RECOMMENDATIONS FOR USING VIRTUAL ENVIRONMENTS FOR DISMOUNTED SOLDIER TRAINING

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ABSTRACT

The U.S. Army has made a considerable investment in the use of virtual environments (VEs) for training. Beginning in the early 1980's with the SIMNET program, the Army has made a commitment to use virtual simulations to train combat forces and to evaluate new systems and operational concepts. While these simulations have predominately focused on training mounted soldiers, the need to train infantry and other dismounted soldiers has been recognized. Although VEs have the potential to immerse dismounted soldiers directly in simulations, there are few successful examples of their use to provide effective training. The effective use of VE for training requires more than just VE hardware and software. It also requires identification of the types of tasks for which VE training is most appropriate, the characteristics of VE systems that are required to provide effective training, and the training strategies that are most appropriate for use with VE. This paper presents selected recommendations for the use of VE for dismounted soldier training and mission rehearsal, and identifies future research needs. The recommendations and research needs are based on the results of our in-house research program, related programs in which we have participated, and the work of other VE researchers. Recommendations include identification of the types of tasks for which VE training is or is not appropriate, design recommendations for the VE interface, and ways to reduce side- and after-effects.

Biographical Sketches

Bruce W. Knerr, Donald R. Lampton, Michael J. Singer, and **Bob G. Witmer** are research psychologists with the Army Research Institute Simulator Systems Research Unit, Orlando, FL. All are actively engaged in the conduct of research on the use of VE to train dismounted soldiers. Collectively, they have over 65 years experience conducting training research for the U.S. Army. Dr. Knerr received a B.S. in Psychology from the Pennsylvania State University and M.S. and Ph.D. degrees in Industrial Psychology from the University of Maryland. Mr. Lampton has a M. A. in Experimental Psychology from the University of Louisville. Dr. Singer received a B.A. in Psychology from the University of West Florida and M.S. and Ph.D. degrees in Cognitive Psychology from the University of Maryland. Dr. Witmer received a B.S. in Electrical Engineering from Tennessee Technological University and a Ph.D. in Experimental Psychology from the Georgia Institute of Technology.

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INTRODUCTION

The U.S. Army has made a considerable investment in the use of virtual environments (VEs) for training. Beginning in the early 1980's with the SIMNET program, the Army has made a commitment to use virtual simulations to train combat forces and to evaluate new systems and operational concepts. While these simulations have predominately focused on training personnel who fight from within combat vehicles, there is an unfilled need to train infantry and other dismounted soldiers in simulated environments. This will provide the Army with the capability to: train dismounted soldiers to operate with mounted units; train dismounted leaders, teams, and individuals to perform unit tasks; and plan and rehearse specific missions.

Although VEs have the potential to immerse dismounted soldiers directly in simulations, there are few successful examples of their use to provide effective training. This requires more than just VE hardware and software. It also requires identification of the types of tasks for which VE training is most appropriate, the characteristics of VE systems that are required to provide effective training, and the training strategies that are most appropriate for use with VE. In order to develop this knowledge, the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), with the support of the Institute for Simulation and Training (IST) initiated a program of experimentation to investigate those issues in 1992. This paper presents selected recommendations for the use of VE for dismounted soldier training and mission rehearsal, based on that program, related programs in which we have participated, and the work of other VE researchers. It also identifies needed future research. The recommendations and research needs are presented in more detail in an ARI report (Knerr, Lampton, Witmer, Singer, Parsons, and Parsons, in preparation).

Our research program can be described as a progression up the levels of a pyramid (see Figure 1). Following an initial analysis of the task requirements for dismounted soldier training, and a review of previous VE training research (a very sparse area when we began), we conducted four experiments to investigate interface effects on the capabilities of participants to perform simple tasks in VE. Variables investigated included the type of control device, amount of task practice, stereoscopic vs. monoscopic helmet-mounted displays (HMDs), and type of display device (monitor, Boom, or HMD). At the next level of the pyramid, we conducted two experiments that addressed the effectiveness of VE for teaching route and configuration knowledge of large buildings, and the transfer of this knowledge to the real world. The results of these experiments led to a program of basic research on distance estimation in VE. At the third level, we investigated the use of VE to represent exterior terrain for training both land navigation skills (identifying landmarks and learning routes) and terrain knowledge. Research at the top two levels of the pyramid is investigating the use of VE for training more complex tasks. An experiment examining the effects of self-representation on performance has been completed. An experiment involving the training of two-person hazardous materials teams is underway. Overall, we have conducted 13 experiments involving over 500 human subjects.

The following section presents selected recommendations (in italics) regarding the use of VE for dismounted soldier training, followed by a brief discussion of the rationale for that recommendation.

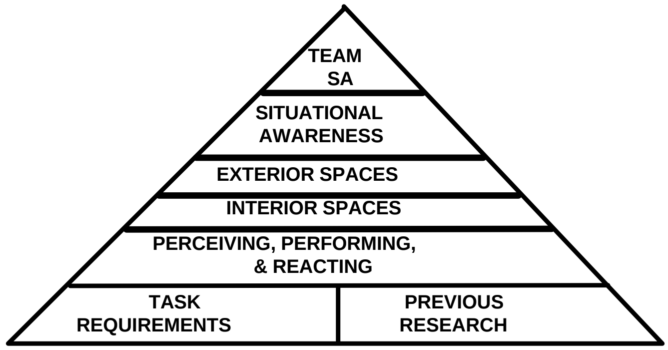

Figure 1. Research program structure.

RECOMMENDATIONS

Individuals can learn to find their way through real world spaces by rehearsing in virtual representations of those spaces. Currently it may be more efficient to rehearse in the real environment, but if the real environment is not available, then VEs are recommended as the best substitute for learning about complex spaces.

Goldin and Thorndyke (1982) described three general levels of spatial knowledge. The base level is knowledge about individual landmarks; the intermediate level is comprised of knowledge about routes between landmarks; and the highest level is survey or configuration knowledge, which relates landmarks and routes into a connected structure (a mental map) that allows the generation of new routes with some level of accuracy. Regian, Shebilske, and Monk (1992) showed that spatial skills could be acquired in a VE, but did not report a real world test of training transfer. Witmer, Bailey, and Knerr (1995) and Witmer, Bailey, Knerr, and Parsons (1996) investigated the acquisition and transfer of route and configuration knowledge in a virtual model of a large office building. On a transfer test, building-trained participants made fewer wrong turns but were not significantly faster than VE-trained participants, who in turn made fewer wrong turns and took less time to traverse the route than did symbolically trained (written directions and photographs) participants. No group of participants demonstrated configuration knowledge (indication of direction and distance to unseen landmarks). Johnson and Wightman (1995) demonstrated that Army pilots could navigate a heliport (on foot) after being trained in a VE model of the heliport. Bliss, Tidwell and Guest (1997) showed that civilian firefighters could follow a route through a building to perform a rescue (route knowledge) and exit via a different route after training in a VE model of that building (configuration knowledge). Grant and Magee (1997) found that a VE trained group did as well locating landmarks in a science center as did a map-trained group, and better than a group that received no training. The VE group took more time to locate all of the landmarks, but did not walk significantly farther than did the group trained in the actual building. VR-trained students were more disoriented (i.e., made larger errors when pointing to their starting point) than were those trained in the actual building.

Wilson, Foreman and Tlauka (1997), using several different measures of configuration knowledge, were successful in demonstrating transfer of configuration knowledge from a simulated building environment to the real world, as were Darken and Siebert (1993, 1996). Wilson et al. attributed their success in demonstrating transfer of configuration knowledge to the use of a relatively simple environment in comparison with the more complex environment utilized by Witmer et al. (1995, 1996).

Singer, Allen, McDonald, and Gildea (1997) found that college students trained in VE developed significantly better configuration knowledge of exterior terrain than did participants trained in comparable map exercises tested in VE. No transfer test was performed. Singer, Allen McDonald, and Fober (in preparation) replicated portions of this experiment with Army Infantry Officers and found that, as in the first experiment, the VE-trained group performed significantly better than the map-trained group in the VE test. When tested in the field, however, there was no difference between the groups.

Thus there is consistent evidence that all types of spatial knowledge can be acquired in VE, although it appears that the acquisition of configuration knowledge is more difficult and may require the use of more sophisticated instructional strategies and features than simply rehearsing a route. Knowledge about buildings and, we suspect, built up areas rich in distinctive cultural features, transfers well to the real world. However, transfer of knowledge about open terrain may be more difficult to obtain. This may be because high fidelity modeling of open terrain is more difficult than is modeling of buildings.

VE can be used effectively to train cognitive skills that have a spatial component, such as ship handling.

Grant and Magee (1996) found transfer of ship handling skills from their VE simulator, the Maritime Surface/Subsurface Virtual Reality Simulator (MARS VRS), to the real world. The system represented the bridge of a normal training ship and allowed instruction in low-level ship maneuvers. When VE-trained students were compared with ship-trained students on the trained maneuvers, during a delayed transfer test on-board training ships, the VE-trained students performed better. When more difficult, untrained maneuvers were introduced during shipboard training, no differences were found between the VE-trained and ship-trained students.

Hayes, Vincenzi, Seamon, and Bradley (1998) found that use of the Virtual Environment for Submarine Officer of the Deck Ship Handling Training System (VESUB) improved ship handling skills such as position determination, contact management, emergency operations, and communications. They did not assess transfer.

VE is not currently recommended for training psychomotor tasks, particularly those that involve precise or rapid motor activity. Systems that use HMDs are also not recommended for tasks that require rapid head movements. VE is not currently suitable for training tasks that require accurate use of individual weapons.

These related recommendations generally reflect the state of the art in VE hardware. If the task requires some reaction to environmental stimuli for adequate performance or for training, then the physical speed with which stimuli can be generated and changed in the VE and the accuracy and speed with which body parts can be tracked are important. Humans can respond with speeds that vary from a few to hundreds of milliseconds (Boff and Lincoln, 1988), using motions that can vary dramatically in speed, range, and complexity. The major problem in VE task representations that range from simple, whole hand movements (e.g. throwing or catching) to complex psychomotor manipulations (assembly of complex parts) is in the accurate position tracking of the critical body parts (Durlach and Mavor, 1995). Technological capabilities still lag human capabilities in this area. Moreover, some VE equipment is encumbering and hampers rapid or successful task performance. Some examples will illustrate these points.

Lampton, Gildea, McDonald, and Kolasinski, 1996) found that performance of a 360-degree search task was slower with a head-tracked HMD than with a monitor controlled by a joystick. The difference was attributed to the weight and mass of the HMD, which slowed head movements.

During the Dismounted Warrior Network experiments (Lockheed Martin Information Systems, 1997), soldiers fired simulated rifles at targets from a standing position using different simulators. Average absolute error from the center of a target at a range of 100 meters was approximately one meter. Soldiers using two simulators in which they could physically assume the prone position also attempted to fire from that position. After 15 trials it was obvious this change in position had increased the transmitter-receiver distance of the weapons trackers to the extent that neither system could engage targets reliably.

We expect that VE systems will become faster and more accurate, and may already be better than that indicated in the examples. In addition, software "fixes" can improve weapons accuracy sufficient to permit use in unit tactical training. The training of fine motor skills using instrumented devices within a limited physical area (e.g., surgery) may also be possible. However, matching human motor capabilities, particularly that of skilled performers, will continue to be extremely challenging.

Trainees should always receive training and practice in the use of the interface before they begin training on the target task or tasks. The goal of this interface training should be to insure that all trainees meet defined minimum standards for the use of the interface.

Contrary to some claims, VE is not a completely natural interface. If it were, VE users would not collide with walls and other objects as frequently as they do. No VE configuration replicates reality exactly. Nearly all use some "work-around" solutions, such as the use of a joystick to control locomotion, or the use of enlargement or color to make distant objects visible. As a consequence, trainees usually need to learn some new, VE-specific skills to train effectively in the VE. A structured training session to provide these skills should be one of the first elements in the VE based training program.

The process of moving through the VE should require minimal attention on the part of the user. If the task requires use of the hands to perform other tasks simultaneously or nearly simultaneously with movement, then some form of foot-based locomotion control will be required. If the simultaneous use of the hands to perform other tasks is not required, a well-practiced method, which is not like the real world (such as a joystick), may be preferable to a novel method that is more similar to actual walking.

In most dismounted soldier training applications, trainees will need to move at realistic rates while performing other tasks. The method of movement should be simple enough and familiar enough that it will not interfere with or detract from the performance of other tasks or the training that is the goal of the VE session. Researchers have used a variety of simple and sophisticated approaches to simulating self-motion. Simple ones include the joystick and spaceball (Lampton, Knerr, Goldberg, Bliss, Moshell, and Blau, 1994; Bailey and Witmer, 1994), buttons to move forward and backward along the direction of gaze (Witmer, et al., 1996), and an instrumented treadmill (Singer, et al., 1997). Templeman (1997), Grant and Magee (1997), and Singer, Ehrlich, and Allen (1998) have independently developed "walking simulators" that permit 360-degree body rotation and use walking in place to move forward in the direction that the body is oriented. The Dismounted Warrior Network (DWN) experiments (Lockheed Martin, 1998) involved interface suites with four different locomotion techniques: a foot pedal to control forward and backward movement in the direction of gaze; a human joystick (automatic forward acceleration and movement when standing in a pre-defined area); a sophisticated joystick; and an omni-directional treadmill.

Experimental comparisons of different locomotion simulators have been limited in scope and used different criteria. Lampton et al. (1994) found that a joystick produced faster movement through the VE than did a spaceball. Bowman, Koller, and Hodges (1997) found gaze-directed steering to be no better than hand pointing when moving directly to a target, but found hand pointing better when moving relative to targets. Witmer and Kline (1998) found that using a joystick to "walk" down a hallway and walking on a treadmill produced similar estimates of distance traveled. Singer et al. (1997) compared a treadmill paired with a head-tracked HMD with a joystick paired with an HMD without headtracking for movement control. No significant differences in spatial learning were found. Grant and Magee (1997) compared their walking interface with locomotion using a joystick. The two groups made similar orientation errors during training when asked to point to their original starting location. The walking simulator group walked significantly less distance to find all of the landmarks during a transfer test in the actual building, but did not find them significantly faster.

The DWN experiments (Lockheed Martin, 1997) compared the four interface suites described above in terms of how well soldiers using them could negotiate a fixed course thorough a simulated built-up area, including building interiors. Maximum possible movement rates were the same for all systems. The interface that used a foot pedal to control movement produced both more rapid course completion and more collisions with walls and other objects than did the other interfaces. The omni-directional treadmill took the longest and produced the fewest collisions. Soldier participants reported that it was more difficult to move in a straight line, maintain balance while moving, and change direction while moving with the omni-directional treadmill than with the other interfaces.

These results suggest that while trainees learn to move through VE using any of a variety of well-designed interface devices, use of a "walking simulator" may produce better spatial learning than joysticks, gaze-directed, and hand-pointing controls. However, the cause of this advantage is not clear. Is it because it provides better cues for changes in direction, better cues for distance traveled, or simply because it places less cognitive demand on the trainees, allowing them to attend more carefully to other cues? An obvious benefit for dismounted soldiers is that they can carry and use simulated equipment (e.g. a rifle) instead of having to control movement with hand controls.

If the hands are available to control movement, a joystick is an alternative. There is a variety of data to show that college students, junior Army enlisted personnel, and company grade officers are particularly proficient in the use of a joystick, perhaps because of experience with video games and computer games (Lampton et al., 1995; Lockheed Martin, 1997; Singer et al., in preparation).

Low-end HMDs provide poor visual resolution relative to human visual capabilities. These devices are not appropriate where successful task performance or training require fine visual discriminations, such as identifying targets at long distances.

An HMD with VGA resolution (640x480) and a 46-degree horizontal FOV provides a resolution of about 4.3 arc minutes per pixel (or triad), compared with a one arc minute resolution of the human eye. Lampton et al. (1996) found actual human visual performance to be worse than would be predicted from the display characteristics alone.

For tasks requiring accurate estimation of distance, use the largest FOV display device available. Both horizontal and vertical FOV may be important. Also consider using compensatory cues or some similar method for calibrating distance judgments in the VE.

Rationale: There is a substantial amount of data showing that distance estimates made in VE are less accurate and more variable than those made in the real world. In different experiments, average estimates were 50% (Witmer and Kline, 1998) 67% (Witmer and Kline, 1998), and 234% (Lockheed Martin, 1997) of actual distance. Performance is somewhat better (85%) if participants walk the perceived distance rather than give a verbal estimate, but still worse than real world performance (Witmer and Sadowski, in press). Estimates are influenced by field of view (Kline and Witmer, 1996), type of display device (Lampton et al., 1996), movement speed, and compensatory audio cues (Witmer and Kline, 1998). Perspective cues (linear perspective, foreshortening, and texture gradient) are effective at distances up to 7 feet (Surdick, Davis, King, and Hodges, 1997). Head tracking and stereopsis are effective at distances of less than 10 feet (Singer, Ehrlich, Cinq-Mars, and Papin, 1995). Witmer and Kline (1998) found that manipulation of textures, movement method (treadmill, joystick, or teleporting), and visual edge rate had little effect on distance estimates.

Cutting and Vishton (1995) have identified which depth cues are most effective at different distances and related these cues to three egocentric regions or zones of space: (1) *personal space* extends just beyond arms reach and refers to space used by a static observer; (2) *action space* extends to about 100 feet and refers and includes distances in which an observer can throw an object to another person or easily talk to others; and (3) *vista space* extends beyond 100 feet. In personal space the most important depth cues are occlusion, binocular disparity, relative size, convergence, and accommodation. HMDs typically eliminate accommodation as a distance cue by placing all objects on a single focal plane. The primary distance cues in action space and vista space are the pictorial cues, including occlusion, height in the visual field, convergent linear perspective, relative size, and relative textural density. In addition two other distance cues, binocular disparity and motion perspective, are effective distance cues in action space. Comparing this model with obtained experimental results suggests that height in the visual field, convergent linear perspective, relative size, and binocular disparity are the most likely candidates for explaining the observed discrepancies between VE and real world judgements of distance.

The National Research Council (1997) has suggested that the restricted FOV provided by VE displays degrades height in the visual field and convergent linear perspective as cues for distance at some point. Relative size as a distance cue may be degraded as well. The limited vertical FOV found in most VE displays (ranging from 40 to 90 degrees) may be responsible for this degradation. By comparison, the real world vertical FOV is approximately 120 degrees. A reduced vertical FOV may result in distant objects appearing closer in VE than they would in the real world because these objects would be compressed into a smaller visual frame as they recede into the distance. Kline and Witmer (1996) showed that a reduced horizontal FOV can also adversely impact the accuracy of distance estimates by reducing or eliminating linear perspective cues. Because linear perspective cues are among the most effective distance cues in simulated environments (Surdick et al., 1997), reducing or eliminating these cues can have a major impact on the accuracy of distance estimates.

Simulator sickness is a real but manageable problem. Its reduction should be a major consideration in the design and development of a VE-based training system, and in determining the environment, activities, and duration of the trainee's first exposure to the VE.

Simulator sickness refers to unwanted side effects and aftereffects that may result from using simulators such as flight or driving training simulators. Symptoms include nausea, dizziness, and headache or eyestrain. Simulator sickness is a concern because it can potentially degrade training effectiveness and affect the well being of trainees. Kolasinski (1995) identified dozens of factors that previous research has indicated are involved in simulator sickness.

Simulator sickness symptoms in our program have been sufficiently severe that 5.6% of the participants withdrew before completing their experiment. Rates for individual experiments varied from 0% to 25%. Other researchers have reported withdrawal rates of 10% (Garris-Reif and Franz, 1995) and 0% to 5 % (Regan, 1995). Individuals have differed greatly in their susceptibility. Fifteen percent listed no symptoms, and 52% listed only mild symptoms. On the other hand, 4.6% rated at least one symptom as severe. Eyestrain was by far the most frequent symptom (reported by 54%), followed by general discomfort (46%) and fatigue (45%). Some level of nausea was reported by 22%. Nausea was rated severe more frequently (2.9%) than any other symptom.

Of particular relevance to the use of VE for training applications are the findings in previous research, indicating that, all other things being equal, a trainee is most susceptible to simulator sickness during the first session with a simulator. For most trainees, simulator sickness declines during subsequent sessions. Lampton, Kraemer, Kolasinski, and Knerr (1995), Lockheed Martin (1997), and Regan (1995) have all reported fewer and less severe symptoms of simulator sickness with subsequent sessions. Consequently, early training sessions, in particularly the first session, should be carefully structured to avoid conditions that are likely to produce symptoms. The first session should:

- Be brief (inoculate against the simulator sickness)
- Be designed to minimize sickness-producing activities such as rapidly slewing the field of view, collisions, and viewing objects at very short distances.
- Avoid depicting self movement not under the participant's control.

RESEARCH ISSUES

The research on the use of VE for dismounted soldier simulation that has been conducted has identified a number of new research issues. The more important ones are described briefly below.

Visual display field of view and performance. Based on our observations, small FOV display devices increase disorientation and reduce the efficiency of spatial learning in VE, and probably are responsible for poor distance perception in VE. Research is need to confirm these observations, and to determine the most appropriate FOV for dismounted soldier training.

Separation of orientation and distance in locomotion simulation. There are methods for locomotion that maintain a constant relationship between real world and VE orientation (Templeman, 1997; Grant and Magee, 1997; Singer, et al., 1998; Lockheed Martin, 1997). The user turns in place in the VE as he or she would in the real world, and therefore receives the same kinesthetic and vestibular cues as in the real world. This aspect of the interface can be used in conjunction with a variety of techniques for moving forward, backward, or sideways. There is no research, which assesses the relative contributions of these more realistic turning and movement cues to distance estimation, route learning, or configuration learning.

Cognitive demand of VE interfaces. The cognitive demand imposed by various VE interfaces requires investigation. No research has been conducted which looks at the extent to which the different methods of interaction demand the attention of the user and, therefore, are likely to detract from training effectiveness. Locomotion is the major interface that should be investigated, but certainly not the only one

Compensatory distance cues. Compensatory auditory cues improved distance estimation performance in one experiment (Witmer and Kline, 1998). It is not known how long the effects of these cues would persist if they were removed, or how well they would transfer to different tasks in the same environment, or to similar environments.

Training strategies for spatial learning. Darken and Siebert (1993, 1996) and Wilson et al. (1997) have shown that VEs can effectively train configuration knowledge, but additional work is needed to determine how VEs can be used to their best advantage in training this type of spatial knowledge. While wider FOV VE displays and more natural VE movement paradigms would alleviate some of the spatial disorientation that occurs in VEs, other alternatives for reducing VE disorientation should be investigated.

VE technology improvements and simulator sickness. Simulator sickness may decrease with improvements in the speed and accuracy of head tracking and image rendering systems, the design and alignment of HMDs, and our knowledge of how to use VE training systems. Alternatively, it may increase as the VE experience approaches, but does not equal, real world experience. The need for simulator sickness research is highly dependent on the outcome of this issue, yet there is not sufficient data to determine whether technological improvements are having an effect on simulator sickness.

SUMMARY

VE can be used effectively to train spatial knowledge and cognitive skills that have a spatial component, such as ship handling. It is not currently recommended for training psychomotor tasks that involve precise or rapid motor activity. This includes training tasks that require accurate use of individual weapons. Systems that use HMDs are also not recommended for tasks that require rapid head movements. Low-end HMDs provide poor visual resolution, and are not appropriate where successful task performance or training require fine visual discriminations, such as identifying targets at long distances. For tasks requiring accurate estimation of distance, use the largest FOV display device available. Both horizontal and vertical FOV may be important. Also consider using compensatory cues or some similar method for calibrating distance judgments in the VE.

The process of moving through the VE should require minimal attention on the part of the user. If the task requires use of the hands to perform other tasks while moving, then some form of foot-based locomotion control will be required. Otherwise, a well-practiced method that is not like the real world (such as a joystick) may be preferable to a novel method which is more similar to actual walking. Trainees should always receive training and practice in the use of the VE interface before they begin training on the target task or tasks.

Simulator sickness is a real but manageable problem. Its reduction should be a major consideration in the design and development of a VE-based training system, and in determining the environment, activities, and duration of the trainee's first use of the VE.

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