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# Does Teleporting Length Affect Spatial Awareness?

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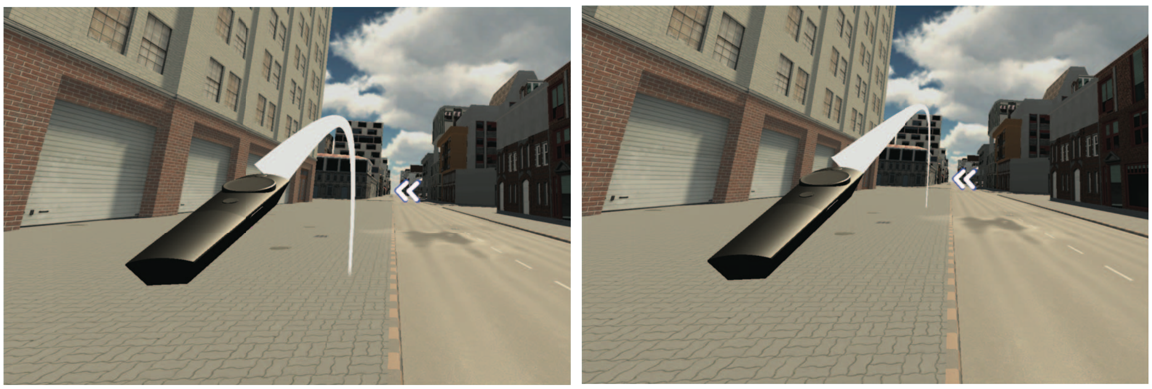

(a) (b)

Figure 1: (a) The urban environment showing the 5 m teleport ray (b) The environment showing the 15 m teleport ray. Participants traversed the environment using jumps of a fixed length and were then assessed on their spatial knowledge.

## Abstract

Teleporting, or jumping, is a common method of moving through virtual environments. It provides a simple user interface, but deprives users of self-motion cues that are important to acquiring spatial knowledge. This paper examines one parameter of the teleportation interface, the teleportation or jump distance, and how that may affect spatial knowledge acquisition. We report the results of an experiment that examined the effects of two different, but fixed teleportation distances on how users could acquire knowledge of landmarks and routes. The results suggest that the teleport distance does not matter, hence teleportation as an interface is robust. However, use of teleportation resulted in significantly increased simulator sickness, a surprising result.

**Index Terms:** Human-centered computing—Human computer interaction (HCI)—Interaction Paradigms—Virtual Reality

## 1 Introduction

The increased popularity of the metaverse and the consequent availability of consumer-level virtual reality (VR) hardware has made VR a more accessible technology. Most applications of VR focus on entertainment and education, and many of these applications are set in large virtual environments where users move through the environment using a locomotion method provided by the application.

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When users locomote through a virtual environment, they are typically both navigating and wayfinding while attempting to acquire spatial knowledge of the virtual world. There is a significant body of work showing that the locomotion method used in VR affects the acquisition of spatial knowledge [5, 8, 12, 15–17, 19]. Regardless, locomotion methods in VR are often not optimized to facilitate acquisition of spatial knowledge.

Teleportation, or jumping from one location quickly to another, is a popular locomotion method in virtual reality (VR) [3, 16, 18]. Its popularity rests on its ease of use and the finding that it does not lead to cybersickness, especially when compared to continuous locomotion methods such as steering [2]. However, a disadvantage of teleportation is that it typically leads to a loss of spatial knowledge [12, 14]. Some research has attempted to alleviate the problems of teleportation for acquiring spatial knowledge, by employing mixed-mode locomotion methods that are continuous for local navigation, but transition to teleportation when larger distances need to be traversed [1, 20]. Given teleportation's popularity, this paper further investigates the question of teleportation's effect on spatial memory by testing whether the rate of teleportation is an important factor. Specifically, we ask if the length of a teleport affects the ability of users to effectively update their locations when traversing a route, which then may affect their spatial memory for that route. One group of users learned the positions of landmarks while traversing a route using teleport jumps of a short length, while a second group of users learned the positions using teleport jumps of a longer length. Spatial knowledge was assessed with two measures: a pointing task and a map drawing task. To our knowledge, this is the first study that has directly examined the effect of teleportation jump length on spatial knowledge, though other research has examined different mechanics of teleportation and their affect on spatial updating [12].

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## 2 Related Work

Because teleporting is simple to implement, most implementations follow a point and teleport paradigm [4]. Kelly et al. [12] explored two interfaces for teleporting that modified (or did not modify) a user's orientation along with the teleporting jump. This work found that preserving user's orientation cues resulted in better teleportation performance than allowing the interface to intefere with the orientation cues. Kelly and colleagues came close to addressing the question addressed in this paper, in that they varied the path length that user's traversed together with the jump length, comparing both their teleporting interfaces against them. However, in their experimental setup, it is difficult to untangle the effect of teleporting distance from other factors.

There has been little formal study of teleportation jump length. Kelly et al. [12] did not control the length, but their short path length was 1.6 m, and their long path length was 6.7 m. Bozgeyikli et al. [4] likewise did not control the jump length, but their testing environment was 16 m x 16 m; similarly, Langbehn et al. [14] used a 13.9 m x 10.4 m testing environment. Paris et al. [16] allowed a maximum jump length of 20 m, while Adhikari et al. [1] allowed a maximum jump of 8 m over all of their conditions. Thus, to our knowledge, no research has explored extremely large jump lengths, which we do not explore, either, and we select a short and long jump length that represents reasonable differences in the previous literature.

This paper judges the effectiveness of teleportation by assessing how well users acquire spatial knowledge [21] of their surroundings as they move through it. In the real world, and in some locomotion modes in virtual environments, when people move through an environment, they update their self-position using internal cues, i.e., cues based on self-motion and not based on external objects such as landmarks, through a process called path integration [11]. In the real world, path integration is a process fundamental to maintaining orientation in space [6, 9]. However, teleportation disrupts path integration as it provides no body-based internal cues, and only discontinuous translation-based cues. Fortunately, other forms of spatial knowledge are available, including landmark knowledge, that is, knowledge of visual structures that can help people orient themselves, and route knowledge, the memory of a sequence of locations and environmental features that comprise a navigable path. These types of knowledge can be developed into survey knowledge, metric knowledge of straight line distances and directions between locations in space. Survey knowledge arises through familiarization of an environment. Our performance tests attempt to assess how well users have developed survey knowledge over repeated exposures to an environment through the teleportation locomotion mode.

## 3 Experiment

The primary aim of this study is to investigate the impact of teleporting distance on spatial knowledge during navigational tasks within an urban virtual environment. Specifically, the research question is: Does the teleporting distance significantly affect spatial learning?

We assessed spatial learning using two methodologies: by measuring participants' accuracy in pointing to remembered landmarks subsequent to each of the three exploration trials, and by evaluating how well participants could recreate the spatial location of specific landmarks on a blank map that only indicates the starting point and the starting direction of the exploration. Our study employed a between-subjects design with two experimental conditions: a short teleportation distance of 5 meters and a long teleportation distance of 15 meters. The order of the conditions was counterbalanced, and participants were randomly assigned to one of the two conditions.

Based on the aforementioned research question, we formulated the following hypotheses:

H1-a: Participants teleporting short distances (5 m) will exhibit better spatial knowledge as revealed by less angular error in the pointing task compared to those using teleporting longer distances (15 m) during exploration in the virtual urban environment.

H1-b: Participants using the short teleporting distance will be more accurate in the map drawing task than those using the long teleporting distance.

### 3.1 Participants

A total of 40 participants, ranging in age from 18 to 29 (average age: 20.97), took part in the study. The participant group consisted of 24 females (average age: 20.91) and 16 males (average age: 21.06). Each participant was paid $12 USD for one hour of their time.

### 3.2 Design

#### 3.2.1 Virtual Environment

The virtual urban environment for the experiment was the same design utilized in Zhao et al [24]. This urban environment resemble a modern city laid out in a grid-like pattern with an average distance between buildings of about 20 m. We selected route1 from Zhao et al. as the exploration route for participants in both conditions. The urban environment was developed in Unity version 2020.3.20f1 with C# scripts. The environment covered an area of 1 $km^2$ and was created using assets from CScape City System and Modern City Pack. The exploration route extended approximately 1 km, featuring twelve decision points along with seven visually or semantically salient landmarks positioned along the route, including the start and end locations.

We render navigational instruction cues visible by utilizing customized shaders with stencil buffers. Objects representing AR cues were assigned specific stencil referencing numbers, allowing them to appear half-transparently and in front of any other virtual objects in the environment, i.e., buildings, regardless of the actual depth relationships. This enables participants to see navigation guidance without visual occlusion.

#### 3.2.2 Teleportation

To facilitate teleportation in the environment, a projectile trajectory starting from the head of the controller was drawn in white whenever the button for teleportation was pressed down. We set the width at the end of the line (i.e., endWidth) to 0.05 in the Unity Line Renderer, so as to make it more visible for participants to see their destination once they released the button. The horizontal distance from the controller to where the projectile hit the ground (i.e., the displacement of the projectile on the x-z plane) was fixed at either 5 m or 15 m, regardless of the orientation or tilt that participants held the controller. This ensured a consistent teleporting distance for participants in each condition.

While the horizontal jumping distance was fixed, the maximum height of the arc (i.e., the projectile path) changed in response to the tilt of the controller. To avoid an overly high peak resulting from close to a 90° tilt, we disallowed the white arc to be rendered under circumstances when the angle between the controller's pointing direction and the horizon exceeded 70°, even if participants pressed the button for teleportation. Moreover, we halted teleportation function and switched the arc's color from white to red whenever the trajectory intersected a building in the urban environment, indicating that jumping was then illegal. As soon as participants moved the controller away from pointing at the building, the arc would turn white, indicating teleportation was again allowed.

#### 3.2.3 Apparatus

The experiment was conducted using a Varjo XR-3 head-mounted display (HMD) powered by a Lenovo ThinkStation P520. The Varjo XR-3 HMD weighs around 980g. This high-resolution HMD provided a focus area of 27°× 27°at 70 PPD uOLED, with 1920 × 1920 pixels per eye, and a peripheral area of over 30 PPD LCD, with

2880 × 2720 pixels per eye, operating at a refresh rate of 90Hz. We utilized two HTC SteamVR base stations for HMD tracking.

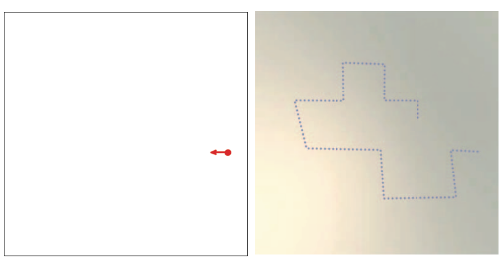
### 3.3 Procedure

Before beginning the experiment, each participant was informed about the study and provided their written consent. Participants were then asked to fill out the simulator sickness questionnaire (SSQ) to determine the potential for motion sickness prior to the experiment [13]. Participants were then randomly assigned to either the short-length teleport condition (5 m) or the long-length teleport condition (15 m).

Next, they were instructed on how to use the Vive controller for teleportation. Upon donning the Varjo XR-3 HMD, participants were instructed to practice teleporting via the Vive controller in an urban-style virtual environment that was different from the one used in the formal experiment. This training familiarized participants with teleporting the distance corresponding to their assigned condition. They were given sufficient time to explore the training scene until they felt comfortable with the teleportation method.

The experimental trials for spatial learning consisted of a total of seven tasks performed in the following order: an exploration task (trial) and pointing task (to all objects from all other objects), repeated three times (three trials total), followed by a map drawing task (at the end of all other tasks). Participants were asked to fill out the SSQ again after the second pointing task and before the map drawing task to assess their susceptibility to motion sickness after the two trials.

Before the first exploration task, participants were shown images of the seven target landmarks and asked to remember their positions while they navigated to a designated destination in the environment. During the exploration task, participants followed the AR navigation cues to reach the destination of the route. Upon reaching the destination, audio feedback notified participants of their arrival.



(a) (b)

Figure 2: (a) White board in the map drawing task. Red dot indicates the starting point participants were teleported to. Red arrow indicates navigation's starting direction. and (b) The route layout in a bird's eye view.

After each exploration trial, participants completed a pointing task to evaluate their spatial memory of the target landmarks seen during exploration. Participants were randomly teleported to the front of one of the seven target landmarks and shown the image of one of the remaining six target landmarks. They were asked to point to the direction in which that different target landmark was located relative to their current egocentric position and heading via the Vive controller. Participants were asked to point to all of the remaining six target landmarks shown in the image one by one and then relocated to the front of a different target landmark to do another six pointing trials. The process was repeated until they completed 42 (6×7) pointing trials in total. For each trial, the pointing direction and its angular error along the x-z plane were recorded.

Lastly, participants engaged in a map drawing task, serving as a secondary measure to assess the accuracy of their survey spatial representation of landmark locations. For this task, participants were immersed in a virtual environment featuring a white board in the front with only a red dot and a red arrow stemming from the dot indicating the starting point and starting direction of the previous navigation at a bird's eye view (see Fig.2). Next to the white board were images of the seven target landmarks used in the navigation and pointing tasks. Participants were instructed to drag and position them on the board via the Vive controller based on where they believed the landmarks were located in the space they explored.

All tasks were performed without any time constraints, allowing participants to complete them at their own pace. The average total time it took participants to finish all the tasks was 45 minutes. Furthermore, throughout the experiment, participants received no feedback on their performance.

## 4 Results

### 4.1 Pointing Task Performance

We ran a 2 (teleporting distance: long, short) by 3 (trial) repeated measures ANOVA with the first factor as between-subjects and trial as within-subjects. The dependent variable was performance in the pointing task (as measured in degree of accuracy). Three participants were excluded from the analysis due to the data not recording properly. A Greenhouse-Geisser correction was applied for violations of sphericity and we report the Greenhouse-Geisser corrected results below.

Pointing errors for each trial and for each teleporting condition are shown in Fig. 3. There was a significant effect of trial ($F(1.46, 50.9) = 46.41, p < .001, \eta^2_G = .140$). As trials progressed, pointing errors decreased. Pairwise comparisons found significant differences between angular errors between the first and second ($p < .001$), the first and third ($p < .001$), and the second and third trials ($p = .005$). There was no effect of distance teleported on pointing performance ($p = .837$), and there was no teleporting distance × trial interaction ($p = .325$).

Because this analysis fails to reject the null hypothesis, we turned to a Bayesian analysis to evaluate the relative strength between the null hypothesis and the alternative. Thus, we calculate the likelihood of the observed data occurring under the alternative hypothesis to the likelihood of the observed data occurring under the null hypothesis. The Bayesian analysis was run in R using the *rstan*, *brms*, and *BayesFactor* packages. A limitation of our analysis is that we employed a null prior in the analysis. Since Bayes factors can be strongly influenced by the choice of prior [10], we describe them together with credible intervals to interpet our results. The Bayesian credible interval we report is the parameter range in which the teleporting distance would fall 95% of the time given our observed data. If the credible interval contains 0, then the between group mean difference can be zero, which is strong evidence for the null effect. The Bayesian analysis resulted in 95% credible interval that ranged from -10.03 to 16.30. As stated, since 0 nearly falls in the center of 95% credible intervals, we interpret an effect of 0 as highly plausible for teleporting distance. The Bayes factor when comparing the full model to a model excluding teleporting distance term was ≈ .014, suggesting the data is approximately 8 times more likely under the null hypothesis (i.e., there is no performance difference between different teleporting distance conditions) than the alternative hypothesis.

We also added the target landmark (L1, L2, L3, L4, L5, L6, L7) as an additional factor in our ANOVA to assess how people performed when teleported in front of different landmarks. The results showed that participants generally performed better when pointing from the first several landmarks along the route compared to the later ones. Specifically, pairwise comparisons revealed that the pointing error was significantly smaller when participants were in front of L1 compared to L6 ($p = .014$) and L7 ($p = .006$). Additionally, the

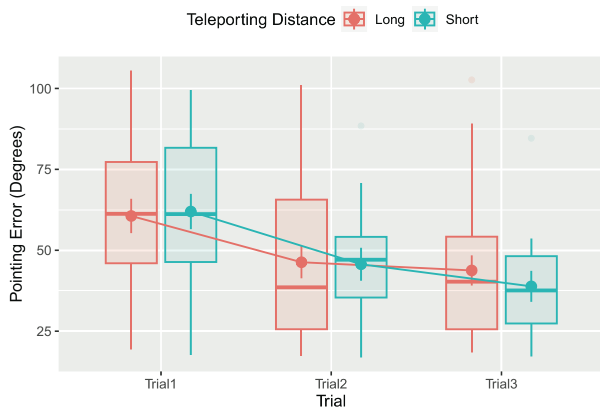
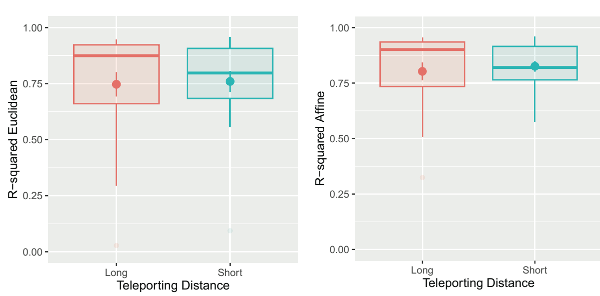



Figure 3: Pointing error plotted against trial by teleporting distance. Middle-colored lines are the medians and the box covers the 25th to 75th quartile range. Colored dots indicate the means. Error bars indicate one standard error above and below the mean.

pointing error was significantly smaller when participants were in front of L3 compared to L6 ($p = .007$) and L7 ($p = .003$).

### 4.2 Map Drawing Task Performance

To evaluate map-drawing performance, we used configurational accuracy, which measures the similarity between participants' mental spatial representation of landmark coordinates and the reference landmarks in the actual environment. We employed bi-dimensional regression models with Affine and Euclidean transformations to quantify the accuracy. The regression coefficient $R^2$ ranges from 0 to 1, with higher values indicating higher accuracies. The results demonstrated that there was no detectable effect of teleporting distance on Euclidean $R^2$ ($W = 207, p = .849$) and Affine $R^2$ ($W = 211, p = .765$). The average Euclidean $R^2$ for all participants is 0.747 ($SD = 0.250$), and the average Affine $R^2$ is 0.760 ($SD = 0.204$) (see Fig. 4). Although the performance did not reach the level observed in [24], where the $R^2$ value reached up to 0.9, participants demonstrated fairly good performance in the map drawing task after exploring the environment three times without the route layout clue.




(a) (b)

Figure 4: (a) Euclidean $R^2$ across participants plotted against teleporting distance and (b) Affine $R^2$ across participants plotted against teleporting distance.

### 4.3 Simulator Sickness

We computed SSQ ratings using the methodology outlined in [13], which provided us with scores for nausea (N), oculomotor disturbance (O), disorientation (D), and total simulator sickness (TS). To evaluate sickness symptoms during locomotion in the virtual environment with various teleport lengths, we conducted 2 (teleport distance) x 2 (pre/post) ANOVAs on the SSQ ratings that were taken before and after the virtual navigation task. We incorporated the teleport distance (short, long) as a between-subjects independent variable, and the order of completing the questionnaire (post-test, pre-test) served as the within-subjects variable. The teleporting distance did not have a significant effect on self-reported simulator sickness. However, significant differences were observed between post-test and pre-test scores for both short and long teleporting distances in terms of nausea ($p < .001$), oculomotor disturbance ($p = .001$), disorientation ($p < .001$), and total simulator sickness ($p < .0001$). For the total simulator sickness scores, the pre-test average was 7.3 (SE = 1.57), qualitatively suggesting minimal sickness symptoms. After the three trials, with each being an exploration task followed by a pointing task, the average simulator sickness score was 20.3 (SE = 2.73), qualitatively suggesting more severe symptoms.

For the nausea score, the pre-test average was 4.88 (SE = 1.43); while the post-test average was 13.93 (SE = 2.00). For the oculomotor disturbance, the pre-test score was 8.04 (SE = 1.70); the post-test average was 17.94 (SE = 2.69). Regarding disorientation, the pre-test score was 5.29 (SE = 1.47), and the post-test average was 22.19 (SE = 4.54). We also ran an ANOVA analyzing the scores for an effect of gender, but failed to detect one.

## 5 Discussion

This paper attempted to determine if teleporting distance affected acquisition of spatial knowledge. We did that by fixing the teleport jump distance at a shorter distance (5 m) and longer distance (15 m), but found no effect of the distance on people's ability to acquire knowledge of the environment. We chose our distances consistent with commonly used teleport distances in prior work. We hypothesize that if the jumping distance were increased significantly, e.g., by a factor of ten, beyond what we tested, then we would see effects on the acquisition of spatial knowledge, consistent with prior work that has shown that increasing optic flow rates significantly in joystick-based steering navigation decreases acquisition of spatial knowledge [23]. However, such large teleport distances appear to not be common in practice, and thus were not of practical interest to our study. The message from this work, then, is that although teleporting has been shown to be inferior to other locomotion methods in terms of users' ability to acquire spatial knowledge while using it [12, 14, 16], its implementation is simple and appears robust.

There were a number of results of note in this experiment that have implications for the development of locomotion modes in virtual reality, as well. People were able to learn the route over three trials, showing significant improvement every trial. Qualitatively, there was no difference between the pointing accuracy of this experiment and that of Zhao et al. [24], which used joystick-based steering. A priori, we would have predicted worse performance based on prior work of our lab and others, cited previously. It is true that the map drawing task had worse performance, but the map drawing task was different, and harder in this experiment than that of Zhao et al. [24], which had a route pre-drawn on it. Consistent with prior work [22], pointing error was lowest when performed from the starting location to other landmarks. The ability of subjects to learn the route with accuracy using teleporting is interesting, as this route is significantly longer than used in most prior work on teleporting (1 km) with twelve decision points.

Also of interest is that teleporting caused a significant rise in simulator sickness scores, into the qualitatively bad area as classified by Kennedy et al. [13]. However, no one dropped out of the experiment or asked to halt the experiment. Unfortunately, we cannot compare this result with Zhao et al. [24], as they did not measure simulator sickness. However, this rise in simulator sickness scores is consistent with prior work showing cybersickness increased with exposure time for both teleporting and steering [7]. It is perhaps noteworthy that route lengths and trial times were longer than most prior work. The only comparable case of which we are aware is that of Adhikari et al. [1], with route lengths approximately two hundred meters; unfortunately, pre/post SSQ scores are not reported in that work. Future work could delve into our finding in more depth.

Future work could also include allowing the teleport jump length to be dynamic, as in most implementations, or extending the jump distance beyond 15 m to test our hypothesis about longer jump lengths. Based on the results of this study, however, it seems that teleporting is a viable interface for navigation. Its ease of implementation and robustness, together with the ability of people to acquire spatial knowledge using it over long routes make it a reasonable choice.

## Acknowledgments

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