TRAINING DISMOUNTED SOLDIERS IN VIRTUAL ENVIRONMENTS: ROUTE LEARNING AND TRANSFER

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ABSTRACT

The U.S. Army Research Institute is conducting a research program with the goal of using virtual environments (VE) to train dismounted soldiers. To accomplish this goal, the conditions necessary for transfer of training from VE to real world environments must be identified. This paper reports the results of two experiments investigating the use of VE for training spatial knowledge as it relates to learning routes through large buildings. This task is especially relevant to a hostage rescue situation or other missions performed by special operations forces. Both experiments used the same highly detailed computer model of a large office building. In the first experiment, 60 college students first studied directions and photographs of landmarks for a complex route, then rehearsed the route using either the VE model, the actual building, or verbal directions and photographs. Everyone was then tested in the actual building. Building-trained students made fewer wrong turns and travelled less distance than did VE-trained students, who in turn made fewer wrong turns and took less time to traverse the route than did verbally-trained students. In the second experiment, 64 students practiced a different route using either a landmark-oriented or a left/right direction-oriented instructional strategy, and with their field of view either linked solely to body orientation or controlled by both body orientation and head movements. These data indicate that the use of an instructional strategy that increases the amount of exploration of a VE tends to improve route learning. The use of head tracking, however, had no effect on learning. The results indicate that individuals can learn how to navigate through real world places by training in a VE. While the building model was not quite as effective in training subjects as the actual building, it was much better than verbally rehearsing route directions. The results also suggest that instructional strategy is an important determinant of learning in a VE.

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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 armored vehicles, not on dismounted soldiers fighting on foot. Currently DIS does not train dismounted soldiers well, nor does it represent their contribution to the outcome of simulated battles.

We believe that the dismounted soldier can be integrated in the DIS simulated battlefield through the use of virtual environments (VE) technology. Our goal is to determine, through a comprehensive research program, how to best use VE to train dismounted soldiers to perform combat related tasks and to include their contribution to combat outcomes in DIS. To accomplish this goal, the conditions necessary for transfer of training from VE to real world environments must be identified. This paper will report the results of two experiments investigating the use of VE for training spatial knowledge as it relates to learning routes through large buildings. This task is especially relevant to a hostage rescue situation or other missions performed by special operations forces.

VE RESEARCH PROGRAM

The overall scheme for our research program is shown in Figure 1, the Virtual Environment Research Pyramid. The figure shows our research program as a sequential progression from the base to the tip of the pyramid. At the base of the pyramid are task requirements for dismounted soldier training as reported by Jacobs, Crooks, Crooks, Colburn, Fraser, Gorman, Madden, Furness, & Tice (in press). The next level represents previous research in the use of VE for training. Only a few published studies discuss empirical findings in using VE for training (Regian, Shebilske & Monk, 1993; Knerr, Goldberg, Lampton, Witmer, Bliss, Moshell, & Blau, 1993; Kozak, Hancock, Arthur, & Chrysler, 1993). The third level of the pyramid represents four experiments that investigate psychophysical and psychomotor capabilities of observers performing simple tasks in VE. We reported the results of two experiments at this level at the 15th I/ITSEC (Knerr at al., 1993). Research at the fourth level of this pyramid includes two experiments that address the use of VE to teach spatial knowledge, particularly the configuration of and routes through large buildings. The procedures and findings of these two experiments are the subject matter of this paper. At the fifth level, we will evaluate the use of VE to represent exterior terrain, both for training land navigation skills and for applying those skills in the conduct of mission rehearsals and combat simulations. Research at the sixth level will involve the use of VE for tasks that require situational awareness, i.e., complex tasks performed in a changing environment, such as searching for a landmark or a moving object. The top level, team situational awareness, explores the same tasks as level six, but requires communications and cooperation among team members.

LEARNING ABOUT PLACES AND SPACES

Regian, Shebilske, & Monk (1993) list two characteristics of VE that indicate its potential value for training: (1) the VE interface preserves the visual-spatial characteristics of the simulated environment; and (2) the VE interface retains the linkage between motor actions of the participant

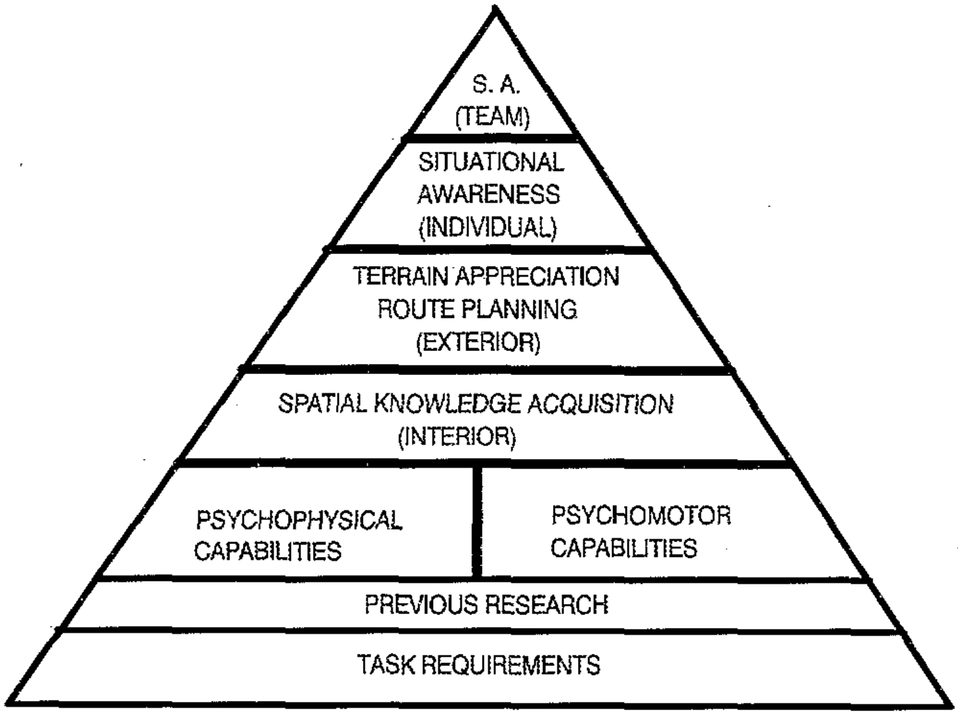

FIGURE 1. THE VIRTUAL ENVIRONMENT RESEARCH PYRAMID

and resulting effects in the simulated environment. These characteristics suggest that VE should be an effective medium for teaching individuals how to find their way around unfamiliar places such as cities or buildings. Because VE preserves the spatial relations and allows you to actively survey the environment through simulated movement and vision, we expect the spatial relationships learned in VE to transfer to the real world environment.

Considerable theorizing and research have been done in order to understand how humans learn to find their way around cities and other complex environments. Nearly a half century ago, Tolman (1948) suggested that animals learned by using a cognitive map. While controversial at the time, Tolman's notion that cognitive maps are instrumental in learning about places is now widely accepted (Lynch,1960; Evans, 1980; Siegel 1981). Siegel and White (1975) suggest that a person's knowledge of spaces generally begins with noticing and remembering landmarks. Landmarks are ".... the strategic foci to and from which one travels" and they help the traveler stay on course (Siegel and White, 1975). Routes linking the landmarks are formed while acting in the context of these landmarks. With sufficient experience in following routes, an overall gestalt of a city, neighborhood, or building may be formed. This gestalt consists of routes and landmarks interrelated in network-like assembly which is or becomes configurational.

A landmark is a unique pattern of perceptual events at a specific geographic location. Lynch (1960) suggests that the number, type, and distinctiveness of landmarks in an environment influences how well individuals can find their way from one place to another in that environment.

Route knowledge consists of the procedural knowledge required to successfully traverse a path between an origin and a destination (Golledge, 1991). It consists of explicit representation of points along the route where turns occur and the actions to be taken at each one. Routes may be learned by associating changes in bearing with landmarks at intersections or choice points (Siegel and White, 1975). The difficulty of learning a route has been shown to vary with the route length, the number of changes in route direction, and the number of route choices at each choice point (Best, 1969). Active exploration of one's environment usually results in the acquisition of routes over a period of time. In some cases, however, routes may be learned more quickly with the aid of maps, written and verbal directions, or both.

The usefulness of using maps, landmarks, and verbal directions for learning about real world spaces has been studied extensively (Canter, 1977; Streeter, Vitello and Wonsiewicz, 1985). The usefulness of these variables in VE, on the other hand, is largely unknown. We performed two experiments to determine the extent to which these variables and others contribute to learning about spaces and places in a VE. The performance of participants trained to follow a specified route in a VE (VE Group) was compared to the performance of participants who were trained in the actual building (Building Group), and to the performance of participants who were trained using only verbal instructions and photographs of landmarks (Symbolic Group). The Building Group and the Symbolic Group served as control groups against which to evaluate the effectiveness of the VE as a training medium. The Building Group was included to determine the best performance that could be expected from naive participants with limited route study and route rehearsals. The Symbolic Group was included to determine how less expensive representations of the building route compared to VE as a training alternative. Half of each group was allowed to study a map in order to evaluate the contribution of map study to learning for each training medium.

MATERIALS

Both experiments used the same highly detailed computer model of a large office building. The University of Central Florida Institute for Simulation and Training (IST) modeled the four-floored building in great detail using Multigen by Software Systems and WorldToolKit by Sense8 Corporation. The completed building model, comprising areas on three floors of the building, consists of over 40,000 flat-shaded polygons, many of which are texture mapped and capable of dynamic behavior. The simulated building was run on a Silicon Graphics Crimson Reality Engine. The model is very rich in detail and includes all of the most prominent landmarks, many of the office furnishings, and many other details including overhead lights, baseboards, and exit signs.

Participants in Experiment 1 used the Fakespace Labs two-color BOOM2 high resolution display from a standing position to view and control their movement through the VE, while seated participants in Experiment 2 used a joystick to move, and viewed the VE through the low resolution Flight Helmet, an HMD designed by Virtual Research.

EXPERIMENT 1. TRAINING TRANSFER

Procedure

In the first experiment 30 male and 30 female participants first studied written directions and photographs of landmarks for a complex route, either with or without a map, then rehearsed the route using either the VE model (VE Group), the actual building (Building Group), or verbal directions and photographs (Symbolic Group). Participants were limited to 15 minutes for reviewing the route study materials. Each participant then rehearsed the entire route three times, with unlimited rehearsal time. Following rehearsal, we tested all participants for their knowledge of the route by asking them to traverse the route in the actual building. Participants were stopped and informed that they had taken a wrong turn each time that they deviated from the prescribed route. The experimenters recorded the number of attempted wrong turns and the total time to traverse the route. Total distance traversed was also recorded using a pedometer.

Results

The primary objective of this research was to assess differences in training transfer as a function of rehearsal mode (Group effect). These differences were evaluated using a Multivariate Analysis of Variance (MANOVA) with Rehearsal Mode, Map, and Gender as the independent measures. Only the main effect for Rehearsal Mode was significant, both overall, $p<.001$, and for each of the dependent measures: route traversal time, $p<.001$; number of wrong turns, $p<.001$; and total distance travelled, $p<.05$. Participants trained in the building made fewer wrong turns, $p<.05$, and travelled less distance, $p<.05$, than did subjects who were trained in the VE. VE participants, in turn, made fewer wrong turns, $p<.01$, and took less time to traverse the route, $p<.01$, than did participants who were trained symbolically. These means are summarized in Figure 2.

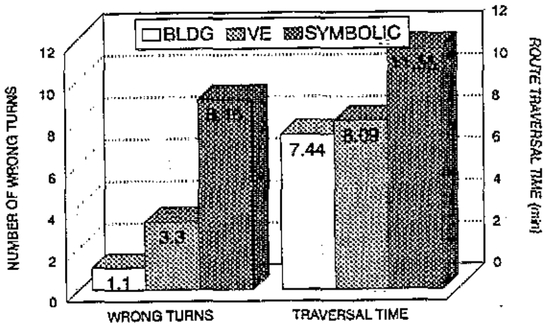

FIGURE 2. WRONG TURNS AND ROUTE TRAVERSAL TIME AS A FUNCTION OF TRAINING MODE

The finding that the VE Group performed significantly better than the Symbolic Group indicates that training transfer from VE to the real world occurred, but small significant differences between the VE Group and the Building Group suggests that the transfer was not perfect. The advantage of VE as a training medium for training spatial skills is clear when you consider that the Symbolic Group made nearly three times as many wrong turns as the VE Group and took almost four minutes longer to traverse the route on the training transfer test. For cases where it is impossible or impractical to train in the actual environment, VE appears to be an excellent alternative.

A look at performance across the three rehearsal trials (see Figures 3 and 4) provides insight about the change in performance for the various training media groups, and may explain why the VE Group did not do as well on the transfer test as the Building Group.

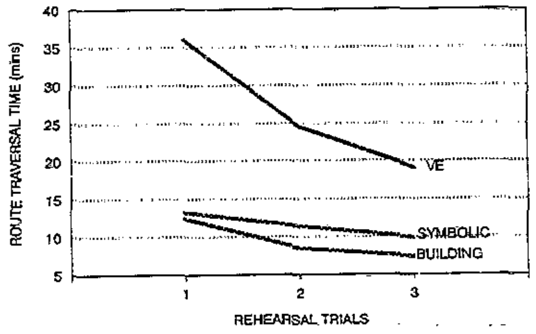

FIGURE 3. ROUTE TRAVERSAL TIME AS A FUNCTION OF NUMBER OF REHEARSAL TRIALS AND TRAINING MEDIUM

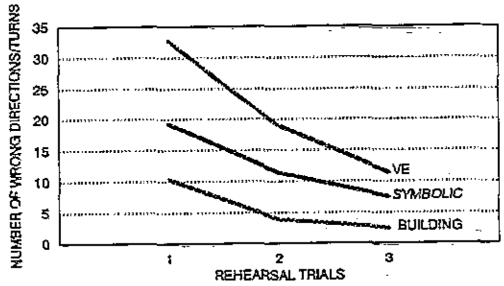

FIGURE 4. ROUTE TRAVERSAL ERRORS AS A FUNCTION OF NUMBER OF REHEARSAL TRIALS AND TRAINING MEDIUM

Route rehearsal times for the VE Group as shown in Figure 3, are significantly slower than the rehearsal times of the Symbolic and Building Groups, $p<.01$, as revealed by post hoc contrasts. Also, the learning curve of the VE Group has a steeper slope than learning curves of the Symbolic and Building Groups, $p<.01$. VE Group rehearsal times decrease across trials at a faster rate.

The differences in rehearsal times and the slope of the learning curves may be attributed to the skill requirements imposed by each of the training environments. Participants in the Symbolic and Building groups were not required to learn any new skills in addition to learning the route. The VE participants, however, in addition to learning the route, were required to learn how to maneuver in the VE using the BOOM2. Learning how to negotiate a winding stairway and how to maneuver away from walls after a collision using the hand controls on the BOOM2 may account for the slower rehearsal times and steeper learning curve observed for the VE Group.

This experiment answered several questions regarding the effectiveness of VE for teaching individuals about places. It clearly demonstrated that navigation skills learned in a well-designed VE transfer to the real world. It also showed that some characteristics of today's VEs can slow the course of learning when compared to training in real world environments.

However, this experiment left many issues unresolved. For example, is it necessary to use a high resolution display device to train routes through a building as was the case in this experiment or might a lower resolution device be as effective? Is it necessary to couple head movements to a changing view for effective training or might the same result occur using a joystick to "look around"? Finally, can the amount of learning in a VE be increased by instructions that are designed to increase exploration of that environment?

EXPERIMENT 2. INSTRUCTIONAL STRATEGY AND CONTROL

Procedure

In the second experiment, 32 male and 32 female participants rehearsed a circuitous route in the VE using an instructional strategy either based on following successive landmarks (exploratory instructions) or following left/right style directions (restrictive instructions). The attention of participants who used the landmark-based strategy was directed toward paintings on the wall or to other landmarks strategically located at the intersection of hallways. Participants' field of view (FOV) was either linked solely to body orientation (controlled by joystick manipulation) or controlled by both joystick manipulation and head movements (i.e., coupled to head movements via a head tracking device). Following rehearsals, all participants completed route knowledge and building configuration knowledge tests. Route knowledge was measured in two ways: (1) by recording time, attempted wrong turns, and distance traveled as participants traversed the route using a joystick and CRT display; and (2) by recording each participant's score on a route photograph ordering task. For the latter measure, participants placed a series of randomly ordered photographs taken along the route in the actual building in the correct order.

Results

Photograph Ordering Test. A 2 x 2 between subjects analysis of variance was performed on the photograph ordering test data. A participant's score was the rank-order correlation between the participant's ordering of the photos and the true photo order. The independent variables were instructional strategy (exploratory and restricted) and head-tracking (tracking and no tracking).

The only significant effect was instructional technique, $\underline{p}<.05$. The exploratory instruction group ($\underline{M}$ = .68) had significantly higher correlation scores than the restricted instructions group ($\underline{M}$ = .57). This indicates that the exploratory instruction resulted in better recognition of real-world photographs and superior ability to place the photographs in order as they occurred along the route.

Route Traversal Test. Because the raw data for the route test did not follow a normal distribution, a natural log transformation was used to normalize the data before performing the statistical analysis. A 2 x 2 between subjects multivariate analysis of covariance (MANCOVA) was performed on the transformed data for the number of wrong turns and traversal time. The independent variables were instructional technique (exploratory and restricted) and head-tracking (tracking and no tracking). The covariates were participants' scores on a test of spatial ability (paper-folding test) (Ekstrom, French, Harmen, & Dermen, 1990) and their reported confidence in using computers.

A Multivariate Analysis of Variance (MANOVA) showed that combining the number of wrong turns with route traversal time yields a significant effect for instructional technique, $\underline{p}<.01$, but not for head-tracking. There was no significant interaction.

Instructional technique significantly affected route traversal time, $p<.05$, but not the number of wrong turns. Participants who had exploratory instructions traversed the route significantly more slowly (M = 4.85 min.) than participants who had restricted instructions (M = 4.29 min.). These results are opposite to what one would expect if the exploratory instructions had resulted in superior learning of the route (e.g. one would expect them to move smartly through the route without lingering or hesitating). It is possible that the exploratory participants were more cautious or deliberate in traversing the route. This possibility is supported by the fact that the number of wrong turns made by the exploratory group was less than the number made by the restrictive group; however, as noted above this difference was not statistically significant.

Route Traversal Test Without Sick Participants. The route traversal test data was reanalyzed using MANCOVA with the data from any participants who had experienced moderate or severe simulator sickness symptoms removed. The combined number of wrong turns and route traversal time was significantly affected by instructional technique, $p<.01$, but not by head-tracking. An investigation of the means revealed that the significance of the combined variables was likely due to a trade-off of route traversal time and wrong turns. Participants who had exploratory instructions traversed the route more slowly (M = 4.69 min.) than restrictive participants (M = 4.23 min), but the exploratory participants made fewer wrong turns (M = 3.21) than the restrictive participants (M = 4.08). The results are shown in Figure 5.

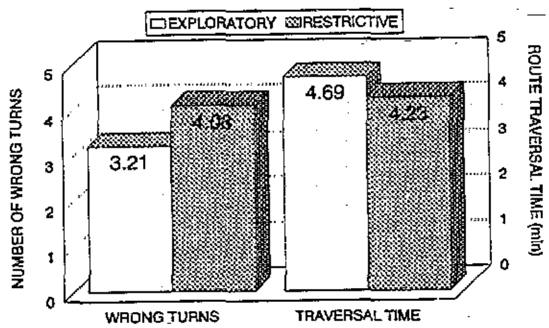

FIGURE 5. WRONG TURNS AND ROUTE TRAVERSAL TIME AS A FUNCTION OF INSTRUCTIONAL STRATEGY

MEASURING SIDE EFFECTS

Simulator Sickness

In both experiments we administered a self-report measure of simulator sickness, the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lillienthal, 1993). The SSQ measures three dimensions (Oculomotor Discomfort, Disorientation and Nausea), each consisting of several related factors that represent symptoms associated with sickness in simulators, as well as an overall Total Severity score. Symptoms include eyestrain, difficulty focusing, blurred vision, headache, dizziness, vertigo, nausea, stomach awareness, salivation and burping. Knerr, et al. (1993) have shown that VE can produce significant simulator sickness that may exceed that produced by standard aircraft simulators.

Figure 6 shows the simulator sickness profiles for participants who completed each of the two experiments. Four of 24 VE Group participants in Experiment 1 and 11 of 75 participants who started Experiment 2 could not complete the experiment because of simulator sickness. Participants who dropped out appeared to have much higher Nausea scores than those who did not.

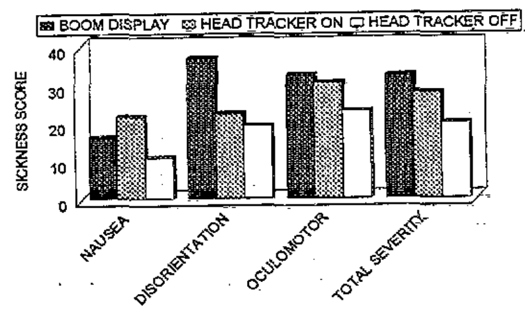

FIGURE 6. SIMULATOR SICKNESS SUBSCALE AND TOTAL SCORES

The Total Severity scores were higher in Experiment 1, probably because of the longer exposure to the VE, but also because the head movements of half of the participants in Experiment 2 (those participants without head tracking) did not change their field of view. In Experiment 2, the group with head tracking (M = 21.76) reported significantly more Nausea, $F(1, 60) = 4.01$, $p<.05$, than the group without head tracking (M = 10.74). Also, of the 11 participants who were unable to complete Experiment 2 due to simulator sickness, eight were in the head tracking condition and three were in the no head tracking condition. Note that the group using the Flight Helmet with head tracking experienced slightly more Nausea than the participants who had the BOOM2 display, despite longer exposures for the latter. Greater lags between the initiation of movement and scene change for the participants using the HMD with head tracking, coupled with more head movement, may be responsible for the differences in Nausea among the groups. Another difference that might account for the higher Nausea scores in the group who had head tracking was that some frames were intentionally dropped out to reduce the perceived lag that would otherwise occur when the participants quickly turned their heads.

Presence

Presence may be defined as the subjective experience of being in one place when you are physically in another (Witmer & Singer, in press). The amount of presence experienced in a particular environment may depend on a number of individual and environmental factors, including the degree, immediacy and naturalness of control experienced by the user, the degree to which the user perceives movement, consistency of information across modalities and with the objective world, attention to external distractions, and ability to modify the physical environment (Sheridan, 1992; Held and Durlach, 1992). Witmer and Singer (in press) have developed a questionnaire, incorporating these factors and others, to measure presence in VEs. We administered this Presence Questionnaire (PQ) to participants in both experiments following their exposure to the virtual building model. The mean presence score reported in Experiment 1 using the BOOM2 device was M = 144.55. The presence scores reported in Experiment 2 using the Flight Helmet differed slightly for those participants who had head tracking (M = 143.84) and those who did not (M = 139.63).

Experiment 1 and Experiment 2 PQ scores were significantly negatively correlated with Simulator Sickness scores, $r = -.60$, $p<.01$, and $r= -.35$, $p<.005$, respectively. This finding is contrary to the prediction of researchers (e.g., Kennedy, Lane, Lillienthal, Berbaum, & Hettinger, 1992) who equate high levels of presence to increases in simulator sickness. Consistent with our finding, one might expect participants who focus on feelings of discomfort due to simulator sickness to be less immersed in VE than someone who is not feeling sick and can concentrate more on other aspects (e.g., images, sound, task characteristics) of the VE.

In Experiment 2, neither head tracking nor type of instructions had a statistically significant effect on the amount of presence reported on the PQ. The additional simulator sickness experienced by the participants who had head tracking may have moderated the differences in presence that might be expected as a function of head tracking. The mean values of presence reported in the two experiments were nearly equal, indicating that the type of display used was not a strong determinant of presence.

DISCUSSION

In a recent movie, VEs were portrayed as presenting information in a way that resulted in very rapid knowledge acquisition. The VE was so effective that a character in the movie was transformed from a simpleton to a genius in a matter of months. In reality, there is no evidence to suggest that learning occurs more rapidly in a VE than it would in the real world. Knerr et. al. (1993) have presented data that show that performance of psychomotor tasks trained in a VE improves with additional practice in that environment. While Regian, Monk, & Shebilske (1993) have provided some evidence that real world skills can be trained in a VE, Kozak, et. al. (1993) were unable to demonstrate transfer from the VE to the real world. Regian, Shebilske, & Monk (1993) compared the effectiveness of using a 2-D "God's eye view" of a building for training configuration knowledge with a virtual reality representation of that same building. Tests of navigation in the real building tended to favor the 2-D representation, but the differences in the two training conditions were small. Regian, however, did not compare the effectiveness of VEs with a real world environment as a training medium. And previous work has done little to identify the conditions that influence learning in a VE.

Experiment 1 clearly demonstrates positive training transfer from a VE to the real world, and also shows the effectiveness of the

VE as a training medium compared to the real world environment. Experiment 2 shows that instructions that encourage exploration may enhance learning in a VE. In addition it was clear that route learning occurred in Experiment 2 despite the poor resolution (approximately 16 arc minutes per pixel) of the Flight Helmet.

Both experiments support the observation that VE can produce significant simulator sickness. Note that simulator sickness occurred despite differences in type of display device (head-mounted vs boom-mounted) and body posture (sitting vs standing). Total Severity scores and scores on two of the subscales were higher in Experiment 1, possibly due to the longer exposures to VE in that experiment. Nausea seems to be less affected by length of exposure, and participants who experience significant Nausea often report feeling nauseous in the first few minutes that they are in the VE.

The amount of presence reported in Experiment 2 was about the same as reported in Experiment 1 despite differences in control and display devices. The amount of presence reported was slightly less for participants who did not have head tracking, which suggests that presence may be affected by that factor.

IMPLICATIONS FOR DISMOUNTED SOLDIER TRAINING

This research has demonstrated that spatial skills learned in a VE transfer to the real world. Thus, we may create virtual models of enemy terrain or other strategic sites, and dismounted infantry can learn about the terrain or site without ever having set foot on enemy territory. This will allow our soldiers to rehearse a mission without compromising their safety or security. We have seen that VE incorporating low resolution displays can train effectively, and that spatial learning without head tracking may be just as effective as learning with head tracking, and may produce less simulator sickness. It remains to be seen whether systems with head tracking that produce less lag are more training effective than are systems that do not incorporate head tracking.

IMPLICATIONS FOR FUTURE RESEARCH

When the task is to learn routes, configurations, and other spatial skills, it should not be necessary to do a separate transfer study each time that a new VE is developed if the following conditions exist: (1) the VE being considered is a reasonably close approximation of the actual environment; and (2) there are not characteristics (e.g., larger lags) of the simulation that would grossly interfere with learning. In conducting future VE training research, it would be wise to remember that VEs that require participants to acquire new skills in addition to the primary task will slow the course of learning in those environments. Researchers might also try to minimize the amount of head movement if the VE under study produces high rates of simulator sickness.

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