Bauhaus-Universität Weimar
Faculty of Media
Degree Programme Human-Computer Interaction

Jumping for Guided Navigation in Immersive Virtual Environments

Master's Thesis

Ramsha Saad Thaniana
Matriculation number: 121766
born on 07th October 1996 in Karachi, Pakistan

First referee: Prof. Dr. Bernd Fröhlich
Second referee: Junior-Prof. Dr. Jan Ehlers

Submission date: 08th November 2021

Declaration of Authorship

I hereby declare that I have written this thesis without the use of documents and aids other than those stated in the references, that I have mentioned all sources used and that I have cited them correctly according to established academic citation rules, and that the topic or parts of it are not already the object of any work or examination of another study programme.

Date Ramsha Saad Thaniana

Abstract

With the advance of Virtual Reality, there is a case to be made for narrative experiences such as tours and storytelling to be made virtual as well. This thesis presents a technique for automated guided jumping navigation in immersive virtual environments. The implementation of this technique includes how jumps will take place, pre-travel feedback and gesture control to pause, resume and make choices when needed. To investigate the benefits of this technique, this thesis presents a user study comparing automated guided jumping with free jumping using visual guidance. The results from conducting this study with 9 participants show that automated guided jumping provides similar path recall scores to free jumping. They also show that although free jumping gives lower discomfort scores, higher user comfort, lower task load scores and better comprehensibility of jumps, automated guided jumping still has good results for all these variables. Overall, the study shows that the technique has benefits and potential for further improvement in future work to create immersive environments that provide a narrative structure and require minimal user control.

Contents

1 Introduction

Many navigation techniques exist for both Desktop and Immersive Virtual Environments (VE) that define how users move around these VEs. The goals of navigation are to move towards a target location and orientation to explore the environment. Navigation should facilitate way-finding in the VE, which means allowing the user to know where they are, where they will go next and how they will get there. This also means that the user should have a good perception of the VE and path that they took. Navigation techniques have to ensure that there is minimal motion sickness; sufficient environmental awareness which means that while navigating the user knows where they are in an environment compared to where they were before; and that it is easy to reach important places in the environment. Two common metaphors for navigation are steering and teleportation.

Steering navigation is a technique where there is continuous movement in a direction indicated either by gaze, pointing, or use of a physical device. In some cases an additional action can be added to specify the velocity. With steering navigation, spatial awareness is generally good but can cause motion sickness. Teleportation navigation is a target-based metaphor that discretely specifies where the goal position is by pointing or choosing a location and orientation to be moved towards. This form of navigation minimizes motion sickness but results in less environmental awareness as compared to the steering metaphor. Some techniques try to reconcile these two metaphors to minimize motion sickness while still maintaining a good environmental awareness. One example is the jumping metaphor presented by Weissker et al. which *'only allows to teleport to locations in the currently visible part of the scene'* which makes it a short-range version of the teleportation metaphor [1].

Navigation techniques can be active such that the user is controlling their movement; passive such that the user is being automatically moved around the environment; or they can be a mix of active and passive. Navigation techniques can also provide the user with guidance, regardless of whether this is active or passive. The river analogy presented by Galyean, which guides *'the user's continuous and direct input within both space and time* *allowing a more narrative presentation'*, using automatic steering for guided navigation is a guided navigation technique. These allow for the addition of a narrative structure to a VE [2]. In this work, we will explore guided navigation using the jumping metaphor instead of a steering one and investigate the benefits of an automatic approach over a user-controlled one for a museum setting.

This thesis will discuss work related to navigation techniques and guiding in VEs on Head-Mounted Displays (HMD)s in Chapter 2. Then in Chapter 3 it will look into the motivation and use cases for a technique that combines guiding with navigation for an automated guided navigation technique using jumping. Based on these motivations, Chapter 4 will look at the design and development of an automated guided navigation technique. To justify the benefits of this proposed technique in comparison to a technique with free jumping using visual guidance, a study design and procedure will be introduced in Chapter 5. Then Chapter 6 will look at the results of this study. Chapter 7 will then conclude the thesis by summarizing the results and propose some future work that can be done on the topic of automated guided jumping for navigation in VEs.

All in all, the contributions of this thesis are as follows:

- Discussion of related work on navigation techniques, including quality factors, travel metaphors and guiding techniques for navigation.
- Exploration of use cases that motivate the need for an automated guided jumping navigation technique.
- Implementation of a potential interaction design for automated guided jumping, including the way jumps take place and travel feedback.
- Presentation of the design, procedure, and evaluation of a user study with 9 participants comparing our automated guided jumping technique with a free jumping technique using visual guidance.

2 Related Work

As mentioned in Chapter 1, this thesis aims to investigate a technique for automated guided navigation using the jumping metaphor. To understand where the concept for this technique comes from, we will take a look at different navigation metaphors for HMDs and see what the advantages of jumping navigation are. We will then see what the purpose of guiding in VEs is and why it can be useful for navigation to be guided. Based on this, we will then show the motivation for bringing together jumping and guiding into one navigation technique.

2.1 Navigation

Navigation is the task of moving around and when it comes to 3 Dimensonal (3D) environments it is one of the most common actions that is carried out by users. According to Bowman, Kruijff et al. navigation *'presents challenges such as supporting spatial awareness, providing efficient and comfortable movement between distant locations, and making navigation lightweight so that users can focus on more-important tasks'*. Navigation can be divided into the motor and cognitive components, travel, and way-finding, respectively. Navigation tasks include exploration, search, and manoeuvring [3]. Our technique will focus on exploration, which is navigation with no explicit target to investigate the environment and search, which is navigation to go to a target that is known or finding one which is not known.

2.1.1 Quality Factors

Quality factors of a technique are what makes it effective. Some of the quality factors that we decided should be taken into consideration before designing and comparing navigation techniques for Immersive VEs from the quality factors outlined by Bowman, Koller et al. are as follows:

1. *'Spatial Awareness'*, which is a user's knowledge of their position and orientation in an environment while travelling. We want to focus on this because we want our technique to be useful for navigating spaces where the environment is important and therefore, we do not want our technique to compromise on spatial awareness.

2. *'Ease of Learning*, which is how easy the technique is for a novice user to learn. This quality factor is important because we want our technique to be useful for novice users so that they do not need to spend too much time learning the technique and can easily understand it.

3. *'Ease of Use'*, which is how complex a user finds using the technique. [4]. This is again relevant for our technique as we want users to be able to focus on the environment or task rather than have task load from using the technique.

   In addition to the above, there is also a final quality factor:

4. *'Feeling Well'*, which is that the technique should minimize simulator sickness, as it can be a great concern for some users in VEs [5]. Reducing simulator sickness is an essential part of our design decisions as we want users to be comfortable using our technique rather than wanting to stop.

2.1.2 Travel Metaphors

Travel metaphors can be divided into many categories such as physical movement, viewpoint manipulation, steering, target-based and route planning [3]. These different metaphors consider the quality factors as mentioned in Section 2.1.1 to different extents depending on the goal of navigation. When the goal is not to travel but some other task which requires navigation, the technique must be more simplistic to not take away focus from the task. Hence, two very common metaphors of travel used in such cases are steering and teleportation, which is a form of target based travel.

Steering navigation is a continuous movement of the user's viewpoint in a specific direction that is controlled by gaze, pointing or a physical device. Velocity may also be varied as an additional action. When steering, the user is moving continuously through the surrounding environment and hence, has good spatial awareness. However, the movement may cause motion sickness as they are physically standing still while their surroundings are moving. [6].

Teleportation, which is also a technique where users are physically standing still, tries to reduce motion sickness by moving directly to a target instead of continuously travelling through the surroundings. Habgood et al. mention that a solution to the problem of simulator sickness *'has been to provide locomotion through teleportation'* [6]. However, due to this discrete movement, users may miss out on parts of the environment as they go directly to another position and orientation than they were in. Therefore, when using teleportation, users would have less spatial awareness than if they were steering. Habgood et al. try to reduce this by proposing a *'node-based navigation system which allows the player to move between predefined node positions using a rapid, continuous, linear motion'* [6].

Weissker et al. on the other hand try to reconcile steering and teleportation metaphors to minimize motion sickness while still getting a similar spatial awareness (or spatial updating) compared to steering, through the jumping metaphor. This is a short-range teleportation technique because it is target based travel to visible parts of the scene. Findings by Weissker et al. were that this technique resulted in *'significantly faster travel times'* as compared to steering but *'similar spatial updating accuracies in both conditions'* for 75% of the participants. It also *'induced significantly less simulator sickness'*. Therefore, the technique can be used in most cases as an alternative for steering. However, there may be some individuals that would have their ability for spatial updating impaired [1].

Based on this, we decided that we would like to use jumping navigation for our technique, moving users through sets of nodes at points of interest with way-points in between each node to be jumped to. Due to this, we felt that our technique would not work well for navigation tasks that related to manoeuvring, although they would be suited for tasks going through an environment to find a specific target (search) or to explore (exploration).

2.2 Guiding for Navigation

According to Beckhaus, most common travel metaphors rely on direct user control [7, p. 6]. However, there have been studies that propose travel metaphors that are more automatic. Examples of these include:

- The river analogy [2].
- Navigation guidance to reduce cognitive load of way-finding [8] [9].
- Managing coherent groups using path planning to dynamically move them [10].
- Dynamic potential fields for guided exploration or guided exploration through automated target based travel [7].

Beckhaus also found that *'self-navigation, automated travel, and guided exploration in a virtual environment'* worked together to form a *'supportive system'* that provided users with helpful guided navigation without: confusing them, removing their self control or feeling of presence [7, p. 8]. This shows that a balance of user control and automation is useful. This also introduces us to the concept of guided exploration.

Guiding means helping someone find a target object or location. Guiding through an environment would mean showing them the recommended path through it to give them the best experience. This would still apply for a VE but requires additional considerations that come with doing anything in Virtual Reality (VR). Guiding can be potentially be done for any VR interaction tasks, however, here we will talk about guiding for navigation in VR.

The wish to *'balance the notion of interaction with guidance (telling)'* and to provide a narrative structure to an experience motivates guided navigation techniques. Galyean presented the River Analogy which is an automatic steering technique for guided navigation and guides *'the user's continuous and direct input within both space and time allowing a more narrative presentation'*. The technique was useful when applied to a VR experience in a museum, showing that there are cases where guided interaction for VEs is useful [2].

Another example of guided navigation presented by Freitag et al. uses more passive guiding and simply supplements a user's free exploration of the VE. It visualizes the paths a user can follow based on what has already been explored and shows the users what their final location would be if they follow it. A study of this technique showed that it *'improves the knowledge of the scene, leads to a more complete exploration, and is experienced as helpful and easy to use'*. In comparison, during free exploration users *'miss important parts, leading to incorrect or incomplete environment knowledge and a potential negative impact on performance in later tasks'*, thus showing the importance of guiding when complete environmental knowledge is essential or beneficial [11].

2.3 Conclusion

Section 2.1 and Section 2.2 explored research on navigation techniques and why guiding can be useful for interaction in VR, particularly navigation. Based on this research, we realized how useful a guiding technique using jumping would be and the considerations that need to be taken when designing it. The motivations for this will be discussed further in Chapter 3 and the considerations when designing it will be further discussed in Chapter 4.

3 Guided Jumping Motivation

In the previous chapter, we discussed navigation techniques and why guiding for interaction to show why we decided to design a guided navigation technique using jumping instead of steering. In this chapter, we will look at use cases where navigation in a VE is required to further demonstrate the motivation for automated guided jumping for navigation. We will also introduce our research questions for this thesis.

Guiding facilitates exploration of 3D data where it is *'arranged on purpose'* and also applications in which *'the structure and meaning of the 3D data is unknown'*. Beckhaus focused on the former types of applications and tested their CubicalPath system for guided exploration on such applications. This included a Virtual Art Museum [7]. These types of applications can include those where a narrative structure needs to be provided within a VR experience [2] or where complete environmental knowledge is essential [11]. This particularly lends itself to Storytelling in VR and Virtual Tours.

3.1 Storytelling in VR

Storytelling, the art of sharing stories, has existed in humanity for millennia. As society has developed, so have ways of accomplishing storytelling. With the advent of a technological age, this transformed onto screens. Now, in recent times there has been a further breakthrough in storytelling with the advances in VR and the increase in ways of presenting immersive content. As Bucher explains; the concept of VR has existed long before the technology itself yet storytelling in VR follows different rules from the traditional stories as the perspective of a story is different in an Immersive Environment [12].

This makes it quite compelling to look into VR techniques that could be used to support this crafting of immersive narratives. Quite a few techniques for designing better VEs for storytelling already exist, but the question arises about what the best way of allowing users to move around in these VEs is. We need to ensure the provision of a structure instead of just allowing an *emergent narrative*, which is a story that emerges as a *'product of our interactions and goals as we navigate the experience'*. This is where guiding would come to *'balance the interaction (exploration) with an ability to guide the user, while at the same time maintaining a sense of pacing or flow through the experience'* [2].

According to Rodriguez et, al. *'Providing effective 3D exploration experiences is particularly relevant when the goal is to allow people to appreciate, understand and interact with intrinsically 3D virtual objects'* [13]. This is a part of storytelling, as the narrative structure within the environment may include interacting with 3D objects that are part of it. This is why we believe that storytelling could benefit from a guided 3D exploration experience. Automatic guiding techniques would be the best to maintain a narrative structure and prevent users from influencing it. However, if the experience has room to give users some choices, there can be ways to do so.

3.2 Virtual Tours

Similar to storytelling, tours have existed for a long time. People may need tours of any new place they visit or that they become a part of. For example, new students at a school may need a tour of it initially so that they know how to navigate it themselves later on. Tours are also a part of the tourism industry as tourists may take tours of a city they visit or just some important locations in the city. People may also want tours of specific locations such as museums to get more out of exploring those places than they would on their own. Tours would allow them to get information that they do not have through the tour guide.

As we entered the age of technology we started getting virtual worlds that contain schools, cities, museums, other spaces that are either modeled exactly after some existing physical counterparts or are made from a creator's imagination. Either way, this means that now there are virtual spaces just like physical ones that users could benefit from learning about through a tour. This raises the question of what the best way to tour these virtual spaces is. One option would be to have someone physically present where the user is using the VR hardware and guide them verbally. If that is not an option, there can be a tour guide embodied as an avatar and present remotely in the VE. Finally, an algorithm-driven agent could also be a virtual tour guide for users. We felt that this may be useful but wondered about alternatives where we do not want another person or agent in the environment. This made us think about techniques that provide visual guidance and then let the user move themselves following the guiding lines. An example of this is the technique by Freitag et al. that shows possible paths and the target location they would lead to [11]. Besides visual guidance, guiding can also be done automatically, such as the River Analogy which was applied to a virtual museum. This is useful when the author of an experience wants to ensure that users follow their intentions for the tour rather than freely controlling their navigation [2].

3.3 Conclusion

Based on use cases presented in Section 3.1 and Section 3.2 along with the literature review that led us to find that jumping navigation is preferable to steering in most cases, we came up with the following goals for our technique:

- Providing a narrative structure to the immersive environment.
- Facilitating the acquisition of complete knowledge of the environment.
- Novice friendly interface.
- Reducing motion sickness and disorientation.
- Moving to the currently visible part of the scene at each point to maintain a visible route.
- Balancing interaction with guiding in an immersive environment.
- Avoiding obstacles, collisions, ghosting and being too close to objects or walls.

Considering these goals of the technique, we thought that the following Research Questions were important to keep in mind when developing and evaluating it:

RQ_1: How can guided navigation techniques facilitate the acquisition of relevant knowledge of the scene while avoiding motion sickness?

RQ_2: How can we maximize the comprehensibility of a sequence of automated jumps?

RQ_3: Will having guided jumping improve comfort and reduce task load compared to free jumping with visual guidance?

4 | Automated Guided Jumping

In this chapter, we will start by discussing the interaction design for an automated guided jumping navigation technique that would meet the research questions referenced in Section 3.3. This will be followed by details about the development of the technique, which can be divided into two parts; the setup of an environment and narrative structure for using this technique and the development of automated jumping in a way that jumps are comprehensible to users.

4.1 Interaction Design

Looking at the use cases and motivation discussed in Chapter 3 we will first lay out a scenario in which our technique would be used and then go through the interaction design of the technique based on this scenario.

4.1.1 Scenario

We developed our automated guided jumping navigation technique for a virtual tour of an indoor space, which a user can do alone without a tour guide. There is potential to think of how this can be extended to a virtual tour of indoor spaces for a group of users without a tour guide as well. The goal of this virtual tour would be to explore specific objects and exhibits that could have a similar theme that a user is interested it and learn about them while also remembering what they have seen and where they saw it.

4.1.2 Exploration Steps

A tour of the VE would take place by ensuring that users go to specified locations of interest or nodes. Since these could be quite far from each other there should be way-

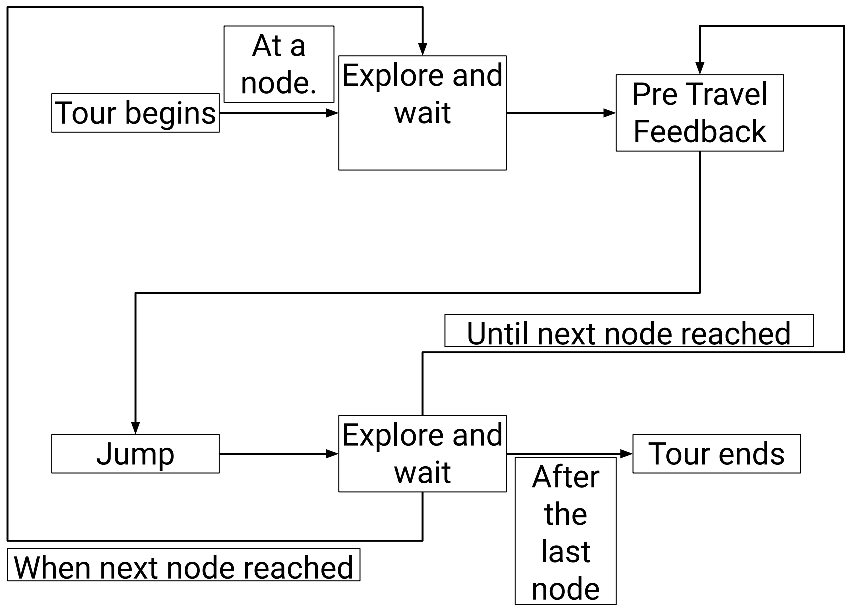


Figure 4.1: Steps that would be followed in an exploration of a VE using the automated guided jumping navigation technique.

points in between each node so that users would travel shorter distances to the nodes, hence, justifying the navigation being a jumping metaphor instead of teleportation. As shown in Fig. 4.1, when a user is touring the environment, they start at the first node. Here they can explore and wait for a while till they are willing to move on. When they are ready to jump, they get some form of travel feedback, so they are aware that a jump is about to take place. Then a jump takes place to either the next node or a way-point. The user can now explore and wait or again jump to the next node or way-point. On reaching the final node, the jumps would stop, and the tour would end.

Travel Feedback

Before a jump takes place, a user needs to know the following information:

- The location they will jump to.
- Their orientation after the jump.
- The time left until the jump takes place.

- Whether the guided jumping is paused, allowing them to explore.

Pause to Explore

As the jumping is done automatically, it is important to provide the user with some way to control the technique. This can be done by allowing them to somehow pause the jumping, either implicitly or explicitly so that they can take the time to explore or look around rather than being worried about automatically moving to the next position. Similarly, users would then also have the ability to implicitly or explicitly resume once they are ready to continue. Resuming would reset the countdown to a jump, to avoid sudden jumps after resuming. Looking away from the next node implicitly pauses the guiding and looking back at it resumes it, as looking around is a natural behavior that someone may use to explore an environment. Explicitly pausing or resuming the guiding requires some form of conscious user input, required instead.

Choice between Nodes

In addition to users having the option to pause, users should also have some control over the path they take. This can be provided by adding some nodes that give a choice to the users between multiple possible nodes they can go to. Users get information and travel feedback about each node, and then they can select their preferred node from the given options.

4.2 Environment Setup

Once we came up with a suitable interaction design for the technique, we had to decide how an environment would need to be set up to use this technique. Fig. 4.2 shows a basic environment in which our guided jumping technique can be used. As mentioned in Section 4.1.2, a user has to travel from one node to the next. As nodes are points of interest and can be far apart from each other, to ensure short jumps there are way-points between them. Fig. 4.2 shows these nodes as and way-points as black and yellow spheres, respectively. As we see in Section 4.1.2, sometimes there can be more than one node to

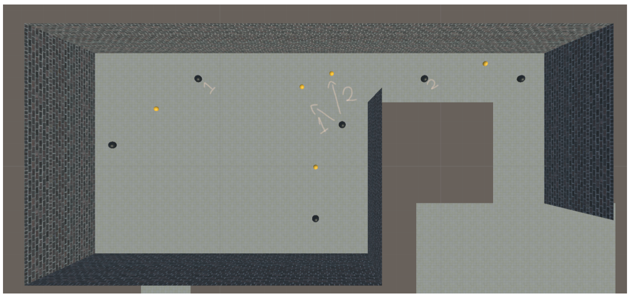


Figure 4.2: This is a potential setup of an environment in which the automated guided jumping navigation would be used. Black spheres = nodes, yellow spheres = way-points, arrows and numbers where there is a choice between nodes

choose from as the next node. This is indicated in the figure through numbers and arrows.

This environment setup with nodes, way-points and choices is something that would be a part of the environment design by the creator of an experience or tour. The nodes have to be points of interest so should be placed where there is some exhibit or interesting object for users to look at. Nodes should be linked to their next node by giving them index values. Way-points should also be set up between the nodes. Lastly, any nodes where there can be a choice of next node between more than one node should be set up accordingly with the same index value but different choice number and next node.

4.3 Automated Jumping

An environment that is ready with nodes and way-points can use the automated jumping technique. The technique works by moving a user from each way-point or node to the next, while keeping in mind important aspects of teleportation techniques. These are specified by Weissker et al. as: *'target specification, pre-travel information, transitions and post-travel feedback'* [1] and are what make the jumps comprehensible.

4.3.1 Comprehensibility of Jumps

The target specification in this case is automatic and has been preassigned as the next node or way-point, except for when there is a choice between more than one way-point or node

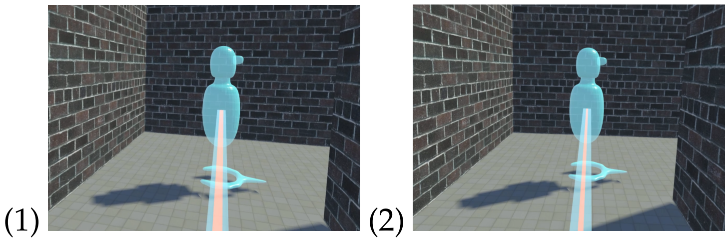


Figure 4.3: Avatar at target position facing orientation the user will face after jump. The orange line can be seen to decrease in width between (1) and (2) indicating time left till jump.

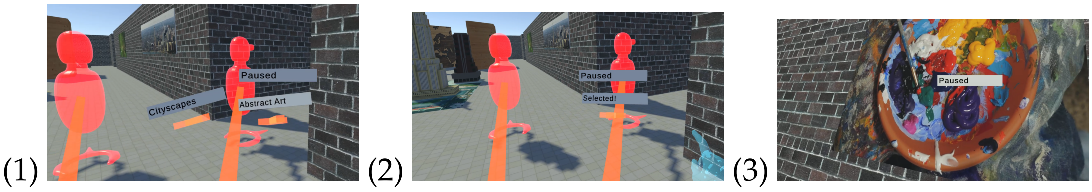


Figure 4.4: Feedback when making a choice or pausing: (1) Arrows and signs pointing to the different avatars, indicating a choice. (2) The selected avatar is indicated by a sign, while the arrow and sign for the avatar not selected disappear. (3) A sign showing that automated jumping has been paused.

as the next target. Pre-travel information is provided as avatars positioned at the target's location and facing the direction that a user would be oriented towards after a jump. In addition, the time left till the jump will take place is also indicated by a line that gets narrower proportional to the time left. This can be seen in Fig. 4.3. We decided to go with simple instant transitions for the jumps. There is no specific post-travel feedback, however, after a jump users can already see the pre-travel information for the next jump and are therefore aware that they have completed the current jump.

Finally, there has to be feedback when the user has to make a choice or when they pause the automated jumping. This feedback is provided through User Interfaces (UI). To indicate a choice that needs to be made by the user for what path they want to take, there is a combination of arrows and signs pointing to the avatars that indicate the next possible positions to choose from. On selection, a sign that says *'Selected!'* is used to show which option has been selected. In addition, the arrow and sign for the option that is not selected disappear. Once feedback has been given for making a choice, the guiding continues with the node or way-point represented by the selected avatar as the next node or way-point. To indicate that the automatic guiding is paused, a sign that says *'Paused'* becomes visible. Fig. 4.4 shows the different UI's for feedback on pausing or making a choice.

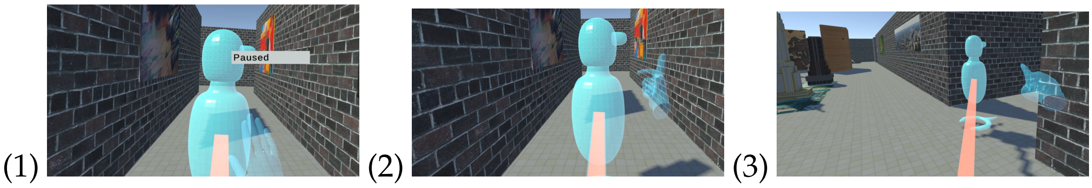


Figure 4.5: Gesture control to (1) pause, (2) resume and (3) make a choice.

4.3.2 Gesture Control

Since we wanted to reduce the learning difficulty for users and also the hardware that would be required to use the technique, we decided on allowing users to use hand gestures with a HMD that allows for gesture tracking. Users can pause and resume the automated guiding explicitly through hand gestures. They can also use a pointing hand gesture to choose the next node or way-point when there is a choice between more than one. These hand gestures should be natural and represent how a person may do a similar action in a non-virtual environment. Fig. 4.5 shows the hand gestures being used in our VE using an Oculus Quest 2.

5 | Design and Procedure of the User Study

5.1 Hypotheses

In Chapter 4 we looked at a technique for automated guided navigation using the jumping metaphor. We also saw how the jumps in this technique could be made comprehensible so that a user could know when and where they will jump. We also discussed the motivations and scenarios that might require such a technique in Chapter 3. Keeping in mind the motivation to have a virtual museum that novice VR users are able to explore, we came up with the research questions $\mathbf{RQ_1}$, $\mathbf{RQ_2}$ and $\mathbf{RQ_3}$ that are mentioned in Section 3.3.

To study the developed technique with regard to these research questions, we decided to design a study that would compare our developed technique for automated guided jumping with a user-controlled (free) jumping technique having visual guidance. With this study we hoped to prove the following hypotheses:

$\mathbf{H_1}$: Participants do not get more simulator sickness while using automated guided jumping compared to free jumping with visual guidance.

$\mathbf{H_2}$: Visual previews before automated jumps will have similar comprehensibility of the jumps compared to free jumping with visual guidance.

$\mathbf{H_3}$: Automated guided jumping will reduce task load compared to free jumping with visual guidance.

$\mathbf{H_4}$: Users will be able to recall their path when using automated guided jumping as well as when free jumping with visual guidance.

(1) (2)

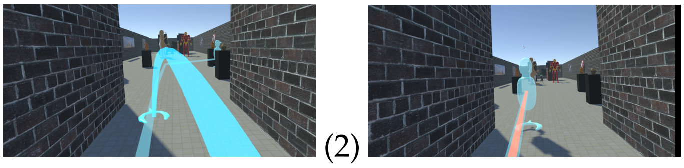


Figure 5.1: Free jumping with visual guidance.

Hypothesis $\mathbf{H_1}$ is important because we want to justify the need to automate the guided jumping without compromising on the reason for using jumping as the navigation metaphor, that is, reduced motion sickness. To also justify that spatial awareness is similar in our technique versus free jumping, the study must prove $\mathbf{H_2}$ and $\mathbf{H_4}$. $\mathbf{H_2}$ also needs to be proved to show that the technique is easy to understand and users will not get confused when using it compared to free jumping. In order to prove the benefit of automated guided jumping over free jumping with visual guidance, the study must show that $\mathbf{H_3}$ is true.

5.2 Study Task and Limitations

As the study will be comparing automated jumping with free jumping using visual guiding, it was important to plan a controlled study design such that there would be no other influencing variables besides the automation. Therefore, when developing the free jumping technique that would be used for comparison, we had to make sure that the only difference between it and our automated jumping technique would be the absence or presence of automation of jumps. There are still nodes and way-points in the scene that are used to show visual guidance, with an avatar being visible at the next node and a path drawn through way-points as in Fig. 5.1. The figure also shows the teleportation indicator with a curve pointing to it that users can use to select the position and orientation they want to be at after the jump.

As discussed in Section 3.2 one of the use cases for guiding techniques is virtual tours, and we developed our technique for such a scenario as mentioned in Section 4.1.1. Therefore, the study design also kept in mind a virtual tour situation and considered the potential problem situations that may occur and the possible tasks that may be expected when touring through a virtual space. For this study we narrowed the task to touring a virtual museum with exhibits and trying to remember the path taken as well as the objects seen.

This is a useful when going through a museum and gives answers about whether the techniques used are facilitating acquisition of relevant knowledge as we hoped or not and can be seen in $\mathbf{RQ_1}$.

The task situation for this study will not cover all possible situations that may arise when taking a virtual tour, such as:

- Exhibits that are very close or far from each other.
- More than 2 possible paths to choose from at some nodes.

5.3 Variables and Conditions

Keeping in mind the task of touring a museum and remembering the path and objects, there are certain variables that need to be varied between the two techniques and others that need to be measured.

5.3.1 Independent Variables

As we saw in Section 5.2, automation is the only variable that should be different between the two techniques that are being compared. This means that one technique will have automated jumping and the other will not, but the visual guidance and ability to have a choice must remain the same. In addition, it is important to keep the number of nodes and way-points the same. It is also necessary to keep the environment and objects of similar complexity.

5.3.2 Dependent Variables

The variables depending on the automation of the jumping are related to the hypothesis that we introduced in Section 5.1. The amount of simulator sickness needs to be measured somehow to answer $\mathbf{H_1}$. A higher amount of simulator sickness is undesirable, while lower amounts are better. $\mathbf{H_2}$ can only be answered by finding some way to determine the comprehensibility of jumps. The more comprehensible users find a jump the better. The variable needed to answer $\mathbf{H_3}$ is the task load that users feel they had. A lower task load means that users felt they had to make less effort to complete their task and is, therefore, better. Finally, we also need to measure path recall so that we can prove $\mathbf{H_4}$. The more a user is able to recall their path, the better. We will look into details on how to extract these variables during the study procedure described in Section 5.4.

5.3.3 Study Conditions

Since we have two techniques to be compared, we decided to go with a within user design with 2 study conditions, one using automated guiding and the other using free jumping with guidance. To avoid participants recall of the environment after the first condition affecting their recall of the environment for the second condition, it is necessary to have two different but comparable scenes. In addition, to avoid the environment or the study order impacting the results of the techniques, we decided to alternate the order of the conditions while keeping the environment order the same each time.

5.4 Study Procedure

In the previous section, we defined variables and conditions for the study. Based on these we planned the study procedure which we will now outline in this section starting with the study setup followed by the study plan.

5.4.1 Study Setup

The study setup can be divided into three parts, which we will discuss in this section. The hardware setup within a physical space, the virtual environment setup and the user feedback.

Hardware

We conducted the study using an Oculus Quest 2 which we implemented our hand tracking for. The Quest 2 has **'Oculus Insight technology'**, which tracks changes in the

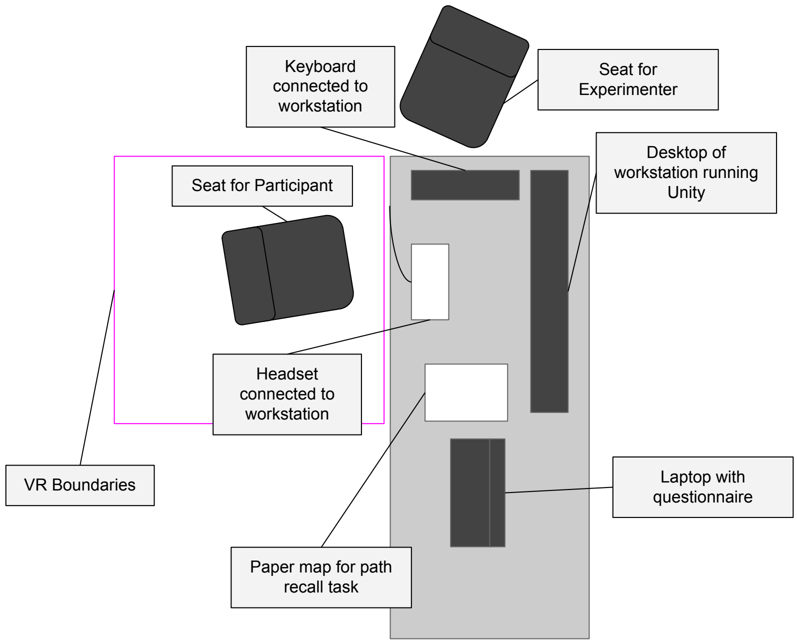


Figure 5.2: A drawing of the study setup in the Laboratory Space. The experimenter and participant were on the same workspace as the experimenter only needed to use the keyboard.

users' position and orientation without the need for external tracking. We set the play-space to stationary so that users could remain seated while doing the task, as there was no need for physical movement. However, a revolving chair was present for users to sit on to ensure they could physically rotate. We gave participants the Oculus Quest 2 right controller for the free jumping technique and did not need to use a controller for the automated jumping. The display resolution for the environment was 1832×1920 pixels per eye with a refresh rate of approximately 72 Hz. We connected the headset to a computer running the VE on unity with a USB cable through Oculus Link. An additional laptop computer was also set up so that participants could answer questions on it in between the tasks and at the end of the study. There was also some space on the desks with a paper for a drawing task for the path recall, which will be explained more in Section 5.4.2 and is linked in the appendix. Finally, the experimenter controlled study conditions via the keyboard connected to the workstation running the environment on Unity. Fig. 5.2 shows a drawing of the physical study environment and setup.

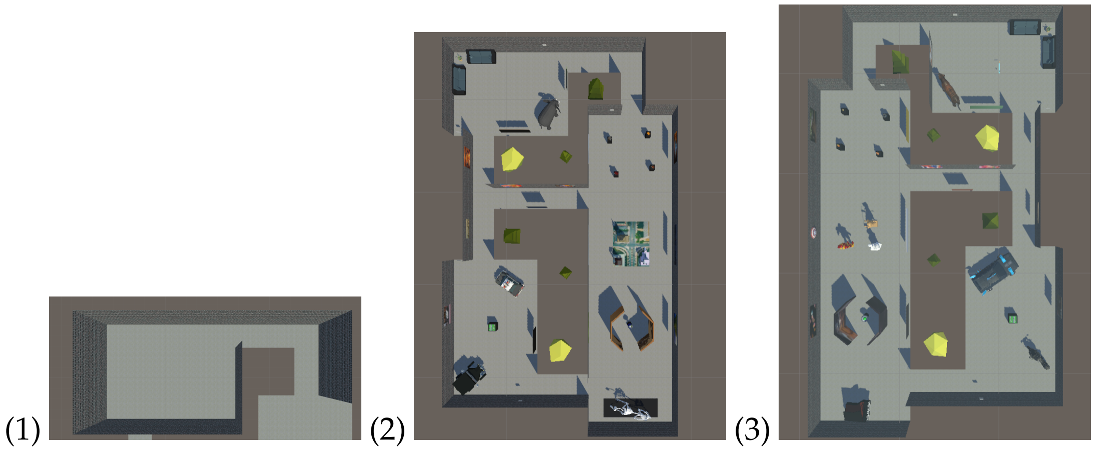


Figure 5.3: The virtual rooms used for the study with a (1) Tutorial room, (2) Room A and (3) Room B.

Virtual Environment

We used more than one virtual environment for the study. These could be divided into rooms between which the user would switch after the end of a study condition. There was one tutorial room in which tutorials for both techniques would take place. There were then two other rooms which were the actual environment for the study tasks. These rooms were a simple museum setup with three rooms connected by one T-shaped corridor and two simple corridors. The rooms had a total of 11 exhibits. There were also 15 paintings distributed along the walls of the rooms and corridors. There are a total of 12 nodes with 29 way-points unevenly distributed between them. Because of a choice between 2 nodes at the 5^{th} node, participants only end up going through 8 nodes with 19 unevenly distribute way-points in one tour. Top-down views of these three rooms can be seen in Fig. 5.3. Room B is a mirror of Room A, but has different exhibits and paintings. The node and way-point placement order is also a little different, but the number of nodes and distribution of way-points among nodes is the same. The node at which the choice is to be made between 2 nodes is also the same.

5.4.2 Study Plan

We explained the study setup in Section 5.4.1 and now we will see the study plan. Before the study was even conducted, participants were emailed with the details of the study and asked for consent to be sent over email. Due to the Covid-19 pandemic, certain precautions

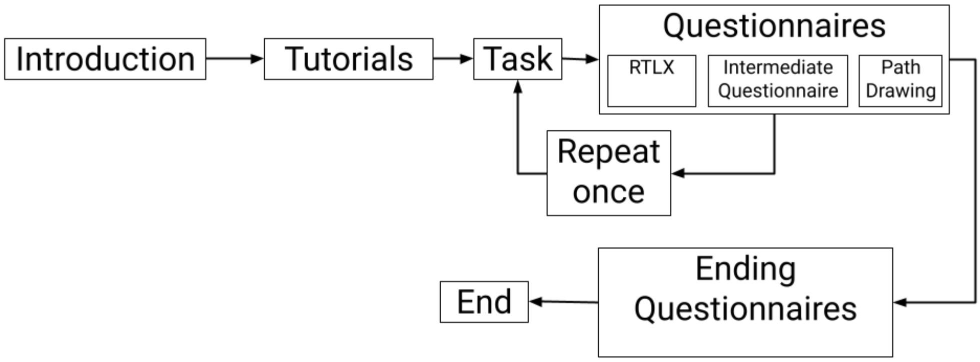


Figure 5.4: The study steps. Participants undergo one round of tests for each study condition. The study order was alternated between participants.

had to be given in the email as well. The exact draft of the email can be found in the appendix. Once the participants arrived, the study could begin in the order shown in Fig. 5.4. The steps shown in this diagram will be explained further in this section. Before and after the study, all hardware and stationery that the participant would use were sanitized in accordance with Covid-19 hygiene guidelines. The experimenter also wore a mask during the study.

Tutorial and Tasks

When participants arrived they were seated in the chair where they would remain for the duration of the study. Then they were once again reminded of what they are consenting to before beginning an audio and screen recording. Participants were also reminded that they could stop the study at any time. They were then given a short briefing on the study process and told that they would begin with a tutorial on two techniques and then carry out two tasks with a questionnaire in between and at the end of these tasks. They also entered some demographic information to the questionnaire before beginning.

Before wearing the headset, participants were shown the hand gestures that would need to be used as well as the button on the controller that they would need. The hand gestures were called name thumbs up, hand up and pointing. The controller button used would be the trigger button on the right controller. Pressing down on the button would give

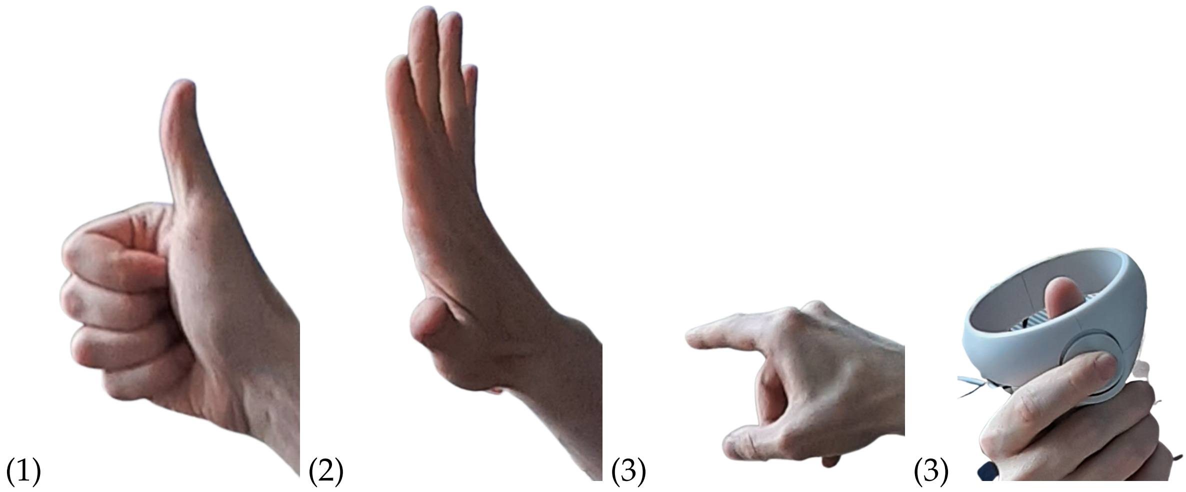


Figure 5.5: The gestures: (1) Thumbs Up to resume, (2) Hand Up to pause and (3) Pointing to choose between nodes for the Automated Guided Jumping technique. (4) The right controller trigger button that has to be pressed and released to make a jump in the Free Jumping condition.

feedback to allow the user to choose where to jump. Rotating the hand around the wrist would allow participants to control the orientation they would be at after the jump, while moving the hand forward and back would influence the position. Once the position and orientation are selected, the trigger button can be released to make the jump. Gestures and button mapping are shown in Fig. 5.5. Then the user could wear the Oculus Quest 2 and begin with the study tasks. The study started with a tutorial that was divided into two parts for the two techniques, with the order they were presented in depending on the study order that they would be following. There were two possible study orders that could be followed. Automated guiding in the first task and free jumping in the second, or vice versa. The tutorials would also be presented in this order. The study orders were alternated between participants. The participants could repeat the tutorials for each technique till they were comfortable with it. The time taken for each tutorial was also recorded.

Once participants completed both the tutorials, they could begin with the tasks. Each task was the same, except for the technique and environment. Participants were told to use the technique to move through the environment. They could pause when necessary and look around at objects. When presented with a choice between 2 nodes, they could pick whichever node they wanted. They were informed that they would need to draw their path and what they saw, and therefore they should try and pay attention to where they were going. As participants moved through the environment, their time, positions and orientations were recorded into a log file on every move and any time they paused or had to make a choice. When they chose a node, the selected node was also logged. Example logging data is shown in the appendix to demonstrate the format.

Questionnaire

In between tasks, participants could take off their headset and go to the second computer to answer some questions and draw their path. The questions for each task were the same. Finally, at the end of the study participants answered some final study questions about both techniques. The exact questions in the questionnaire can be seen in the appendix.

The demographic questions obtained from the questionnaire were age and gender. The intermediate questions used for the study included a question on simulator sickness, which was introduced by Fernandes et al. to give a discomfort score [14]. Then the participants were also asked their perceived level of comfort and their reasons.

To measure the task load we decided to use an electronic version of the Raw Task Load Index (RTLX) questionnaire as introduced by Hart et al. as a method for mental workload assessment [15] [16]. We then had some questions about the technique used to get information regarding the comprehensibility of jumps. The questions were both quantitative and qualitative to get a clear understanding of what the participants understood about the technique and whether they were confused at any point about their position and orientation. After the task questions were answered, participants had to draw the objects they saw and their paths on a provided map, which was a top-down view of the room without any objects in it. This map can be seen in the appendix. This would then be compared with the actual environment for accuracy and given a Path Recall Score (PRS) based on the Eq. (5.1) where **INW** stands for the number of correctly identified nodes and way-points, **INW** stands for the total number of nodes and way-points the participant saw including the ones they had to choose from but did not, **IEP** is the number of correctly identified exhibits and painting and **TEP** is the total number of exhibits and paintings. These ratios are multiplied by a hundred to get them as a percentage, and then divided by two to get the average. This means that the range of possible path recall scores is from 0 to 100. Nodes and way-points are considered **INW** if they are drawn within a circle of 1 centimeter radius around the actual position to account for human errors when remembering relative positions. This 1 centimeter on paper is equivalent to 2 meters on the unity environment. Paintings and exhibits that are drawn by participants on the map are considered **IEP** in the same way.

$$PRS = \frac{100\left(\frac{INW}{TNW} + \frac{IEP}{TEP}\right)}{2} \tag{5.1}$$

Finally, after participants answered questions for Task B there were some final study questions to get quantitative feedback on their preferred technique and the reasons for it, as well as additional feedback on what they liked about each technique, what situations they would prefer it in and any other feedback about the techniques. This allowed us to have a more holistic view of the experience the users had with each technique.

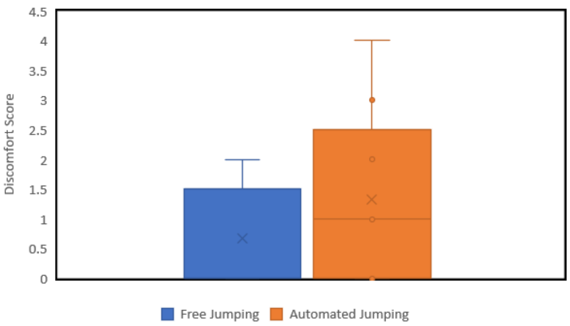
6 Evaluation of the User Study

In the previous chapter, we saw the study design and procedure. Based on this, we planned to conduct the user study with 10 participants. However, 1 participant had to drop out before the study, which left us with 9 participants. The demographics showed us that they were between 22 and 33 years. 7 out of 9 were under 30. 3 out of 9 participants were female. In this chapter, we will evaluate and discuss the findings of the study and then look at what insights this gives about the possible uses of our automated guided jumping technique. While explaining the results, we will refer to the two techniques for the study tasks as **FJ** for the **Free Jumping** condition and **AJ** for the **Automated Jumping** condition. We will also represent mean averages, median values and standard deviations with their common symbols which are **Avg**, **Mdn** and σ respectively. These values will all be rounded to the nearest hundredths. Individual participants will be referred to as $\mathbf{P}_n$ where n is the participant number.

6.1 User Comfort

During the study, none of the participants felt too sick that they could not continue with it. The maximum discomfort score was 4 during AJ when the participant had this condition in their second task. Overall, there was a positive skew for discomfort score during both conditions, as can be seen in Fig. 6.1(1). However, the FJ condition was more positively skewed and had lower simulator sickness than AJ (Avg_{FJ} = 0.67, Mdn_{FJ} = 0, σ_{FJ} = 0.86; Avg_{AJ} = 1.33, Mdn_{AJ} = 1, σ_{AJ} = 1.5). It also seems as if the order in which the conditions were presented to participants did not impact the discomfort score as for most participants AJ always has a higher discomfort score regardless of when it was presented. While this proves $\mathbf{H_1}$ false, we do see that the simulator sickness for AJ is not that bad, even if it was worse than for FJ, and hence our technique still manages to avoid excessive simulator sickness.

In addition to the discomfort score, we also got results for the general user comfort which showed that it was better for FJ as can be seen in Fig. 6.1(2). Both the conditions show a

(1) 

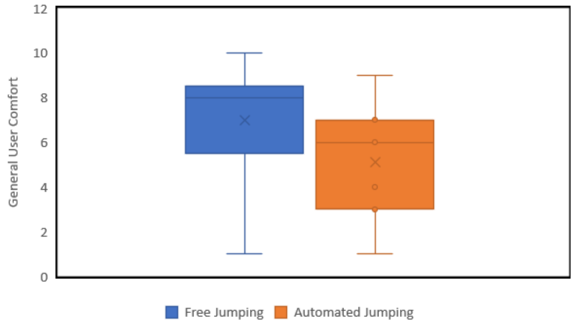
(2) 

Figure 6.1: Box plots illustrating the (1) simulator sickness and (2) user comfort scores reported by participants during each of the study tasks.

negative skew with the results for FJ more negatively skewed than for AJ with higher user comfort ($Avg_{FJ} = 7$, $Mdn_{FJ} = 8$, $\sigma_{FJ} = 2.78$; $Avg_{AJ} = 5.22$, $Mdn_{AJ} = 6$, $\sigma_{AJ} = 2.52$). However, when looking at the reasons for these reported comfort levels, we realized that they were more subjective. P_1 was comfortable with FJ because they *'felt in control'* and P_7 preferred FJ due to familiarity with using a controller for movement.

6.2 Task Load

RTLX scores were obtained by averaging values from the RTLX questionnaire for each participant. The scores for both conditions were found to be slightly positively skewed with higher RTLX scores in AJ ($Avg_{FJ} = 26.57$, $Mdn_{FJ} = 25$, $\sigma_{FJ} = 17.03$; $Avg_{AJ} = 36.94$, $Mdn_{AJ} = 36.67$, $\sigma_{AJ} = 17.52$) as shown in Fig. 6.2. While this disproved **H3** because task load was less for FJ, only 2 out of 9 participants had scores higher than 40 for AJ. This meant that most of these participants still felt that they had less task load even in AJ. There were also 2 out of 9 participants that had lower scores for AJ than FJ.

6.3 Comprehensibility of Jumps

Fig. 6.3 shows that the participants had higher confusion about their position ($Avg_{FJ} = 0.89$, $Mdn_{FJ} = 0$, $\sigma_{FJ} = 1.17$; $Avg_{AJ} = 2.89$, $Mdn_{AJ} = 2$, $\sigma_{AJ} = 2.52$) and orientation ($Avg_{FJ} = 2.22$, $Mdn_{FJ} = 2$, $\sigma_{FJ} = 2.59$; $Avg_{AJ} = 5.22$, $Mdn_{AJ} = 6$, $\sigma_{AJ} = 2.91$) in the AJ condition. Results

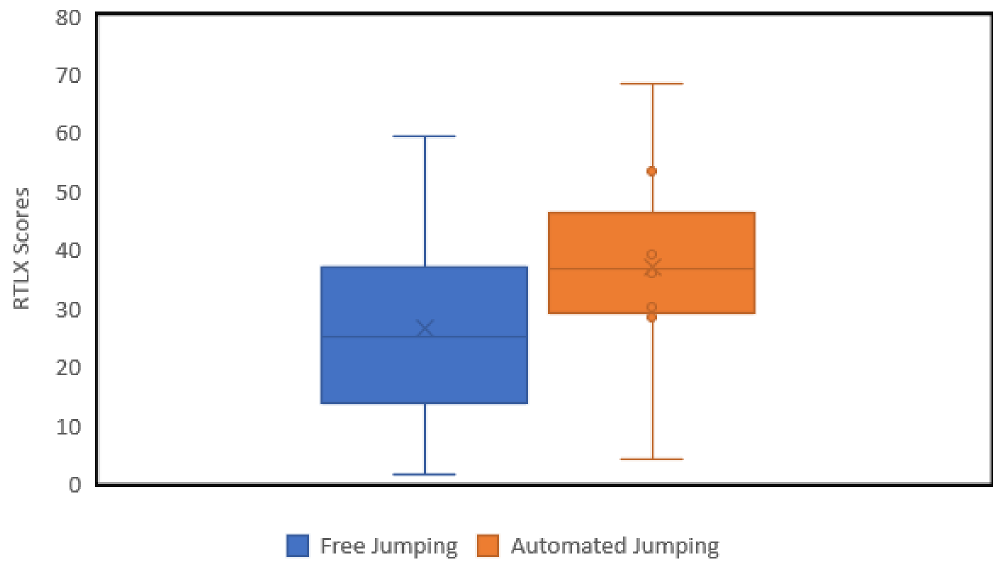


Figure 6.2: Box plot illustrating the RTLX scores reported by participants during each of the study tasks.

were positively skewed for position and negatively for orientation in both conditions, with FJ having more positively skewed results for position than AJ. Despite this proving **H_2** wrong, we do see that in general the jumps are still comprehensible for AJ and the qualitative answers also show that 8 out of 9 participants did correctly understand how they were getting to the next position and what it would be in the AJ condition. However, only 6 out of 9 participants correctly understood what their next orientation would be when using AJ. Alternatively, all participants correctly understood how to get to the next position, what it would be and what their next orientation would be as well. Nonetheless, it is unclear whether this could have been influenced by the fact that participants may have used HMDs before in environments where they could freely navigate using controllers and were, therefore, just more comfortable with the technique beforehand. This means that **H_2** should be studied again in a different study.

6.4 Path Recall

The Path Recall Score (PRS)s for both the conditions were very similar (Avg_{FJ} = 37.91, Mdn_{FJ} = 39.01, σ_{FJ} = 19.01; Avg_{AJ} = 37.09, Mdn_{AJ} = 39.15, σ_{AJ} = 13.69), although it is clear from Fig. 6.4 PRSs have a greater range in the FJ condition with the maximum score

(1) (2)

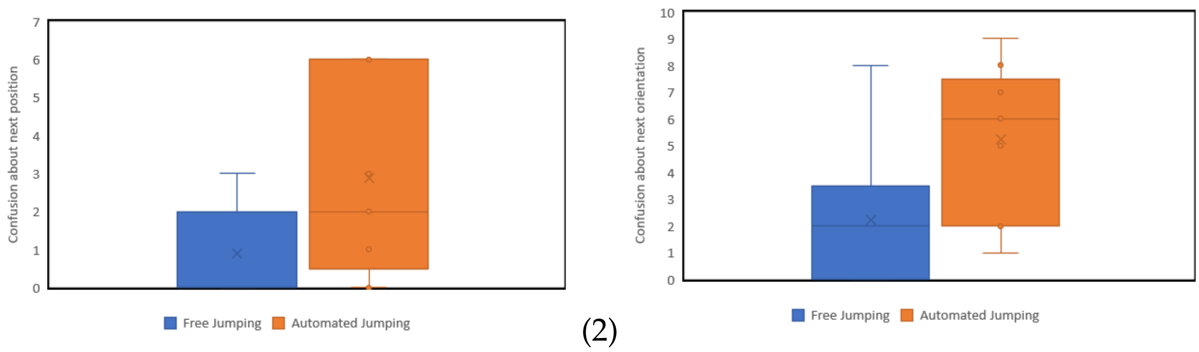


Figure 6.3: Box plots illustrating how often participants felt confused about their (1) next position and (2) next orientation as reported by them during each of the study tasks.

being 68.54 compared to a maximum score of 55.63 in the AJ condition. The scores for path recall are also negatively skewed, with a more negative skew in AJ. This proves $\mathbf{H_4}$ true.

6.5 Additional Feedback

After the questions that were aimed towards answering our hypotheses, we also had some further questions on what participants felt about the techniques they were presented with. These qualitative results showed us that 7 out of 9 participants preferred free jumping, as shown in the pie chart in Fig. 6.5. However, the reason for this preference was always that the participant had more control when they were using the free jumping technique. As our goal with the automated guided jumping technique is to not allow users to have a lot of control, this preference does not mean that the AJ technique is not relevant. Instead, we can perhaps reconsider the scenario so that users do not feel like they should have control. We also need to think of ways to make users more comfortable with not having as much control.

Furthermore, even though most participants did not prefer AJ over FJ, 8 out of 9 of them still liked it and had positive things to say about it. For example, P_8 preferred FJ and liked it because of *'The feeling of being in control because of moving further and looking around being independent of each other.'*. However, they still liked that AJ gave them the *'feeling of "I can navigate fast without having to do much with the controller and being intuitive with my hand in*

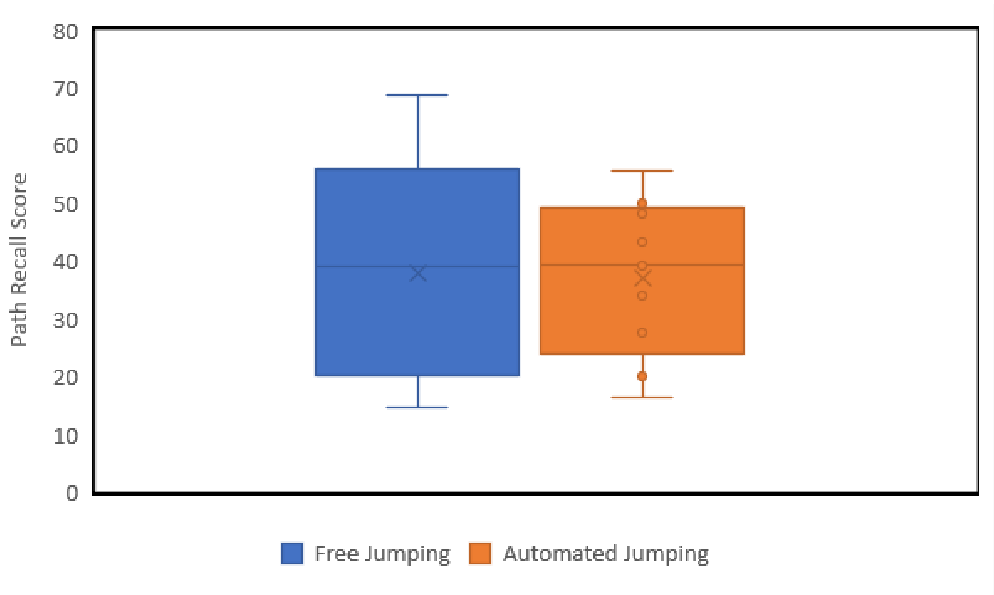


Figure 6.4: Box plots illustrating the PRS calculated based on the path and objects drawn by participant during each of the study tasks.

the air :)'. Meanwhile, P_5 liked using their hands when using AJ, P_9 found AJ faster than FJ. Both these participants had indicated that their preferred method was FJ due to the control it provided. Participants also understood that there could be scenarios in which AJ would work better. Despite preferring FJ, P_2 stated that they would prefer to use AJ in scenarios where the *'virtual public simulations where the hand motions can be kind of universal. Similar to the task example (museums)'*. Therefore, it can be seen that participants just did not prefer it in the scenario of the experiment and wanted more control in this case. This indicated that the scenario was perhaps not an ideal use case for a technique where users should have limited control. There was also some feedback on the AJ technique that can be used to further improve it. This feedback included:

- Time between automated jumps should be longer based on feedback from P_6.
- Gesture tracking was sometimes not precise according to P_1.

Finally, one realization we had while conducting the study was that participants did not understand that there was a visual countdown for the timer, and this may have led to some participants feeling like they were jumping too fast and had limited control. However, this cannot be verified in the scope of this thesis.

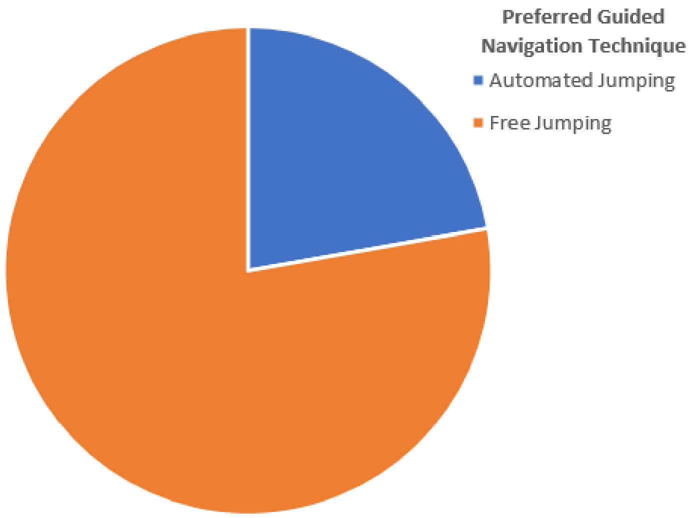


Figure 6.5: A pie chart representing the technique preferred by participants.

6.6 Further Discussion

As seen in the previous sections, only 1 out of 4 hypotheses were proven true. However, since this was a single study with only 9 participants, this does not automatically mean that the automated guided jumping technique does not have its benefits or does not meet the research questions. It is also unclear if the level of experience that participants had with VR may have affected results. Perhaps in a future study, this could be kept consistent either with all participants having barely used HMDs or those who had quite a bit of experience with using HMDs. Additionally, the study condition could be changed as well to one that had even less of a focus on navigation and more on the narrative of the environment. This may reduce the need for participants to want more control while navigating, as they might want to focus more on the story told by the environment instead of trying to move wherever they want. These are a number of ways in which we can further study our automated guided jumping navigation technique after refining it even more based on the feedback received about it.

7 Conclusion and Future Work

In this thesis, we looked into the need for a guided jumping navigation technique for immersive virtual environments.

We started with a look at related work in navigation and guiding for navigation. We looked into three travel metaphors, steering, teleportation and jumping. This led to a decision to focus on the jumping metaphor, as it balances a good spatial understanding with reduced simulator sickness for a majority of users. We also looked into guiding navigation techniques that included techniques with automatic guiding using steering navigation and free guiding with exploration assistance. We decided to focus on an automatic guiding technique using jumping navigation and compare it with a technique using free jumping with visual guidance. The only difference between these techniques would be the level of user control to jump. We decided on developing an automated guided jumping technique because we wanted a technique that would provide users with the ability to navigate a completely new environment with a pre-existing narrative structure without the need for tour guides to guide them through the environment. We also wanted the interface to be novice-friendly and allow users to focus on the environment rather than the navigation technique. Finally, we wanted the technique to allow users to get relevant knowledge of the environment and avoid simulator sickness or any other kind of discomfort. We also noted that such an automated guided jumping technique could be quite useful in environments where a narrative structure is important, such as for virtual tours or storytelling in VR.

After a look at the literature review and motivation, we looked into the design and development of the automated guided jumping technique. The technique was developed such that the user would be automatically jumping from one node or way-point to another. Nodes in this case are points of interest, while way-points are points in between the nodes to break the navigation from one node to the next into smaller distances such that it could be called a jump and users would not miss anything. To ensure users were not surprised by the jumps we also designed and developed visual feedback about the jump including avatars at the next position and orientation, a visual countdown before a jump and signs for pausing and making a choice. Finally, to allow users to have some control over pausing, resuming and making a choice, we implemented simple hand gestures that users could use.

To explore the benefits of our technique, we decided to conduct a study comparing it with a technique that would allow users to jump freely instead of being automatically guided. This free jumping technique would also have visual guidance that would be the same as the visual feedback given to the users in our automated guiding technique. The study comparing these techniques was conducted using 9 participants. The results from this study show that while users had mostly positive things to say about the guided jumping navigation technique, they still preferred free jumping because of the level of control they had with it, indicating that the automated jumping technique needs to be refined in a way that users feel more comfortable with not having control. This can be seen from the feedback received, which has also been referred to in Section 6.5. The results also indicate that in general, automated guided navigation does facilitate the acquisition of relevant knowledge of the environment that is similar to when using free jumping and avoids motion sickness even though motion sickness levels were higher than with free jumping.

Through the study, we also realized that the comprehensibility of jumps was not the best with our technique but could be improved as future work. Some ways in which to improve it is to refine the gesture control further by a deeper look at the hand tracking functionalities for the HMDs. Perhaps different HMDs could be compared for their hand tracking to determine which one gives the best user experience. Another improvement could be on the visual countdown for the time. This could be made more visible or another way of visualizing it could be used instead of the line that goes narrower as has been used in the current implementation. Finally, the avatar that indicates the next position could be further improved so that the next position shown is even clearer.

The study also showed us that while the comfort and task load scores were good for the automated guided jumping technique, they were not better than for free jumping with visual guidance. This means some further studies need to be conducted to find ways in which the automated guided jumping technique can be improved so that the comfort and task load for it could be equal to or better than for free jumping with visual guidance. As we can see from our findings, there are definitely more open questions that could not fit into the scope of this thesis that can be looked at in future work on automated guided jumping to improve on the implementation suggested in this thesis.

One such question is the narrative structure in the environment. The current implementation only placed nodes at points of interest and did not focus on what these could provide to the experience. There is potential to explore how the environment can be set up to have an interesting narrative structure and where time and other factors could be part of the design space of an environment that would use an automated guided navigation technique. In particular, implementations of such a technique for a storytelling use case could be further explored because there the focus of users is more on the storytelling and less on the navigation.

Another question to be asked is how the technique could be extended for multi-user cases, such that groups of users can be guided through the environment together. In such a case, there would be additional questions related to group navigation that would arise.

Future work can also look into ways that the narrative structure could be created dynamically during or before the exploration, either by one user in a group of users or just a single user rather than being pre-loaded into the experience. There are a lot of possible scenarios for which implementations where experiences are created dynamically can be considered, for example, an experience using automated guiding navigation may be set up in a museum which allows users to have a custom tour. In this case there would need to be a way to customize the tour. Another example could be that there is a group of users in which one user is setting the path and the others are being moved using automated guided jumping.

All in all, automated guided jumping has its benefits and use cases in which it can be very beneficial and therefore, there is room to explore different implementations for it. While we have presented one implementation that focuses on the jumps and the travel feedback there is still the challenge to improve travel feedback, for more comfort and better comprehensibility of jumps, as well as the challenges of designing better experiences, hardware and interaction techniques for automated guided jumping. There also remains the challenge of extending this into multi-user VR. Future work in this direction should ensure that users do not feel frustrated by the lack of control of such a technique.

Bibliography

[1] T. Weissker, A. Kunert, B. Froehlich, and A. Kulik, "Spatial updating and simulator sickness during steering and jumping in immersive virtual environments," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 97–104, 2018.

[2] T. A. Galyean, "Guided navigation of virtual environments," in *Proceedings of the 1995 Symposium on Interactive 3D Graphics*, I3D '95, (New York, NY, USA), p. 103–ff., Association for Computing Machinery, 1995.

[3] D. Bowman, E. Kruijff, J. Jr, and I. Poupyrev, "An introduction to 3-d user interface design," *Presence*, vol. 10, pp. 96–108, 02 2001.

[4] D. Bowman, D. Koller, and L. Hodges, "Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques," in *Proceedings of IEEE 1997 Annual International Symposium on Virtual Reality*, pp. 45–52, 215, 04 1997.

[5] J. LaViola, "A discussion of cybersickness in virtual environments," *ACM SIGCHI Bulletin*, vol. 32, pp. 47–56, 01 2000.

[6] J. Habgood, D. Moore, D. Wilson, and S. Alapont, "Rapid, continuous movement between nodes as an accessible virtual reality locomotion technique," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 03 2018.

[7] S. Beckhaus, *Dynamic potential fields for guided exploration in virtual environments*. PhD thesis, Otto-von-Gueicke Universitate, Magdeburg, 2002.

[8] N. Elmqvist, M. E. Tudoreanu, and P. Tsigas, "On navigation guidance for exploration of immersive and desktop virtual environments." 2005.

[9] N. Elmqvist, M. Tudoreanu, and P. Tsigas, "Evaluating motion constraints for 3d wayfinding in immersive and desktop virtual environments," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1769–1778, 01 2008.

[10] R. Silveira, E. Prestes, and L. Nedel, "Managing coherent groups," *Computer Animation and Virtual Worlds*, vol. 19, pp. 295–305, 08 2008.

[11] S. Freitag, B. Weyers, and T. Kuhlen, "Interactive exploration assistance for immersive virtual environments based on object visibility and viewpoint quality," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 03 2018.

[12] J. Bucher, *Storytelling for Virtual Reality: Methods and Principles for Crafting Immersive Narratives*, pp. 1–27. New York, NY: Routledge, 07 2017.

[13] M. Balsa Rodriguez, M. Agus, F. Marton, and E. Gobbetti, "Adaptive recommendations for enhanced non-linear exploration of annotated 3d objects," *Computer Graphics Forum*, vol. 34, 06 2015.

[14] A. S. Fernandes and S. K. Feiner, "Combating vr sickness through subtle dynamic field-of-view modification," in *2016 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 201–210, 2016.

[15] S. G. Hart and L. E. Staveland, "Development of nasa-tlx (task load index): Results of empirical and theoretical research," *Advances in psychology*, vol. 52, pp. 139–183, 1988.

[16] S. G. Hart, "Nasa-task load index (nasa-tlx); 20 years later," *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 50, pp. 904 – 908, 2006.

A Appendix

A.1 Email to Participants

Subject: VR Study Participation and Consent

Consent form

Dear Participant,

I would like to confirm your participation in my study on <Date> at <Time>. Below is a consent form for the study. Please read and reply with your consent as per the instructions. Below the consent form is a list of requirements for the study.

This is a consent form for the Social VR project pilot study.

In my project I have developed tools for navigating in a virtual environment. In this study I want to determine how effective these tools are for navigating and understanding an environment.

During this study you will be asked to carry out two Tasks. Each task will be of maximum 10 minutes and 10 minute breaks for answering some questions after each task. You will also have some final questions to answer at the end of the study. Participation would take about 50 minutes.

I would like permission to:

- Record input from your microphone and tracking sensors.
- Record the video of your VR view.
- Get some data of your movement within the application.
- Get your answers to some questions in a questionnaire.

I will anonymize and store this recorded data and the answers to the questionnaire for further analysis to be published in my project report.

Please, inform me immediately if you are feeling unwell during the study process and want to take a break or stop.

You are free to leave the study at any time.

Please reply with your agreement as follows:

I, <Name>, agree to participation in a user study and the recoding of my data following the above conditions

Requirements List

To be able to participate please follow the steps outlined below prior to the study time:

- Make sure that you will not be disturbed for the time of the study.
- Prepare to be standing for the duration that you are in VR (except for breaks).
- Make sure you are following all Covid guidelines when coming to the location of the study.

The following details are the location of the study Please be here at least 5 minutes before the start time:

<Location>

Thank you for your participation. Please email me if you have any concerns or questions

Regards,

Ramsha Saad Thaniana

A.2 Questionnaire

The following are the questions that were in the questionnaire given to participants in the user study. Questions asked after each task were specific to the task and can be divided into questions on user comfort, task load and comprehensibility of jumps. There were also some end of study questions.

A.2.1 User Comfort

- On a scale of 0 to 10, 0 being how you felt coming in, 10 is that you want to stop, where are you now?
  Answered on a discrete scale from 0 (How you felt coming in) to 10 (You want to stop)
- How comfortable were you during the task? coming in, 10 is that you want to stop, where are you now?
  Answered on a discrete scale from 0 (Not comfortable) to 10 (Very comfortable)
- Please explain the reasons for the level of comfort that you chose above.
  Answered on a free text field

A.2.2 Task Load

The electronic version of the Raw Task Load Index (RTLX) questionnaire had the following questions that have to be answered on a scale of 0 to 100 in steps of 5 with a slider and numbers hidden to the participant.

- Mental Demand - How mentally demanding was the task?
  0 (Very Low) to 10 (Very High)
- Physical Demand - How physically demanding was the task?
  0 (Very Low) to 10 (Very High)
- Temporal Demand - How hurried or rushed was the pace of the task?
  0 (Very Low) to 10 (Very High)

- Performance - How successful were you in accomplishing what you were asked to do?
  0 (Perfect) to 10 (Failure)
- Effort - How hard did you have to work to accomplish your level of performance?
  0 (Very Low) to 10 (Very High)
- Frustration - How insecure, discouraged, irritated, stressed and annoyed were you?
  0 (Very Low) to 10 (Very High)

A.2.3 Comprehensibility of Jumps

- How were you getting to the next position?
  Answered on a free text field
- How often were you confused about what your next position would be?
  Answered on a discrete scale from 0 (Never) to 10 (At every jump)
- How did you know what your next position would be?
  Answered on a free text field
- How often were you confused about what direction you would be facing after a jump?
  Answered on a discrete scale from 0 (Never) to 10 (At every jump)
- How did you know what direction you would be facing after a jump?
  Answered on a free text field
- If you have mentioned that you were confused about your next position/direction please explain what you were confused about.
  Answered on a free text field
- Were you confused about anything else? If so what were you confused about?
  Answered on a free text field
- Do you have anything more to add for this task?
  Answered on a free text field

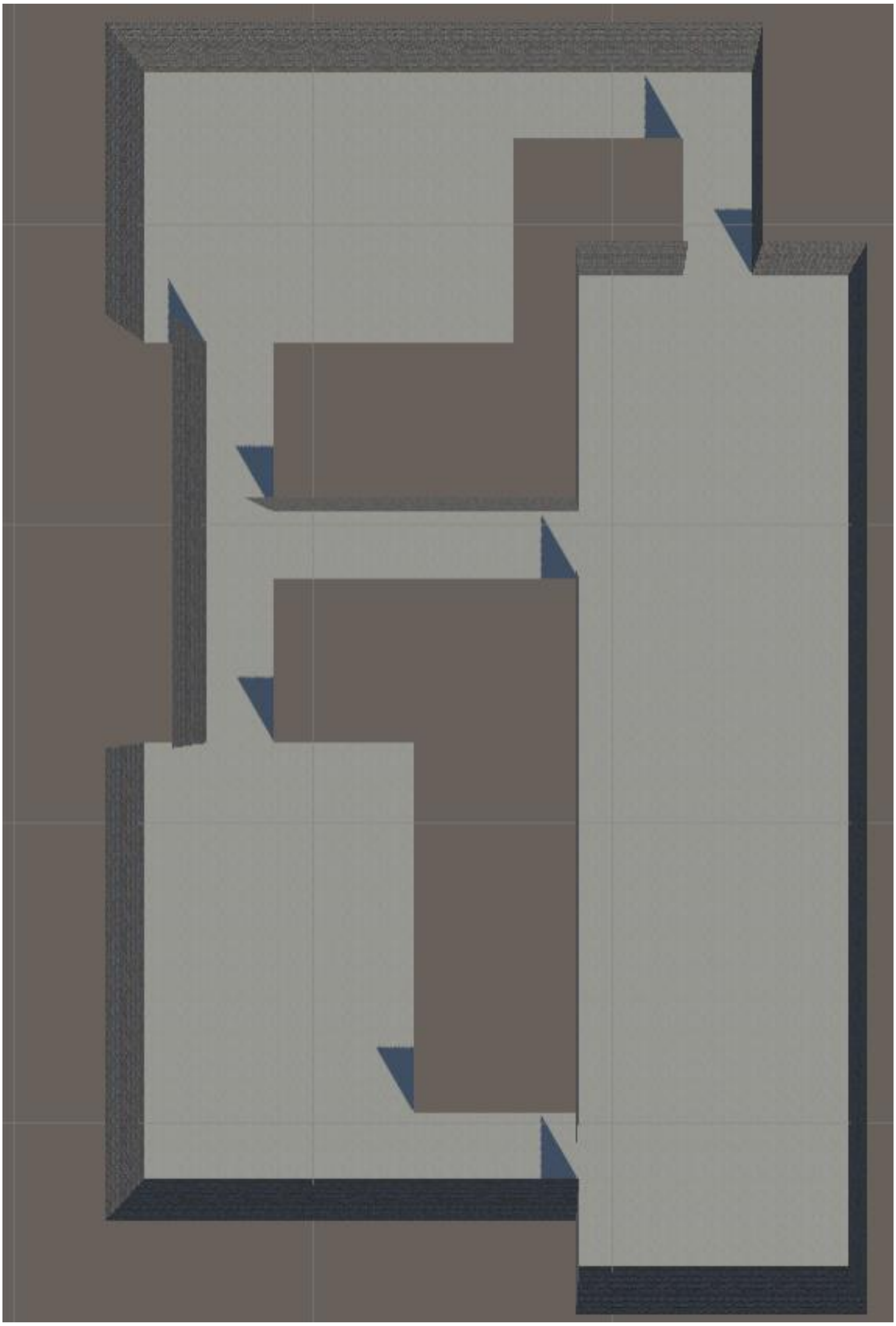
A.2.4 Final Questions

For these questions participants were aware that Task A refers to the task they did first and Task B refers to the task that they did second.

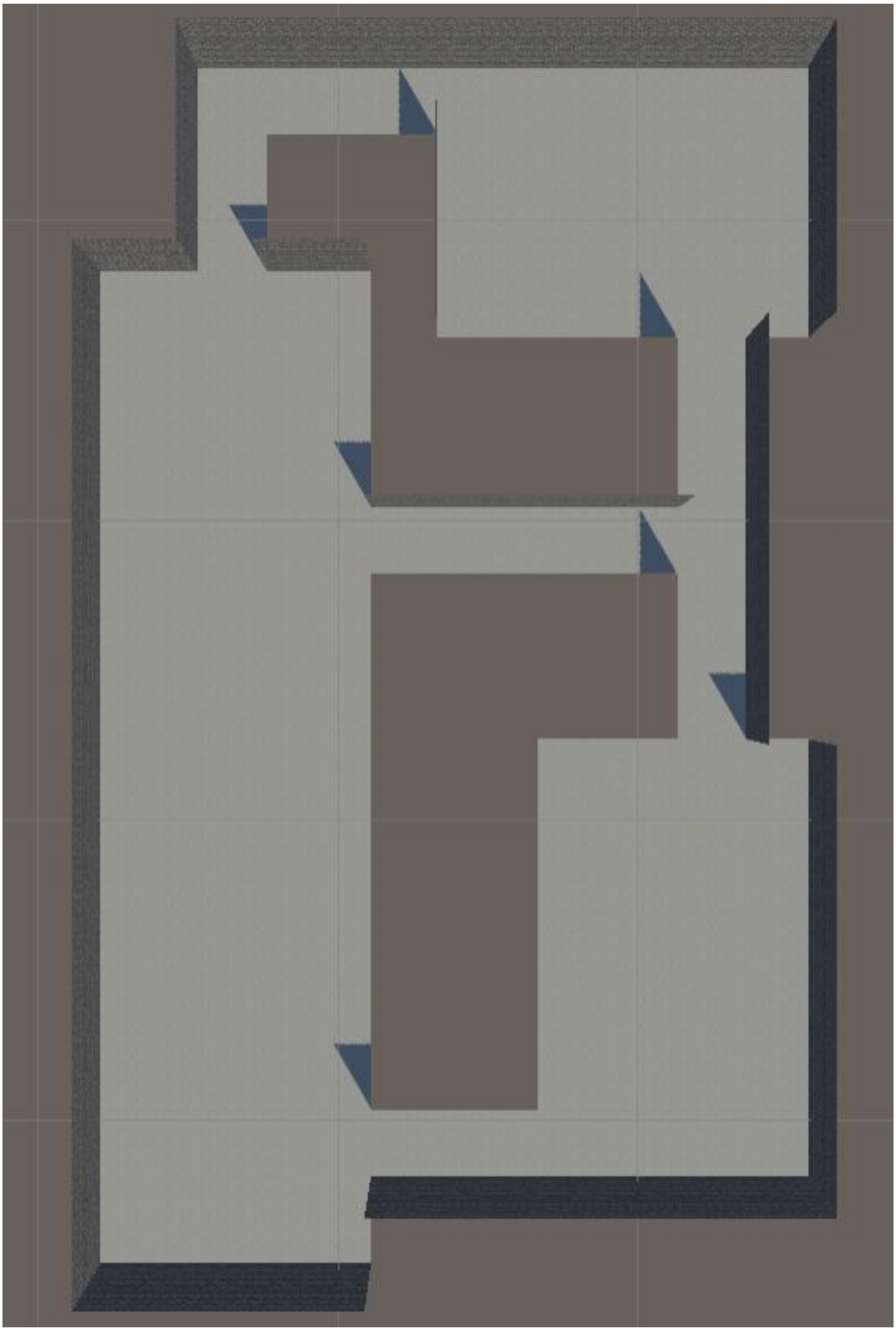
- Which method did you prefer?
  Answered by choosing an option from the options (Task A, Task B)
- Why did you prefer this method?
  Answered on a free text field
- Can you think about any scenario in which you would prefer to use the method in Task A for?
  Answered on a free text field
- Can you think about any scenario in which you would prefer to use the method in Task B for?
  Answered on a free text field
- What did you like about the method in Task A?
  Answered on a free text field
- What did you like about the method in Task B?
  Answered on a free text field
- Do you have anything more to add about the method in Task A?
  Answered on a free text field
- Do you have anything more to add about the method in Task B?
  Answered on a free text field
- Any final comments?
  Answered on a free text field

A.3 Maps for Path Recall

Task A



Task B



A.4 Sample Logging Data

Participant 1 Tutorial A
Guided Jumping
NODE 0: 0, (4.3511, 0.8000, -2.1717), (0.0000, 0.0000, 0.0000)
3.006682, (4.3511, 0.8000, -2.1717), (0.0000, 0.0000, 0.0000)
NODE 1: 3.006682, (4.3511, 0.8000, -2.1717), (0.0000, 0.0000, 0.0000)
6.018946, (4.3511, 0.8000, 0.0083), (0.0000, 15.0000, 0.0000)
9.032545, (5.4811, 0.8000, 1.7962), (0.0000, 0.0000, 0.0000)
NODE 2: 9.032545, (5.4811, 0.8000, 1.7962), (0.0000, 0.0000, 0.0000)
CHOICE: 9.032545, (5.4811, 0.8000, 1.7962), (0.0000, 0.0000, 0.0000)
STOPPED: 9.032545, (5.4811, 0.8000, 1.7962), (0.0000, 0.0000, 0.0000)
SELECTED 0: 20.77742, (5.4811, 0.8000, 1.7962), (0.0000, 0.0000, 0.0000)
RESTART: 21.29119, (5.4811, 0.8000, 1.7962), (0.0000, 0.0000, 0.0000)
24.30542, (3.7711, 0.8000, 3.3983), (0.0000, 285.0000, 0.0000)
27.3175, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
NODE 3: 27.3175, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
STOPPED: 29.42882, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
GESTURE 0: 29.42882, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
STOPPED: 29.58094, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
GESTURE 0: 29.58094, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
STOPPED: 33.37119, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
GESTURE 0: 33.37119, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
RESTART: 33.59335, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
GESTURE 1: 33.59335, (-0.6289, 0.8000, 3.7383), (0.0000, 270.0000, 0.0000)
36.60647, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
STOPPED: 36.89751, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
GESTURE 0: 36.89751, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
STOPPED: 37.00922, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
GESTURE 0: 37.00922, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
STOPPED: 39.79932, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
GESTURE 0: 39.79932, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
RESTART: 39.89653, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
GESTURE 1: 39.89653, (-2.4089, 0.8000, 2.4683), (0.0000, 220.0000, 0.0000)
42.91005, (-4.2689, 0.8000, 0.9383), (0.0000, 270.0000, 0.0000)
END OF TASK
Time Taken: 42.91005
Repeat

A Appendix

Participant 1 Tutorial B
Free Jumping
NODE 1: 0.0158651, (4.3511, 0.8000, -2.1717), (0.0000, 0.0000, 0.0000)
13.27261, (3.8611, 0.8000, -1.8642), (0.0000, 178.9646, 0.0000)
32.34929, (4.3954, 0.8000, -2.1083), (0.0000, 357.9292, 0.0000)
45.88664, (6.4643, 0.8000, -2.4187), (0.0000, 346.5254, 0.0000)
58.78469, (5.6683, 0.8000, 0.8079), (0.0000, 356.8633, 0.0000)
NODE 2: 58.79811, (5.6683, 0.8000, 0.8079), (0.0000, 356.8633, 0.0000)
CHOICE: 58.79811, (5.6683, 0.8000, 0.8079), (0.0000, 356.8633, 0.0000)
65.12926, (6.8776, 0.8000, 3.7052), (0.0000, 2.5725, 0.0000)
69.47525, (10.0721, 0.8000, 3.5810), (0.0000, 11.9871, 0.0000)
77.5007, (7.2686, 0.8000, 3.5936), (0.0000, 18.4924, 0.0000)
83.69274, (5.6695, 0.8000, 1.8863), (0.0000, 10.1380, 0.0000)
101.7564, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.7702, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.7846, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.7981, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8121, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8262, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8398, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8535, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8676, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8816, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.8951, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.9093, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.9234, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.9368, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.9511, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.965, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.9788, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 101.9927, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.0066, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.0204, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.034, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.0487, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.0622, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.0757, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.0897, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1036, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1174, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1316, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1452, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1592, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1728, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.1872, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.201, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.2145, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.2287, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.2426, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.2559, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.2702, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
SELECTED 1: 102.2844, (5.1226, 0.8000, 3.5835), (0.0000, 15.0280, 0.0000)
114.0716, (8.4528, 0.8000, 3.6781), (0.0000, 27.4893, 0.0000)
NODE 4: 114.0854, (8.4528, 0.8000, 3.6781), (0.0000, 27.4893, 0.0000)
116.8763, (11.8244, 0.8000, 3.6839), (0.0000, 37.5431, 0.0000)