

Effects of Travel Technique and Large Displays on Cognition in Virtual Environments

Abstract— We performed two studies to investigate the cognitive effects related to two important dimensions of virtual environment systems: travel technique and display. Options for both elements vary significantly in quality and cost. Our first study examined four different methods of travel in an virtual environment and their effect on cognition. Our second study examined the effects of large displays and large field-of-view on cognition . Both studies employed a between-subjects experimental design to investigate cognitive effects. In each study, users explored a virtual room and answered a set of questions based on Crook’s condensation of Bloom’s taxonomy. The questions were targeted to assess the participants’ cognition of the virtual room with respect to knowledge, understanding and application, and higher mental processes. Participants also drew a sketch map of the virtual environment and the objects within it from memory. Users’ sense of presence was measured using the Steed-Usuh-Slater Presence Questionnaire.

Our results suggest that a natural travel technique impacts VE cognition (understanding and application), and that further studies are necessary to determine the effect of display size and field of view .

1 Introduction

Virtual environment systems employed numerous approaches to allow users to explore a virtual environment (VE). Large displays, tracking systems, novel interaction devices are all used by the user to more naturally visualize and interact with the virtual world. While much prior research has explored the effect of these technologies on such aspects as memory(Timpf, Volta, Pollock, & Egenhofer, 1992), mental maps (Whitton, Cohn, Feasel, Zimmons, Razzaque, Poulton, McLeod, & Brooks, 2005), presence, and immersion (Barfield, Zelter, Sheridan, &

Slate 1995), we aim to investigate a more basic question. Do the common approaches to travel in, and display of, the virtual world impact the user's fundamental learning of the VE?

With the wide range in space, infrastructure, and development costs for many of these technologies, such as Head Mounted Displays (HMDs) and CAVE™ systems, it is important to investigate and identify if there is a cognitive benefit over basic approaches such as fishtank Virtual Reality (VR) and non-headtracked monitor approaches.

Numerous techniques have been implemented in VEs to allow a participant to move about a virtual space. In general they can be categorized as either techniques that try to replicate the energy and motions of walking, or as purely virtual travel techniques. Examples of the former include treadmills (Iwata & Yoshida, 1999) and walking in place schemes (Iwata & Fujii, 1996 Templeman, Denbrook, & Sibert 1999). Examples of the latter usually use a joystick to “fly” through a space in a direction specified by either head orientation or a handheld pointer (Bowman, Koller, & Hodges, 1997). All of these approaches assume that the physical tracked space available to the user is smaller than the virtual space that is to be experienced. However, recent advances in wide area position tracking technology now enable us to track a user's movement through spaces that are much more expansive than the 2 - 3 meter diameter spaces normally tracked by electromagnetic tracking devices (Welch, Bishop, Vicci, Brumback, Keller, & Colucci, 2001). This upgrade in available technology allows us to create virtual environments that a user can experience by simply walking around in the environment in the same way she would walk around a physical space. It also provides us the opportunity to measure the relative efficacy of experiencing a space via normal walking versus any of the simulated walking metaphors. The goal of our first user study was to investigate the differences in participant cognition between exploring a virtual environment using common joystick-based travel

techniques and being able to actually walk about the space in a natural manner.

Similarly, large screen size is often seen as a desirable feature in a VE system. Some VE systems, such as CAVE™ and NAVE systems, go to great lengths to fill a large portion of the user's field-of-view with the virtual world. A clear benefit of large displays is the ability to support multiple users. Projectors, plasma displays, and projection TVs provide users with large high-fidelity displays, which can also increase the users' field-of-view of the VE. The rapid development of new display technologies has lowered their costs and enabled large displays to be a viable option for many companies and research labs.

Prior research into large displays has explored benefits to multi-user collaboration (Dudfield, Macklin, Fearnley, Simpson & Hall, 2001, Elrod, Bruce, Gold, Goldberg, Halasz, Janssen Lee McCall, Pederson, Pier, Tang, & Welch, 1992) and spatial performance (William, Fitzmaurice, Balakrishan, & Kurtenbach, 2000). The goal of our second user study was to investigate the differences in participant cognition between exploring a virtual environment using different sized and field-of-view displays..

2 Previous Work

2.1 Travel Interfaces in Virtual Environments

Immersive virtual environments provide the participant with a first person perspective from the “inside” of a virtual space. View-point control is usually accomplished by a combination of head motion and by some travel technique that may be entirely virtual (such as a joystick), or that may try to replicate real-world modes of travel such as walking or riding in a vehicle.

Although numerous techniques have been proposed for travel, there have been surprisingly few analytic comparisons reported in the literature of the relative effectiveness of different travel modalities for different types of tasks.

Bowman, Koller and Hodges (1997) have conducted experiments on virtual joystick-based travel in immersive virtual environments that indicate that “pointing” techniques are advantageous relative to “gaze-directed” steering techniques for a relative motion task. They also report that motion techniques which instantly teleport users to new locations are correlated with increased user disorientation. In the evaluation of systems that try to replicate the energy and motions of walking, behavioral measures and reported sense of presence has been rated higher in real walking and walking in place compared to joystick ‘flying’ conditions (Usuh, Arthur, Whitton, Bastos, Steed, Slater, & Brooks, 1999). In studies that compared actually walking through a virtual maze to virtual travel, Chance, Gaunet, Beall, and Loomis (1998) found a significant difference between walking as compared to joystick controlled travel in participants’ ability to indicate the direction to unseen target objects from a terminal location in the maze. A secondary finding of this study was that the degree of motion sickness depended upon travel mode, with the lowest incidence occurring in the real walking mode.

2.2 Effect of wide field-of view and Large Displays

Much work has been done on the benefits of large displays for collaborative efforts, however single user systems have not been as widely investigated. Most research on cognitive effects of large displays have focused on spatial tasks.

Researchers have compared a projected display with a desktop monitor for a reading comprehension task and a spatial orientation task (Tann, Gergle, Scupelli, & Pausch, 2003). They found no significant difference with the reading comprehension task, but a 26% increase in performance for the spatial orientation task on the large display.

With further investigation, they theorized that the increase in performance was linked to a higher level of immersion provided by the larger display. This leads a user to take a more

efficient egocentric strategy, as opposed to an exocentric one, when performing the task.

Other work has reported that women perform better on spatial navigation tasks if given a wider field-of-view (Czerwinski, Tan, & Robertson, 2002).

3 Motivation for Studies

Cognition is defined as the process of receiving, processing, storing, and using information (Heffner, 2003). As opposed to perceptual motor tasks (e.g., pick up a pen), cognitive tasks require problem-solving decisions on actions (e.g., pick up a red pen).

In context of cognition, we asked the following two questions:

1. Is there an effect on cognition if we explore a virtual space by walking around in a natural manner as compared to using a virtual travel technique?
2. Is there an effect on cognition if we explore a virtual space with a large display (with a large field-of-view) compared to using smaller field-of-view and smaller displays?

To investigate these questions, we developed a task to explore a virtual room for five minutes. Participants were told that they would be asked questions about the room at the end of their exploration. Different groups of participants used various travel techniques and VE display approaches.

4 User Study 1: Travel Technique

4.1 Study Design and Methods

4.1.1 Participants

49 participants completed the study. We discarded data from three participants who failed to complete a minimum of 67% of the cognition questionnaire (as a control against participant apathy). In addition, due to procedure failures, cognition questionnaire data from two participants was not collected.

This left us with 44 participants' data to be included in the analysis of the cognition questionnaires (eleven from each condition), and 46 in the remainder of the questionnaires, sketch maps, and debriefing (eleven participants using real walking, twelve and eleven in two virtual walking conditions, and twelve using a joystick).

Participants were recruited from [Removed For Anonymous Submission] summer school courses, fliers, and by word-of-mouth. The average age of participants was 27 [18...63]. Participants were required to have taken or be currently enrolled in a higher-level mathematics (e.g. Calculus I) class and be able to comfortably communicate in written English. The mathematics requirement was intended to reduce variability in spatial ability between subjects.

There was no significant difference among groups in computer use, video game experience, and prior VR experience.

4.1.2 Design

The experiment was a between-subjects design. The independent variable was the travel method. The dependent variables were performance on a cognition questionnaire and sketch map accuracy. The participants were randomly assigned to one of the four conditions described below.

4.1.3 Conditions and Rationale

One of the most commonly implemented methods of locomotion in a virtual environment is to use a handheld button device that moves the user in the direction that she is looking when a button is pressed. There are several variations to this approach. We can simulate "flying" if we allow the user to move in her look-at direction without constraints. Virtual "walking" is usually implemented by moving the user in a 2D plane parallel to the ground plane of the environment. The most common tracking technologies are either six-degrees of freedom (position and

orientation) trackers with a limited effective range or three-degrees of freedom (orientation-only) tracking devices. With the former the user can use normal body motion, such as squatting down or moving the head side-to-side, as she experiences a VE. With the latter approach, the user can change her view of the world by turning her head in a natural way, but her position can only be changed via virtual techniques such as button pushes on a hand-held device.

(Figure 1 here)

For this study we compared the following four conditions:

1. **Real Walking (RW)** – Participant position and orientation are tracked in a physical tracked space the same size as the virtual room (4.5m x 4.6m x 2.6m). The participant walks around the virtual room in a natural manner (Figure 1).
2. **Virtual Walking using Six-Degrees-of-Freedom Tracking (VW6)** – Participant's head position and orientation are tracked but the physical tracked space is smaller than the virtual room. The participant uses a wireless joystick to navigate about the room. When a button is pressed, the participant is translated forward or backward (depending on the button) along the participant's look-at vector in a plane parallel to the floor. The participant stands within a 1.2m by 1.2m enclosure that both gives them something to hold on to for balance, and simulates the reduced tracking volume of common electromagnetic and acoustic tracking devices (Figure 1).
3. **Virtual Walking using Three-Degrees-of-Freedom Tracking (VW3)** – Participant head orientation is tracked. A joystick is used to implement virtual walking. The participant's viewpoint is moved in a plane parallel to the floor of the room. The viewpoint can also be moved up and down relative to the floor of the room with a different set of buttons. The participant stands within the same 1.2m by 1.2m enclosure used in the VW6

condition(Figure 1).

4. **Joystick with a Monitor (M)** – The participant sits in front of a 17-inch flat panel display at a distance such that the field-of-view is equal to the HMD conditions (Figure 1). She navigates about the room in a manner identical to the VW3 condition (button arrangement, etc.) except that the joystick is now used to control the view direction.

One way to view our choices of travel techniques is as a comparison of cost and capability versus performance. Large area six-degrees-of-freedom (RW) tracking systems are expensive in both monetary and space requirements as compared to orientation-only tracking (VW3). Limited range six-degrees-of-freedom trackers (VW6) are somewhere in between.

<i>Condition</i>	<i>Tracked (DoF)</i>	<i>Tracked Volume</i>	<i>Immersive?</i>
RW	6	4.5m x 4.6m x 2.6m	Yes
W6	6	1.2m x 1.2m x 2.6m	Yes
VW3	3	-	Yes
M	0	-	No

Table 1 Condition Properties

4.2 The Environment and Equipment

4.2.1 Equipment

For the RW, VW6, and VW3 conditions, participants wore a stereoscopic V8 HMD (640 X 480 resolution in each eye) that was tracked by a 3rdTech HiBall 3100 tracking system. The HiBall updates position and orientation at approximately 1.5kHz. Our HiBall system has a tracked volume of 4.5m x 4.6m x 2.6m. For condition M, we used a 17 inch flat screen monitor. We used a Logitech Wireless Joystick.

All the conditions ran on a Pentium 4 Dell PC with an nVidia GeForce4 Ti 4200 graphics card.

Condition M ran at 60 FPS, while the three HMD conditions ran between 24-30 FPS in stereo.

4.2.2 Training VE

Immediately before exploring the testing VE, participants practiced navigation in a training virtual environment. The training VE had four different colored cubes at different locations in a single room. We asked the participants to locate and travel to each of these cubes.

4.2.3 Testing VE

The testing VE was a single room measuring, 4.2m x 4.5m x2.6m. We populated the room with furniture, pictures, books, magazines, etc (Figure 2,Figure 3).

(Figure 2 here)

(Figure 3 here)

Several objects in the testing VE were grouped into themes. The books were all by Steven King, the pictures were all of landscapes, and the magazines were all about golf. In addition, several sports items were distributed throughout the room.

4.3 Measures

We used the following measures: a cognition questionnaire (CQ) based on a condensed version of Bloom's Taxonomy of the Cognitive Domain(Bloom, Englehart, Furst, Hill, & Krathwohl, 1956), a sketch map (Billinghurst & Weghorst, 1995), and the Steed-Usoh-Slater (SUS) Presence Questionnaire(Usoh, Catena, Arman, & Slater, 2000). Additional measures were used to help determine if there were any confounding factors affecting the results between the different conditions.

4.3.1 Cognition Questionnaire (CQ)

We created a set of 27 questions to assess the participants' cognition of the VE. These questions were selected and modified from an original set of 37 questions used in a pilot study (n=12).

The questions were based on Bloom's taxonomy (Bloom et al, 1956). Bloom's original

taxonomy describes six cognitive categories: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. We followed Crooks' condensation of the six categories into three (Crooks, 1988):

- Knowledge: the recall or recognition of specific information
- Understanding and Application: combines comprehension (understanding of facts and principles, interpretation of material) and application (solving problems, applying concepts and principles to new situations)
- Higher Mental Processes: combines analysis (recognition of unstated assumptions or logical fallacies, ability to distinguish between facts and inferences), synthesis (integration of learning from different areas or solving problems by creative thinking), and evaluation (judging and assessing).

The questions focused on objects evenly distributed about the room, such that roughly the same number and category of questions were asked about each part of the room.

The following are example questions from each category:

1. Knowledge:

- How wide was the couch?
- How many darts were in the dartboard?

2. Understanding and Application:

- What was the common theme of the paintings?
- How many people are coming to eat? How did you come to your answer?

3. Higher Mental Processes:

- Name all the objects made out of wood.
- Given the genre of books in the room, name a book that the residents might buy.

Each question was worth 1 point, for a maximum score of 27. Most of the questions (19) had a single answer for a possible score of either a 0 (wrong) or a 1 (correct). The remaining questions were posed such that an answer could be partially correct or approximately the correct answer. Answers were ranked by how close each participant's response was to the correct answer. We quantized the rankings to these questions and gave scores of 0, 0.25, 0.5, 0.75, or 1.

4.3.2 Sketch Maps

Participants were asked to draw a top-down view, a sketch map, of the testing VE and the objects within it. Then, each participant's sketch map was given a set of goodness and object positioning scores.

Maps were ranked for goodness on a scale of 1 (poor) to 5 (excellent) by three graders who were blind to subject identity as was done by Billingham and Weghorst (1995). The map goodness rating is a subjective measure of how useful the map would be as a navigational VE tool. The graders ignored drawing ability and concentrated on overall room layout accuracy. The final goodness score for a map was an average of the scores given by the three graders.

Maps were also graded on the relative position of the objects within the VE. Each map was given two scores:

- A total object position score based on how many objects in the room were correctly positioned in the sketch. There were a total of 63 objects in the room.
- A significant object position score based on the five most commonly drawn objects. The significant objects were the sofa, dining table, divider, TV, and the coffee table.

4.3.3 Other Measures

We measured sense-of-presence using the Steed-Usoh-Slater Presence Questionnaire (SUS) (Usoh, Catena, Arman & Slater, 2000), spatial ability using Guilford-Zimmerman Aptitude

Survey Part 5: Spatial Orientation (Guilford & Zimmerman, 1948), simulator sickness using the Kennedy – Lane Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilienthal, 1993), and visual memory using the Kit of Factor-Referenced Cognitive Test Factor MV-1: Shape Memory Test (Educational Testing Services, 1976). In addition, each participant was video taped and his/her position and orientation were automatically logged during the experimental session in the VE.

4.4 Experiment Procedures

The pre-testing, experiment session, and post-testing took each participant approximately one hour to complete.

4.4.1 Pre-Experiment

The participant first read the Participant Information Sheet and was asked if she had any questions. She then read and signed the Informed Consent Form. Next, the participant filled out questionnaires about demographics, computer use, computer anxiety, and simulator sickness. She then took the Guilford-Zimmerman Spatial Ability test.

4.4.2 Experiment

Next, the participant entered a different area of the lab where the experimenter showed and explained to her the equipment particular to her condition. The participant then was fitted with the equipment and practiced navigation in the training environment.

After the training session, the testing VE was loaded. The participant was asked to explore the environment for five minutes.

4.4.3 Post-Experiment

The participant filled out another simulator sickness questionnaire and the SUS Presence Questionnaire. Next, the participant filled out the cognition questionnaire. She also filled out the

visual memory test. She was then asked to draw a top-down sketch map of the VE. Finally, the participant was orally debriefed.

5 Travel Technique Study Results

A multivariate analysis of covariance (MANCOVA) was first conducted on the three categories of the cognition questionnaire, using travel technique as the independent variable and controlling for visual memory. We intended on also using spatial ability as a covariate, but this measure was not correlated with the CQ scores. MANCOVA was deemed appropriate because it accounted for prior differences while determining if there were mean differences among the travel techniques on the CQ categories (Tabachnick & Fidell, 1996). A univariate analysis of covariance (ANCOVA) was used for the sketch map scores, controlling for both spatial ability and visual memory. Finally, a one-way-between-subjects analysis of variance (ANOVA) was used for analysis of the remainder of our data (Iverson & Helmut, 1987). An alpha level of 0.05 was used for significance on all measures.

5.1 Cognition Questionnaire

Although the difference in the total score on the CQ was not statistically significant, the results become interesting when broken down by categories: Knowledge (K), Understanding and Application (UA), and Higher Mental Processes (HMP).

The MANCOVA across conditions for the three CQ categories, with visual memory as the covariate, revealed a significant multivariate effect of travel technique, Wilk's Lamda = 0.56, $F(9, 90) = 2.66$, $p < 0.01$. This means that travel technique had a significant effect on the participants' performance on the cognition questionnaire. Univariate follow-ups indicated a significant effect of travel technique on scores of both the UA, $F(3,39) = 3.63$, $p < 0.05$, and HMP categories, $F(3,39) = 3.12$, $p < 0.05$, but not on the K category of the CQ, $F < 1$.

<i>Condition</i>	<i>UA</i>	<i>HMP</i>
RW	4.60	3.69
VW6	2.78	2.36
VW3	3.23	3.04
M	2.96	2.84

Table 2 Adjusted Means for UA and HMP by Travel Technique

Planned contrast tests (α planned = $0.05/3 = 0.016$) showed that, after adjustment by the covariate, the CQ scores for RW were significantly higher than VW6 and M. The difference between RW and VW3 was not significant ($F(3, 37) = 2.44, p = 0.079$). Scores on the UA and HMP categories of the CQ for RW were significantly higher than those for VW6 ($F(1, 39) = 8.76, 9.01$, respectively, $p < 0.005$). Scores on the UA and HMP categories for RW were also significantly higher than those for M ($F(1, 39) = 7.69, p < 0.01$, and $F(1, 39) = 3.93, p < 0.05$, respectively). Scores on the UA category for RW were significantly higher than those for VW3 ($F(1, 39) = 5.19, p < 0.05$). These results imply that the ability to explore a VE in a natural manner might be beneficial for situations which require problem solving, interpretation, synthesis, or evaluation of information. The adjusted means for UA and HMP by travel technique are shown in Table 2. The differences on the K category of the CQ was not significant among groups, which indicates that travel technique does not have an effect on the simple recall of objects within a VE.

5.2 Sketch Maps

Analysis of the sketch maps revealed that travel technique had a significant effect on sketch map goodness scores. Table 3 shows the adjusted means for the sketch map scores by travel technique. The ANCOVA across conditions for sketch map goodness, with spatial ability and visual memory as covariates, revealed a significant multivariate effect of travel technique, $F(3, 40) = 4.60, p < 0.01$. Planned contrast tests, using $\alpha = 0.05$ for significance, showed that the map goodness scores for RW were significantly higher than those in VW3 and M. Table 4 shows the

results of these planned contrast tests.

<i>Condition</i>	<i>Map Goodness</i>	<i>Map Sig. Object</i>
RW	3.71	5.15
VW6	2.97	4.09
VW3	2.38	4.21
M	2.27	4.01

Table 3 Adjusted Means for Sketch Map Scores by Travel Technique

<i>Condition</i>	<i>F</i>	<i>Significance</i>
RV-VW6	2.580	0.116
RW-VW3	7.948	0.007*
RW-M	10.123	0.003**
VW6-VW3	1.696	0.200
VW6-M	2.485	0.123
VW3-M	0.061	0.806

Table 4 Planned Contrast Tests for Sketch Map Goodness

***Significant at the $\alpha=0.01$ level**

****Significant at the $\alpha=0.005$ level**

*****Significant at the $\alpha=0.0005$ level**

The ANCOVAs across conditions for sketch map total object position scores and significant object position scores were not statistically significant. Object position scores were not statistically different across conditions, indicating that natural walking did not have an advantage over other travel techniques for simple recall of objects and their relative positions within the VE. However, it appears that the ability to walk around naturally in the virtual environment seemed to be useful in terms of forming an accurate mental model of the VE, as depicted by the sketch map goodness scores.

<i>Condition</i>	<i>P-value</i>
RV-VW6	0.883
RW-VW3	0.999
RW-M	0.004***
VW6-VW3	0.932

VW6-M	0.024*
VW3-M	0.006**

Table 5 Tukey Test: SUS Presence Mean

5.3 Other Factors

Spatial ability, computer anxiety, and visual memory were not significantly different among groups. Simulator sickness was also not significant among groups. There was no significant difference among groups in computer use, video game experience, and prior VE experience. A one-way-between-subjects ANOVA across all conditions for the SUS Presence Means was significant, $F(3, 40) = 5.28, p < 0.005$. A post hoc Tukey test revealed significance between all the HMD conditions and the monitor condition.

6 User Study 2: Large Displays

After completing the first study, two natural questions arose when discussing the results with other VR researchers. Some spoke that they used large displays VR systems, such as a CAVE™ or NAVE. They wondered if the increased field-of-view provided by these systems, would impact a user's cognitive ability, as composed to the monitor and HMD conditions tested.

To examine this, we conducted a follow-up study to investigate the effects of large displays and a large field-of-view on cognition. We evaluated the following question:

- Do large display devices affect the users' cognitive ability when exploring a virtual space?

Using the infrastructure from the travel technique study we investigated user performance with large projection-based systems and compared the results to the baseline of a monitor-based condition (the 'M' condition in the travel technique study).

6.1 Study Design and Methods

6.1.1 Participants

47 participants completed the study. All answered over 67% of the questions in the cognition

questionnaire (our incomplete threshold).

Participants were recruited from 2nd year [Removed For Anonymous Submission] computer science summer classes. The average participant age was 21 years old [19...23].

There was no significant difference among groups in computer use, video game experience, and prior VR experience.

6.1.2 Design

The experiment was a between-subjects design. The independent variable was the Display System. The travel technique for all conditions was identical, the joystick approach of VW3. When a button is pressed, the participant is translated forward or backward (depending on the button) along the participant's look-at vector in a plane parallel to the floor. Again the dependent variables were performance on the cognition questionnaire and user sketch map accuracy.

Users were randomly assigned to one of the three display conditions outlined below.

6.1.3 Conditions and Rationale

Projection based systems are employed often to extend a virtual experience to multiple users. They also are used to enhance single user systems by providing a large field-of-view that approaches visuals we experience in real life.

Our intuition is to believe “bigger is better”, but is this really the case? This study focused on the cognitive effects of large displays. Does having a very large field-of-view help in cognition tasks? A large field-of-view can provide more information to the user and make less travel necessary to view the entire scene; however, will it provide a significant improvement over a lower field-of-view – though substantially cheaper and smaller – desktop system?

(Figure 4 here)

We designed three conditions that represent common display size and field-of-views of VE systems:

1. **NAVE (N)** –The scene is displayed on a projected based system called the NAVE (Non-expensive Automatic Virtual Environment). The NAVE is a three screen back-projected display. Each screen measures 8ft by 6ft. The side screens can be angled from the center at 90°, 120°, and 180°. We chose the 120° configuration for both sides. For all conditions we used a resolution of 1024x768. In effect, the two side NAVE screens tripled the visible horizontal resolution of the scene making the total scene resolution 3072x768. The user sits a distance of approximately 1.6 m away from the screen, giving them a near 180 degree horizontal field-of-view(HFOV).The NAVE condition provides the largest HFOV, and is the most expensive. Figure 4 shows a diagram of the NAVE setup.
2. **Single Screen Projection (SS)** – The virtual environment is the back projected at 1024x768 onto a single NAVE screen measuring 8 ft by 6 ft. This setup is typical of a single projector, single PC system. The user sits in the same location as the NAVE condition and thus has a reduced field-of-view HFOV of 60 degrees, however it provides a large image centered in the users view. This condition has the second best HFOV and has the second highest cost. Figure 4 illustrates the SS condition.
3. **Monitor (M)** – The monitor is our baseline condition and is similar to the Study I monitor condition. It is a standard 19” Monitor running the scene at 1024x768. The user sits 2 ft away from the screen. It is the smallest display, has the lowest HFOV, and is lowest cost system.

	Display Size	Resolution (Pixels)	HFOV (Degrees)	Cost (USD)
N	24x6 ft	3072 x 768	180	Hundreds
SS	8x6 ft	1024 x 768	60	Thousands
M	15.2 x 11.4 in	1024 x 768	40	Tens of Thousands

Table 6 Condition Properties

6.2 The Environment and Equipment

6.2.1 Equipment

The NAVE used three Pentium 3 PCs. Each PC was dedicated to rendering a single screen. The Monitor and Single Screen Projection each used a single PC of the same specifications. All conditions ran at condition ran at 60 frames per second.

6.2.2 Virtual Environment

Study participants were trained and tested in the same virtual environments as the Travel Technique study. The purpose of the training environment was again to familiarize the users with how to navigate via the 6 D0F joystick interface. Figure 5 shows a participant navigating in the NAVE condition.

(Figure 5 here)

6.3 Measures

The measures used were identical to the Travel Technique study.

<i>Metric</i>	<i>Measures</i>
Cognition Questionnaire	VE Cognition
Sketch Map	Memory
Steed-Usoh-Slater	Sense of Presence
Guilford-Zimmerman Aptitude Survey	Spatial Ability
Kit of Factor Shape Memory Test	Visual Memory
Kennedy-Lane Simulator Sickness	Simulator Sickness

Table 7 Metrics and Measures

6.4 Experiment Procedures

The experiment procedure was identical to the Travel Technique study.

7 Large Display Study Results

For data analysis, we used a one-way-between-subjects ANOVA with $\alpha=0.05$ level for significance.

The null hypothesis was that across the conditions, users would exhibit no difference in the cognitive questionnaire and Sketch Maps. We were unable to reject the null hypothesis because the differences between conditions for the overall cognition scores, and individual category scores were not significantly different. The Sketch Maps were also found not significant across the conditions.

(Figure 6 here)

To insure that the condition populations were relatively homogenous, we did a between groups ANOVA analysis on the subjects scores for Spatial Ability, Computer Anxiety, and Visual Memory tests.

We found no significant difference between condition populations.

<i>Conditions</i>	<i>P-value</i>
M-NAVE	0.499
M-SS	0.776
SS-NAVE	0.844

Table 8 Tukey Test: SUS Presence Mean

There was no significant difference in the Self-Reported Sense of Presence or simulator sickness among subjects across conditions.

8 Discussion

8.1 Travel Technique Discussion

We found that Real Walking showed a significant improvement in cognition performance over the monitor condition. We found no significant difference between the display conditions.

8.1.1 Debriefing Trends

Analysis of the post-experience interviews resulted in the following trends:

When asked “What percentage of the time you were in the lab did you feel you were in the virtual environment?” The mean response of the participants in RW was 69.1% (s.d. = 24.9), 52.1% in VW6 (s.d. = 31.7), 58.1% in VW3 (s.d. = 33.7), and 33.8% in M (s.d. = 29.9).

When asked “How long did it take for you to get used to the virtual environment, in terms of navigation and interaction?” The mean response of the participants in RW was 15.5 seconds (s.d. = 18), 54.2 seconds in VW6 (s.d. = 43), 34.8 seconds in VW3 (s.d. = 26), and 117.5 seconds in M (s.d. = 104).

55% of the RW and 17% of the M participants reported that they tried to avoid objects.

0% of the RW and 33% of the M participants reported that navigation was difficult.

36% of the RW and 8% of the M participants thought that the experience was realistic.

8.1.2 Observations

Time in training: The time taken to perform the training tasks differed in each VE condition. Participants in the monitor condition took a noticeably longer time to train than it took for participants in other conditions. Generally, participants in conditions VW6 and VW3 took a longer time to train than participants in condition RW.

8.2 Large Displays Discussion

8.2.1 Debriefing Trends

Analysis of the post-experience interviews resulted in the following trends:

When asked “What percentage of the time you were in the lab did you feel you were in the virtual environment?” The mean response of the participants in NAVE was 55.7% (s.d. = 33.5), 40.8% in SS (s.d. = 27.0), and 36.7% in M (s.d. = 33.4).

When asked “How long did it take for you to get used to the virtual environment, in terms of navigation and interaction?” The mean response of the participants in NAVE was 114.8 seconds

(s.d. = 144.8), 72.3 seconds in SS (s.d. = 72.1), and 80.22 seconds in M (s.d. = 93.5).

When asked if participants tried to avoid objects, 63% of NAVE participants (s.d. = .50) and 60% of SS participants (s.d. = .50) reported that they did. Only 44% of M participants reported (s.d. = .53) trying to avoid objects.

Overall the participants had mixed feelings about the usefulness of the large displays

- Participant 52 from NAVE commented that the NAVE was “cooler with three screens” than a typical monitor setup.
- Participant 24 from NAVE felt that the “peripheral vision helped” with navigation
- Participant 55 from SS said “The large screen threw me off”.

The primary concern of the participants across the conditions however came not from the choice of display but from features of the virtual environment such as physics and logical issues. Many comments were made about things such as the clock not working, not being able to open doors. Almost every participant commented about the lack of collision detection citing it as a fault with the environment. Given the nature of the previous study, collision detection did not make sense because it would be disorienting for participants. Since all of this study’s users were using the joystick, some form of collision detection should probably have been implemented.

8.2.2 Observations

Participants seemed more interested in the large display area offered by the NAVE. This however did not correlate to any increase in cognitive performance. The previous study suggests that lowering the cognitive load by allowing natural movement increases performance. The unnaturalness of the joystick interaction may have been accented by the NAVE. This may have negated any potential benefit of having the increased field-of-view and large screen size.

8.3 Path Visualizations

Participants' position and orientation in both the virtual environment and the real lab were logged during their exposure to the virtual environment. This information allowed us to visualize the path the participant took in the VE. We have conducted a thorough analysis of the path visualizations[Removed For Anonymous Submission] . Anecdotally, we feel the path through the VE for participants in the NAVE and SS conditions were similar to that of the M condition participants.

9 Summary

On the understanding and application portion of the cognition questionnaire, participants in RW performed significantly better than participants in M and VW6. There was also a strong trend toward better performance of RW as compared to VW3 for understanding and application. Participants in RW performed significantly better than participants in VW6 with respect to higher mental processes. There was a strong trend toward better performance with RW as compared to M for higher mental processes.

Sketch map total object position scores were significantly better for participants in RW as compared to participants in M.

sense of presence on the SUS Questionnaire was significantly higher for all the HMD conditions as compared to the monitor condition. There was no difference in sense of presence among any of the conditions in which the participant wore the HMD. In the debriefing, there was only a significant difference in Self Reported Presence between RW and M. This difference was strongly supported by comments from the participants during the debriefing. For example:

- Participant 31 from RW commented "I was afraid to hit my shin on the table."
- Participant 47 from VW6 commented "I almost ran into the divider!"
- Participant 2 from VW3 commented "I wanted to stand on the skateboard"

- Participant 26 from M commented “It did not feel like walking”

It was also clear that participants were much more comfortable with RW as a navigation technique than they were with any of the others. This attitude is illustrated by their answers to the question: “How long did it take for you to get used to the virtual environment, in terms of navigation and interaction?”, our observations as to actual time in training, reported difficulty of navigation during debriefing, and quotes from the debriefing. For example:

- Participant 20 from M commented “I never got used to the navigation!”
- Participant 24 from RW commented regarding navigation: “It was easy... I just walked around!”

We were surprised to find no significant difference in the cognition questionnaire or the Sketch Maps among the groups in the large displays study. We felt that the large field-of-view and screen size offered by the NAVE would allow the participants to examine more of the world, in more detail, while reducing the need for navigation. In the previous study, the monitor condition took the longest time for participants to get used to. In the large displays study the NAVE took much longer than the other conditions. This trend seems to indicate that there were benefits to using the NAVE, but that these benefits were offset by the increase in navigation difficulty.

Our results suggest that for applications where problem solving and interpretation of material is important or where opportunity to train is minimal, then having a large tracked space so that the participant can walk around the virtual environment provides benefits over common virtual travel techniques. Also, any benefits of a large field-of-view display might be negated if the navigation interface is unnatural or unwieldy.

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Captions

Figure 1 Top left: Participant in Monitor condition. Bottom Left: Participant in Real Walking condition. Right: Participant in Virtual Walking condition.

Figure 2 Top down view of testing VE

Figure 3 First person view of testing VE

Figure 4 Diagram of NAVE and SS condition setups

Figure 5 A participant in the NAVE condition uses the joystick to navigate around the testing room

Figure 6 Mean Cognition Questionnaire Scores

Figures



