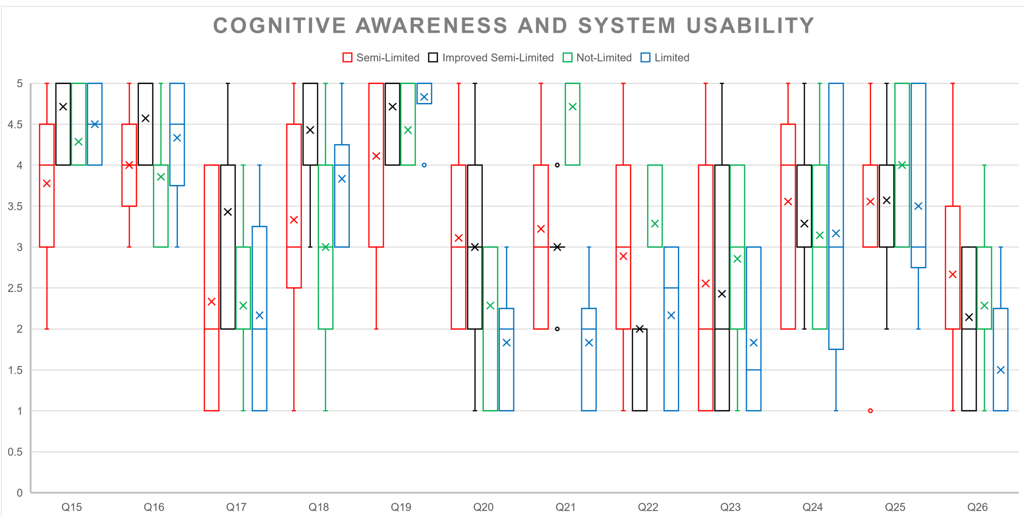

Figure 6. The box plot of the cognitive awareness and usability of following mechanism results.

4.1. Game Experience Questionnaires

The GEQ measures a player's engagement and skills in playing video games. It also measures the playability and attractiveness of the game. With the GEQ, we want to know how the following mechanism can affect the gaming experience and examine the design issue of different mechanisms. Figure 5 shows the results of GEQ for the following mechanisms. First, the improved SL performs better overall than the original SL. Only question Q13: "I had to put a lot of effort into it" performs worse; the average grade (M) and standard deviation of the grade (SD) of SL are (M = 1.44, SD = 0.68), which is less than the grade of ISL (M = 2.57, SD = 1.40). The reason is that the participants who participate in ISL tend to keep up with the tour guide by using the controller. In contrast, participants rarely use the controller to move around during a virtual tour because of the frequent repositioning in the original SL. In other words, participants in the original SL tend to be forced by the system, so the grade of the SL is close to the grade of the limited mechanism (M = 1.67, SD = 0.75).

Considering the difference between ISL and the other mechanisms, for questions Q2, Q5, Q9, and Q10, ISL received the highest score. According to the guideline of in-game GEQ [32], Q2 and Q9 belong to the flow component, and Q5 and Q10 belong to the competence component. The participants giving the ISL the highest grade in the flow component means that subjects have more immersion when they have a reasonable degree of locomotion control. Additionally, the participants giving the ISL the highest grade in the competence component means that the ISL following mechanism gives the user a positive experience in the VR tour and also lets the user have a sense of accomplishment. In Q12, "I felt challenged", the grade of Improved SL is a little less than NL, since the participants may enjoy tracking the guide by themselves. On the other hand, ISL subjects did not lose the tour guide as NL subjects did. Overall, ISL shows a generally better experience. Other questions have no significant difference among the four mechanisms. However, we can still observe that in most questions, improved semi-limited performs better.

4.2. Cognitive Awareness and Usability of Following Mechanisms

We can determine a participant's cognitive engagement and knowledge acquisition in the virtual tour through environmental questionnaires. The following mechanism questionnaire assesses the helpfulness of mechanisms in the tour. Figure 6 demonstrates the results for the cognitive awareness and following mechanism questionnaires. Considering the environmental questionnaires, ISL has the best performance overall. The grades of the ISL mechanism in Q15: "I am interested in the environment" and Q16: "I felt immersion" are a little higher than the limited mechanism, which infers that the immersive experience of ISL is similar to the limited mechanism and did not degrade like the original SL. For question Q17: "Given a map with a start and an endpoint, I can draw the guiding path.", we found ISL scores higher (M = 3.43, SD = 1.05) than L (M = 2.17, SD = 1.21) and NL (M = 2.29, SD = 0.88). Likewise, question Q18: "Given a map, I can point out the landmarks mentioned in the guiding tour." shows ISL (M = 4.43, SD = 0.73) significantly ahead of L (M = 3.83, SD = 0.69) and NL (M = 3.00, SD = 1.20). In other words, ISL provides participants with a better understanding of the virtual tour layout and helps them remember the surroundings. The improved semi-limited mechanism also presents a better result than the original semi-limited in the usability questionnaires. Comparing ISL to other mechanisms, we found that Q22: "I miss the narration." indicates ISL helps participants concentrate on narration more than other mechanisms. The score of ISL is (M = 2.00, SD = 0.93), which is better than SL (M = 2.89, SD = 1.12), L (M = 2.17, SD = 0.90) and NL (M = 3.29, SD = 0.45). For question Q20: "The mechanism is annoying.", the grade of ISL (M = 3.00, SD = 1.20) shows no significant difference from SL (M = 3.11, SD = 1.10) but is larger than L (M = 1.83, SD = 0.69) and NL (M = 2.29, SD = 0.88). This implies that transposition is an annoyance and the visual cues did not help much.

4.3. Qualitative Analysis

This section summarizes the open-ended questionnaire responses for each mechanism to discover how participants felt about the virtual tour and how it differed from a real-world tour.

Limited (L): Most participants are concerned with not being able to move freely, so they want to control the walking speed of the guide ("I think the touring can speed up a little bit; I want to control the speed dynamically during the tour."). Some participants found that it is easy to lose their sense of direction ("My position is similar to that of a passenger in a car as the tour guide turns; I have no way to know where the guide is faced."). It is related to the quantitative results in the environmental questionnaire.

Improved Semi-Limited (ISL): A participant pointed out that we could add a play/pause control into the tour "I can ask the tour guide to wait if I want to take a closer look at something during a real-world guided tour, but in the virtual, I did not have the ability.". Except for this, the mechanism was not criticized much. The participants complained most about details in the environment, "It might be interesting to add some pedestrians or enhance the details of the buildings.", which implies that the mechanism helps immerse them in the virtual world.

Not-Limited (NL): Feedback on the NL mechanism most focuses on the fact that participants got lost in the virtual world. They offer several solutions such as "Place a pin on the location of the tour guide.", "I wish I could teleport back to the tour guide by pressing a button.", and "It might be helpful if a map showed the route to the tour guide.". All of these suggestions may have a substantial impact on the user experience.

Some feedbacks are not directly related to the mechanism but are nonetheless helpful. Some of the feedback is suggestions for the content in the tour, such as "If there were some non-play characters for us to interact with, I would appreciate it.". Though adding more content to the tour or adding interactions can make users more encouraged, we want to make the scene as simple as possible so the evaluation difference only comes from the following mechanism and not from personal preferences. A participant also suggested using the virtual tour as a pre-tour experience, which we think is terrific; travelers can get a feel for the environment before they start their trip.

5. Discussion

In the pilot experiment, the original SL gives the participants a significantly worse experience. Participants even report feeling dizzy or uncomfortable with the mechanism. Therefore, we have redesigned the SL mechanism, fixing the space discontinuity problem and minimizing the transition impact. As the SL is improved, the improved semi-limited mechanism performs much better in most questionnaires. The evaluation result shows that the ISL mechanism combines the benefit of the limited and non-limited mechanisms. The participant can immersively dive into the VR tour, paying attention to the guide's narration, just like the limited mechanism, and have a sufficient degree of freedom in moving and exploring the unknown space with a high sense of achievement, just like the non-limited mechanism.

However, existing classic following mechanisms such as limited and non-limited also have advantages in some use cases. While the limited mechanism allows users to immerse themselves more in the game, it has worse performance than the non-limited mechanism due to a lack of control over locomotion. On the other hand, limited and non-limited make the user feel less annoyed. The unexpected and compulsive transition in the original semi-limited mechanism annoys the user and gives the user a negative experience. Even the improved semi-Limited mechanism can only slightly reduce the effect.

We think the annoyance comes from unexpected transitions. According to the user's response, giving the user a transition button may reduce the problem. Another idea would be to use the user's gaze as a control method. An eye-tracking device may be helpful to observe when the user is paying attention to the environment and when the user is looking at the tour guide. When the user stares at the tour guide for a while, the tour guide will start moving and stop when the user looks around. However, according to [36], gazing-directed movement caused more cybersickness than teleportation. Adding more navigational effects and attention guidance in the guided system may improve the user experience. We can add different attention guidance according to the events and narrations. For example, before the reposition is triggered when the tour guide is far from the user, we can modulate the illumination, darken the environment, and enlighten the guide. This attention guidance may help users to find the tour guide quickly, implying them to move forward to the tour guide and reducing the frequency of teleportation.

Last but not least, in this preliminary study, we did not pay much attention to the space size. Because of the restriction on space size, most of our participants use artificial locomotion to move. Thus, the relationship between physical locomotion and the following mechanism is not discovered in this study. Zanbaka et al. [11] found that a larger tracking space may benefit cognitive awareness. Therefore, we believe that if the available space is larger, the user may use more physical locomotion to move, reducing the frequency of teleportation and increasing spatial awareness. These benefits may affect the grade of the following mechanisms, especially the SL and NL. While the space size is limited, perhaps some redirected walking (RDW) techniques should be implemented [37,38] since the locomotion user chooses in the virtual environment will affect spatial continuity. Last, the guide path may be dynamically generated to fit the physical room restriction. Keshavarzi et al. [39] proposed an algorithm to discover an optimal shareable space for different remote users. If the virtual environment is aligned to the physical room with RDW techniques, the user may use more physical locomotion(by foot) than other moving techniques, thus enhancing the user's spatial awareness.

6. Conclusions

In this paper, we aim to reduce the frustrations users may encounter while following a specific target in virtual reality. We proposed and compared three different types of following mechanisms: limited, semi-limited, and not-limited. In summary, the semi-limited mechanism is superior to the other two mechanisms. The experiment shows that the semi-limited mechanism outperformed others in most questionnaires. The performance in touring experience, cognitive engagement, and knowledge acquisition are better with the semi-limited mechanism. Additionally, the semi-limited mechanism helps users pay attention to the tour content while not being distracted by using different moving approaches to chase the tour guide. Though the two existing classic following mechanisms, limited and not limited, also have advantages in some use cases, experiments show that better following and transition mechanisms may help the user in learning efficiency and user experience.

There are several limitations in this preliminary work. First, the HMD restricted the range user can move by their feet. Since our experiment took place in our laboratory and the space was narrow, most of the participants used artificial locomotion. We did not make much effort to discover the relationship between physical locomotion and the following mechanisms. Besides that, all of our subjects are young and healthy. Even though all the participants did not report cybersickness in this experiment, we cannot ignore that different subjects may suffer motion sickness during teleportation and forced movement.

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