

# Using a Large Projection Screen as an Alternative to Head-Mounted Displays for Virtual Environments

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## ABSTRACT

Head-mounted displays for virtual environments facilitate an immersive experience that seems more real than an experience provided by a desk-top monitor [18]; however, the cost of head-mounted displays can prohibit their use. An empirical study was conducted investigating differences in spatial knowledge learned for a virtual environment presented in three viewing conditions: head-mounted display, large projection screen, and desk-top monitor. Participants in each condition were asked to reproduce their cognitive map of a virtual environment, which had been developed during individual exploration of the environment along a predetermined course. Error scores were calculated, indicating the degree to which each participant's map differed from the actual layout of the virtual environment. No statistically significant difference was found between the head-mounted display and large projection screen conditions. An implication of this result is that a large projection screen may be an effective, inexpensive substitute for a head-mounted display.

## Keywords

Experiment, virtual reality, spatial knowledge, field of view, cognitive map, head-mounted display, projection screen, monitor.

## INTRODUCTION

The acquisition of spatial knowledge for an unfamiliar physical environment progresses through three stages. In the first stage, people learn the locations of landmarks. This is referred to as *landmark knowledge*. As they learn to navigate from place to place in the environment following familiar paths, people gain *route knowledge*. Finally, *survey knowledge* for the environment is achieved—knowing the way around well enough to have a mental (or cognitive) map of the environment [6].

Virtual reality (VR) provides an opportunity for people to gain spatial knowledge for an environment other than the one in which they are physically located, and therefore has

the potential to be an invaluable educational and training tool [1,15]. Acquisition of spatial knowledge for a virtual environment has been shown to follow the same three stages as for a physical environment: landmark knowledge, route knowledge, and survey knowledge [18]. However, previous research suggests that in order for a VR experience to seem the most realistic, an immersive experience in a head-mounted display is necessary [8].

Scientists from various disciplines have investigated differences in the accuracy of spatial knowledge acquired from still images projected onto a surface compared with spatial knowledge of the real world [7]. Variations in spatial knowledge between head-mounted displays and monitors for viewing virtual environments have also been studied [18]. This experiment was designed to augment prior work by investigating the perception of physical relationships between landmarks in a virtual environment, and the acquisition of survey knowledge under three viewing conditions: head-mounted display, large projection screen, and desk-top monitor.

## Spatial Cognition

Cognitive maps, or internal, mental representations of spatial environments, are a component of spatial knowledge [9]. This internal representation is the basis for human interaction with the world, guiding people's decisions and interactions [6]. Spatial problem-solving activities such as wayfinding and navigation rely heavily on cognitive maps, which act as internal conceptualizations of the problem to be solved. Cognitive maps for real-world environments are more accurate when they are formed by viewing a paper map of the environment than from cursory navigation through the environment. However, repeated navigation in the environment results in a cognitive map that is as accurate as if it was learned from a paper map [20].

People develop a cognitive map for a virtual environment in a similar manner to the way they do a real-world

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environment. One way to measure differences that occur in cognitive maps arising from experiencing virtual versus real environments is by asking people to estimate distances between landmarks. Previous research examining the accuracy of distance judgments in the real world indicates that they are not perfect—they are generally 87-91% of actual distances. Interestingly, people are significantly even less accurate at estimating distances when viewing a virtual environment [22,11].

*Field of view*, measured in degrees, indicates how much of the world can be seen at a given time. For example, someone looking through a window towards the outdoors has a more restricted field of view than someone who is actually standing outdoors because the edges of the window make the visual field smaller. Field of view has a large impact on the underestimation of distances, both in the real world and in a virtual environment [2,3]. A smaller field of view results in compression of distance judgments—people think things are closer than they actually are. Hagen (1978) hypothesized that this is because people underestimate the unseen foreground distance between themselves and what they are viewing.

#### Immersion and Presence

An immersive experience can be described as one in which a person is enveloped in a feeling of isolation from the real world. One can feel immersed in movies where interaction is not possible, as well as in video games, which allow a high degree of interaction. In a virtual environment, having a task to perform increases the feeling of immersion.

A different, but related aspect of a virtual experience is presence: the extent to which a person's cognitive and perceptual systems are tricked into believing they are somewhere other than their physical location [22]. Display devices that evoke a great sense of presence often cause simulator sickness (a variant of motion sickness); symptoms include paleness, dizziness, nausea, and vomiting [12].

Head-mounted displays, which can produce an experience high in both immersion and presence, have been shown to be the most effective way to gain accurate spatial knowledge for a virtual environment. Cognitive maps formed in a head-mounted display perform significantly better than cognitive maps learned by viewing a virtual environment on a desk-top monitor [18]. Ruddle, Payne & Jones (1998) found that participants navigating a virtual building using a head-mounted display were able to do so significantly (approximately 12%) faster than participants using a desk-top monitor. Estimations of straight-line distances by participants using a head-mounted display were also significantly more accurate. In addition, participants using a head-mounted display were found to have spent a significantly greater amount of time looking around than those using a desk-top monitor. Researchers hypothesized that these significant differences were due to

additional perceptual cues provided by peripheral vision and the ability to look around in the head-mounted display [18]. Peripheral vision plays a critical role in learning the spatial layout of an environment [18,19]. It is important for educational and military training applications of VR that spatial knowledge learned is as accurate as possible so that the information learned will transfer to a real environment [21]. However, the equipment required can be prohibitively expensive and uninviting to use. In addition, increased simulator sickness can result from exposure to a head-mounted display [15].

This paper discusses differences in spatial knowledge that occurred when study participants traveled through a virtual environment viewed in a head-mounted display, on a 3.35 m wide x 2.30 m tall projection screen, or on a desk-top monitor. Data consisting of judgments of the relative position of landmarks in the virtual environment was gathered after participants had experienced it. The data was then analyzed to determine its accuracy or inaccuracy when compared with the actual layout of the virtual environment. [5,17]. Participants' survey knowledge was expected to be more accurate when the environment was viewed in a head-mounted display than projected onto a screen, and least accurate when the environment was displayed on a desk-top monitor.

#### METHOD

##### Participants

Students and staff were solicited from the University of Pittsburgh and Carnegie Mellon University in Pittsburgh, Pennsylvania. Potential participants completed a questionnaire to determine their eligibility to participate in the study. Participants were excluded from the study if they reported any of the following characteristics:

- training or professional experience in architecture, mechanical or civil engineering, or industrial design
- vision that was not correctable to 20/20
- played any first-person navigation-based video games (e.g. Quake) more than 5 hours per week or 20 hours per month
- reported wearing a head-mounted display more than twice per year

Eligible participants fell within the age range of 18 to 33 years old and were randomly assigned to one of three conditions: Screen, Monitor, or Head-Mounted Display (HMD). 67 participants completed a pre-test of their spatial perceptual abilities. Data from 19 participants scoring more than one standard deviation from the mean in either direction was excluded from the statistical analysis of the experimental results. The remaining 48 participants were balanced for gender and age in each condition. The experiment took 40 - 55 minutes to complete, and each participant was paid \$10.00.

## Apparatus

### Hardware and Software

All participants were asked to navigate through two virtual environments created using Alice, a freely available VR authoring and playback tool [14]. A Windows 95 Pentium II 300 MHz computer equipped with 128MB of RAM and two video cards was used to run the Alice software during the experiment. The computer's main video card (a Nvidia RIVA 128) was plugged into a standard desk-top monitor so the experimenter could start Alice and load the virtual environments. Meanwhile, Alice sent the output of the virtual environment to the second video card (a Diamond Monster 3D II), used to drive one of the display devices (head-mounted display, projection screen, or desk-top monitor).

### Display Devices

The HMD condition used a Visette Pro head-mounted display with Ascention SpacePad tracking system (640x480 resolution, 16 bit color; see Figure 1). This brand was chosen because it offered a wide field of view, and cost less than \$10,000. Tracking devices for the head-mounted display were mounted to a cardboard square and suspended from the ceiling approximately .5 m from the participant's head when seated. The head-mounted display was placed on the participant's head by an experimenter with experience in fitting these devices, and time was taken to ensure that the equipment did not strain the participant's neck or bind too tightly. Field of view for this device was 60° horizontal x 46.8° vertical. The display resolution and field of view for both the Screen and Monitor conditions was matched to the capabilities of the head-mounted



**Figure 1: head-mounted display**

display. Participants in the Monitor condition were seated 0.69 meters from the desk-top monitor, and 2.66 meters away from the projection screen. None of the display conditions used stereo.

The Monitor condition used a standard 21" (53 cm) computer monitor (model Iiyama Vision Master 500) raised to eye level and positioned closely on the table in front of the participant at the appropriate height. The

Screen condition used a rear-projection screen apparatus, consisting of a Toshiba TLP511A projector, a flat, rectangular mirror to increase the projector's throw distance, and a 3.35 m wide x 2.30 m tall screen (material custom-manufactured by Gerriets International of Revue). When mounted in the experiment room, this screen spanned floor to ceiling.

### Navigation Device

Previous spatial cognition research has taken one of two approaches to the issue of navigation in a virtual environment: either participants are allowed to freely explore or they view a scripted presentation of a virtual environment. This study combined those approaches by allowing participants the freedom to navigate; yet the experimenter verbally led them through a scripted sequence of actions. A steering wheel was used to control navigation, rather than a mouse or joystick. This decision was motivated by a desire to provide a method of interactivity that would be easy to learn, and thus enhance the reality of the virtual experience [8]. Participants used a Thrustmaster Grand Prix steering wheel game controller, which allowed car-like steering (see Figure 2). The wheel had two levers that could be grasped by the fingertips of each hand while steering and used to propel the participant forward or backward in the virtual environment at a constant speed.

### Procedure

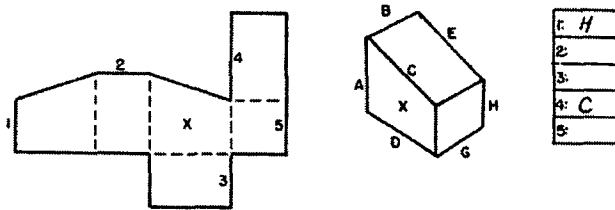
The experiment consisted of a standard spatial ability pretest, exploration of two virtual environments, and a posttest to discover what participants could remember about locations of landmarks in the second, experimental virtual environment.



**Figure 2: steering wheel**

### Pretest

The experiment took place on the Carnegie Mellon University campus. Upon their arrival, participants were asked to complete the Educational Testing Service "Surface Development Test—VZ3," an instrument to measure ability for mental manipulation of 2-dimensional objects into 3 dimensions [4]. Participants were shown several line drawings (see Figure 3) and were required to visualize how



**Figure 3: practice problem from the ETS "Surface Development Test—VZ3"**

the items depicted might be folded to form a 3-dimensional shape. This particular test was chosen because the posttest (described below) draws upon similar cognitive abilities [3]. Data from participants scoring more than one standard deviation from the mean in either direction was excluded from the statistical analysis of the experimental results, in an effort to control for variability in the sample.

#### Exploration

After completion of the pre-test, participants were led to the location of the equipment for displaying the virtual environments. For the Screen condition, this room contained the previously described screen apparatus at a preset distance from the chair where participants sat. For the Monitor condition, a computer monitor was placed on a table in front of the chair. For the HMD condition, participants were shown a head-mounted display, and its function was explained. The experimenter fit the head-mounted display device to a participant's head, and instructed participants to turn their head and look around the virtual environment. Because nausea was a concern, and because higher temperatures can promote simulator sickness while viewing a virtual environment [13], two box fans were used to blow air on participants in all three conditions. Navigation through the virtual environments was restricted to ground-level navigation; that is, participants were not able to fly.

#### Practice Environment

Participants first experienced a practice virtual environment, so that they could learn how to use the steering wheel for navigation. A second purpose for the practice environment was to ensure that participants were able to recognize a landmark they would later see in the experimental environment, called an entrance booth (see Figure 4). As explained below, the entrance booth was an integral part of the task to be performed in the experimental environment. The practice environment consisted of an intersection between two streets in an urban setting. Aside from the entrance booth, it bore little resemblance to the experimental environment; however, the method of interaction was identical. Participants were instructed in the use of the steering



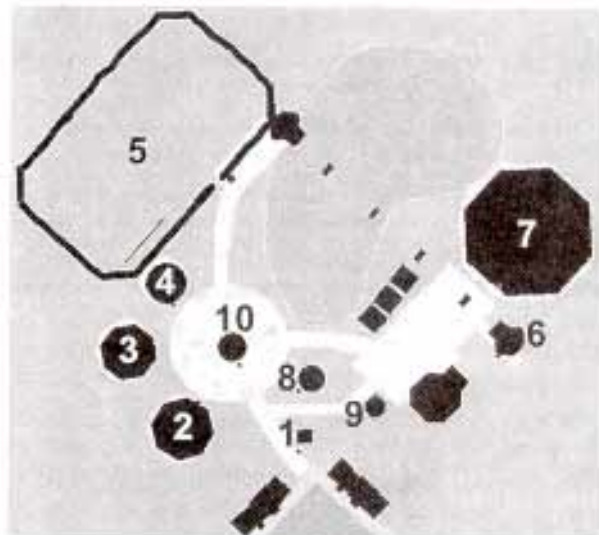
**Figure 4: Entrance booth**

wheel, placed in the practice environment, and encouraged to freely explore. The practice session continued until the participant indicated that he or she was comfortable with the wheel and levers, approximately 3-5 minutes.

#### Experimental Environment

The experimental virtual environment consisted of a virtual amusement park, created for this study. The layout of the park bore no similarity to any real-world amusement park. The park contained a total of 10 rides and attractions. Attractions in the amusement park were arranged to approximate the appearance of a real amusement park (see Figure 5). Care was taken to ensure that the virtual environment had sufficient complexity to avoid a ceiling effect [17]. Participants were asked to imagine that they were the groundskeepers of the park, and were responsible for driving through it on a golf cart each morning to turn on the rides. This was accomplished by navigating into close proximity to an entrance booth, which was present in front of each attraction. When a participant moved close enough to a ride's entrance booth to activate the ride, a particular sound was played and the participant received visual feedback that the ride was activated.

To ensure that participants would recognize and understand the names used for the rides in the amusement park, a color printout consisting of images of all ten rides along with their names was shown to participants. Prior to participants' interaction with the experimental environment, the experimenter pointed to each image on the printout and spoke the name of the ride aloud. Finally, participants were instructed to pay close attention to the location and orientation of the entrance booths, because they would be asked to recall them later.



**Figure 5: Layout of the Virtual Amusement Park**  
 1 - Park Entrance; 2 - Teacup Ride; 3 - Octopus Ride;  
 4 - Swings; 5 - Roller Coaster; 6 - Lion's Head Skyway;  
 7 - Haunted House; 8 - Fountain; 9 - Double Ferris  
 Wheel; 10 - Carousel





**Figure 6: Octopus Ride**

Participants then began interacting with the virtual amusement park. The experimenter proceeded to read aloud step-by-step instructions regarding which ride to turn on next. These instructions provided enough information to allow most participants to find the next ride with little trouble. However, in the few cases where participants appeared to be struggling or asked for help (e.g. they forgot what the Octopus Ride looked like), the experimenter assisted them by describing the ride's appearance or instructing them to "turn left" or "turn right." The experimenter was careful not to give any verbal associations between landmarks that might affect the formation of participants' cognitive maps [9]. For example, the experimenter might say, "Look to your right to see the Octopus Ride," rather than "The Octopus Ride is just to the right of the Teacup Ride." The final step in the instructions allowed participants to turn around and look at the park one more time before exiting it. While there was no strict time limit in which to complete the instructions, most participants spent 7 to 10 minutes in the virtual amusement park.

#### *Posttest*

Finally, participants were escorted back to the room where they took the pretest and presented with a large sheet of white paper (approximately one meter square, completely covering the top of a small table) and ten 3 cm x 3 cm squares (made from foam core). Printed on each square was the name of one of the ten amusement park rides, and it represented the entrance booth for that ride. Participants were allowed to look briefly at the images of the ten rides again, to ensure that he or she could correctly associate names with the rides. They were then instructed to take as much time as needed to place the ten squares on the paper so that the ten rides' entrance booths were represented as they would appear from above. No indication of the correct orientation or scale was provided on the paper; participants who asked were told that the squares were not intended to be to scale and that as much or as little of the paper could be used to place the squares. After this task was completed, participants were asked to fill out a questionnaire regarding any illness or discomfort they might have experienced while navigating in the virtual environment. Finally, they were given \$10.00 for participating.

After each participant had left, the experimenter traced and labeled the foam-core squares on the white paper. During later analysis, vertical and horizontal reference lines were added to each participant's map and distances from these reference lines to the center of each square were recorded. This raw data resulted in coordinates for each ride, allowing angles between landmarks and scaled distances to be recorded for each participant.

#### **RESULTS**

The hypothesis that the HMD condition would show better performance than Screen or Monitor conditions was not supported. Results indicate no significant difference between HMD and Screen conditions or HMD and Monitor conditions. The Screen and Monitor conditions were significantly different.

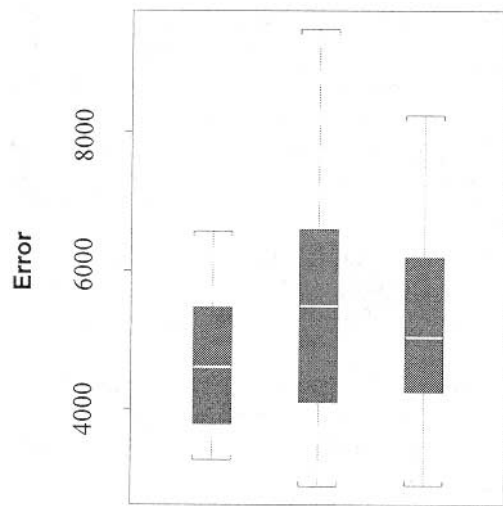
#### *Data Preparation*

Distance is a conceptualization of the physical relationship between objects, used as a standard measurement in spatial cognition research. The knowledge of distances between objects is the foundation for understanding the structure of the physical world [6]. For the posttest of this experiment, participants were instructed to re-create the layout of the amusement park as it would appear if viewed from above, paying close attention to location of the rides, or landmarks, in relation to each other. We chose to provide for participants a blank piece of paper with no indication of orientation or scale, to avoid influencing the interpretation of distances between landmarks in participants' cognitive maps [6].

Because no scale or orientation information was provided, distances between landmarks in participants' reported maps could not be compared directly to the actual distances between landmarks in the virtual environment. Reported landmark relationships, encompassing both distances and angles between landmarks, were compared to their true relationships in the virtual environment to determine placement error. Simply comparing the angle between a set of three landmarks accounts for error in relative orientation, however it fails to sufficiently account for error in relative position, or distance.

It is possible to normalize for orientation and scale by transforming each reported map to most appropriately match the virtual environment, and then measure errors in relative orientation and position. One approach would be to provide participants with the location of two landmark from the virtual environment, upon which to base the rest of their reported map. While this single given relationship would provide an orientation and scale, it would bias every error calculation by exerting an external influence on participants' cognitive maps. This is undesirable. So, for each landmark pair ( ${}_{10}C_2 = 45$ ), we oriented and scaled the entire reported map until the pair matched its analog in the virtual environment. Distance error (in meters) was then calculated for the remaining eight transformed landmarks.

The cumulative placement error score (360 distance measurements per participant) evenly weights every landmark relationship.



**Figure 7: placement error scores across conditions**

#### *Pretest and Simulator Sickness*

Pretest score was found to be a significant predictor of posttest score for all 69 participants, validating the choice of pretest for this experiment. Scores for the 48 participants scoring within one standard deviation of the mean on the pretest were used in later statistical analysis. Mean sickness scores were highest for the HMD condition, but did not affect performance on the posttest. Mean scores were about equal in Screen and Monitor conditions (see Table 1). A Wilcoxon sign rank test was performed on the simulator sickness data. This statistical method is more robust than others that are based on the assumption that data is normally distributed. Results showed that participants felt significantly more ill when using the head-mounted display than in the other two conditions (see Table 2).

#### *Placement Error*

Due to equipment failure and a high level of discomfort in the head-mounted display, one participant was dropped

|         | n  | Mean   | Variance |
|---------|----|--------|----------|
| Screen  | 16 | 2.625  | 6.65     |
| Monitor | 16 | 2.8125 | 7.09     |
| HMD     | 16 | 5.6    | 10.54    |

**Table 1: mean and variance for sickness scores**

|                  | n  | z-value | p-value |
|------------------|----|---------|---------|
| Screen x Monitor | 32 | 0.4219  | 0.6731  |
| Screen x HMD     | 31 | 2.5826  | 0.0098  |
| Monitor x HMD    | 31 | 2.811   | 0.0049  |

**Table 2: Wilcoxon sign rank test on sickness scores**

from the HMD condition after the experiment had been conducted. Table 3 shows means and variance for the normalized placement error scores. The mean placement error score was lowest for the Screen condition, and highest for the Monitor condition, meaning that Screen performed better than Monitor on average (see Figure 7).

After completing descriptive statistics, Bartlett's Test for homogeneity of variance was performed. Because results for Bartlett's Test were nearly significant ( $p = 0.060$ ), indicating that the variances for the three conditions were too different for an ANOVA to yield useable results, the decision was made to perform more robust pairwise unpooled t-tests. Instead of averaging, or pooling, the variances for the two conditions compared by the t-test, each variance was used independently in computing the t-statistic.

P-values for the unpooled t-tests show that the difference between the Screen and Monitor conditions is close to significant (see Table 4). Because pairwise t-tests do not take into consideration the spatial pretest as a covariant, a regression analysis was performed, using condition as an indicator variable. A negative regression coefficient indicates that the placement error scores for the condition being compared with the base case are lower, meaning that participants performed better (see Table 5).

After accounting for the influence of pretest scores on the outcome of the posttest, t-values were calculated a second time. The Screen condition was found to outperform the Monitor condition ( $p=0.0497$ ). There were no other significant differences. A complete report of the analysis can be found in Table 5.

#### **Discussion**

Results indicate that there is little difference in survey knowledge for a virtual environment when viewed through a head-mounted display or projected onto a large screen. Even with a head-mounted display's increased peripheral vision and capability to allow a participant to freely look around the virtual environment, this study found that the large screen still leaves participants with comparable spatial knowledge. While contrary to the original hypothesis, this result is consistent with Johnson (1999)

|         | n  | Mean    | Variance |
|---------|----|---------|----------|
| Screen  | 16 | 4666.43 | 986814   |
| Monitor | 16 | 5640.16 | 3136277  |
| HMD     | 15 | 4981.45 | 1274196  |

**Table 3: mean and variance for normalized error scores**

|                  | n  | t-value | p-value |
|------------------|----|---------|---------|
| Screen x Monitor | 32 | -1.92   | 0.068   |
| Screen x HMD     | 31 | -0.82   | 0.42    |
| Monitor x HMD    | 31 | -0.23   | 0.23    |

**Table 4: results of unpooled t-tests on error scores**

*Screen vs. Monitor*

|                        | Coefficient | Std. Error | t-value | p value |
|------------------------|-------------|------------|---------|---------|
| (Intercept)            | 7493.9277   | 1422.0577  | 5.2698  | 0.0000  |
| Pretest                | -39.4142    | 29.2824    | -1.3460 | 0.1887  |
| Condition <sup>a</sup> | -1029.619   | 502.6221   | -2.0485 | 0.0497  |

*Monitor vs. HMD*

|                        | Coefficient | Std. Error | t-value | p value |
|------------------------|-------------|------------|---------|---------|
| (Intercept)            | 6853.9857   | 1576.8487  | 4.3466  | 0.0002  |
| Pretest                | -39.1196    | 32.7696    | -1.1938 | 0.2429  |
| Condition <sup>b</sup> | 626.087     | 550.6973   | 1.1369  | 0.2656  |

*Screen vs. HMD*

|                        | Coefficient | Std. Error | t-value | p value |
|------------------------|-------------|------------|---------|---------|
| (Intercept)            | 6940.5775   | 997.1337   | 6.9605  | 0.0000  |
| Pretest                | -40.9806    | 20.6173    | -1.9877 | 0.0571  |
| Condition <sup>c</sup> | -404.816    | 372.9730   | -1.0854 | 0.2874  |

<sup>a</sup> base case monitor, coefficient 0      <sup>b</sup> base case HMD, coefficient 0

<sup>c</sup> base case HMD, coefficient 0

**Table 5: regression and t-test results**

who found no significant difference between a head-mounted display and a projection screen used to train soldiers to navigate an unfamiliar environment.

The unexpected absence of a significant difference between the HMD and Monitor conditions also contradicts the original hypothesis. The belief that the HMD condition would perform significantly better than either of the fixed-display conditions (screen, monitor) was based on the head-mounted display's additional display capabilities. By allowing the participant to turn their head, he or she could gain a greater sense of presence and potentially take in more information from the environment. However, it was consistently observed that participants in the HMD condition did not turn their head very much, as previously reported by Pausch (1996). This unintended reduction of the head mounted display to a fixed display could account for the lack of significant difference. Also, negative aspects of the head-mounted display such as weight, low acuity, and a higher degree of simulator sickness could possibly account for the higher mean error score in the HMD condition as compared with the Screen condition.

While variances in the Screen and HMD conditions were similar, the variance in the Monitor condition was found to be significantly different. A possible explanation for the greater variance observed in the Monitor condition lies in the relationship between field of view and judgments of distance. Participants' seated position when viewing the monitor was not artificially fixed, and it is possible that small movements forward or backward from the display might have had altered their field of view, causing

differences in their interpretation of the spatial relationships between landmarks in the experimental environment.

The difference in error scores between the Screen and Monitor conditions was statistically significant. In addition, based on regression of Screen vs. HMD, the negative coefficient value, while not a significant difference, might be an indication that participants in the Screen condition tended to perform better than those in the HMD condition. Also, the smaller variance and lower mean placement error for the Screen condition compared with the HMD condition may indicate that the Screen is a more consistent and reliable display method.

What caused the screen to outperform the other two conditions? It is possible that a large image engenders more presence by tricking a person's perceptual systems into thinking they are really there, a phenomenon that is normally associated with HMD but not with flat displays. Images projected onto the screen may have been big enough to appear real, and therefore promote more accurate judgments of relative position.

This finding suggests an intriguing conclusion; that the low-cost projection screen might be as effective as a head-mounted display for educational or training exercises involving spatial cognition. The screen cost only \$400 to build, while the head mounted display equipment used has a purchase price of approximately \$6000. While the projector used in the Screen condition was quite expensive, it was possible to use it with a minimal amount of effort. Head-mounted display equipment is much more labor-intensive to install, as well as being invasive and uninviting technology to use. These advantages, combined with the lower incidence of discomfort due to simulator sickness, make the use of a large projection screen an attractive alternative to head-mounted displays.

Additionally, this study opens up many interesting avenues for future work. While viewing a virtual environment in a head-mounted display is a single-user experience, using a large projection screen has the potential to facilitate multi-user experiences. It is unknown at this time whether multiple participants simultaneously viewing the virtual environment would have gained the same degree of survey knowledge as the single participant who was driving. While there is no quantitative data to support the observation that participants generally did not look around when in the head-mounted display, a new study examining the impact of spatial cognitive ability and high vs. low head motion on survey knowledge for a virtual environment could produce interesting results. Finally, if indeed a large projection screen is a suitable substitute for head-mounted displays, it will be important to discover to what extent spatial knowledge learned from a virtual environment projected onto a screen is accurate in the real world.

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