Technical Report 1029

The Virtual Environment Performance Assessment Battery: Development and Evaluation

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U.S. Army Research Institute

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13. ABSTRACT *(Maximum 200 words)*

The Virtual Environment Performance Assessment Battery (VEPAB) is a set of tasks developed to support research on training applications of VE (Virtual Environment) technology. VEPAB measures human performance on vision, locomotion, tracking, object manipulation, and reaction time tasks performed on three-dimensional, interactive VEs. It can be used to provide a general orientation for interacting in VEs and to determine entry-level performance and skill acquisition of users. In addition, VEPAB allows comparison of task performance, side effects and aftereffects, and subjective reactions across different VE systems. By providing benchmarks of human performance, VEPAB can promote continuity in training research across different technologies, separate research facilities, and dissimilar subject populations. This report describes the development of VEPAB and summarizes the results of an experiment to test the sensitivity of the tasks to differences between input control devices and to examine practice effects.

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Personnel Systems and Performance Technology

FOREWORD

The U.S. Army has made a substantial commitment to Distributed Interactive Simulation (DIS) and the electronic battlefield for training, concept development, and test and evaluation. The current DIS training system, Simulation Networking (SIMNET), and the next generation system, the Close Combat Tactical Trainer (CCTT), provide effective training for soldiers fighting from vehicles, but are unable to do the same for individual dismounted soldiers. Virtual Environment (VE) technology has the potential to provide Individual Combat Simulations (ICS) for the electronic battlefield. However, several research challenges must be overcome before VE technology can be used for practical training applications. These challenges include: (a) providing all trainees with the necessary prerequisite skills for operating in VEs; (b) identifying and quantifying the effects of VE system characteristics that influence skill acquisition and transfer; and (c) ensuring that unwanted side effects and aftereffects that might result from immersion in VEs do not pose unacceptable risks.

This report describes our initial research conducted to obtain quantitative data on human performance and learning in VEs, and the research tools developed for this and future research. Portions of the research have been presented at a variety of Army, Department of Defense, and scientific conferences. A less detailed version of this report was published in *Presence: Teleoperators and Virtual Environments*, Volume 3, Number 2, Spring 1994.

The U.S. Army Research Institute for the Behavioral and Social Sciences Simulator Systems Research Unit conducts research to improve the effectiveness of training simulators and simulations. The work described is a part of the ARI research task titled VIRTUE—Virtual Environments for Combat Training and Mission Rehearsal.

EDGAR M. JOHNSON
Director

THE VIRTUAL ENVIRONMENT PERFORMANCE ASSESSMENT BATTERY (VEPAB): DEVELOPMENT AND EVALUATION

EXECUTIVE SUMMARY

Requirement:

The U.S. Army has made a substantial commitment to the use of virtual environment (VE) technology, such as networked simulators to create virtual battlefields for combat training and mission rehearsal, development of military doctrine, and evaluation of weapon system concepts prior to acquisition decisions. All of these functions would be improved by a better representation of dismounted infantry on the virtual battlefield. Immersive VE technology, also known as virtual reality, may provide an interface to allow dismounted soldiers to fight on virtual battlefields. However, several research challenges must be met before this technology can be applied. These challenges include (a) providing all trainees with the necessary prerequisite skills for operating in VEs; (b) identifying and quantifying the effects of VE system characteristics that influence skill acquisition and transfer; and (c) ensuring that unwanted side effects and aftereffects that might result from immersion in VEs do not pose unacceptable risks.

Procedure:

The Virtual Environment Performance Assessment Battery (VEPAB), a set of VE perceptual and psychomotor tasks, was developed to support research on training applications of VE technology. Tasks were developed for each of five categories: vision, locomotion, tracking, object manipulation, and reaction time. These tasks are components of essential soldier functions (move, communicate, and employ weapons). The tasks were administered to college students and government employees to measure the initial level of performance, practice effects, the effects of different interface devices, and the incidence and severity of side effects and aftereffects resulting from VE immersion.

Findings:

Performance on most VEPAB tasks was sensitive to differences between input control devices. Most were also sensitive to practice effects. All of the tasks could be performed by our diverse group of participants. However, significant variation was observed across individuals in their initial abilities to perform

tasks in VEs. Individual differences were also observed in self-reports of the occurrence and severity of symptoms of discomfort resulting from VE immersion. Most individuals enjoyed the VE experience. However, most reported some symptoms and one of 24 withdrew because of symptoms similar to those of motion sickness.

Utilization of Findings:

The results of this research confirm that the VEPAB can be an effective research tool. Overall, task performance is sensitive to the effects of different control devices and the amount of practice performing the tasks. It is also sufficiently reliable. The tasks will be used in future experiments investigating the effects of different visual display devices on task performance and training.

THE VIRTUAL ENVIRONMENT PERFORMANCE ASSESSMENT BATTERY (VEPAB): DEVELOPMENT AND EVALUATION

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THE VIRTUAL ENVIRONMENT PERFORMANCE ASSESSMENT BATTERY (VEPAB): DEVELOPMENT AND EVALUATION

Introduction

This report describes the development and initial evaluation of an integrated battery of tasks to measure human performance in immersive virtual environments (VEs). Immersive VEs, sometimes referred to as Virtual Reality, have been defined as human computer interfaces "in which the computer creates a sensory-immersing environment that interactively responds to and is controlled by the behavior of the user" (Pimentel and Teixeira, 1993, p. 15). At the time we designed VEPAB there was little or no published information on how people perform in immersive VEs. The battery was developed to support a research program on training applications of immersive VE technologies. A goal of the program is to determine those technologies that produce cost-effective transfer of training from VE practice to real-world performance, and strategies for the effective use of these technologies.

The U.S. Army has made a substantial commitment to the use of networked simulators to create virtual battlefields for combat training (Alluisi, 1991; Sterling, 1993). VE training systems in use, such as Simulator Networking (SIMNET), and under development, such as the Close Combat Tactical Trainer (CCTT), provide training for soldiers fighting from within vehicles such as tanks and helicopters. In these training systems, crew members operate inside physical mockups of combat vehicles with video monitors providing their views of the simulated outside world (the virtual battlefield) as seen through vision blocks of armored vehicles, cockpits of aircraft, and the electro-optical sights of weapon systems. Trainees crouch, sit, or recline in the simulators in positions similar to those they would assume in actual combat vehicles. The ways in which the crew members view and hear the world, control vehicle movement, and employ weapon systems correspond closely to those of actual combat vehicles. In marked contrast, the representation of dismounted infantry is limited to a unit leader, seated at a workstation, controlling a group of icons that represent dismounted soldiers. This approach may train mounted soldiers to fight with and against dismounted soldiers, but it is inadequate for training the dismounted soldiers themselves.

Gorman (1990) proposed that immersive VE technologies could provide an interface to enable dismounted soldiers to train on virtual battlefields. With this approach a head-mounted display (HMD) would present a view of a computer-generated, three-dimensional environment relative to an eye point within the environment. The human user could control the direction and movement of the eye point and interact with simulated objects within the VE. In this manner the user is "immersed" in the VE. This interface would allow trainees to move, shoot, and communicate in VEs. Simulation of these three basic soldier functions could allow training on complex scenarios requiring real-time tactical decision making.

Gorman (1990) has also emphasized the importance of enabling dismounted troops to train on virtual battlefields. In addition to training applications, virtual battlefields can support several other functions important to the U.S. military (Alluisi, 1991). For example, virtual battlefields can be used to develop and evaluate military doctrine and to evaluate weapon system concepts prior to acquisition decisions. All of these functions would be improved by a better representation of dismounted infantry.

The Army Research Institute for the Behavioral and Social Sciences (ARI) has established a research program to determine the characteristics of the VE technologies needed to provide an interface for dismounted soldiers to train with virtual battlefields such as SIMNET and CCTT. As part of this effort, ARI contracted with the University of Central Florida's Institute for Simulation and Training (IST) to develop a laboratory for the conduct of psychological research addressing human performance in VEs. IST provides computer science expertise in the development and operation of the laboratory, acquiring off-the-shelf system components such as hardware and software for the laboratory, or developing them when necessary. IST scientists predicted rapid improvements in capabilities and prices of VE technology, therefore ARI decided to begin with equipment sufficient to support initial research (a low-cost stereoscopic HMD, a head tracker, a manual controller device) and to expand the testbed as necessary. Development of the testbed is described in greater detail by Moshell, Blau, Knerr, Lampton, and Bliss (1993).

Currently available immersive VE technologies have high costs and performance limitations, such as the limited resolution of HMDs, which preclude the immediate, widespread application of those technologies for training dismounted soldiers (Levison & Pew, 1993). A long term goal of our research is to demonstrate that immersive VE training enables the learning and practice of skills that transfer to field training and can be expected to transfer to actual combat.

We believe that our research with the admittedly limited immersive VE technology available today can guide the timely and cost-effective development of VE training systems as technology improves. In networked training simulations there will be limits on the kinds and amount of information that can be passed across the network. In addition, the requirement to network many trainees simultaneously will place an emphasis of using inexpensive equipment.

Pimentel and Teixeira (1993) have pointed out that absolute realism may not be necessary to create a sense of immersion; the created world need only be real enough for the user to suspend disbelief for a period of time. They compared immersion in virtual reality to being absorbed in a good novel or a computer game. Pimentel and Teixeira stated that interactivity has two primary components; navigation and the dynamics of the environment. Navigation is the user's ability to move about in the environment. The dynamics of the environment are determined by the rules for how the contents, people or manipulable objects for example, can interact.

Initial Research Considerations

Several research challenges must be overcome before VE technology can be used for practical training applications. These challenges include: (a) providing all trainees with the necessary prerequisite skills for operating in VEs; (b) identifying and quantifying the effects of VE system characteristics that influence skill acquisition and transfer; and (c) insuring that unwanted side effects and aftereffects which might result from immersion in VEs do not pose unacceptable risks.

Individual Differences in VE Performance

In order to engage in meaningful training, trainees must have at least some minimum level of skill in perceiving, moving through, and manipulating objects in the VE. For example, we created a prototype training scenario that involved some of the action which might be performed in a hostage rescue mission. The scenario required individuals to explore and search a VE model of an art museum. There were substantial individual differences in initial skills in operating in a VE. Some individuals could not find or pass through the front door of the building, much less learn the interior configuration of the building. This tended to confirm our informal observations made at a variety of VE demonstrations that for many individuals task performance in those VE implementations is not "intuitive." Identification of the sources of the individual differences may be an interesting research topic; however, for the short term an important need is to provide a systematic familiarization to VEs, that is, a method to train basic VE skills. In addition, a method is needed to measure those skills in order to determine that individuals have achieved at least some minimum level of VE skill before proceeding with training on more complex tasks. These measures can also be used as covariates to strengthen analyses of performance on complex tasks performed in VEs.

Measuring Human Performance as a Function of VE System Characteristics

Development of effective VE training systems will require many tradeoff decisions in the selection of components and system operating parameters. Examples of these decisions are: What is an appropriate tradeoff between width of the field of view versus the resolution of the visual display? What is an appropriate balance of scene detail versus frame rate? Empirical data to support these decisions are limited. There is some relevant previous research. For example, Padmos and Milders (1992) present a comprehensive list of quality criteria for visual displays in vehicle simulators used for training. The list includes spatial resolution, contrast ratio, chromatic color attributes, field size, luminance, update frequency, and refresh rate. However, for new technologies such as immersive VE the adequacy of the visual presentation to support training can not be predicted solely from specification of the physical characteristics of individual components, e.g., pixel density of the HMD, due to the complex interactions of the many components that make up a VE system. Furthermore, subjective judgements of what "looks best" may not accurately predict task performance. Empirical measures of human performance are needed to allow comparisons of different VE components and system parameters.

Concerns about Unwanted Side Effects and Aftereffects

There are anecdotal reports that immersive VEs can lead to symptoms similar to motion sickness symptoms. Kennedy, Lane, Lilienthal, Berbaum, & Hettinger (1992) documented the frequency and severity of such symptoms associated with training in flight simulators, but similar data for immersive systems are lacking. For practical applications, even mild effects may diminish training effectiveness.

If immersion in VEs results in sickness similar to that which has been found with flight-training simulators then the effectiveness of dismounted infantry training using HMDs will be diminished in several ways. For example, some trainees will be unable to use the training system, others will be able to tolerate sickness but training will be diminished through distraction or adoption of coping strategies. In addition, aftereffects will pose safety problems. In the short term, the most important consideration is that we need a realistic assessment of the risks to the participants of our experiments.

Development of the Virtual Environment Performance Assessment Battery (VEPAB)

We developed the Virtual Environment Performance Assessment Battery (VEPAB) to provide a set of standard materials and procedures to investigate the issues discussed in the previous section. The materials are simple VEs in which movement, tracking, object manipulation, and reaction time tasks can be performed. The procedures are the instructions, presented to VE users, which describe the tasks to be performed and the measures of task performance. An example of a VEPAB task is to use an input control device to "walk" through a series of connected rooms. The instructions direct the participants to move through the connecting corridors as rapidly as possible without "bumping into" walls or doorways. Performance measures are speed (the time to move through each successive room) and accuracy (the number of collisions with walls or door frames). The VEPAB will allow us to maintain a common baseline in our research program as new VE technologies become available, different training applications are investigated, and diverse participant pools are employed.

The VEPAB consists of a set of simple generic tasks that represent components of more complex activities. Simple tasks, in contrast to detailed training scenarios, are easier to develop, provide a general context applicable to other areas of training research, allow isolation of critical variables, and facilitate measurement of performance.

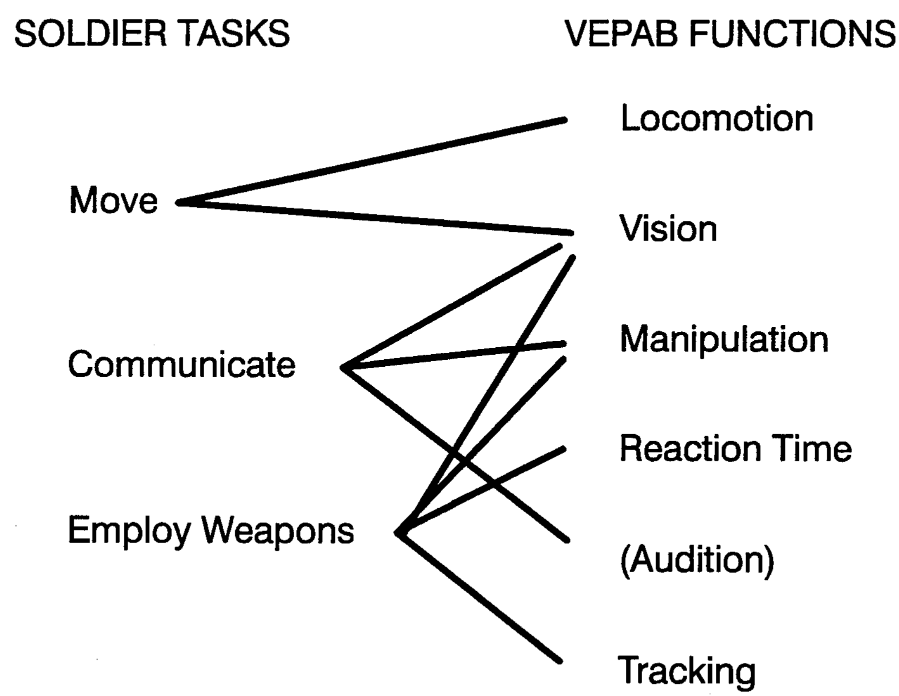


Figure 1. Relationships between VEPAB tasks and soldier functions. (Audition Tasks are not yet developed.)

We developed tasks for each of five categories: vision, locomotion, tracking, object manipulation, and reaction time. These tasks are components of the soldier tasks in which we are interested. They are components of many non-military activities as well. Figure 1 depicts the relationship of the VEPAB tasks to soldier functions. Although the VEPAB tasks are clearly related to soldier functions the tasks were designed so that previous military training is not required for successful task performance. Therefore civilians, such as college students, can be used as research participants in testing the VEPAB tasks.

Table 1 provides a summary of VEPAB tasks by task category. We developed more than one task for each category anticipating that some tasks would fail to meet the criteria we had established and therefore be unsuitable for future use. These criteria included adequate reliability and an appropriate degree of difficulty (neither too difficult nor easy). Task performance should demonstrate sensitivity to differences in display and input systems and show improvement with practice. Also, we wished to have available a pool of tasks from which to select, based on specific research requirements.

In order to implement the tasks quickly and inexpensively, we simplified several aspects of the tasks and the interface with them. Only visual cues were provided. No auditory or haptic devices were used. The participant's body was not visually represented in the VE. The manipulation tasks were performed using the same control devices used for the other tasks. The use of more sophisticated display and control devices (such as three-dimensional sound, instrumented gloves, and instrumented treadmills), and visual representation of the human figure are important areas for future research. However, their investigation was beyond the scope of our initial effort.

Both because of the importance of military missions in urban areas, such as hostage rescue or house-to-house searches for weapons, and because it was somewhat easier to develop realistic, visually rich building interiors than exterior terrain, many of the VEPAB tasks are situated in the interiors of buildings. However, the interiors have no explicit military connotations and were roughly modeled after the offices which we occupied when we developed the VE design specifications. The level of detail of the interiors was selected to provide a variety of visual cues at an acceptable frame update rate. Figure 2 illustrates the scheme used in modeling the building interiors for the locomotion tasks: floors have checkerboard patterns, walls are 12 ft high with narrow vertical stripes every 5 ft, ceilings have horizontal light panels every 10 ft, and corridors are 3 ft wide.

Table 1

Virtual Environment Performance Assessment Battery Task Descriptions by Category

TASK CATEGORY	TASK NAME	TASK DESCRIPTION
Vision	Acuity	Read letters in a Snellen eye chart
	Color	Detect colors in Ishihara plates
	Object Recognition	Identify an object (a human figure) at the end of a 40 ft hallway
	Size Estimation	Estimate the height of a human figure at the end of a 40 ft hallway
	Distance Estimation	Indicate when the image of a human figure, moving toward the viewer from an initial distance of 40 feet, is 30, 20, 10, 5, and 2.5 ft away
	Search	Detect a target moving about the walls, floor, or ceiling of a room
Loco-motion (walking)	Straight-away	Move down a straight corridor to a circle on the floor, turn around, and return to the starting point
	Back-up	Move down a straight corridor to a circle on the floor, then move backwards to the starting point
	Turns	Move through a corridor formed by 10 alternating left and right 90 degree turns
	Figure-8	Move around a figure-8 shaped corridor
	Doorways	Move through a series of rooms connected by doorways that are offset so that a curved course must be followed
Loco-motion (flying)	Windows	Like Doorways, except that some of the openings are elevated, so that vertical, as well as horizontal, movement is required
	Elevator	Move forward through a structure while going over or under a series of vertical obstacles

Table 1 (continued)

TASK CATEGORY	TASK NAME	TASK DESCRIPTION
Tracking	Head Control, Stationary Target	Use head movements to move a cursor, centered in the viewing device, onto a stationary target
	Head Control, Moving Target	Use head movements to move a cursor, centered in the viewing device, onto a target moving in a straight line
	Device Control, Stationary Target	Use a control device to move a cursor onto a stationary target
	Device Control, Moving Target	Use a control device to move a cursor onto a target moving in a straight line
Manip-ulation	Slide	"Grasp" a control bar and move it hor-izontally to a marked location
	Dial	"Grasp" a dial and rotate it to an indicated orientation
	Bins	"Grasp" a ball located in a vertical rack of open containers (bins), pull it out of the original bin, and push it into a target bin
Reaction Time	Simple	Indicate when an "X" pops into view
	Choice	Indicate in which of four boxes an "X" has appeared

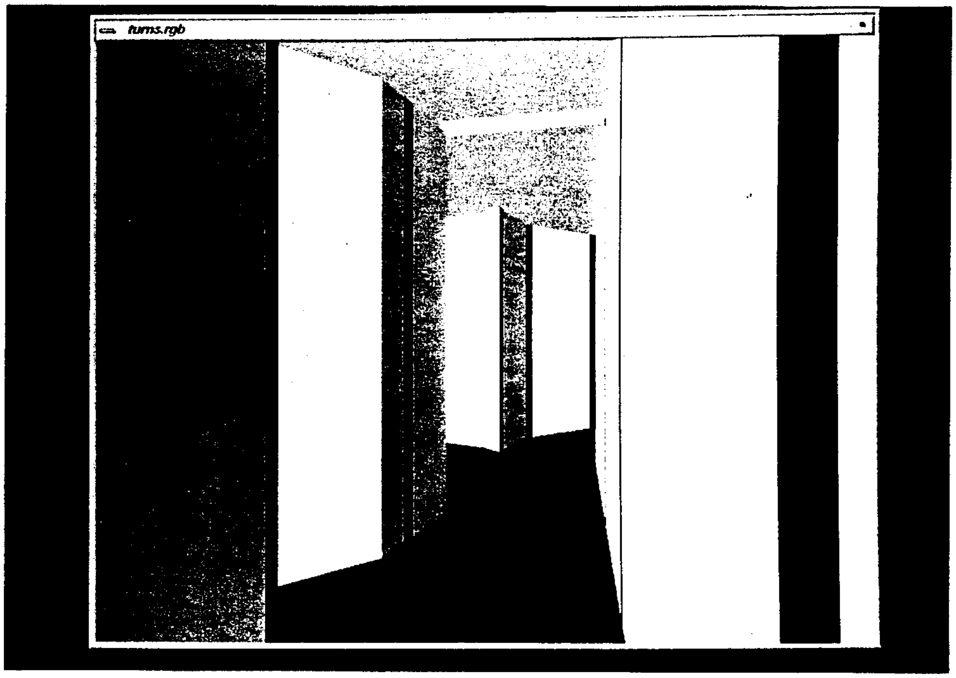


Figure 2. An example of interior design: The intersection of the Figure-8 task.

VEPAB Task Descriptions

Vision Tasks

The vision tasks include acuity, color, and search. Other vision tasks address the recognition of a familiar object, a human figure, and the estimation of the size of, and distance to, the object. These visual skills are important to the performance of many real-world tasks. The vision tasks require participants to report aloud what they perceive.

Acuity

A Snellen eye chart, a virtual reproduction of the familiar letter chart found in every doctor's office, was created by modeling each individual letter. The chart is presented at eye level at the end of a 20-foot corridor. The participant is instructed to describe the visual scene and is not told that there is an eye chart at the end of the corridor. From twenty feet away the correct identification of only the top letter of the chart corresponds to an acuity of 20/200. We anticipated that the resolution of some VE visual displays would result in acuity worse than 20/200. To enable the measurement of acuity worse than 20/200 the VEPAB acuity task allows the eye point to be moved toward the chart. The experimenter moves the participant's eye point forward, toward the chart, in one-foot intervals and records the distance at which the participant first reads the top line of the chart. Additional measures are the number of lines of the chart that can be read at each distance interval.

Color

Standard color vision test plates were digitized to produce VE tests for mild (red-green) and severe (blue-yellow) color vision deficiencies. Three circles made up of colored dots appear on each plate. Dot patterns within the circles form numerals. Participants read the numerals aloud. The performance measure is the number of numerals correctly recognized for each plate. The participant's real-world color vision is measured before this VE test is administered. Thus, this task is a gross measure of the capability of the VE system to present appropriate colors.

Object recognition, size estimation, and distance estimation

A digitized picture of a human figure appears at the end of a forty-foot corridor. The participant is asked to identify the object and estimate its height. The participant is told the correct height, 6 ft, and asked to estimate the distance to the figure. The experimenter then tells the participant that the figure is 40 ft away and that the figure will begin to move forward. The participant calls out when the figure appears to be 30, 20, 10, 5, and 2.5 ft ("arms length") away.

Search

The participant's viewpoint is at eye-level in the center of a room. A red ball appears near the floor, ceiling, or walls, and moves slowly around the room. The participant searches for the target by making head movements and turning in their chair, then calls out when the target is detected. One practice trial and ten performance trials are conducted. For the practice trial the target appears in the participant's field of view. For the performance trials, the starting location of the target is determined by random number generation with the restriction that the target is not initially in the participant's field of view. The performance measure is the time to report the target. The Search task provides a transition from the vision tasks to motor tasks in that the Search task is presented more than once and a more active role is required of the participant.

Locomotion Tasks (Walking)

Many VE applications will require participants to move at realistic rates while simultaneously attending to other tasks; the cognitive load imposed by walking in VEs should not be significantly greater than real-world walking. We designed a series of progressively more complex locomotion tasks to systematically train participants to move at a reasonable speed while avoiding collisions with obstacles such as walls and door frames. In addition to providing an efficient way to train VE locomotion, the tasks provide objective performance measures, and indirectly provide diagnostics of problem areas.

The locomotion tasks require the participant to "walk" through the VE by using an input control device to direct the speed and direction of the participant's simulated body. (We refer to this mode of virtual locomotion as walking inasmuch as the height and rate of movement of the viewpoint are constrained to match that of walking, and the contexts (hallways, doorways, rooms) are those in which walking is normally conducted.) The dimensions of the virtual body represent the 50th percentile male; the height is 68 in., elbow-to-elbow breadth is 16.5 in. (McCormick & Sanders, 1976). Eye level is set at 65 in. above the floor. There is no visible representation of the body. The body can move forward or backward, laterally, or rotate. Software settings, chosen to represent normal walking parameters, control the maximum speed and the rates of acceleration and rotation. The body interacts with the VE through collisions with walls and door frames. Because collisions almost always stop forward progress, requiring the participant to back up, movement at a reasonable rate requires emphasis on both speed and accuracy of movement.

The performance measures for each of the tasks are the time to complete the task and accuracy. Accuracy is defined as the number of collisions with walls or door frames. These measures can be obtained for each task as a whole and the individual segments, e.g., the turns or rooms, that make up the task.

Straightaway (Figure 3)

The first locomotion task requires the participant to move down a straight corridor to a target location indicated by a circle on the floor, turn 180 degrees, and return to the starting point which is also indicated by a circle on the floor. The walls at opposite ends of the VE corridor have color and form cues to help the participant orient.

Backup

This task is conducted in the same VE as the Straightaway task. The participant moves down a straight corridor to the

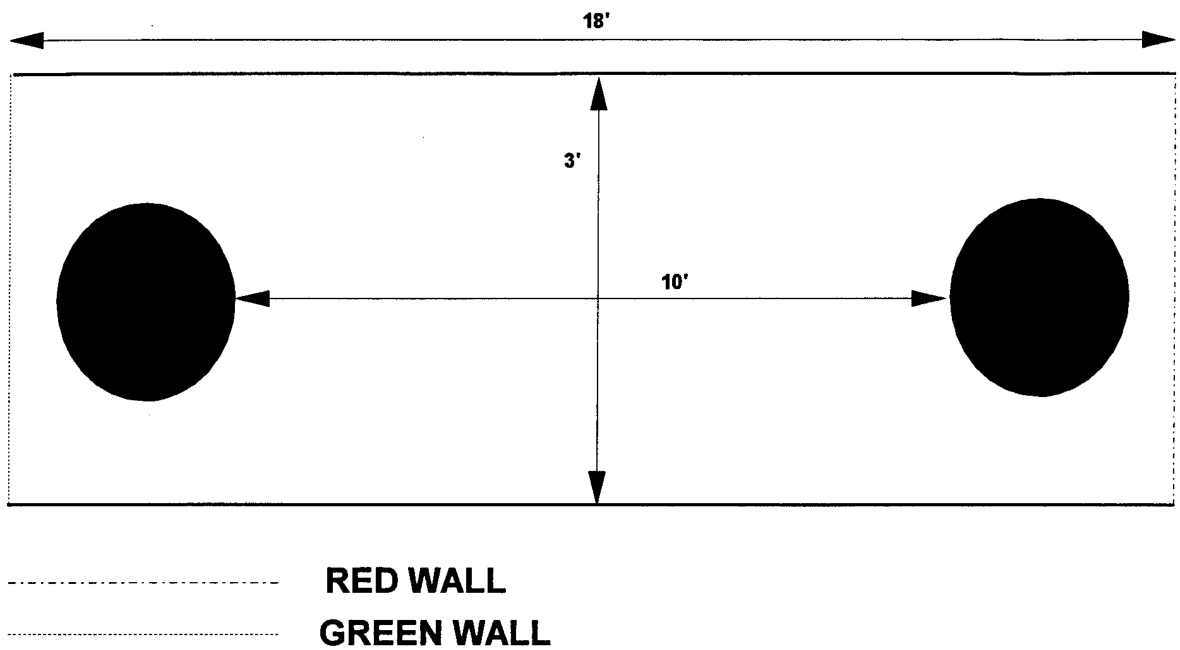


Figure 3. Overhead view of the Straightaway and Backup tasks.

target location, then moves backwards to the starting point without turning around.

Both the Straightaway and Backup tasks can be conducted as discrete trials or as continuous movement. For discrete trials the experimenter can terminate a trial when the participant announces the return to the initial starting point. For continuous movement, the participant is instructed to move from circle to circle until told to stop.

Turns (Figure 4)

The task consists of a continuous narrow corridor formed by straightaways joining alternating 90 degree turns to the left and right for a total of ten turns. Lengths of the straightaways are varied, with two twenty-foot segments alternating with two ten-foot segments.

Figure-8

Two adjoining oval corridors form a Figure-8 course. A small diameter oval, rounded on each end with straightaways in the middle, is connected to an oval of larger diameter to form a closed loop. Walking through the course without colliding with the walls requires gradual turns to the left and right. Performance measures are the number of collisions and either the

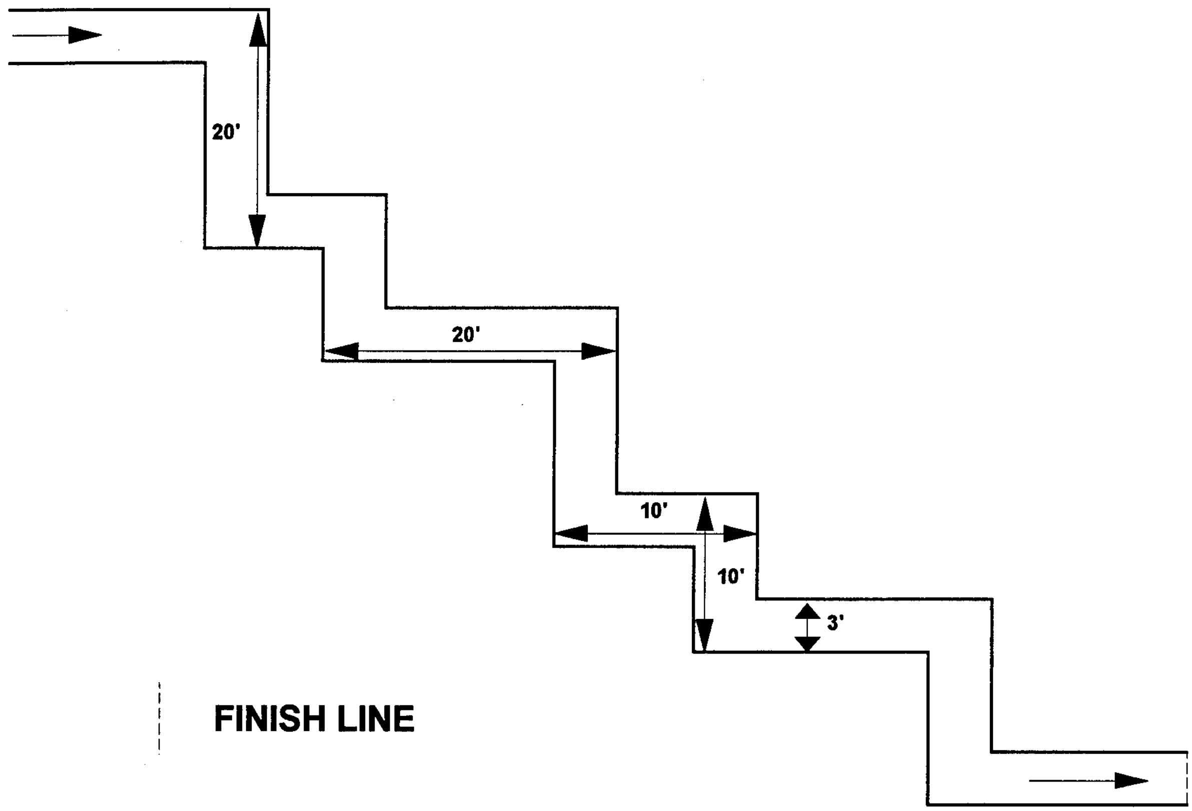


Figure 4. Overhead view of the Turns task.

number of laps completed within a time limit or the time to complete an arbitrary number of laps.

The intersection where the Figure-8 course crosses over itself presents a complex visual scene. Figure 2 is a photograph of a monitor showing the intersection from the participant's perspective. Three paths are visible: a sharp turn to the left (incorrect), a gradual turn to the left (correct), and a gradual turn to the right (incorrect).

Doorways (Figure 5)

The Doorways task represents a VE "road test" of the kind and difficulty of walking performance that might be required in a VE training application. The course is formed by a series of rooms connected by 7 by 3 ft doorways. The positions of the doors in the walls vary so that a series of non-90 degree turns must be made to navigate the course efficiently.

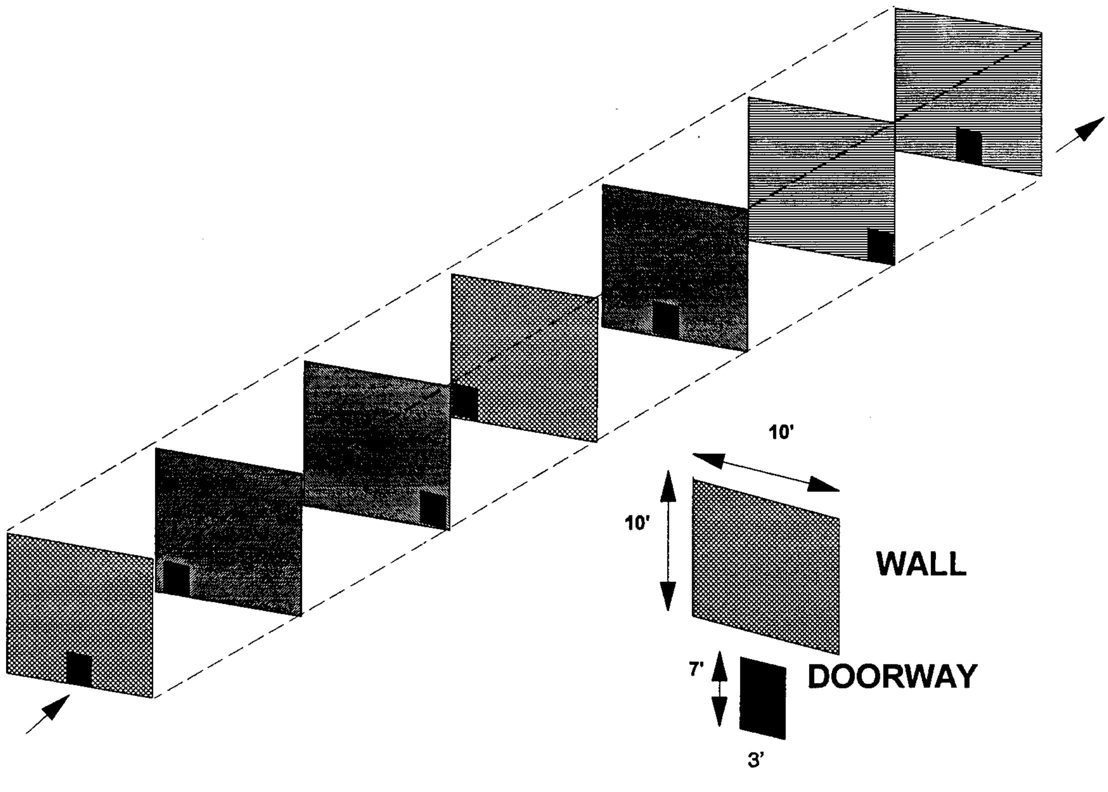


Figure 5. A perspective view of the Doorways task (walls, floor, and ceiling have been removed).

Locomotion Tasks (Flying)

Two flying tasks were developed for a different purpose than that of the walking tasks. Flying could be used during mission planning to move rapidly from one place to another or to gain a top-down view of a physical space.

Windows (Figure 6)

This task requires lateral, horizontal, and vertical ("flying") movement through a series of ten rooms. On the far wall of each room is a 7-ft x 3-ft window that provides the only access into the next room. Windows vary in terms of both their vertical (top, center, or bottom) and horizontal (left, middle, or right) positions.

Elevator (Figure 7)

This task involves "flying" over and under a series of nine vertical partitions while moving forward. Efficient performance requires the participant to look up and down while moving. There

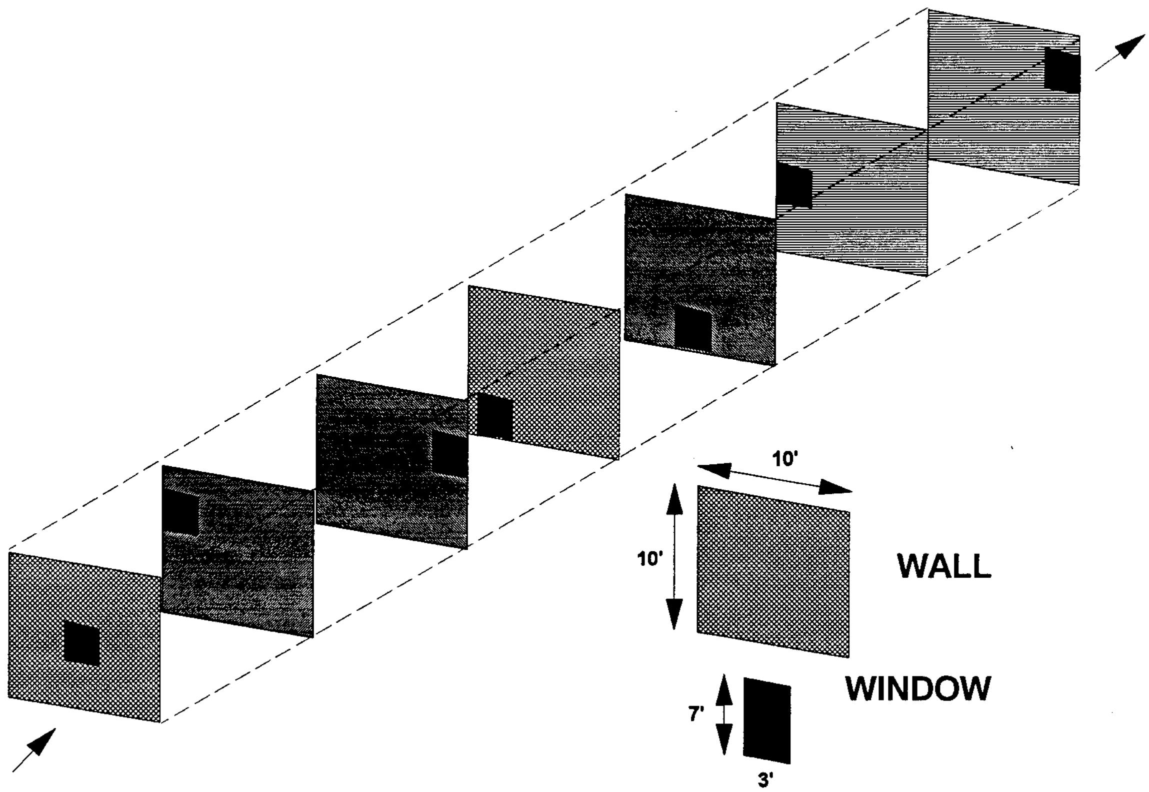


Figure 6. A perspective view of the Windows task (walls, ceiling, and floor have been removed).

are nine vertical turns in this task.

Tracking Tasks

The tracking tasks measure skill in controlling the position of a cursor relative to stationary and moving targets. Two modes of pursuit tracking are employed. In the HMD control mode the aiming cursor, a white cross hair, appears at the center of the field of view. The cursor is slaved to the center of the field of view, so that participants are required to use head movement to track the target. The HMD mode was designed to measure the ability to control the direction and steadiness of head movement. In the control device mode the cursor is aimed by a hand-controlled input device. The two modes of cursor control and two modes of target movement were combined to form four tasks: <u>HMD mode, stationary target</u>; <u>HMD mode, moving target</u>; <u>Controller mode, stationary target</u>; and <u>Controller mode, moving target</u>. The target, a ball .7 ft (8.4 in.) in diameter, appears on a wall 10 ft away (Figure 8). In the moving-target mode, the ball moves across the wall's surface at about 1.4 ft per second. The target changes color when the cursor is within the target radius. The

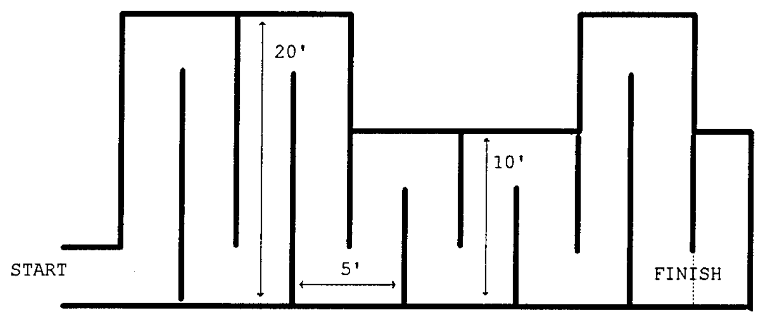


Figure 7. A side view of the Elevator task.

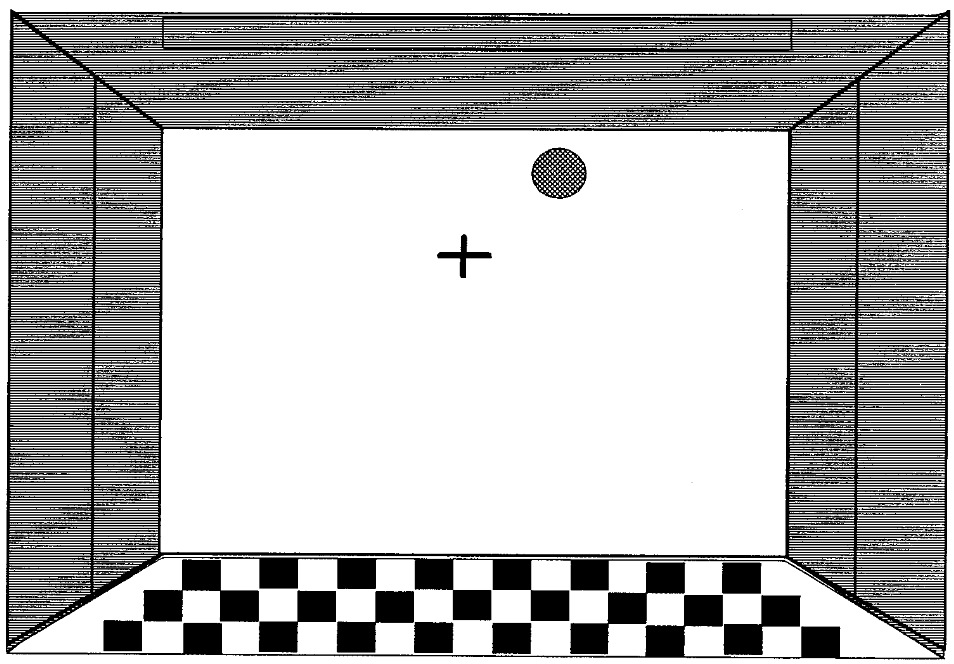


Figure 8. A participant's view of the Tracking tasks.

target disappears, ending the trial, upon reaching another wall or, for the stationary-target mode, when 20 seconds has elapsed. Random numbers determine the placement of stationary targets and the direction of moving targets. The performance measure is the percentage of the total trial time during which the cursor is on the target, i.e., time on target.

Object Manipulation Tasks

The participant uses a control device to move a cursor which interacts with objects in the VE. The position of the cursor in the VE is shown as a 3-D cross. When the cursor is in contact with a manipulable object the color of that object changes. Pushing a button on the control device 'grasps' the object; a successful grasp is indicated by an additional change in the object's color. A grasped object will move with the cursor. Performance measures are whether the task is successfully completed within a designated time limit and the time required to complete the task.

Slide (Figure 9)

Grasp an object, similar to a slider bar on a control panel, and move it horizontally to a target location. A 30-second time limit is enforced for each trial.

Dial (Figure 10)

Grasp a dial, similar to a volume control on a radio, and rotate it to a target orientation. A 30-second time limit is enforced for each trial.

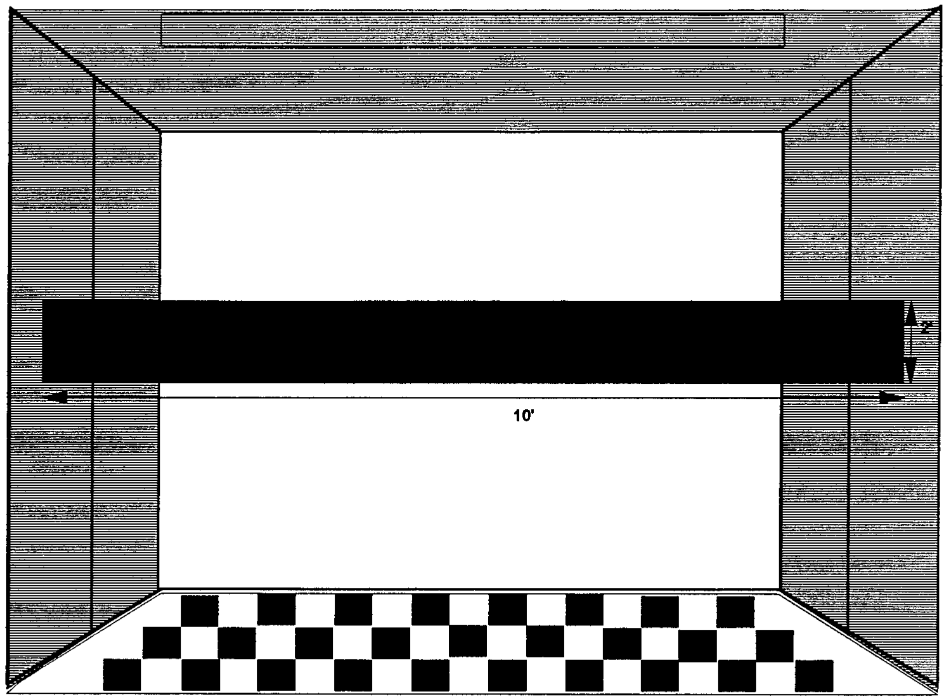


Figure 9. A participant's view of the Slide task.

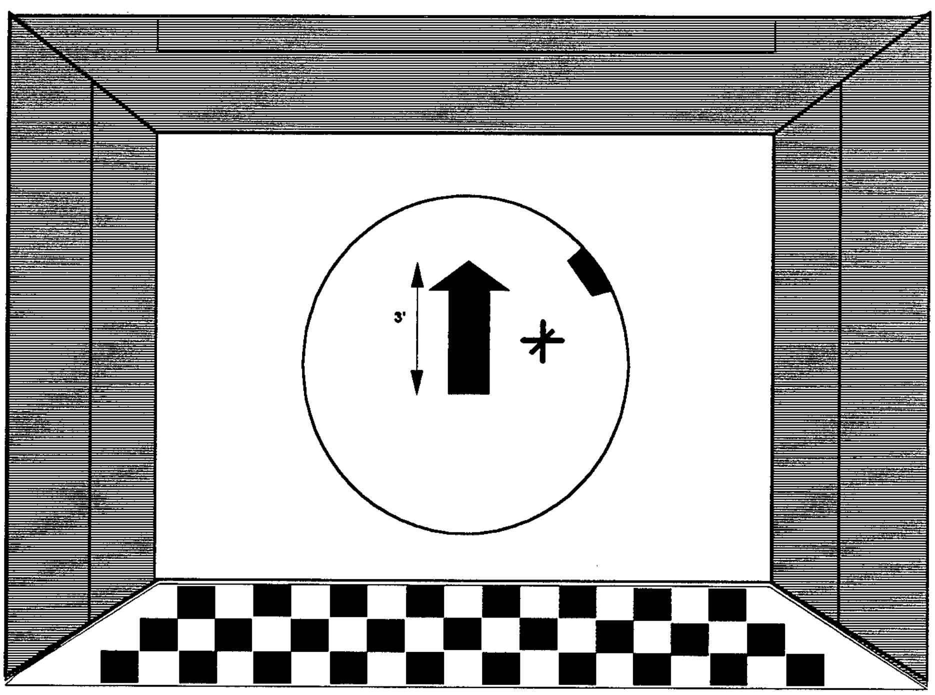


Figure 10. A participant's view of the Dial task.

Bins (Figure 11)

The participant faces a 3 by 3 stack of open-ended, box-like compartments (bins). At the beginning of a trial a ball appears in one of the bins, an X appears in another. The cursor is used to grasp and drag the ball out of the bin and into the bin marked with an X. A 45-second time limit is enforced for each trial. Figure 11 depicts the beginning of a trial. The ball is in the left column of the middle row of bins, the cursor is slightly in front of the center bin, and an X marks the target bin; the middle bin in the top row.

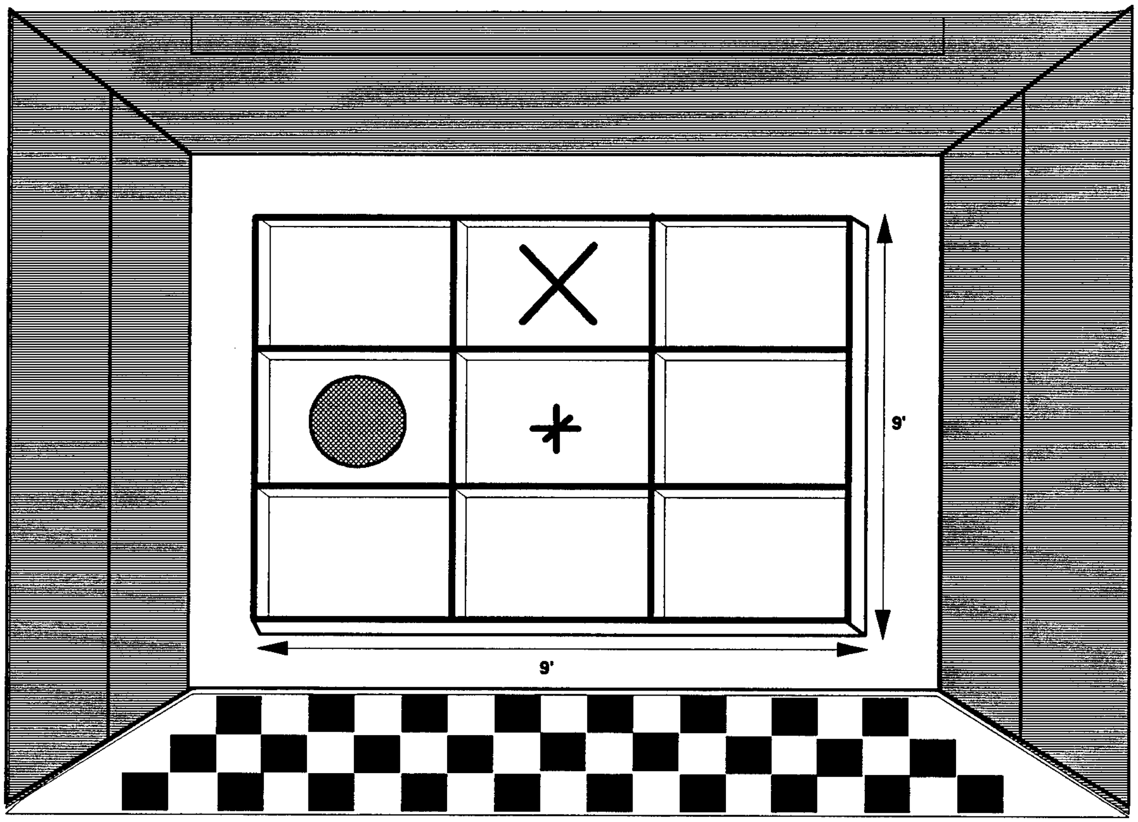


Figure 11. A participant's view of the Bins task.

Reaction Time Tasks

Simple and choice reaction time tasks, Simple RT and Choice RT (Figure 12), were developed to measure response time to VE events and to provide an indication of the time lag of the VE system in presenting and recording events. For Simple RT the participant pushes the control device as soon as a black X appears against a white background. For Choice RT the participant pushes the control device in the appropriate direction to indicate in which of four windows an X appears. Performance measures are the percentage of correct responses and time to respond.

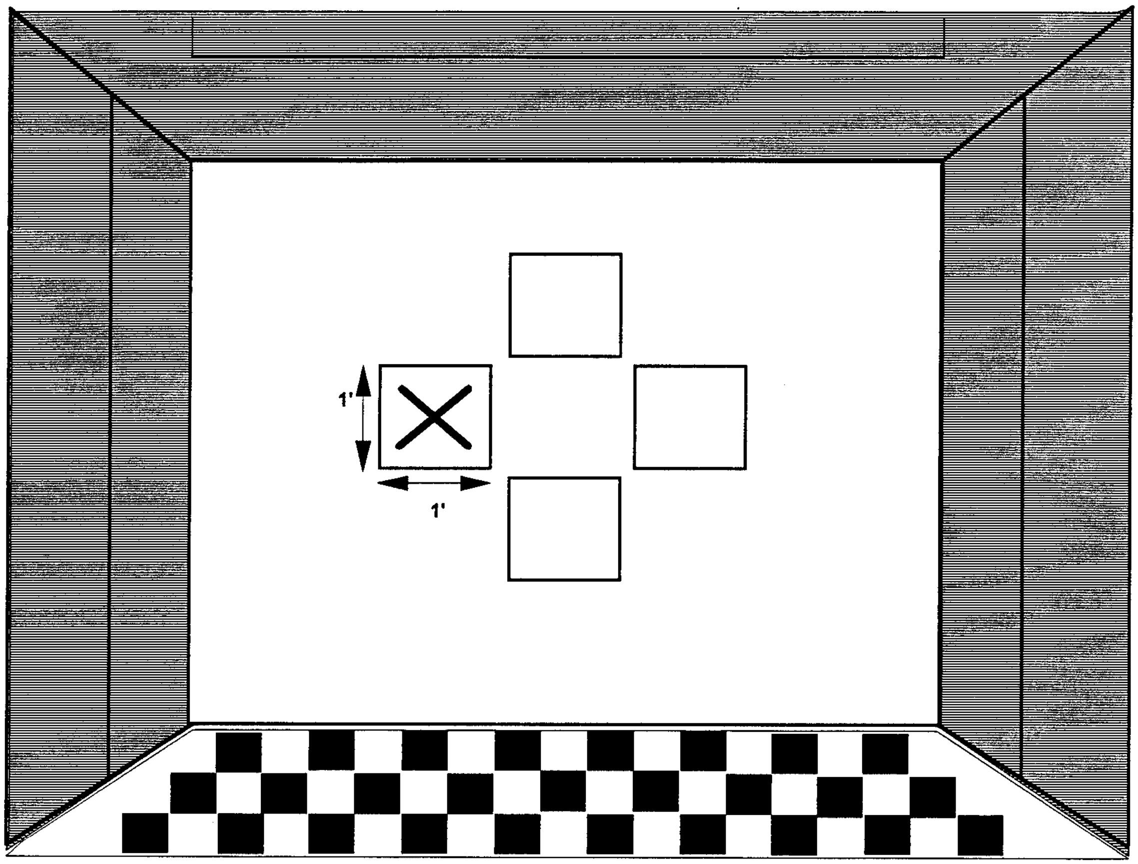


Figure 12. A participant's view of the Choice Reaction Time task.

Evaluation of VEPAB

Our initial evaluation of the VEPAB focused on the sensitivity of the tasks to differences between two input control devices and differences among individual participants. If changing the input interface does not result in a change in task performance, then that task would be of no value in comparing system components. This might happen if the task was too difficult or too easy, if the performance measures were insufficiently sensitive to detect such differences, if performance was largely determined by factors unrelated to the interface, or if performance was artificially limited. We were also interested in how task performance varied as a function of practice. Lack of a practice effect could result from any of the reasons listed above or if the task fails to provide appropriate feedback.

A second experiment is planned in which we will compare VEPAB performance across different visual display devices. That experiment will provide an indication of the sensitivity of the VEPAB vision tasks. However, in this experiment we did collect real-world vision performance data to provide a comparison with performance on the VEPAB vision tasks. In addition to providing comparison data Snellen acuity and color vision were tested before and after VE immersion to check for aftereffects. These tests also served to screen out participants with abnormal vision. We collected real-world data for the distance estimation task because of our concern that the procedure itself, not the visual properties of VE, might lead to systematic error. These real-world distance estimation task data were inexpensive and easy to collect. In contrast, the expense of collecting real-world data for the search, locomotion, and manipulation tasks did not seem warranted. Some tasks do not have real-world counterparts (search or the flying tasks, for example). Others would have required special fabrication of equipment (bins and head tracking, for example).

Method

Participants

Twenty-four research participants completed each of the tasks shown in Table 1. The participants, twenty-one students and three government employees, had normal or corrected-to-normal vision. The age of the participants varied from 17 to 37 years with a mean of 24. Sixteen were male, and 8 were female. Estimated average weekly computer use varied from 0 to 20 hours with a mean of 3.7. Average weekly video game use varied from 0 to 26 hours with a mean of 6.4. The students were paid for their participation.

Apparatus

A Virtual Research Flight Helmet with 83 degree horizontal and 41 degree vertical field of view (50 horizontal by 41 vertical for each eye) provided the visual display. The Flight Helmet displays 234 lines of 238 pixels to each eye and uses LCD technology with LEEP optics. Stereoscopic images were generated by two linked IBM Compatible 486/DX50 mhz PCs equipped with Intel ActionMedia graphics boards. Each computer provided input to one visual channel. A Polhemus Isotrack provided head tracking of yaw, pitch, and roll. Participants controlled their movement in and interaction with the VEs with either a Silicon Graphics Spaceball or a Gravis Joystick. The VEs were developed with Sense8 WorldToolKit software. Two standard monitors provided the experimenter with a representation of the participant's view of the visual channels of the HMD. A menu system allowed the experimenter to select tasks in any order, start and terminate trials, turn head tracking on or off, and reset the participant's view.

Procedure

Overview. Concern for potential side effects and aftereffects strongly influenced the experimental procedure. Participants were warned that they might experience nausea, eyestrain, or dizziness and were encouraged to call a "timeout" at the onset of any of those symptoms. After each twenty minutes of VE activities participants removed the HMD for a short break. Participants remained seated in a swivel chair while wearing the HMD to reduce the danger of falling. The HMD occluded much of the participant's face preventing the experimenter from detecting facial indications of discomfort. Therefore, we required that participants speak frequently throughout the experiment to indicate that they were ready to continue the tasks. Because we had concerns about aftereffects altering participants' ability to drive an automobile safely, we required them to remain at the experiment site for at least one hour after the VE tasks had been completed. During this time they completed questionnaires.

One-half of the participants performed the motor tasks using a spaceball as the control device, and the other half used a joystick. They were familiarized with the appropriate control device, the HMD, and how to recognize collisions but did not practice any specific task prior to data collection. A wooden pedestal supported the control device at hand level. The room temperature was 70 degrees. The tasks were performed in two sessions on separate days.

Day 1. The participant read an overview of the purpose and procedure of the experiment then signed the consent form and completed a background information questionnaire concerning age and previous experience with computers and video games. The participant completed all of the vision tasks and the locomotion tasks in the order shown in Table 1 up to and including the "Doorways" task. The experimenter explained and demonstrated the operation of the control device before the participant began the locomotion tasks. Real-world tests of Snellen acuity, color perception, contrast sensitivity, and stereopsis were administered both before and after the participant performed the VE tasks. These tests were administered to test for aftereffects resulting from immersion in VEs. In addition, questionnaires addressing simulator sickness (Appendix A) and presence (Appendix B) were administered after the VE immersion ended.

Day 2. Beginning with the "Windows" task, the participants completed the remaining tasks in the order listed in Table 1. To test for aftereffects a mirror tracing task was administered both before and after the participant performed the VE tasks. The task involved tracing within double lines which formed a star pattern. The participant did not see the pattern directly but rather saw the mirror reflection of the pattern. In addition, the questionnaires addressing simulator sickness and presence were administered after the VE immersion ended.

Results and Discussion

The results section begins with the presentation of Cronbach's Alpha measure of reliability (Cronbach, 1951) for each of the VEPAB tasks in which there were repeated trials. The results of the administration of the vision tasks are described. The results of the analyses to address the primary focus of the experiment, whether the tasks were sensitive to differences between control devices and to practice effects, are presented. The relationships among performance on the various tasks, and among task performance, background characteristics, and side effects are presented. Finally, the aftereffects resulting from immersion in VEs are described.

Although all participants who had participated in the first session agreed to return for the second, four did not. For one participant the data file of second session performance was unusable. In addition, the system occasionally failed to capture data for some trials. Therefore, not all of the analysis are based upon complete data sets for all participants.

Reliability

Table 2 lists the Cronbach's Alpha measure of reliability for each of the tasks in which there were repeated trials. For several of the tasks, reliability coefficients could not be computed for accuracy scores. The Search and Simple RT tasks were always performed correctly, and consequently, there was no variation in accuracy scores. Accuracy data for the Turns, Doorways, Windows, and Elevator tasks were not captured at the individual trial level.

Table 2

VEPAB Task Reliability (Cronbach's Alpha)

Task	N	Reliability (Alpha)	
		Time	Accuracy
Search	23	.19	N.A.
Straightaway	20	.85	.48
Backup	22	.96	.06
Turns	23	.97	N.A.
Doorways	23	.75	N.A.
Windows	20	.68	N.A.
Elevator	19	.89	N.A.
Bins	19	.85	.82
Dial	19	.88	.87
Slider	19	.83	.67
Simple RT	19	.24	N.A.
Choice RT	19	.75	.42
Tracking - Head Control, Stationary Target	19	.43	.47
Tracking - Head Control, Moving Target	19	.88	.92
Tracking - Device Control, Stationary Target	18	.69	.66
Tracking - Device Control, Moving Target	18	.69	.65

Note. For Tracking tasks, the time measure was percent time on target, and the accuracy measure was the average distance of the cursor from the target.

Task reliability was generally high, but there were some exceptions. Very low reliability was found for the accuracy measure of the Backup task, and low reliability for the accuracy measure of the Straightaway task. Both may reflect a problem with the accuracy measures for the locomotion tasks related to the way in which the data capture system counted collisions. A collision was counted for each frame in which the simulated body was in contact with a wall or door frame. This sometimes resulted in dozens of collisions being counted for what seemed to the participant and the experimenter to be a single collision. The Search task also had low reliability. We believe that the task difficulty varied from trial to trial as a function of the starting position of the target.

The other tasks with low reliability scores were Simple RT (time) and Choice RT (accuracy). For Simple RT the slow system update rate (approximately 90 ms for this task) probably overshadowed any individual differences in reaction time. For some participants the accuracy scores for Choice RT probably reflected a problem with the stimulus/response compatibility in that the up and down responses were occasionally confused.

Vision

Acuity. From a simulated distance of 20 feet the participants reported a uniform white rectangle. At ten feet participants reported a picture with geometric shapes. The mean distance at which participants could first recognize the eye chart and read the top line (the big "E") of the chart was 4.65 ft, for about 20/860 acuity. The distance from which the "E" was first recognized ranged from 6 ft (20/666) to 2 ft (20/2000). In contrast, visual acuity of approximately 20/250 would be predicted based solely upon the pixel density of the HMD. The discrepancy between the theoretical resolution of the HMD and the acuity values we observed may have resulted from several factors. Imperfections in the modelling of the individual letters and in the image-rendering software probably interact so that some image degradation occurs before the image is displayed in the HMD. In addition, physical variation across participants, such as interpupillary distance, may lead to variation in acuity. Robinett and Rolland (1992) described the complex challenge of computing correct stereoscopic images for HMDs.

Acuity was initially measured with head tracking off, then checked with head tracking on. In the head tracking off condition the field of view of the VE is not coupled to the orientation of the HMD. Half of the participants stated that their acuity was better with head tracking off, the other half preferred head tracking on. However, no difference in acuity was detected as a function of head tracking being on or off.

Color. All participants had normal color vision as indicated by maximum scores on the real-world color vision tests. The first sixteen participants also had maximum scores on the VE color vision tests. However, for the last eight participants, not all of the numerals were recognized. We interpreted this as an indication that the HMD color display had weakened over time.

Object recognition, size estimation, range estimation. All participants recognized the object at the end of the corridor as a human figure. The mean height estimate was 62.83 in. (S.D.= 8.27), approximately 9 in. shorter than the actual height of the figure. This may be a function of the VE ceiling height of 12 ft. Participants may have assumed that the ceiling was about 10 ft high. The six ft human figure was exactly one-half of the height of the corridor. One-half of a ten ft corridor would be 60 in., fairly close to the mean estimate.

At an actual range of 40 ft, the average range estimate was 38.22 ft, S.D. = 21.70, with a minimum of 9.00 and a maximum of 100.00. Thus at this distance, the average distance estimate in VE was accurate. However, note the range listed above. Paradoxically, as the figure approached the participant's eye point, and presumably stereoscopic depth cues should be more effective, the VE distance estimates became less accurate. This may be function of the difference between each participant's real world standing eye height and their VE eye point. VE eye point was set at a height of 64 in. for all participants, regardless of real-world eye height. As the figure approached the participant, any cues to distance provided by relative height of the figure would become increasingly inaccurate.

The VEPAB acuity task was modeled after a standard vision task for which real-world baseline data are readily available. For the VE distance estimation task, unlike the acuity task, we did not have real-world data. In addition, we wanted to confirm that the procedure itself did not lead to systematic error in the estimation of distance. Therefore, we recreated the VE distance estimation task in the real-world. That is, a human moved down a corridor similar to that portrayed in the VE. A different set of participants estimated distances following the same method used in the VE task.

Figure 13 depicts the means for the VE and real-world estimates of distance plotted against the actual distance. In this figure the X axis value labeled "40" indicates that the figure was forty ft away when the participant was first asked to estimate the distance to the figure. The Y axis value presents the participant's estimate of the distance when the figure was actually 40 ft away. In contrast, the other X axis values (30, 20, etc.) correspond to the distances at which the participant was supposed to call out as the moving figure reached those distances in approaching the participant. For example, the Y axis represents the actual distance to the figure when the participant estimated the distance to be 30 ft. In other words, except for the value at 40 ft the Y axis values represent the actual distance of the figure.

In the VE, the average distance estimate at 40 ft was very accurate; however, variance was high. VE distance estimation was less accurate at shorter distances, contrary to our expectations that stereoscopic depth cues should assist range estimation at shorter distances. Although real-world distance estimation was poor at 40 ft, estimates at the other distances were accurate. Therefore, we do not believe that inaccurate estimation of distance in the VE is merely an artifact of our distance estimation procedure.

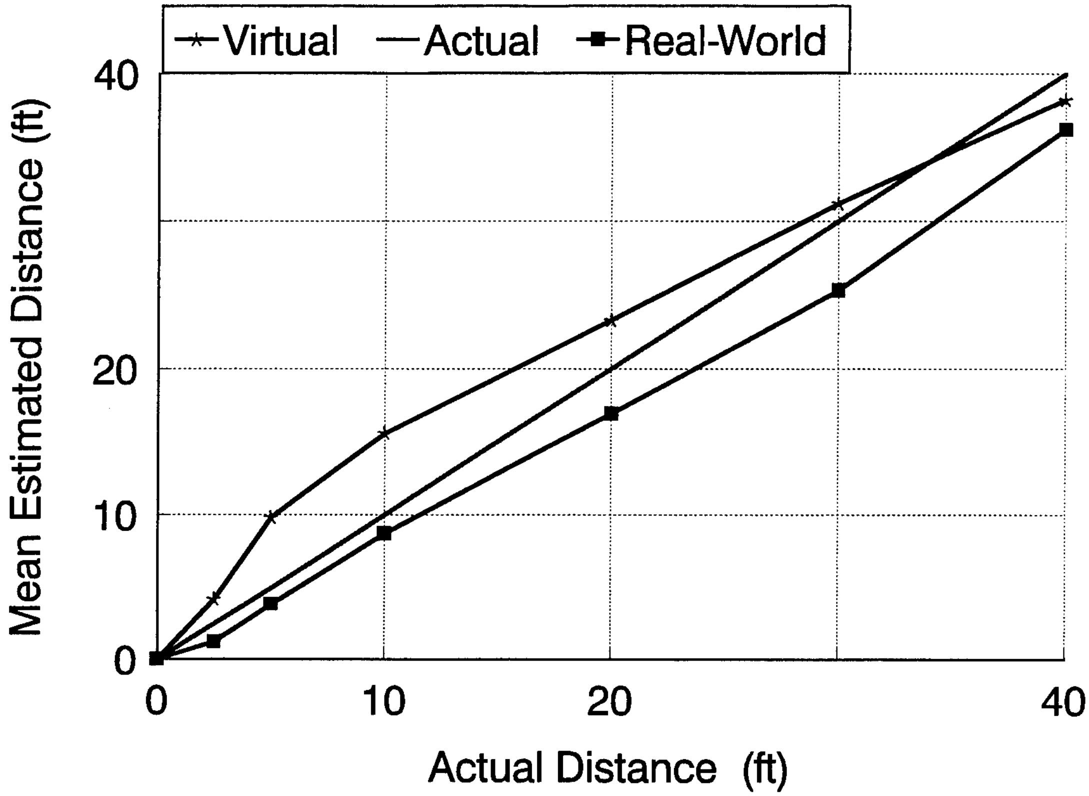


Figure 13. Virtual and real-world distance estimates as a function of actual distance.

<u>Search</u>. All participants were able to perform this task, which required extensive head movement. However, performance varied greatly across participants. The mean search time per participant, averaged across 10 trials, was 10.4 seconds with a minimum of 5.5 and a maximum of 24. We observed that some participants adopted a systematic search strategy, slowly panning up and down the walls while turning in the swivel chair, but others seemingly unsystematically slewed their point of view around the room. We did not have a procedure to categorize the search strategy of each participant and therefore we can not compare performance differences across strategies.

<u>Control Device and Practice Effects</u>

For each task, a separate repeated measures analysis of variance was conducted on the time scores. For these analyses, control device (Device) was the between-participants factor, and practice was the within-participants factor. The practice effects for each of the locomotion tasks are based on the mean completion time of the first five segments versus the mean of the last five segments. For the other tasks the mean completion time of the first five trials was compared with the mean of the last five trials. For several of the tasks similar analyses were also performed on the accuracy scores.

Locomotion tasks. Table 3 summarizes the ANOVAs for the locomotion tasks. For each ANOVA the table lists the F value (indicating the significance level) and the partial ETA squared index of effect size. For each of the locomotion tasks the group effect (joystick vs spaceball) of an ANOVA on the time measure was significant. Figure 14 shows the mean completion time for each segment of the locomotion tasks as a function of Control Device. For all of these tasks performance with the joystick was faster (better) than the spaceball.

We believe that there were several reasons why joystick performance was superior to that with the spaceball. We suspect that our participants were more familiar with the joystick than the spaceball prior to the experiment. Joysticks are a common component of video games; spaceballs are not. Also, the display was updated relatively slowly, approximately 2 to 9 times per second, depending on the task. The spaceball did not move perceptibly when force was applied, and this may have interacted with the slow update to make it particularly difficult to learn to use. The same results might not be obtained if the effects of applying force to the spaceball were immediately apparent. In particular, the lag between when a participant applied force to the spaceball and the time when this action produced a noticeable effect led participants to the erroneous and counterproductive belief that they needed to apply additional force to the spaceball. We noticed that several participants exhibited "white knuckles" as they struggled to apply force to the spaceball.

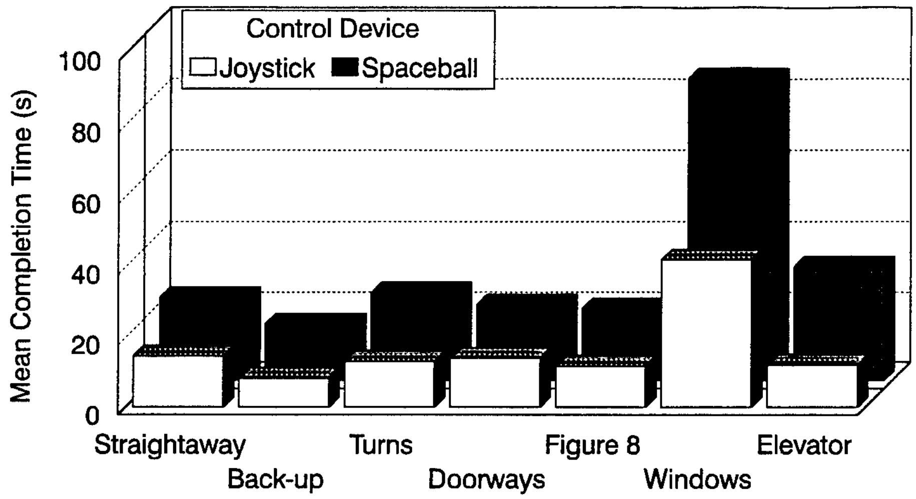
Only two of the locomotion tasks showed significant practice effects: Straightaway, the first locomotion task performed, and Elevator, the second of the two "flying" tasks. Performance improved with practice for both of these tasks. The Straightaway task had a significant interaction of group and practice. Figure 15 presents the group mean completion times for the first five segments and second five segments of the Straightaway task. This figure indicates that spaceball performance was worse than joystick performance on the first five trials and that although both groups improved with practice, the improvement was greater with the spaceball group. The Elevator task has only 9 segments, therefore to examine the practice effect we compared the mean completion time for the first 4 segments, which was 41 seconds, with the mean of last 4 segments, 18 seconds.

Table 3

$\underline{F}$ Values From the ANOVAS of Time and Accuracy Scores for Each Locomotion Task

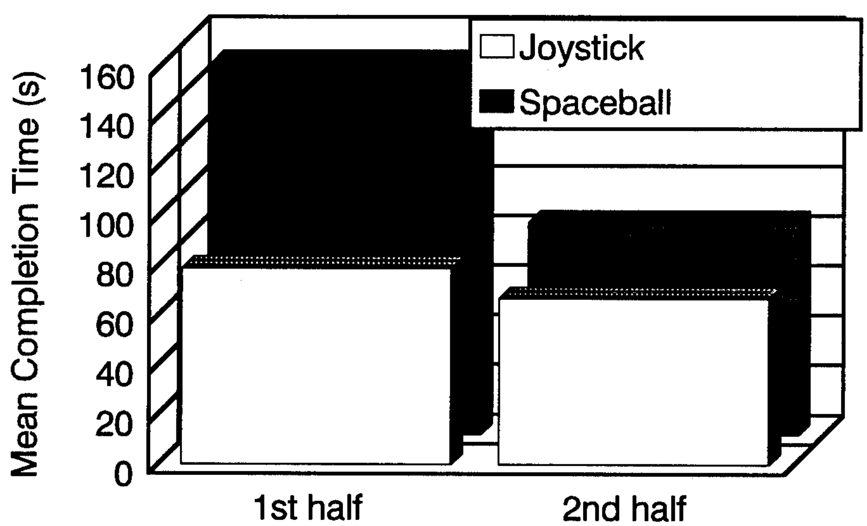
Task	Factor	Time	Accuracy
		$\underline{F}$	
Straightaway	Device	6.51^{*}	.13
	Practice	19.41^{**}	1.96
	DxP	6.82^{*}	.44
Backup	Device	14.06^{**}	.41
	Practice	.48	.11
	DxP	.30	3.8
Turns	Device	17.25^{**}	.92
	Practice	2.71	N.A.
	DxP	3.53	N.A.
Figure-8	Device	12.30^{**}	.12
	Practice	N.A.	N.A.
	DxP	N.A.	N.A.
Windows	Device	7.98^{*}	16.96**
	Practice	1.16	N.A.
	DxP	.05	N.A.
Elevator	Device	9.96^{**}	6.48*
	Practice	62.98^{**}	N.A.
	DxP	.03	N.A.

$^{*}\underline{p}<.05$ $^{**}\underline{p}<.01$



	Straightaway	Back-up	Turns	Doorways	Figure 8	Windows	Elevator
Joystick	14.53	8.11	13.01	13.89	11.58	41.7	11.98
Spaceball	23.54	16.11	24.87	21.53	20.5	85.09	32.27

Figure 14. Locomotion task segment completion time as a function of control device.



	1st half	2nd half
Joystick	78.6	66.5
Spaceball	150	85.3

Figure 15. Straightaway task completion time as a function of control device and practice.

The lack of a significant practice effect for some of the locomotion tasks may have resulted from a problem with the tenth segment in those tasks. The Turns, Doorways, and Windows tasks had a "finish line", consisting of multi-colored blocks, that defined the end of the course. The participants were told what the blocks represented and were instructed to move through the blocks without hesitation. Nevertheless, some participants seemed to pause when approaching the blocks. In addition, the blocks presented a confusing visual pattern such that the final course segment lacked some of the depth cues that had been visible in the preceding segments of the course.

Another factor that may have obscured practice effects is that some of the participants, gaining confidence during the later trials of a task, would experiment with moving at higher speeds which led to more collisions and therefore slower completion times for the later segments. Also, the ten segments or trials of each task provide only limited practice.

Table 4

F Values From ANOVAs of Time and Accuracy Scores for Each Manipulation Task

Task	Factor	*F*	
		Time	Accuracy
Bins	Device	17.77^{**}	7.27^{*}
	Practice	36.98^{**}	26.46^{**}
	DxP	.76	.45
Dial	Device	8.85^{**}	12.06^{**}
	Practice	7.66	4.17
	DxP	.01	.00
Slider	Device	49.06^{**}	21.98^{**}
	Practice	30.15^{**}	6.94^{*}
	DxP	.58	1.03

$^{*}p<.05$ $^{**}p<.01$

Manipulation tasks. Table 4 summarizes the ANOVAs for the manipulation tasks. For each task the group effect was significant for both the time and accuracy scores. For each of the three tasks, significant practice effects were found for comple-

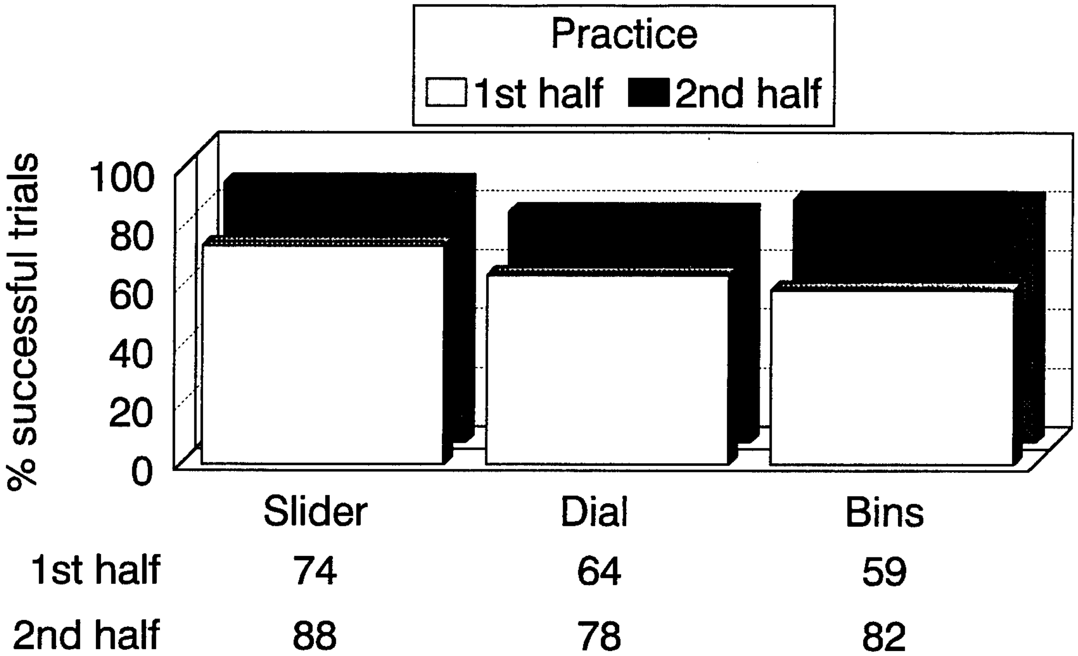
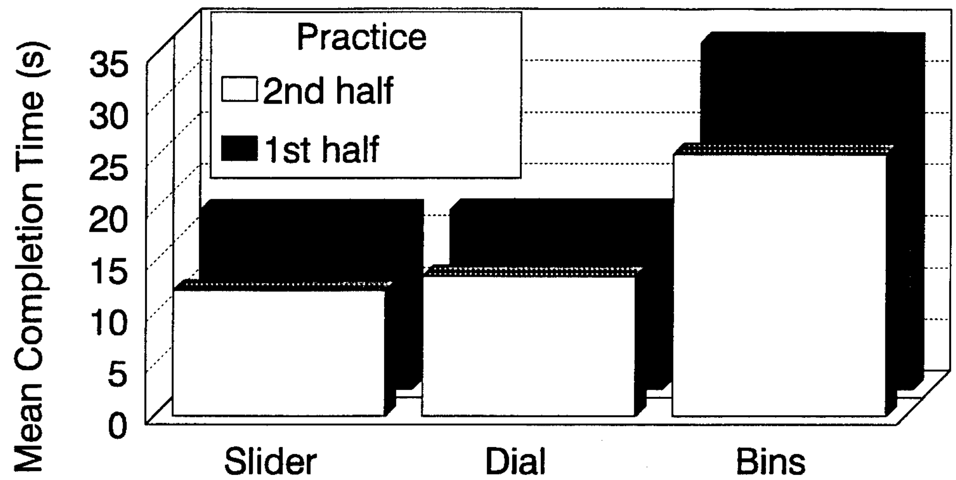


Figure 16. Manipulation task accuracy (percent successful trials) as a function of practice.

tion time measures. The practice effects for accuracy measures were significant for the Bins and Slider tasks, and approached significance (p=.057) for the Dial task. See Figures 16 and 17 for the accuracy and completion time means, respectively, for the practice effect.

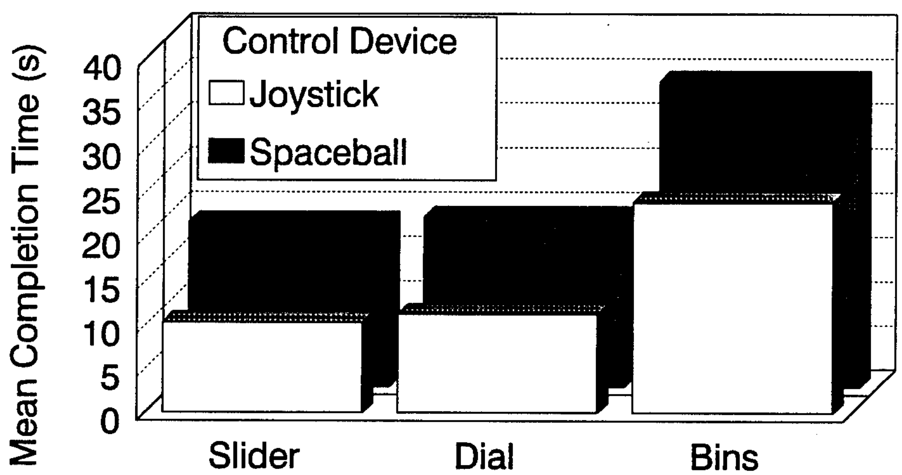
Figure 18 presents the mean trial completion time as a function of control device for each of the manipulation tasks. Figure 19 shows performance accuracy, the percentage of successful trials, for each task as a function of control device. Joystick performance was superior for both speed and accuracy measures.

Tracking. Separate analyses of variance were performed for the two different tracking modes: cursor aimed by the head position tracker on the HMD and cursor aimed by the manual control device (Spaceball or Joystick). The analyses are summarized in Table 5. The duration of the tracking trials varied, therefore analyses are based on the percent of time on target, that is, the ratio of the time that the cursor was on the target to the total time that the target was visible. The Locomotion and Manipulation tasks showed sensitivity to control devices, but the Tracking tasks did not. We suspect that the slow system update rate, approximately 200 ms for the tracking



	Slider	Dial	Bins
2nd half	12.19	13.58	25.37
1st half	17.3	17.32	33.52

Figure 17. Manipulation task completion time as a function of practice.



	Slider	Dial	Bins
Joystick	10.34	11.25	23.88
Spaceball	18.7	19.24	34.45

Figure 18. Manipulation task completion time as a function of control device.

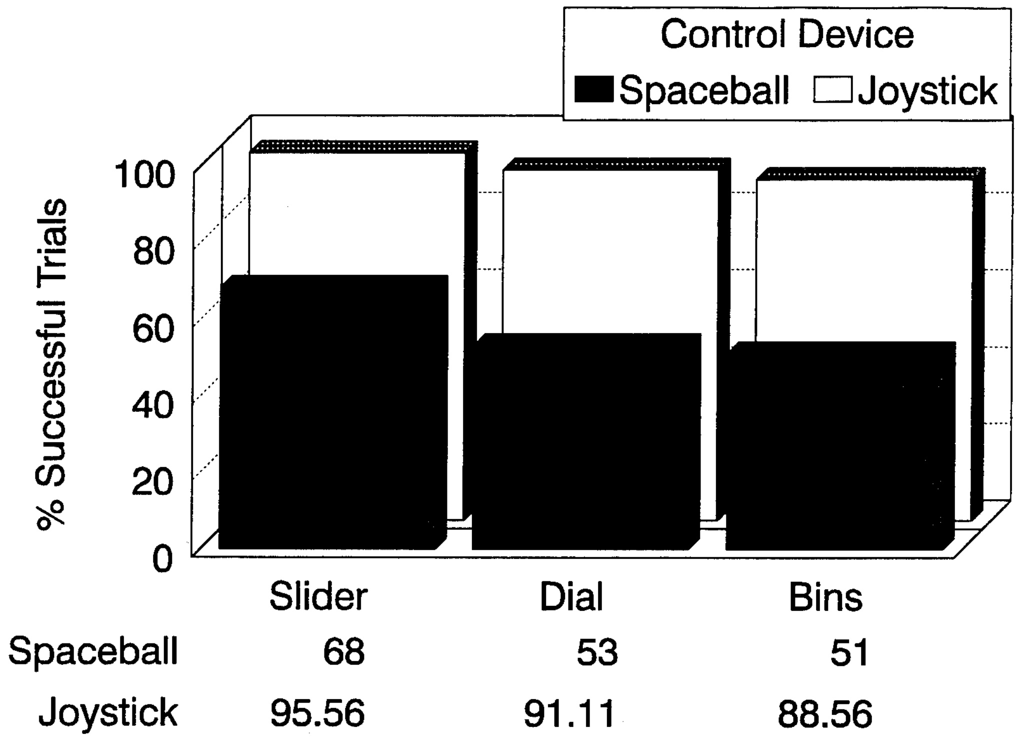


Figure 19. Manipulation task accuracy (percent successful trials) as a function of control device

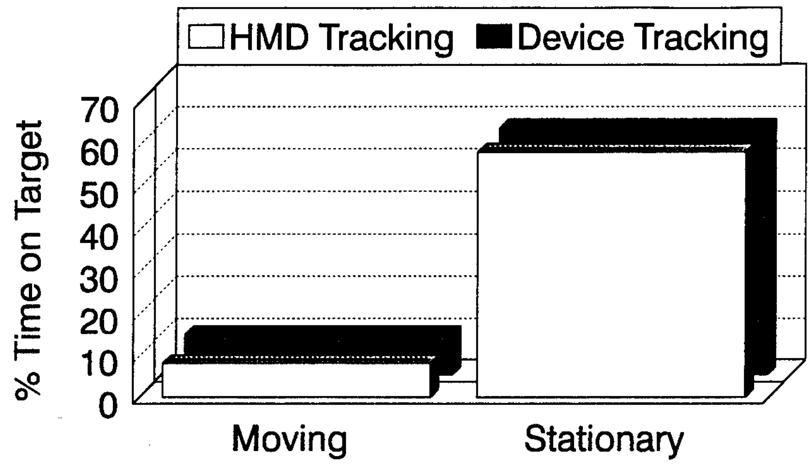
tasks, made the tasks so difficult that they could not be performed well with any control device. Tracking attempts seesawed between lagging and overshooting the target so that time-on-target scores were very poor; participants were able to keep the cursor on the moving target less than 9% of the time. As expected, stationary targets were significantly easier to track than moving targets in both HMD and manual tracking (Figure 20). Manual tracking improved with practice (Figure 21), HMD tracking did not. We believe that the lack of a significant practice effect in HMD tracking was in part the result of a fatigue effect; during the later trials in the head tracking mode some participants grasped and guided the HMD with their hands apparently because their neck muscles were fatigued.

Table 5

F Values From ANOVAs of Time on Target Scores for Each Tracking Task

Task	Factor	*F*
HMD control	Target	565.90**
	Practice	.13
	TxP	1.33
Manual control	Device	.16
	Target	308.31**
	Practice	16.77**
	DxT	.15
	DxP	.22
	TxP	16.32**
	DxTxP	3.11

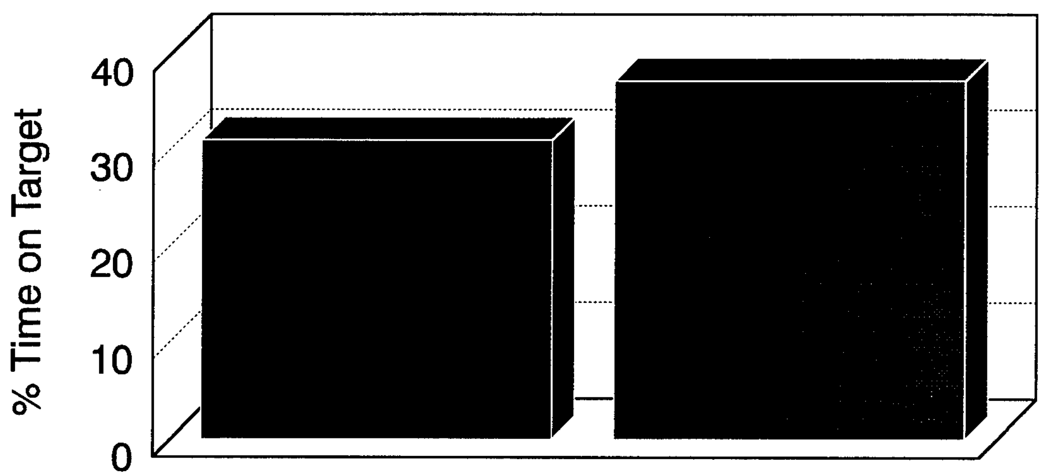
*$p<.05$ **$p<.01$



	Moving	Stationary
HMD Tracking	8	58
Device Tracking	9.72	58.49

Target Movement

Figure 20. Tracking: Percent time on target as a function of target movement and type of control.



1st 5 trials	2nd 5 trials
30.98	37.24

Practice

Figure 21. Manual tracking: Time on target as a function of practice.

For manual tracking there was a significant interaction of target movement and practice. Figure 22 shows that the percentage of time on target improved with practice for stationary targets but not for moving targets. We suspect that the slow system update rate made tracking moving targets so difficult that the effects of limited practice were overshadowed.

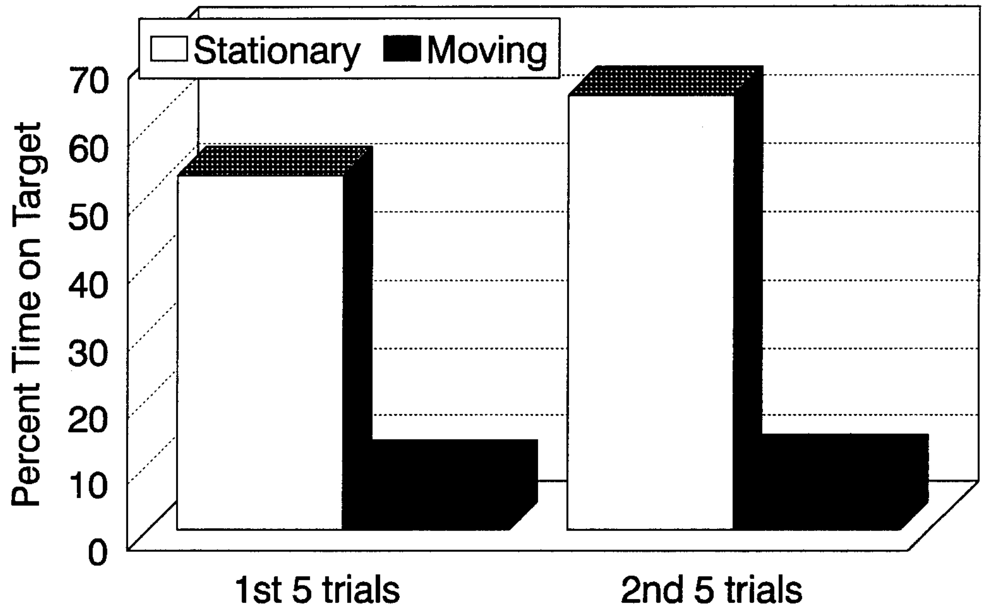


Figure 22. Manual tracking: Interaction of target movement and practice

<u>Reaction Time</u>. The results of the analysis of variance of the reaction time data are shown in Table 6. There were no significant Device effects for the reaction time tasks. An explanation is that, unlike the other motor tasks, success of the reaction time tasks did not require the participants to vary the range of movement of the control device. Therefore, the factors that we believe interacted to degrade performance for the spaceball in other tasks, lack of perceptible movement of the controller and slow system update rate, did not affect performance on the reaction time tasks.

Table 6

F Values From ANOVAs of Time and Accuracy Scores for Each Reaction Time Task

Task	Factor	F	
		Time	Accuracy
Simple	Device	.01	N.A.
	Practice	5.62*	N.A.
	DxP	.02	N.A.
Choice	Device	2.46	1.58
	Practice	7.96*	2.87
	DxP	.21	.06

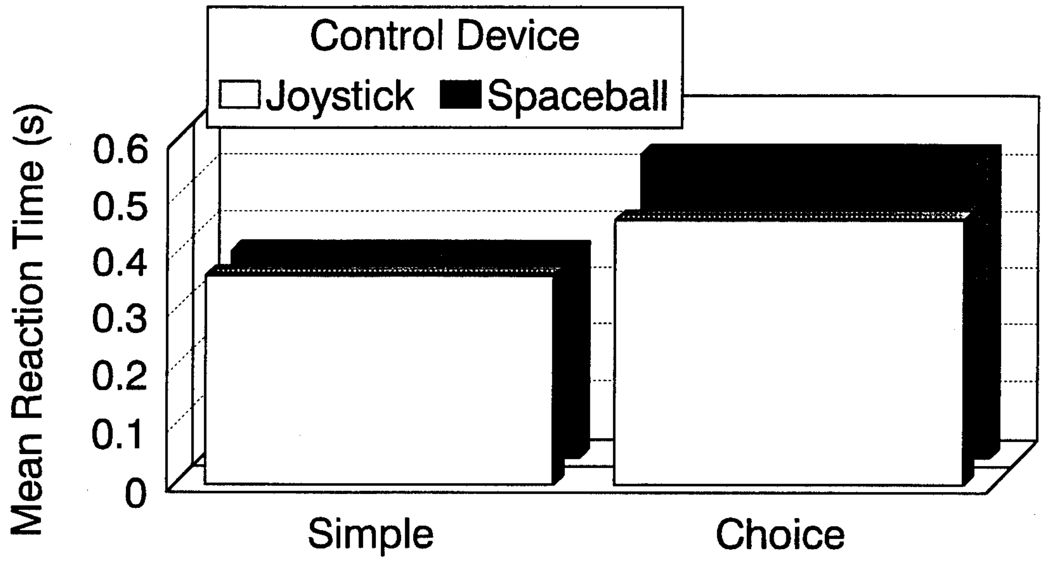
*$p<.05$ **$p<.01$

There were significant practice effects. Figure 23 presents the means for the Simple and Choice reaction time tasks as a function of practice. The reaction times tasks were the only motor tasks for which we did not expect significant practice effects. The experimenter may have inadvertently established a temporal pattern such that the participants could anticipate the presentation of the reaction time stimuli.

The mean for simple reaction time (collapsed across Device) was .36 seconds and the mean for choice reaction time was .50 seconds. McCormick & Sanders (1976) list .2 seconds as a "fairly representative" value of simple reaction time. Relative to what would be expected in similar real-world tasks, the slowness of VE reaction time probably reflects lags in the VE system in presenting the stimulus and responding to activation of the control device.

Correlations among Variables

Because ANOVAs had indicated significant differences between the joystick and spaceball control devices, we derived partial correlation coefficients, with Device as the control variable, to examine the relationships among performance on the various tasks, and between task performance and other variables. Because the time scores were the more reliable measure, we used them rather than the accuracy scores. We examined the correlations among all of the locomotion, manipulation, tracking, and reaction time tasks, and between each of those tasks and other information (age, mirror tracing performance, virtual visual acuity, number of hours of weekly computer use, and number of hours of weekly video game playing). The purpose of these analyses was to identify possible patterns of correlations for confirmation in subsequent research. We did not adjust significance levels to take into account the total number of correlations computed; to do so would result in prohibitively conservative values for explanatory purposes.



	Simple	Choice
Joystick	0.36	0.46
Spaceball	0.36	0.53

Figure 23. Simple and choice reaction time as a function of control device

There were no significant correlations of computer use, video game use, or virtual visual acuity with the score on the VEPAB tasks. The correlations with age, mirror tracing, and simulator sickness following each of the sessions are shown in Table 7. Among the background variables, only age showed a significant correlation pattern with the task variables, with higher age associated with slower task performance. The mirror tracing task provided a better predictor of VE performance than self reported weekly averages of video game or computer use. The data also hint at a relationship between simulator sickness and task performance, with those participants reporting more severe symptoms performing less well on some tasks.

Table 7

Correlations Among VEPAB Task Time Scores, Age, Mirror Tracing, and Simulator Sickness (SSQ) Scores

	Age		Mirror Tracing		Simulator Sickness: SSQ Total Severity - Day 1		Simulator Sickness: SSQ Total Severity - Day 2	
Locomotion (walking)								
Straightaway	.02	(17)	.41	(15)	.28	(15)	.42	(12)
Backup	-.28	(19)	-.07	(17)	-.02	(17)	.01	(14)
Turns	.51*	(20)	.58**	(19)	.52*	(18)	.39	(16)
Figure-8	.42	(20)	.57**	(18)	.30	(19)	.09	(16)
Doorways	.39	(20)	.59**	(18)	.44*	(19)	.26	(16)
Locomotion (flying)								
Windows	.62**	(17)	.70***	(17)	.41	(16)	.34	(15)
Elevator	.02	(16)	.01	(16)	.23	(16)	.10	(15)
Manipulation								
Slide	.56*	(16)	.51*	(16)	.49*	(16)	.42	(15)
Dial	.15	(16)	.47*	(16)	.46	(16)	.36	(15)
Bins	.50*	(16)	.47*	(16)	.46	(16)	.36	(15)
Tracking								
Head, Stationary	.05	(16)	-.21	(16)	-.19	(16)	.05	(15)
Head, Moving	-.14	(15)	-.33	(15)	-.24	(15)	-.25	(14)
Device, Stationary	.25	(16)	-.09	(16)	-.14	(16)	-.28	(15)
Device, Moving	-.01	(15)	-.27	(15)	-.08	(15)	.06	(14)
Reaction Time								
Simple	.00	(16)	-.03	(16)	.42	(16)	.40	(15)
Choice	.34	(16)	-.06	(15)	.31	(16)	.20	(15)

Note: Numbers in parenthesis are degrees of freedom.
*$p<.05$ **$p<.01$ ***$p<.001$

Table 8

Partial Correlations Among Time Scores for the VEPAB Tasks

	Locomotion (walking)					Locomotion (flying)	
	Straight-away	Back-up	Turns	Figure-8	Doorways	Windows	Elevator
Locomotion (walking)							
Straightaway		.81***(17)	.43 (16)	.21 (16)	.43 (16)	.35 (13)	.27 (12)
Backup			.25 (18)	.08 (18)	.24 (18)	.05 (15)	.48 (14)
Turns				.49* (19)	.76***(19)	.51* (17)	.50* (16)
Figure-8					.65***(20)	.72***(16)	.42 (16)
Doorways						.57* (16)	.27 (16)
Locomotion (flying)							
Windows							.35 (16)
Elevator							
Manipulation							
Slide							
Dial							
Bins							
Tracking							
Head, Stationary							
Head, Moving							
Device, Stationary							
Device, Moving							
Reaction Time							
Simple							
Choice							

Note: Numbers in parenthesis are degrees of freedom.
*p<.05 **p<.01 ***p<.001

Table 8 (continued)

Partial Correlations Among Time Scores for the VEPAB Tasks

	Manipulation			Tracking			
	Slide	Dial	Bins	Head, Stationary	Head, Moving	Device, Stationary	Device, Moving
Locomotion (walking)							
Straightaway	.30 (12)	.82*** (12)	.48 (12)	-.20 (12)	-.35 (11)	-.22 (12)	-.18 (11)
Backup	.10 (14)	.61* (14)	.27 (14)	-.17 (14)	-.24 (13)	-.21 (14)	-.14 (13)
Turns	.68** (16)	.65** (16)	.90*** (16)	-.20 (16)	-.59* (15)	-.14 (16)	-.07 (15)
Figure-8	.66** (16)	.34 (16)	.61** (16)	-.17 (16)	-.31 (15)	-.04 (16)	-.38 (15)
Doorways	.61** (16)	.61** (16)	.78*** (16)	-.02 (16)	-.37 (15)	-.10 (16)	-.15 (15)
Locomotion (flying)							
Windows	.53* (16)	.43 (16)	.52* (16)	-.00 (16)	-.19 (15)	-.02 (16)	-.07 (15)
Elevator	.52* (16)	.38 (16)	.51* (16)	-.21 (16)	-.52* (15)	-.29 (16)	-.01 (15)
Manipulation							
Slide		.42 (16)	.78*** (16)	-.05 (16)	-.50* (15)	-.08 (16)	-.12 (15)
Dial			.61** (16)	.02 (16)	-.49* (15)	-.04 (16)	-.24 (15)
Bins				-.24 (16)	-.45 (15)	-.18 (16)	-.06 (15)
Tracking							
Head, Stationary					.37 (15)	.35 (15)	.59* (15)
Head, Moving						.30 (15)	.40 (15)
Device, Stationary							.15 (15)
Device, Moving							
Reaction Time							
Simple							
Choice							

Note: Numbers in parenthesis are degrees of freedom.
$^*p<.05$ $^{**}p<.01$ $^{***}p<.001$

Table 8 (continued)

Partial Correlations Among Time Scores for the VEPAB Tasks

	Reaction Time	
	Simple	Choice
Locomotion (walking)		
Straightaway	-.14 (12)	-.25 (12)
Backup	-.09 (14)	-.38 (14)
Turns	.37 (16)	.53* (16)
Figure-8	-.03 (16)	.12 (16)
Doorways	.29 (16)	.30 (16)
Locomotion (flying)		
Windows	.18 (16)	.21 (16)
Elevator	.35 (16)	.21 (16)
Manipulation		
Slide	.15 (16)	.37 (16)
Dial	.42 (16)	.09 (16)
Bins	.28 (16)	.49* (16)
Tracking		
Head, Stationary	.24 (16)	.02 (16)
Head, Moving	-.18 (15)	-.21 (15)
Device, Stationary	-.03 (16)	-.09 (16)
Device, Moving	.28 (15)	.32 (15)
Reaction Time		
Simple		.51* (16)
Choice		

Note: Numbers in parenthesis are degrees of freedom.
$*p<.05$ $**p<.01$ $***p<.001$

The partial correlation coefficients among the VEPAB tasks, with the effects of control device removed, are presented in Table 8. Although any interpretations must be limited by the small number of participants involved (15 to 22, depending on the particular tasks), some patterns appear to have emerged. Locomotion tasks clustered in three groups: Straight-away and Back-up; Turns, Figure-8, and Doorways; and Windows. The Elevator task was correlated only with the Turns task. The Bins task was correlated with the Slide and Dial tasks, which were not correlated with each other. Significant correlations were found among most of the locomotion and manipulation tasks. The tracking tasks did not correlate highly with other tasks or among themselves. Nothing was correlated significantly with Simple Reaction Time, probably reflecting the low reliability of task performance. Choice reaction time was correlated with a few of the other tasks.

Side effects and aftereffects

Real-world tests of vision and eye-hand coordination were presented before and after administration of the VE tasks to test for aftereffects. These test were: Snellen acuity, contrast sensitivity, stereopsis, color perception, and mirror-tracing. No aftereffects were detected.

Of the 24 participants, we dismissed one from the experiment when she began to experience nausea during the locomotion tasks. A subsequent interview of this participant revealed a history of severe susceptibility to motion sickness. The other participants stated that they enjoyed the VE experience and would like to participate in subsequent VE research.

We employed the Essex Simulator Sickness Questionnaire (SSQ) to measure simulator sickness. Our participants reported total severity scores worse than those of the Navy aviators surveyed by Kennedy et al. (1992). Nevertheless, with the exception of the one participant we dismissed, no participant reported "severe" symptoms of any kind. Seven of the participants reported "moderate" eyestrain as the worst symptom. A majority reported "slight" or "none" to each symptom. The partial correlation coefficient, with Device as the control variable, between the total severity scores for the first and second VE sessions was .81, $p < .001$, indicating that participants who reported higher incidence of symptoms in the first session also reported higher incidence in the second session. A more detailed discussion of our findings concerning aftereffects of VE immersion is presented in Knerr et al. (1993).

Changes to VEPAB

This experiment indicated several areas in which VEPAB could be improved.

Some of our taller participants mentioned that their estimation of the height of objects in the VEs was distorted because of the discrepancy between their real-world eye height and the VE eye height which was arbitrarily set at 64 in. for all participants. In subsequent research we will set the VE eye height equal to that of each participant's real-world eye height.

Some of the locomotion tasks had a "finish line" which confused the participants. This has been removed. Another problem with the locomotion tasks involved the way the system counted collisions. A collision was counted for each frame in which the simulated body was in contact with a wall or door frame. This sometimes resulted in dozens of collisions being counted for what seemed to the participant and the experimenter to be a single collision. We have revised the rules for counting collisions so that each period of continuous contact is counted as one collision, regardless of its duration. However, we expect that as VE hardware, software, and peripherals improve, the incidence of collisions for even novice participants will decline to the extent that collisions are not a useful measure of performance.

The use of random numbers to determine the initial position and direction of movement of targets in the search and, to a lesser extent, the manipulation and tracking tasks, had the intended effect of preventing participants from memorizing response patterns, but led to differences in task difficulty across trials. This can be compensated for by only examining task performance on groups of trial, rather than single trials. If necessary, a limited set of trials of comparable difficulty can be developed for each task.

The use of a VE model of a Snellen eye chart is a short-term approach to measuring visual acuity. One disadvantage of using the Snellen chart, in both the real world and the VE, is that participants can memorize the chart. We want to measure acuity periodically during an experimental session to detect changes that may occur over time. (For example, acuity may improve through perceptual adaptation, or become degraded due to sensory fatigue or changes in hardware resolution.) We attempted to do this with a task that required participants to discriminate the orientation, horizontal or vertical, of black and white stripes. During pilot testing we found that the discriminability of the stripes fluctuated non-systematically as a function of viewing distance. The stripes would disappear into solid fields of black or white and then become discernable again at greater distances. An implication is that, in contrast to real world acuity, measuring VE acuity at a given distance may not consistently allow accurate prediction of acuity at other distances. The development of acuity measures which can be used to assess temporal changes in acuity and factors such as viewer and target movement is an area for future improvement.

Finally, as a longer-term goal, we intend to add audition tasks to the battery. Audition tasks will involve identification and localization of sounds, and speech intelligibility. These tasks will be developed and implemented after we have completed the next few experiments on visual display devices.

Conclusions

This first experiment reinforced our initial subjective impressions about several research issues. First, the data indicate substantial variability in initial performance among participants. Some participants were able to perform the tasks quite well, others were not. One implication of this result is than future research (and later, VE applications) should include provisions for training participants in the basic VE skills, such as locomotion and object manipulation that are required for successful task performance. The VEPAB itself may be useful in this regard. VEPAB provided a systematic orientation for naive participants to learn how to perceive, move through, and interact with objects in VEs.

A second impression that was reinforced is that simulator sickness is a potential problem for the use of VE for training. Although only one participant was unable to complete the experiment, and none of the remaining participants reported any severe symptoms, the overall level of discomfort (mean total severity) was higher than that reported by naval aviators following training sessions in flight simulators. While naval aviators might differ from our population of college students in several ways (less susceptibility to motion sickness, and less willingness to report discomfort, for example), our results do indicate a potential problem, and provide a quantitative confirmation of the anecdotal reports of side effects.

This research has established a set of tasks that can be used to investigate the effects of interface devices on human performance and learning. In general, the tasks showed acceptable reliability. The reliability of locomotion accuracy scores should be improved by the changes we have made to the method used to count collisions. The unreliability of the reaction time tasks is likely due to the slowness of the PC-based systems used in this experiment. Their reliability is expected to improve when the tasks are performed on faster systems.

Although tracking of moving targets was poor, all of the tasks could be performed by our diverse group of participants, who varied in age, sex, and familiarity with computers and video games. Performance on most tasks was sensitive to the effects of different interface devices and amount of practice. This shows them to be free of artificial limitations on performance (e.g., ceiling effects) which would preclude their use as research tools. While five of the tasks showed no significant practice effect, we expect the removal of the apparent barrier at the "finish line" of the Back-up, Turns, and Windows tasks to improve their sensitivity. Performance on the HMD Tracking tasks, on the other hand, may have been limited by system parameters, rather than participant skills.

This experiment also provided baseline data on human performance of a variety of perceptual and motor tasks situated in VEs.

Our research to date with VEPAB has reinforced our initial impressions that immersive VE technology has tremendous potential to support a wide range of training needs. However, we believe that to realize this potential efficiently, systematic research is needed on technology requirements and, as important, how to use the technology. The availability of standard VE materials and procedures can help support this research. VEPAB is a step in the development of these materials and procedures.

The contribution of the VEPAB, we think, lies in its use as a tool kit of tasks which can be used to design and evaluate proposed VE interfaces. Tasks can be selected based on the research needs and the real-world tasks of interest. For example, a wide variety of hardware and software interfaces for self-locomotion in VE have been proposed (and implemented). How do these compare in terms of ease of use for novice or experienced users? Do they differ in terms of the feedback they provide to the user about distance traveled or orientation in the VE? How does system update rate affect self locomotion? Does "flying" facilitate or hamper locomotion? A subset of the locomotion tasks could be used to answer these and similar questions. Moreover, the answers could be obtained without the expense and time required to build a new environment for testing. It also does not matter whether the particular application is to be used to train dismounted soldiers to "clear" buildings or home buyers to experience their soon to be built home, the results should be applicable as long as the tasks are similar to those the user is to perform, and the research subjects are representative of the user population.

Developing an I-Port for the dismounted soldier will require a large number of interface design decisions. Resources to build prototypes, evaluate them, and redesign the interface are likely to be limited. The VEPAB provides a relatively quick and inexpensive way to test interface devices and concepts.

Three additional experiments with VEPAB are scheduled. First, we will use a subset of the tasks to examine the effects of extended practice on performance, and the extent to which the control device effects we observed in this experiment persist. We will then use VEPAB to evaluate performance as a function of the characteristics of visual displays. One experiment will compare three displays: a standard monitor, the Fake Space Lab Binocular Omni-Orientation Monitor (BOOM), and the Virtual Research Flight Helmet. The monitor condition provides high resolution but no head tracking. The BOOM, with higher resolution than the Flight Helmet and faster mechanical tracking than our Polhemus, represents a preview of improvements we expect to take place in HMDs. Another experiment will compare task performance with stereoscopic versus monoscopic HMDs, with and without head tracking.

To support these latter two experiments the VEPAB software has already been modified to run on a Silicon Graphics Crimson Reality Engine. The Reality Engine will produce faster update rates than the PCs used in our first experiment. The effects of update rate on performance is an important area for future research. The VEPAB tasks are an appropriate tool for investigating those effects because system speed is not an inherent characteristic of the VEPAB.

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APPENDIX A

DISPLAY SYSTEM COMFORT QUESTIONNAIRE

(pre) # ____________

1. Are you in your usual state of fitness: YES NO

   If not, what is the nature of your illness (flu, cold, etc).

2. Please indicate all medication you have used in the past 24 hours:

   (a) NONE

   (b) Sedatives or tranquilizers

   (c) Aspirin, Tylenol, other analgesics

   (d) Anti-histamines

   (e) Decongestants

   (f) other (specify):

3. How many hours sleep did you get last night? ___ (Hours)

   Was this amount sufficient? YES NO

Display System Comfort Questionnaire (post)

1.	General discomfort	None	Slight	Moderate	Severe
2.	Fatigue	None	Slight	Moderate	Severe
3.	Headache	None	Slight	Moderate	Severe
4.	Eye Strain	None	Slight	Moderate	Severe
5.	Difficulty focusing	None	Slight	Moderate	Severe
6.	Salivation increased	None	Slight	Moderate	Severe
7.	Sweating	None	Slight	Moderate	Severe
8.	Nausea	None	Slight	Moderate	Severe
9.	Difficulty concentrating	None	Slight	Moderate	Severe
10.	"Fullness of the Head"	No	Yes		
11.	Blurred Vision	No	Yes		
12.	a. Dizziness with eyes open	No	Yes		
	b. Dizziness with eyes closed	No	Yes		
13.	Vertigo	No	Yes		
14.	*Stomach awareness	No	Yes		
15.	Burping	No	Yes	No. of times ____	
16.	Other: ______________________				

* Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

APPENDIX B

IMMERSION QUESTIONNAIRES

Indicate your preferred answer by marking an "X" in the appropriate box of the seven point scale. Please try to use the entire scale for your responses, as the intermediate levels may apply. For example, if your response is once or twice, the second box from the left should be marked. If your response is many times but not extremely often, then the sixth (or second box from the right) should be marked.

1. Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

2. How easily can you switch your attention from the task in which you are currently involved to a new task?

|________|________|________|________|________|________|________|

NOT SO EASILY FAIRLY EASILY QUITE EASILY

3. How good are you at blocking out external distractions when you are involved in something?

|________|________|________|________|________|________|________|

NOT VERY GOOD SOMEWHAT GOOD VERY GOOD

4. How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

5. Do you easily become deeply involved in movies or tv dramas?

|________|________|________|________|________|________|________|

NEVER OCCASIONALLY OFTEN

6. Do you ever become so involved in a television program or book that people have problems getting your attention?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

7. Do you ever become so involved in a movie that you are not aware of things happening around you?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

8. How frequently do you find yourself closely identifying with the characters in a story line?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

9. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

10. On average, how many books do you read for enjoyment in a month?

|________|________|________|________|________|________|________|
NONE ONE TWO THREE FOUR FIVE MORE

11. What kind of books do you enjoy most and read most frequently? (CIRCLE ONE ITEM ONLY!)

Adventure novels	Autobiographies	Science fiction
Westerns	Romance novels	Historical novels
Fantasy	Mysteries	Spy novels

12. How physically fit do you feel today?

|________|________|________|________|________|________|________|
NOT FIT MODERATELY FIT EXTREMELY FIT

13. How well do you feel today?

|________|________|________|________|________|________|________|

NOT WELL — PRETTY WELL — EXCELLENT

14. How mentally alert do you feel at the present time?

|________|________|________|________|________|________|________|

NOT ALERT — MODERATELY — FULLY ALERT

15. To what extent have you dwelled on personal problems in the last 48 hours?

|________|________|________|________|________|________|________|

NOT AT ALL — SOME — ENTIRELY

16. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?

|________|________|________|________|________|________|________|

NEVER — OCCASIONALLY — OFTEN

17. Do you ever become so involved in a daydream that you are not aware of things happening around you?

|________|________|________|________|________|________|________|

NEVER — OCCASIONALLY — OFTEN

18. Do you ever have dreams that are so real that you feel disoriented when you awake?

|________|________|________|________|________|________|________|

NEVER — OCCASIONALLY — OFTEN

19. When playing sports, do you become so involved in the game that you lose track of time?

|________|________|________|________|________|________|________|

NEVER — OCCASIONALLY — OFTEN

20. Are you easily disturbed when working on a task?

|________|________|________|________|________|________|________|

NEVER — OCCASIONALLY — OFTEN

21. How well do you concentrate on enjoyable activities?

|________|________|________|________|________|________|________|
NOT AT ALL MODERATELY WELL VERY WELL

22. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

23. How well do you concentrate on disagreeable tasks?

|________|________|________|________|________|________|________|
NOT AT ALL MODERATELY WELL VERY WELL

24. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

25. Have you ever gotten scared by something happening on a TV show or in a movie?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

26. Have you ever remained apprehensive or fearful long after watching a scary movie?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

27. Do you ever avoid carnival or fairground rides because they are too scary?

|________|________|________|________|________|________|________|
NEVER OCCASIONALLY OFTEN

28. How frequently do you watch tv soap operas or docu-dramas?

|_______|_______|_______|_______|_______|_______|_______|

NEVER OCCASIONALLY OFTEN

PLEASE DO NOT PROCEED UNTIL REQUESTED!

POST VIRTUAL ENVIRONMENT EXPERIENCE IMMERSION QUESTIONNAIRE

Characterize your experience in the virtual environment, by marking an "X" along the 7-point scale, in accordance with the question and descriptive labels. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE VIRTUAL ENVIRONMENT,

1. To what degree do you feel that you were able to control events?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

|________|________|________|________|________|________|________|

NOT RESPONSIVE MODERATELY RESPONSIVE COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

|________|________|________|________|________|________|________|

EXTREMELY ARTIFICIAL BORDERLINE COMPLETELY NATURAL

4. How completely were <u>all</u> of your senses engaged?

|________|________|________|________|________|________|________|

NOT ENGAGED MILDLY ENGAGED COMPLETELY ENGAGED

5. How much did the visual aspects of the environment involve you?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

6. How much did the auditory aspects of the environment involve you?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

7. How natural was the mechanism which controlled movement through the environment?

|________|________|________|________|________|________|________|

EXTREMELY ARTIFICIAL — BORDERLINE — COMPLETELY NATURAL

8. How aware were you of events occurring in the real world around you?

|________|________|________|________|________|________|________|

NOT AWARE AT ALL — MILDLY* AWARE — VERY AWARE

9. How aware were you of your display and control devices?

|________|________|________|________|________|________|________|

NOT AWARE AT ALL — MILDLY* AWARE — VERY AWARE

10. How compelling was your sense of objects moving through space?

|________|________|________|________|________|________|________|

NOT AT ALL — MODERATELY COMPELLING — VERY COMPELLING

11. To what degree did you experience disconnects or inconsistencies between the information coming from your various senses?

|________|________|________|________|________|________|________|

NO INCON-SISTENCIES — SOME INCON-SISTENCIES — MANY INCON-SISTENCIES

12. To what degree did your experiences in the virtual environment seem consistent with your real world experiences?

|________|________|________|________|________|________|________|

NOT CONSISTENT — MODERATELY CONSISTENT — VERY CONSISTENT

13. To what degree were you able to anticipate what would happen next in response to the actions that you performed?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

14. How completely were you able to actively survey or search the environment using vision?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

15. How well could you identify sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

16. How well could you localize sounds?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

17. To what extent were you able to actively survey or search the virtual environment using touch?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT COMPLETELY

18. How compelling was your sense of moving around inside the virtual environment?

|________|________|________|________|________|________|________|
NOT COMPELLING MODERATELY COMPELLING VERY COMPELLING

19. How closely were you able to examine objects?

|________|________|________|________|________|________|________|
NOT AT ALL PRETTY CLOSELY VERY CLOSELY

20. Were you able to examine objects from multiple viewpoints?

|________|________|________|________|________|________|________|
NOT AT ALL SOMEWHAT EXTENSIVELY

21. Were you able to move or manipulate objects in the virtual environment?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT EXTENSIVELY

22. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

|________|________|________|________|________|________|________|

NOT AT ALL MILDLY DISORIENTED VERY DISORIENTED

23. How involved were you in the virtual environment experience?

|________|________|________|________|________|________|________|

NOT INVOLVED MILDLY INVOLVED COMPLETELY ENGROSSED

24. Was the control mechanism distracting?

|________|________|________|________|________|________|________|

NOT AT ALL MILDLY DISTRACTING VERY DISTRACTING

25. How much delay did you experience between your actions and expected outcomes?

|________|________|________|________|________|________|________|

NO DELAYS MODERATE DELAYS LONG DELAYS

26. How quickly did you adjust to the virtual environment experience?

|________|________|________|________|________|________|________|

NOT AT ALL SLOWLY IN LESS THAN ONE MINUTE

27. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

|________|________|________|________|________|________|________|

NOT PROFICIENT REASONABLY PROFICIENT VERY PROFICIENT

28. To what extent did the visual display quality interfere or distract you from performing assigned tasks or required activities?

|________|________|________|________|________|________|________|

NOT AT ALL INTERFERED SOMEWHAT PREVENTED TASK PERFORMANCE

29. To what extent did the control devices interfere with the performance of assigned tasks or with other activities?

|________|________|________|________|________|________|________|

NOT AT ALL INTERFERED SOMEWHAT INTERFERED GREATLY

30. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY

31. Did you learn new techniques that enabled you to improve your performance?

|________|________|________|________|________|________|________|

NO TECHNIQUES LEARNED LEARNED SOME TECHNIQUES LEARNED MANY TECHNIQUES

32. Were you involved in the experimental task to the extent that you lost track of time?

|________|________|________|________|________|________|________|

NOT AT ALL SOMEWHAT COMPLETELY