RESEARCH IN THE USE OF VIRTUAL ENVIRONMENT TECHNOLOGY TO TRAIN DISMOUNTED SOLDIERS

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ABSTRACT

The Army has made a substantial commitment to the use of a simulated, electronic battlefield for combat training. Current and next-generation training systems can provide a realistic combat simulation for soldiers fighting from vehicles, but not for individual dismounted soldiers. Virtual Environment (VE) technology has the potential to provide that capability. The Army Research Institute, with contract support from the University of Central Florida Institute for Simulation and Training, has initiated a research program to investigate the use of VE for training dismounted soldiers. Issues we are investigating include: are some types of visual displays and controls better suited for training or task performance than others; does visual immersion in a simulated environment improve learning of the configuration, locations of objects, and routes through that environment; what scene details are most important for the acquisition of spatial knowledge and the interpretation of terrain information; does immersion in a virtual world cause disorienting side-effects, and if so, how can they be reduced. This paper describes the initial results of our research program. We developed: a set of tasks, the Virtual Environment Performance Assessment Battery, and a questionnaire to measure "Presence", the extent to which the participant felt immersed in the VE experience. We also included existing questionnaires to measure the frequency and severity of simulator sickness. The tasks measure the underlying skills needed to move, employ weapons, and communicate in a virtual environment, but do not require previous military training. They include the perception of form, color, and distance; control of simulated movement; tracking of targets; manipulation of objects; and reaction time. Thirty participants in two experiments performed the tasks using either a spaceball or joystick. Results indicate that performance on the battery tasks is sensitive to differences between the control devices and amount of practice. The presence scale possesses high internal consistency and is sensitive to the type of virtual environments experienced. Most participants experienced some symptoms of simulator sickness. Future research plans are discussed.

ABOUT THE AUTHORS

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INTRODUCTION

The Army has made a substantial commitment to the use of distributed interactive simulation (DIS) for combat training, concept development, and test and evaluation. The emphasis in the initial version of DIS (SIMNET) and in the next generation Close Combat Tactical Trainer (CCTT) has been on the simulation of combat for soldiers fighting from vehicles, not for soldiers fighting on foot. Representations of dismounted soldiers in these simulations are controlled by individuals at computer workstations, supplemented by "intelligent" software. No matter how well these forces may "populate the battlefield" and prepare mounted soldiers, they provide little or no training for the dismounted soldiers themselves. In contrast, the Army expects that changes in its mission will result in a relative increase in the importance of the dismounted soldier in future military operations. The cluster of technologies generally referred to as Virtual Environment (VE) technology has the capability to integrate the dismounted soldier into DIS. While the concept is not new (Gorman, 1990), very little progress has been made toward its implementation.

Definitions

A Virtual Environment is a simulated space with which a viewer interacts. In most current iimplementaitons, a physical simulation of a vehicle, such as an aircraft or tank, serves as the interface between the individual in the simulation and the virtual environment. In order for an individual to interact directly in a virtual environment, some or all of the following conditions must be met: free motion of the eyepoint within the space; three-dimensional, real-time interactive graphics, with stereopsis if needed; multiple senses beyond visual (e.g., audition, touch); direct manipulation of objects; and multiple interacting, mutually visible, humans.

Individual Combatant Simulation (ICS) technology is the technology necessary to represent individual soldiers in VE. Technology elements include: visual and auditory displays, sensing head and body position and orientation, speech recognition, tactile and force feedback displays, representation of whole body movement, and biomechanical articulation of dismounted soldier models (Levison and Pew, 1993). The state of the art in these areas has been reviewed by Durlach, Pew, Aviles, DiZio, & Zeltzer (1992). While the advancement of technology in these areas is outside the scope of our organizational mission and our expertise, the determination of the technological requirements to meet training objectives, the development of strategies for using VE for training, and the assessment of VE training effectiveness are all appropriate areas for behavioral science research.

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OBJECTIVES AND APPROACH

Our overall VE research objective is to improve the Army's capability to provide effective, low cost training for Special Operation Forces and Dismounted Infantry though the use of VE technology and ICS. Our approach includes: a focus on the requirements for leader and individual accomplishment of unit tasks; determination of the necessary characteristics of VE technology, including fidelity requirements, that are necessary.for successful training; and evaluation of the transfer of ICS training to the real world. We have established a goal of demonstrating a visual and auditory ICS interface for the dismounted soldier by October1994.

Our approach to achieving this objective is multifaceted, and includes cooperating with the Naval Training Systems Center on a review of the state of the art in VE Technology (Durlach et al, 1992) and its applicability to ICS (Levison and Pew, 1993); and an assessment of dismounted unit ARTEP tasks in terms of their supportability in VE (Jacobs et al., 1993). However, the key element in our program is the Virtual Environment Research Laboratory.

The Virtual Environment Research Laboratory was established by a contract between ARI and the University of Central Florida Institute for Simulation and Training (IST) in July 1992. It is located at IST and uses their facilities and equipment. In carrying out research in the laboratory, ARI personnel (research psychologists) plan experiments, develop the specifications for the environments and interfaces, conduct the experiments, analyze the data, and report the results, while the IST personnel (computer scientists) configure and develop the necessary hardware and software to conduct the research.

The overall scheme for the research is shown in Figure 1, the Virtual Environment Research Pyramid. The figure shows our research plan as sequential progress up the levels of the pyramid. At the ground level are the task requirements for dismounted soldier training, as documented in Jacobs et al. The next level represents previous research in the use of VE for training. This is not a thick layer of the pyramid. When we began our research, we found only one article (Regian, Shebilske, & Monk, 1993) on the use of VE for training.

We began our experiments at the third level, which has three distinct elements. The first, psychophysical capabilities, is concerned with how well available technology enables individuals to see and hear in a VE. The second, psychomotor capabilities, is concerned with their skills in performing simple tasks. The third, comfort, convenience, and side effects, is concerned with the impressions and side effects of exposure to VE. The research reported in this paper was conducted at this level in the pyramid.

At the fourth level is research concerned with use of VE to teach spatial knowledge, particularly the configuration of and routes through large buildings. While there is some research in this area, the use of a virtual building model has never been compared with use of the actual building as a means of training, nor have different strategies for the use of VE been compared. We have two experiments planned in this area.

At the fifth level is the use of VE to represent exterior terrain, both for training land navigation tasks, and for applying land navigation skills in the conduct of mission rehearsals and combat simulations. At the sixth level is the use of VE for tasks which involve situational awareness, i.e, complex tasks performed in a changing environment, such as searching a building for a moving object. The seventh level, team situational awareness, involves the same tasks, but performed by teams rather than as individuals, so that communication and cooperation among team members is required.

VIRTUAL PRESENCE

For our purposes, virtual presence is the experience of being in one place when you are physically in another. The strength of this experience is often referred to as the sense of "immersion" that VE provides. Presence could be a valuable concept for enhancing training if it could be shown that those factors which enhance a sense of presence also improve training effectiveness and transfer (Sheridan, 1992). Witmer and Singer (in preparation) have suggested that the extent to which an individual experiences presence is related to two types of factors: individual susceptibility, and the characteristics of the VE itself. They have developed two questionnaires on this conceptual basis: a susceptibility questionnaire to measure an individual's susceptibility to immersion, and a post-immersion questionnaire to assess the extent to which the individual was immersed during the experience. We are using both questionnaires in our research.

THE VIRTUAL ENVIRONMENT PERFORMANCE ASSESSMENT BATTERY

The Virtual Environment Performance Assessment Battery is a set of tasks and performance measures developed to assess human performance and the effects of immersion in the VE as a function of training and system characteristics. The battery serves several important functions. First, the tasks provide a means to bring research participants to a basic level of proficiency in prerequisite VE skills (e.g., locomotion, manipulating objects). Thus students can learn the techniques necessary to "walk" through building models before a specific building model is used to teach them routes through that building. Second, the tasks can be used as "behavioral benchmarks" for interface hardware and software comparisons, to determine quickly the effects of system changes (display resolution, update rate) on task performance. Third, task performance can provide statistical controls for future research. Finally, they provide a baseline for investigating side effects, such as simulator sickness.

The tasks were selected to be components of what soldiers would do in VE, and to some extent "look like" military tasks, but require no military training. This permits the use of college students as research participants. Five task categories were derived from the simple concept that soldiers move, communicate, and employ weapons: vision, locomotion, manipulation, reaction time, and tracking. Brief descriptions of all tasks are provided in Table 1.

We have conducted two experiments using some or all of these tasks. The first examined the sensitivity of task performance to different control devices and limited practice, and provided data on the occurrence of simulator sickness. The second used a subset of the tasks to examine the effects of extended practice on both performance and simulator sickness. The hardware and software used for both experiments were the same. The tasks were presented using two 486/50mhz PCs with Intel DVI display boards, a Virtual Research Corporation Flight Helmet, a Polhemus Isotrak head tracker, and either a Gravis Joystick or a Spaceball Tech Spaceball. Sense8 WorldToolKit software, with a parallel option to connect the two PC's, was used.

Experiment 1

Table 1.

Virtual Environment Performance Assessment Battery Tasks

TASK CATEGORY	**TASK NAME**	**TASK DESCRIPTION**
Vision	Acuity	A Snellen eye chart
	Color	Ishihara color plates
	Distance Estimation	Indicate when the image of a human figure, moving toward the viewer from a distance of 40 feet, is 30, 20, 10, 5, and 2.5 feet away.
	Search	From a seated position in the center of a 20 x 20 x 20 foot room, locate a moving ball initially not within the field of view.
Locomotion	Corridor (Intro)	Move down a straight corridor to a target location, turn around, and return to the starting point.
	Back-up	The same as the Corridor task, except move backwards to the starting point without turning around.
	Turns	Move through a series of corridors connected by 10 alternating left and right right-angle turns.
	Figure 8	Move through a figure-8 shaped corridor.
	Doorways	Move through a series of rooms connected by doorways, offset so that a curved course must be followed.
	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.
Manipulation	Slide	"Grasp" an object and move it horizontally to a target location.
	Dial	"Grasp "a dial and rotate it to a target orientation.
	Bins	"Grasp" a ball located in one of three rows of three bins each, and move it out of the original bin and into a target bin.
Reaction Time	Simple	Indicate when a "X" appears at a designated spot on the display.
	Complex	Indicate in which of four boxes an "X" has appeared.
Tracking	Head Control, Stationary Target	Using head movements, move a cursor centered in the viewing device over a stationary target.
	Head Control, Moving Target 1	Using head movements, move a cursor centered in the viewing device over a target moving in a single straight line.
	Head Control, Moving Target 2	Using head movements, move a cursor over a target moving in a path which includes a single turn.
	Device Control, Stationary Target	Using a control device, move a cursor over a stationary target.
	Device Control, Moving Target 1	Using a control device, move a cursor over a target moving in a single straight line.
	Device Control, Moving Target 2	Using a control device, move a cursor over a target moving in a path which includes a single turn.

Procedure. Twenty-four research participants each completed the first twenty tasks shown in Table 1. Participants were primarily college students who had normal or corrected-to-normal vision and were paid for their participation. One-half of the participants performed the tasks using a spaceball as the control device, and the other half used a joystick. The tasks were performed in two sessions on separate days.

At the end of each session, participants completed the Simulator Sickness Questionnaire (SSQ; Kennedy, Lane, Berbaum, and Lillenthal, 1993) and the Post-immersion Presence Questionnaire. The SSQ is a 16-item questionnaire on which participants report some symptoms on a four-point scale (None, Slight, Moderate, or Severe) and others as being present or absent. It produces a Total Severity score and three subscale scores: Oculomotor (eyestrain, difficulty focusing, blurred vision, headache); Disorientation (dizziness, vertigo); and Nausea (nausea, stomach awareness, salivation, burping).

Results. The most striking results are shown in Figure 2, which shows mean completion time per segment for each of the locomotion tasks as a function of Control Device. The difference between the two groups was significant for each task (p<.03). A similar pattern of completion times was found for the manipulation tasks (see Figure 3). Again all control device differences were statistically significant (p<.02). The pattern did not hold for tracking tasks. There were no differences between head and device tracking, or between spaceball and joystick. There were consistent significant practice effects for all manipulation tasks (p<.05), but for only two locomotion tasks, Intro (the first locomotion task performed) and Windows (the first locomotion task performed which required participants to "fly").

Of the 24 participants, one became too ill to complete a session. Her data are excluded from Figure 4, which shows the results of the SSQ administration for both of our experiments. Zero on any scale represents the complete absence of symptoms. The first two clusters of histograms show the results of the administrations following Session 1 and Session 2. Our participants reported more severe symptoms than Kennedy et al's (1993) aviators. Symptoms were also significantly more severe following Session 2 than Session 1 (p<.05 for each subscale). Nevertheless, no participant reported "severe" symptoms of any kind. Seven of 19 reported "moderate" eyestrain as the worst symptom. A majority of the participants reported slight or none to each symptom.

The presence questionnaires were found to have satisfactory internal consistency (.74 for the susceptibility scale and .74 and .87 for the first and second administrations of the post-immersion questionnaire). Susceptibility did not predict experienced presence. Experienced presence was negatively correlated with simulator sickness (r =-.45 for session 1 and -.48 for session 2, p <.05 for both): the higher the Total Severity score, the lower the amount of presence experienced.

Discussion. The objective for the first experiment was to determine if the VEPAB tasks were sensitive to differences in control devices and to practice effects. The Locomotion and Manipulation tasks showed sensitivity to control devices, but the Tracking tasks did not. We suspect that the slow system update rate for those tasks (about 300 ms.) made them so difficult that they could not be performed well with any control device. Overall, participants were able to keep the cursor on the moving target less than 9% of the time.

Whether or not the tasks are sensitive to practice effects is less clear. Only the manipulation and some locomotion tasks showed practice effects. We expect that this is because participants had little time for practice.

The SSQ data show that simulator sickness is an aspect of VE that must be taken seriously, but it is not a "show stopper." Despite the limits that we placed on exposure (breaks approximately every 20 minutes and total exposure less than one hour per day), we still found that most participants reported some symptoms. There is a lack of other data to use for comparison. We do not know, for example, what symptoms our participants would have reported prior to the start of a session, or after a similar period of time spent word processing. We do not know if there are behavioral consequences of the exposure. For example, is balance affected? We do know that our participants reported more severe symptoms than Navy aviators did following simulator use; but then, Navy aviators are very different from college students.

There are several reasons why reported symptoms might have been more severe after the second session than after the first. The amount of time spent performing tasks in VE was longer in the second session, and this may account for the difference. The SSQ may be a "reactive" measure, that is, completing it once, after the first session, may cause the participant to be more aware of their symptoms during the second session. There may be a cumulative effect of repeated exposures. Finally, task differences between the first and second sessions may have contributed. Both tasks that involved "flying," or vertical movement, were in the second session.

Experiment 1 left us with several questions. How much improvement could we expect with additional practice, and how rapidly would participants reach some sort of plateau? Would extended practice eliminate the difference between the Spaceball and Joystick groups? What is the normal level of occurrence of SSQ symptoms, without exposure to VE? Did the severity (relative to Naval aviators) of the simulator sickness symptoms indicate that there were corresponding vestibular disturbances? To answer these questions we conducted a second experiment which involved extended practice on a subset of VEBAP tasks.

EXPERIMENT 2

Procedure. Six ARI employees with normal or corrected-to-normal vision performed each of five tasks from the VEPAB in 11 experimental sessions on six different days (one session on the first day and two on each of the remaining five). The order of the tasks was counterbalanced across sessions. They were: Turns, Figure 8, Windows, Bins, and one tracking task (Device Control, Moving Target 2). The Turns, Bins, and Windows tasks were the same as those used in Experiment 1. The Figure 8 task was modified so that it ran continuously for five minutes, rather than stopping after two complete circuits. Three participants performed the tasks using the joystick, and three using the spaceball. Participants completed the SSQ prior to and after their daily practice. As an additional measure of simulator sickness, we measured postural stability before and after each participation. This was accomplished by having each participant stand on their non-preferred leg, with their arms crossed over their chest and their eyes closed while wearing the Flight Helmet. The time that they could sustain this position was measured by an observer, and head orientation was recorded approximately eight times per second by the Pohlemus Isotrak.

Results. Task performance is summarized in Figures 5, 6, and 7. Regression analysis showed a significant improvement on all tasks

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with practice (p<.05). On the Turns and Windows tasks, most of the improvement occurred in the first few sessions, while on the others it appeared to be largely linear. Also on the Turns and Windows tasks, practice greatly reduced the differences between the Spaceball and Joystick groups while on the Bins and Figure 8 tasks they remained nearly constant. Again, the tracking task proved to be extremely difficult, no matter what control device was used, although a practice effect was evident.

The results of the SSQ administrations are shown along with those of Experiment 1 in Figure 4. (There were no meaningful differences across days, so the figure shows averaged pre-exposure scores across days, and post-exposure scores for the first and last days, which were representative.) Clearly, our participants were not free of simulator sickness symptoms prior to exposure to VE. The overall level of post-session symptoms reported was slightly lower than those reported by the participants in experiment 1 after their first session, but did not show any cumulative effect, nor on the other hand, was there a noticeable adaptation.

The results of the test of postural stability are shown in Figure 8. There appears to be some slight practice effect, but no decline in stability as a result of exposure to VE. Our analysis of head orientation during this test showed no discernable patterns.

Discussion. We have concluded that the subset of VEPAB tasks we used for this experiment are sensitive to practice effects. While the tracking task is particularly difficult, and the turns task is relatively easy, none of the tasks are so difficult or easy that performance does not improve with practice. We have also concluded that the joystick is preferable to the spaceball for use in our future experiments. While spaceball users eventually performed about as well as joystick users on some tasks, for other tasks the joystick produces superior performance after even extensive practice (55 minutes in the case of the Figure 8 task). This should not be taken to indicate that the spaceball is an inferior control device. 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, our system updated relatively slowly (approximately 3 to 9 times per second, depending on the task). Since the spaceball provided little inherent feedback, this may have interacted with the slow update to make it particularly difficult to learn to use. The same result might not be obtained if the effects of applying force to the spaceball were immediately apparent.

With regard to simulator sickness, we believe it is valuable to assess participant symptoms prior to, as well as after, each experimental session. We did not find any evidence of an increase in simulator sickness as a result of repeated exposures, but neither did we find any evidence for adaptation. However, our sample was very small and unlikely to uncover any but the largest effects. We also did not find any changes in postural stability due to exposures. We are still seeking an explanation for the relatively high level of symptoms encountered in the second session of the first experiment.

FUTURE RESEARCH

These two experiments have produced a set of tasks which we can use for future experiments and a set of experimental procedures we can use for conducting that research. We have also collected baseline data regarding human performance and simulator sickness in virtual environments. This provides the necessary basis for the conduct of experiments which are more directly involved with the use of VE for ICS.

As of this writing we have just completed data collection in one additional experiment, and have made preparations for a second. The experiment just completed compares three media for rehearsing routes through an office building: pictures and written directions; a virtual office building; and the actual building. Since it is an actual building, we will be able to test how well knowledge acquired in the virtual building transfers to the real world. The experiment which we are prepared to conduct will compare VEPAB task performance with three visual display alternatives (monitor, high resolution boom, and low resolution head-mounted display). Following those experiments, we will move to higher levels of the pyramid shown in Figure 1.

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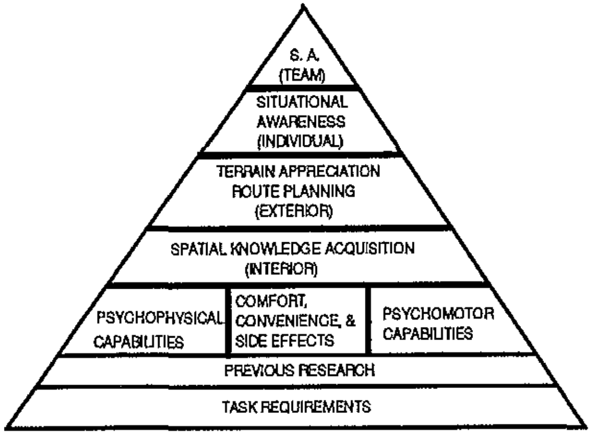

Figure 1. The Virtual Environment Research Pyramid

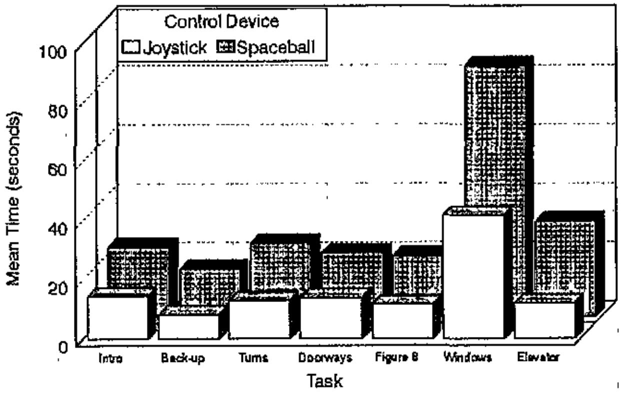

Figure 2. Experiment 1. Locomotion Task Time as a Function of Control Device.

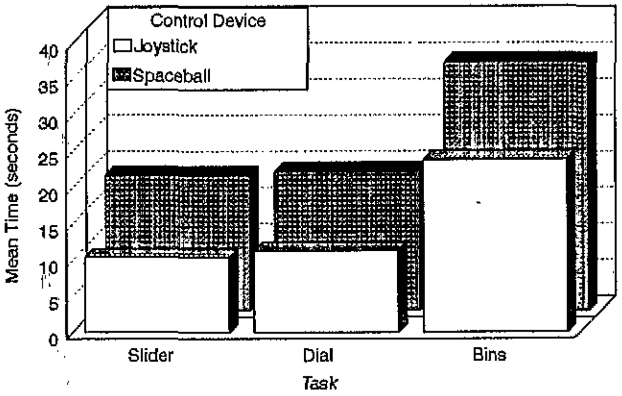

Figure 3. Experiment 1. Manipulation Task Time as a Function of Control Device.

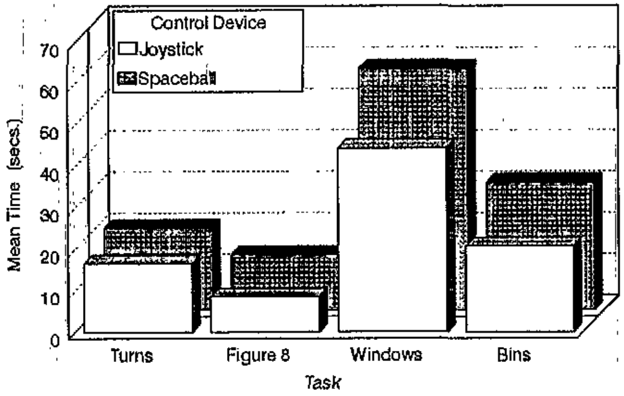

Figure 4. Experiment 2. Task Time as a Function of Control Device.

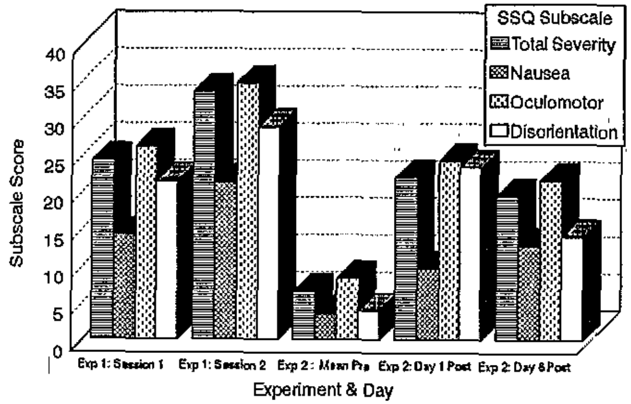

Figure 5. SSQ Subscale Scores for Experiment 1 (Sessions 1 and 2) and Experiment 2 (Pre-VE averaged over all days, and Post-VE for Days 1 and 6).

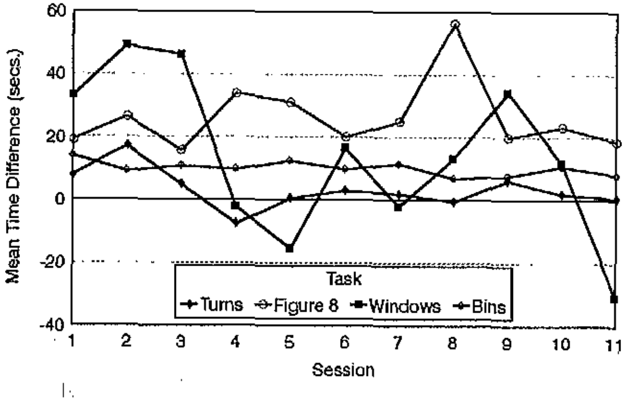

Figure 6. Experiment 2. Task Time Differences (Spaceball Joystick) as a Function of Experimental Session.

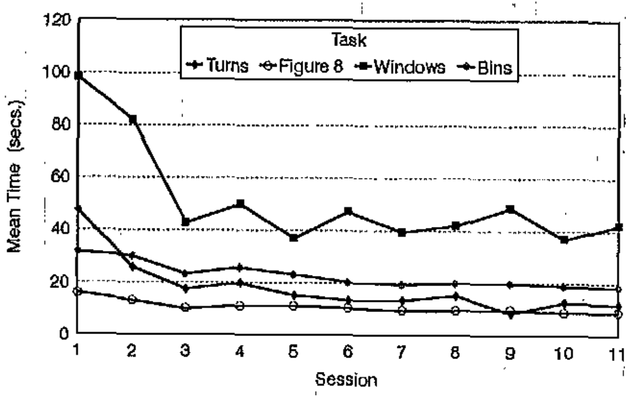

Figure 7. Experiment 2. Task Times as a Function of Experimental Session.

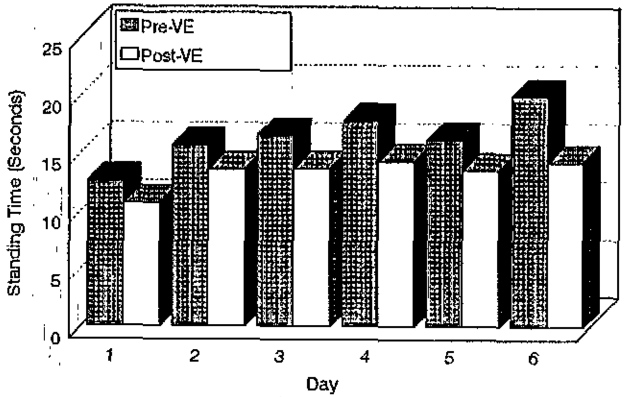

Figure 8. Experiment 2. Postural Stability as a Function of Day.