Comparing Teleportation Methods for Travel in Everyday Virtual Reality

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Abstract

The number of everyday virtual reality (VR) applications is increasing at a remarkable pace. Perhaps the most fundamental interaction in these applications is the ability to travel throughout virtual environments in which users find themselves immersed. Teleportation is often used to support travel in VR applications. While many methods exist for implementing teleportation, relatively little research has been done to compare such methods. In this paper, we describe an experiment to compare four teleportation methods for travel in everyday virtual reality. We found that, for general use, experienced VR users prefer to control a virtual arc with their hand to indicate the location and direction of orientation to which they want to teleport. However, teleporting a single step at a time in the direction of view may support more natural movement and encourage shorter travel paths, but at the expense of longer travel times.

Keywords: virtual reality, teleportation, user studies.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—Human computer interaction (HCI)—Interaction techniques

1 Introduction

The popularity of virtual reality (VR) technologies for use in application areas such as teaching [19], historical reconstructions [20][23], and gaming [21][22] continues to increase. Devices like the Oculus Rift (oculus.com/rift) and HTC Vive (vive.com) have made VR accessible in ways that have never been possible before. Many everyday VR applications require users to travel between two or more locations in the virtual space in which they are immersed. However, traditional travel techniques used for decades in video games (such as pushing on a joystick or touchpad) to move about in virtual environments frequently cause users significant discomfort in VR [10]. This discomfort is thought to be due to a mismatch between what the eyes see and the motion (or lack thereof) that the body experiences. Developers of modern VR applications frequently support travel through teleportation, which causes the user to instantly appear at a new location. Since users do not see themselves moving without their bodies sensing movement, users tend to be more comfortable when teleportation is used as a travel technique in VR.

While many methods exist for implementing teleportation in VR applications, relatively little research has been done to compare these methods. In this paper we describe an experiment to compare four methods for implementing teleportation in VR applications. Our objective is to determine which teleportation methods users prefer as well as which methods allow users to complete travel tasks most efficiently in virtual reality.

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2 Background

While many factors may impact user satisfaction with VR experiences, Yildirim [22] indicates that cybersickness may have a particularly significant effect on user enjoyment. Cybersickness can make VR applications almost entirely unusable for some individuals. Researchers have explored the effects of factors such as display type [11] and narrative context [21] on cybersickness in VR. Considerable research has been conducted to investigate the impacts of user movement in VR on symptoms of cybersickness [5][7][12][13].

Travel through virtual environments is one of the most common user tasks in VR [3][18]. Previous research indicates that travel techniques such as teleportation are associated with lower levels of cybersickness than traditional joystick-based movement controls [10]. While teleportation can be disorienting for some users [2], its potential for reducing occurrences of cybersickness resulting from user movement through virtual environments and relative ease of implementation has made it commonplace as a travel technique in everyday VR applications.

Numerous implementations of teleportation in VR have been described in the literature [1][4][6][8][24]. For example, Bozgeyikli et al. [4] define a "Point & Teleport" technique that relies on hand tracking or a controller to select a destination for teleportation. The destination location is indicated by both a ring on the ground and a line from the user's virtual hand to the ring. The direction the user faces after the teleportation can be manipulated by rotating the user's hand. Bolte et al. [1] describe a "jumper metaphor" to allow users to reach far away locations in a virtual environment when real walking is the primary locomotion technique. With this method, users can focus on a distant object to select the jump location, and then an animation displays to simulate the jump to the location. Griffin and Folmer [6] describe an "out-of-body locomotion" technique similar to teleportation. This technique involves moving the camera position away from the user's avatar representation to provide a third-person perspective of the environment. Users then move the position of the avatar to the desired location before returning to a first-person perspective from the vantage point of the avatar's new position.

While many studies have compared teleportation techniques to other methods for user travel in VR [4][7][10][14][15][16], considerably less research has been conducted to compare multiple implementations of teleportation for the same travel task. One notable exception is the work of Schafer et al. [17], who developed teleportation techniques that are implemented through hand tracking of one or both hands. They found that subjects completed a travel task effectively with either one or two hands tracked, but using the palm of the hand to point to the teleport position was significantly faster than the use of the index finger.

In this paper, we compare four teleportation methods that can be implemented in everyday VR applications using a standard VR controller (such as the Oculus Touch controller). We call the methods **arc**, **hand selection**, **head pointer**, and **step**. With the arc method, users control a virtual arc with their hand to indicate a

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location and direction of orientation to which they would like to teleport. With the hand selection method, users point to one of a discrete set of possible locations in the virtual space to which they would like to teleport. With the head pointer method, users control a virtual arc with their head to indicate a location to which they would like to teleport. With the step method, users press a button on the controller to teleport one virtual step forward in the direction they are facing. All these methods can support user travel throughout virtual environments.

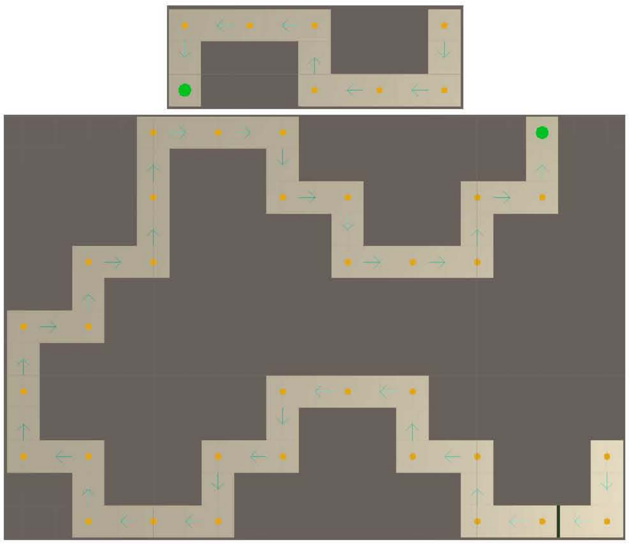

Figure 1: Virtual environments used for the experiment.

3 Experiment

Two virtual reality environments were developed to support our experiment. The training environment (shown at the top of Fig. 1) was designed to allow users an opportunity to familiarize themselves with the teleportation methods. Users begin at the right of the virtual hallway and teleport throughout the environment until they reach the green circle on the floor at the end of the hallway. Cyan arrows were placed on the floor so that users can always easily determine the direction they should travel to reach the hallway end. Yellow circles were placed at each turn in the hallway and in the middle of long hallway segments. While the yellow circles are visible for all teleportation methods, the circles only have meaning for the hand selection method, as the circles indicate the locations to which users may select to teleport. Fig. 2 shows an example of the hand selection method. Note that a gray circular object is placed over the yellow circle at which the user points. Using the thumb stick on the controller, users can control the direction they face at the conclusion of the teleport by changing the direction of the arrow in the middle of the gray circular object (shown in Fig. 2 and Fig. 3). With this method users travel from their current location to the center of the selected yellow circle each time they teleport. While the actual distance traveled depends on the user's starting location, in our environment the distance traveled with this method for each teleportation was typically 20 meters (the distance between the centers of the yellow circles).

The arc method is depicted in Fig. 3. With this method, an arc appears from the user's hand to the floor when a button on the controller is pressed. As with the hand selection method, by using the thumb stick on the controller users can control the direction they face at the conclusion of the teleport by changing the direction of the arrow in the middle of the gray circular object at the end of the arc. With this method users are able to teleport between approximately 1 and 11 meters, depending on how they position the arc. The head pointer method is like the arc method, except that the arc originates from the position of the user's head instead of the hand. Users change the position of the arc by moving their head and change the direction of the arrow using the thumb stick on the controller. With the head pointer method users are able to teleport between approximately 1 and 10 meters, depending on how they position the arc. With the step method, users see no arc or gray circular object. They simply press a button on the controller to teleport one virtual step (two meters) forward in the direction they face. As with all methods, users can turn their head (or entire body) to change the direction they face in the virtual environment.

The test environment (shown at the bottom of Fig. 1) is like the training environment, but much longer. The **time** (in seconds) and total **distance** traveled in the virtual environment (in meters) to reach the green circle at the end of the hallway are recorded for each visit to this environment. Note that the recording starts when users pass over the black line on the floor near the beginning of the test environment (see the bottom right of Fig. 1). This is to ensure that users are fully prepared to travel to the end of the hallway before data recording begins. The virtual reality environments and teleportation methods were implemented using Unity (unity.com) and the Oculus Integration for Unity.

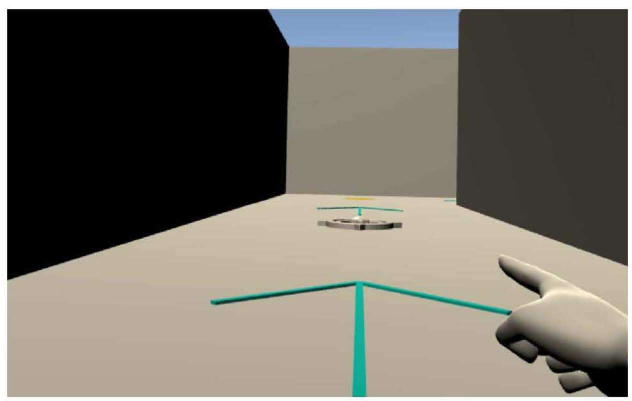

Figure 2: The hand selection method.

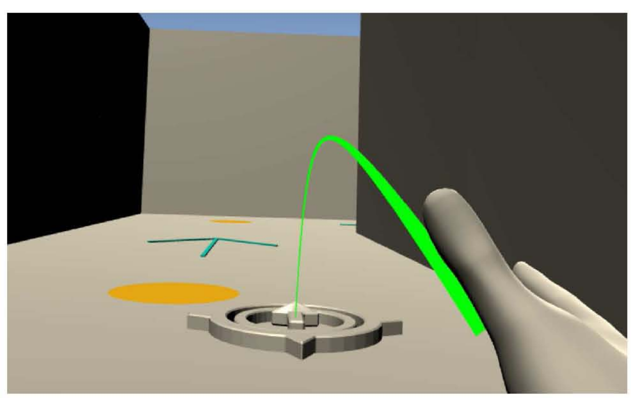

Figure 3: The arc method.

3.1 Subjects

To participate in our experiment, subjects were required to have access to their own Oculus Quest or Quest 2 (oculus.com/quest-2) that they could bring to their session. This was to protect the health and safety of subjects. Eighteen subjects participated in the experiment (16 males and two females). The mean age of subjects was 26.1 years (SD=7.06). All subjects indicated having used an Oculus Quest or Quest 2 several times, and subjects received extra credit in a college course for their participation.

3.2 Procedure

When subjects first arrived for their session, they were asked to read and sign an informed consent document. After signing the document, they were asked their age, gender, and amount of experience using virtual reality headsets such as the Oculus Quest. Subjects attached their Quest to a five-meter long Oculus Link cable connected to the researcher's computer and stood approximately three meters from the researcher to complete the experiment.

Subjects then experienced all four teleportation methods in virtual reality using their Quest and Touch controllers. For each method, subjects first navigated to the end of the training environment once to familiarize themselves with the teleportation method and travel task. Subjects then completed four trials traveling to the end of the test environment with the same method. Note that subjects were told they were being timed and asked to complete the trials as quickly as possible. To remind subjects of the method they were using, the name of the current teleportation method appeared on the screen in front of them prior to experiencing the training environment and before each trial in the test environment. The order that subjects experienced the teleportation methods was counterbalanced across participants. Once subjects finished the training and trials for all teleportation methods, they were asked to rank the methods in order of preference for: 1) traveling to the end of the virtual environment as quickly as possible; 2) comfort; and 3) general use. Subjects were also asked to explain each of their rankings. The entire procedure took approximately 30 to 45 minutes per subject. This procedure was approved by the Institutional Review Board at the authors' university.

4 Results

The data analysis reported in this section was conducted using jamovi [9]. Note that two subjects experienced technical difficulties during a single trial of the study. Both subjects were able to complete the affected trial, but the technical difficulty added to their completion time, so their data for the affected trials was removed from the analysis and treated as missing data. This occurred for one subject during trial 1 of the step method, and for a different subject during trial 2 of the arc method.

Tables 1 and 2 report the mean and standard deviation for each trial of the time and distance traveled variables, respectively. Separate repeated measures ANOVAs were conducted for the two dependent variables (time and distance traveled), with trial number as a within subject variable and teleportation method as a between subject variable. Main effects and interactions are reported only if they are significant.

TABLE I. Mean (and standard deviation) for the time variable (in seconds).

	Trial 1	Trial 2	Trial 3	Trial 4
Arc	42.0s (SD=13.2)	37.1s (SD=14.8)	33.4s (SD=10.4)	33.4s (SD=11.6)
Hand selection	37.3s (SD=9.20)	33.7s (SD=9.41)	29.9s (SD=6.38)	30.2s (SD=6.19)
Head pointer	54.4s (SD=21.4)	46.2s (SD=18.0)	42.6s (SD=16.0)	41.1s (SD=14.1)
Step	59.6s (SD=13.7)	54.6s (SD=11.8)	54.7s (SD=12.3)	54.0s (SD=12.5)

TABLE II. Mean and standard deviation for the distance traveled variable (in meters).

	Trial 1	Trial 2	Trial 3	Trial 4
Arc	529m (SD=35.7)	514m (SD=33.7)	513m (SD=30.9)	517m (SD=41.6)
Hand selection	608m (SD=11.6)	614m (SD=21.9)	614m (SD=25.8)	612m (SD=20.6)
Head pointer	523m (SD=37.3)	532m (SD=47.4)	525m (SD=46.4)	513m (SD=37.6)
Step	493m (SD=17.2)	488m (SD=16.5)	488m (SD=22.1)	488m (SD=21.3)

4.1 Time

There was a main effect of trial number for the time variable ($F(3, 198) = 38.00$, $p < .001$). Tukey post hoc comparisons revealed a significant difference in mean times between trials 1 and 2 ($t(66) = 6.053$, $p < .001$), 1 and 3 ($t(66) = 8.435$, $p < .001$), 1 and 4 ($t(66) = 7.481$, $p < .001$), 2 and 3 ($t(66) = 4.179$, $p < .001$), and 2 and 4 ($t(66) = 3.157$, $p = .013$). These results suggest that subjects did significantly decrease their times as they progressed from trials 1 to 2, and 2 to 3, but were not likely to significantly decrease their times between trials 3 and 4.

There was also a main effect of teleportation method for the time variable ($F(3, 66) = 11.6$, $p < .001$). Tukey post hoc comparisons revealed a significant difference in mean times between the hand selection and step methods ($t(66) = -5.365$, $p < .001$), hand selection and head pointer methods ($t(66) = -3.325$, $p = .008$), and step and arc methods ($t(66) = 4.375$, $p < .001$). The difference between the head pointer and arc methods approached significance ($t(66) = 2.350$, $p = .097$). These results suggest that subjects completed the task significantly faster with the hand selection and arc methods than with the head pointer and step methods.

4.2 Distance Traveled

There was a main effect of teleportation method for the distance traveled variable ($F(3, 66) = 72.6$, $p < .001$). Tukey post hoc comparisons revealed a significant difference in distance traveled between the hand selection and step methods ($t(66) = 13.862$, $p < .001$), hand selection and head pointer methods ($t(66) = 10.196$, $p < .001$), hand selection and arc methods ($t(66) = 10.556$, $p < .001$), step and head pointer methods ($t(66) = -3.813$, $p = .002$), and step and arc methods ($t(66) = -3.260$, $p = .009$). These results suggest that subjects completed the task while traveling significantly more distance using the hand selection method than any other method, and subjects completed the task while traveling significantly less distance using the step method than any other method.

4.3 Subject Rankings

For traveling to the end of the virtual environment as quickly as possible (henceforth referred to as "quickness"), eight subjects indicated a preference for the arc method, eight subjects indicated a preference for the hand selection method, one subject indicated a preference for the head pointer method, and one subject indicated a preference for the step method. For comfort, seven subjects indicated a preference for the arc method, three subjects indicated a preference for the hand selection method, three subjects indicated a preference for the head pointer method, and five subjects indicated a preference for the step method. For general use, 13 subjects indicated a preference for the arc method, two subjects indicated a preference for the head pointer method, and three subjects indicated a preference for the step method. A chi-square goodness-of-fit test was conducted for each variable (quickness, comfort, and general use) to determine if teleportation methods for each variable were preferred by subjects to a statistically significant degree. Significant results were found for quickness, $\chi^2(3) = 10.9$, $p = .012$, with subjects preferring the arc and hand selection methods to the head pointer and step methods. Significant results were also found for general use, $\chi^2(2) = 12.3$, $p = .002$, with subjects indicating a significant preference for the arc method to the other methods. No significant result was found for comfort, $\chi^2(3) = 2.44$, $p = 0.485$.

4.4 Discussion

For teleporting as quickly as possible to the end of the virtual hallway, subjects expressed a significant preference for the arc and hand selection methods. Subjects were also significantly faster using these methods to complete our experimental travel task. Thus, subject opinions are in alignment with experimental results with regards to traveling as quickly as possible to the end of the virtual environment. Subjects suggested that the arc method was "easy to get used to" and "more effective." Subjects commented that the hand selection method "seems the most simple" and lets "you go a set distance which was usually further than the other available methods." Note that while the hand selection method allowed subjects to complete the travel task significantly faster than with the step or head pointer methods, subjects traveled significantly more distance in the virtual environment with this method than with any other method. This is likely because with the hand selection method, subjects were restricted to moving down only the centers of hallways to the locations of the yellow circles. With the other methods subjects had more control over their travel path, which allowed them to cut corners and take routes that were more efficient than with the hand selection method. Subjects made comments on the questionnaire such as "the hand selection method was too limiting in where I could teleport." Interestingly, not a single subject chose the hand selection method as the preferred teleportation method for general use even though this method allowed for fast completion of the travel task. One subject even stated, "Hand selection would feel too restrictive in where I could go."

Subjects expressed a significant preference towards the arc method for general use. This is not surprising since all subjects in our study were experienced VR users. In our opinion, the arc method is the most prevalent teleportation method employed in VR applications today, so our subjects likely had the most prior experience with this method. Subjects completed our travel task covering significantly less distance in the virtual environment using the step method than with any other method, suggesting that subjects took more efficient routes through the virtual environment with this method than with any other method. One subject commented, "The advantage of step is that I can travel to specific locations with motions similar to natural movements without feeling sick." With the step method, subjects likely took travel paths in our virtual environment most like paths they would have taken if they had run through a similar real world environment. However, another subject stated, "Step would take too long if I needed to go far." It may be that the step method supports more natural movement and encourages more efficient travel paths than the other methods, but at the expense of longer travel times.

These results suggest that the best teleportation method may depend on the actual travel task. The hand selection method may be most useful for travel tasks that require quickly traveling long distances in virtual environments. For maneuvering tasks that require smaller, more precise movements [3] (such as examining objects in a small virtual space), the step method may be helpful as it is most like real-world movement. For general travel tasks in everyday VR applications, such as VR games and virtual reality learning environments, the arc method may be preferable.

5 Conclusion

In this paper, we describe an experiment to compare four teleportation methods for travel in everyday virtual reality applications. Subjects completed our travel task fastest using the arc and hand selection methods. Subjects also indicated a preference for these methods to travel as quickly as possible, although the arc method was preferred for general use in VR applications. However, subjects traveled significantly less distance in the virtual environment when completing our travel task with the step method, most likely because this method was more like real world movement and encouraged subjects to take the most efficient travel paths.

There are some important limitations to this research. Due in large part to the difficulty of finding subjects that had access to their own Oculus Quest, we had a relatively small number of subjects participate in our study. Furthermore, since the subjects had access to their own Quest, they were all experienced VR users. Thus, the opinions of our subjects may only be reflective of experienced VR users. It may be that novice VR users prefer different methods for teleportation and perform differently on our travel task. Future work should include more subjects with less previous VR experience.

Our travel task was also fairly simple for subjects to complete. They were only asked to travel in one direction in the virtual environment. When subjects became disoriented, it was only briefly, since we had placed arrows on the floor pointing in the direction that users should travel. Our subjects were able to quickly determine the correct direction to move by referencing the arrows on the floor. Future work could consider comparing teleportation techniques for more complex wayfinding tasks, such as conducting a naïve search [3] of a large virtual space for locations of interest or exploring an unknown virtual environment with multiple travel paths and limited navigation assistance.

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