Int. J. Human–Computer Studies (1996) **45,** 413–428

Virtual spaces and real world places: transfer of route knowledge

Bob G. Witmer,† John H. Bailey‡ and Bruce W. Knerr

U.S. Army Research Institute Simulator Systems Research Unit, 12350 Research Parkway Orlando, FL 32826, USA, email: witmerb@stricom.army.mil/baileyj@stlvm27.vnet.ibm.com/knerrb@stricom.army.mil

Kimberly C. Parsons

University of Central Florida Institute for Simulation & Training, Orlando, FL 32826, USA, email: kparsons@vsl.ist.ucf.edu

(Received 27 June 1995 and accepted in revised form 22 May 1996)

It has been widely suggested, but rarely demonstrated, that virtual environments (VEs) are effective training media. The purpose of this investigation was to evaluate how well a VE model of a complex office building trained individuals to navigate in the actual building. Sixty participants studied route directions and landmark photographs, then rehearsed the route using either the VE model, the actual building, or verbal directions and photographs. The VE model was presented in real time via a head-tracked display. Half of the participants in each rehearsal group also studied route maps. Everyone's route knowledge was then measured in the actual building. Building configuration knowledge was also measured. VE rehearsal produced more route knowledge than verbal rehearsal, but less than with rehearsal in the actual building. Type of rehearsal had no effect on configuration knowledge. Map study influenced neither route nor configuration knowledge. These results suggest that VEs that adequately represent real world complexity can be effective training media for learning complex routes in buildings, and should be considered whenever the real world site is unavailable for training.

1. Introduction

There are a limited number of ways by which we may learn about real world places. These include directly experiencing the place by being there, learning about the place via symbolic representations (e.g. maps, photos, videotape, and verbal descriptions or instructions), or through simulations. Simulations require participants to perform the same activities, or some part thereof, that they will need to perform in the real environment. At one end of the simulation spectrum, a hypothetical situation is presented that requires participants to rehearse activities (e.g. information gathering, planning, problem solving, decision making, and issuing orders) that are necessary to perform the real world task. The participants typically do not receive direct perceptual information about the situation and are informed mainly by verbal information. Samurçay and Rogalski (1993) have employed this

† Author for correspondence.

‡ Present address: IBM Santa Teresa Laboratory, San Jose, CA, USA.

1071-5819/96/100413 + 16$18.00/0

type of simulation in their emergency management research with high ranking fire safety officers. At the other end of the spectrum are simulation devices (e.g. flight simulators) that provide realistic visual, aural, and physical stimulation to participants during task rehearsals.

Virtual environments provide another means of simulating real world places and activities. A Virtual Environment (VE) is a computer-generated simulated space with which an individual interacts. Typically individuals control what they experience in a VE by moving their head or limbs or through voice commands, and the VE responds, providing three-dimensional visual, localized audio, and tactual stimuli through interface devices. The VE interfaces employed determine which senses are stimulated, while the quality of the stimulation depends on the sophistication of the VE hardware, software, and interface devices. VEs may convey information about real world places effectively because they tend to preserve the spatio-temporal aspects and natural modes of interaction characteristic of real world environments.

While we focused on VEs as surrogates for teaching people about the physical arrangement of real world spaces, this is only one of many potential training applications of VEs. VEs can also be used to represent physical spaces which do not exist or are inaccessible in the real world, or to represent abstract or non-physical concepts. For example, we may develop and immerse ourselves in complex virtual environments that are too small to enter (e.g. atomic structures, living cells, or an ant colony), too remote or dangerous to explore physically (e.g. the surface of Mars or a hazardous waste dump), or which do not exist in a physical form (scientific or financial data, or equipment which has not yet been built). VE surrogates for real world places are most useful when it is not possible, practical, or safe to use the actual physical location to train. VE surrogates can provide the means to train military units or police officers to rescue hostages, firefighters to extinguish fires in large buildings, or astronauts to repair satellites in space.

In this paper, we examine the usefulness of one such VE, a model of a large office building, for training route knowledge, and we assess how well this knowledge transfers to the real world setting. We also examine the potential for VEs to induce presence and simulator sickness and determine how these phenomena affect transfer of training. To better evaluate the training effectiveness of the VE, we compare the performance of participants who rehearsed the route in the VE with those who rehearsed in a higher fidelity environment (the real building) and with those who rehearsed using a lower fidelity medium (verbal description of the route and landmark photos).

1.1. LEARNING AND TRANSFER IN VIRTUAL ENVIRONMENTS

When we completed our investigation, only a few studies had explored the training potential of VEs (Regian, Shebilske & Monk, 1992; Kozak, Hancock, Arthur & Chrysler, 1993; Lampton, Knerr, Goldberg, Bliss, Moshell & Blau, 1994; Loftin *et al.* 1994). Initial experiments investigating the training potential of VE technology demonstrated how task performance improves with practice, but did not determine how skills acquired in a VE affect real world performance (Regian *et al.,* 1992; Lampton *et al.,* 1994). Kozak *et al.* (1993) found that learning a simple psychomotor pick-and-place task in a VE had no effect on performance of the same task in the real world. The VEs used by Lampton *et al.* and Kozak *et al.* were relatively small austere environments designed for training simple psychomotor skills. The VEs used by Regian *et al.* (1992) were small and relatively simple environments, designed for training procedural or spatial knowledge. Loftin *et al.* (1994) created a larger and more complex VE by modeling the Hubble telescope and shuttle cargo bay, though neither the size of that VE nor the amount of visual detail was comparable to the building model developed for this investigation. Of the VEs discussed above, only this building model was evaluated for training transfer to the real world.

Subsequent to our investigation, several other researchers evaluated training transfer from VE to the real world. Johnson and Wightman (1995) demonstrated that Army pilots could navigate a heliport in a minimum of time after being trained in a VE model of the heliport. Bliss, Tidwell and Guest (1995) showed that civilian firefighters could follow a route through a building to perform a rescue and exit via a different route after training in a VE model of that building. Preliminary results suggest that VE training can also enhance the performance of shipboard firefighters under low visibility conditions (L. Sibert, pers. comm.).

1.2. ACQUIRING SPATIAL KNOWLEDGE OF REAL WORLD PLACES

Siegel and White (1975) suggest that a knowledge of spaces begins with noticing and remembering landmarks. Routes linking the landmarks are formed while acting in the context of these landmarks. Route knowledge consists of the procedural knowledge required to successfully traverse distances between origins and destinations (Golledge, 1991). It consists of explicit representation of points along the route where turns occur and the direction of those turns. Implicitly, it also represents route distances, orientation cues, and ordering of landmarks (Goldin & Thorndyke, 1981). The difficulty of learning a route varies with the route length, the number of changes in route direction, and the number of route choices at each choice point (Best, 1969). Usually routes are learned by active exploration of one's environment, but they may be learned more quickly with the aid of symbolic media such as maps (Thorndyke & Hayes-Roth, 1980), or verbal directions (Streeter, Vitello & Wonsiewicz, 1985).

With sufficient experience in following routes an overall gestalt of the building or city is formed. This gestalt, or configuration, refers to the way in which spaces are related to one another, not only pairwise but also with respect to the overall pattern that they constitute (Peponis, Zimring & Choi, 1990). Configuration knowledge can accumulate incrementally as the result of repeated direct experience with an environment, or it can be learned directly from a map (Evans & Pezdek, 1980). A learning hierarchy in which configuration learning succeeds and depends on route knowledge, and route learning succeeds and depends on recognizing landmarks, provides the basis for a model of how spatial representations are acquired.

1.3. MEASURING THE ACQUISITION OF SPATIAL KNOWLEDGE

Landmark knowledge is usually assessed by asking observers to recognize or recall the landmarks that they have seen along a route (Evans, 1980). Measures of route knowledge include verbal recollections of spatial experiences (Lynch, 1960), number of wrong turns and route traversal times (Streeter *et al.,* 1985), the number of individuals who lose their way (Best, 1969), and arrangement of photos of route segments and landmarks in their correct order (Evans, Skorpanich, Garling, Bryant & Bresolin, 1984).

Frequently, configuration knowledge is measured by asking learners to sketch an area map (Lynch, 1960; Appleyard, 1970). However, these maps are difficult to score, and may underestimate the knowledge acquired (Siegel, 1981). Another measure, the projective convergence technique (Siegel, 1981), requires participants to estimate the bearing and distance to landmarks obscured from view from three different sighting locations.

1.4. ACQUIRING KNOWLEDGE OF VIRTUAL SPACES

Hypothetically, the processes used to learn routes and configurations in the real world should be operative in virtual spaces. Currently, however, VEs have deficiencies that may reduce their training effectiveness relative to what would be obtained in the real world, thereby diminishing training transfer. The visual stimulation provided by VE display devices is deficient in that the user's ability to resolve detail and the field of view (FOV) are reduced in the virtual environment. The inability to resolve detail may result in poor distance discrimination, while the reduced FOV may affect distance discrimination and contribute to spatial disorientation. A reduced FOV tends to increase the number of collisions, thereby distracting participants from their primary task of learning the route. Participants also may become disoriented following a collision because they must back away from the wall to continue.

Another factor that may affect spatial skills in VE is the mode of locomotion. Many implementations of VEs, including this one, use standard input devices (e.g. mouse, joystick) to move through the virtual space. Hence voyagers moving through the VE do not receive the kinds of proprioceptive feedback that they normally receive in the real world. This might affect their ability to judge how far they have traveled in each direction in the VE. Finally, some individuals may experience simulator sickness when moving through a VE (Lampton *et al.,* 1994). Simulator sickness symptoms include nausea, disorientation, dizziness and eyestrain. Experiencing such symptoms may distract users from learning about the virtual space. Some symptoms could persist and carry over to the real world and impair performance there. This might not only affect training transfer, but may also impair post-experimental activities, such as operating a motor vehicle.

On the positive side, Held and Durlach (1992) have suggested that VEs, by eliciting a strong sense of "being there", or *presence,* may enhance learning and performance of some tasks. Witmer & Singer (1994) define presence as the subjective experience of being in one place when one is physically in another. Many factors known to affect learning and performance, such as selective attention, meaningfulness and coherence of the stimulus array, and the number and types of senses stimulated, also may affect presence. Increased presence may indicate more intense focus or concentration on the task to be learned and more involvement with the learning environment. VEs increase presence by allowing users to interact more naturally and directly with the simulated environment, by immersing users so that they perceive they are inside the virtual space, and by minimizing outside distractions. These same factors should also improve learning and performance. Thus, we might reasonably expect that presence in VE would be related to learning and performance. Supporting this expectation, Witmer and Singer (1994) found significant correlations between how much presence was reported and performance on several VE psychomotor tasks.

1.5. ACQUIRING SPATIAL KNOWLEDGE FROM SYMBOLIC REPRESENTATIONS

Symbolic media typically do not provide the quantity or quality of information provided by a sophisticated VE. When the number of direction changes is small and the landmarks are very distinctive, written or verbal directions describing direction changes and landmarks may suffice for learning a route. With more complex routes, however, route directions may need to be supplemented with route photographs or maps. Maps provide an overall view of the route and can efficiently convey knowledge of the building configuration. None of these symbolic media, however, provide the direct natural interaction or the continuous visual feedback provided by the actual building or by the VE.

2. Method

2.1. PARTICIPANTS

The participants were 34 female and 30 male University of Central Florida students, who had no previous experience in the learning environment. Students could select either monetary compensation or class credit for participating. Four female participants were unable to complete the research.

2.2. EQUIPMENT AND MATERIALS

The focal point of this research was a large office building (approximately 117 950 square feet or 10 958 m^2). A complex route (1500 feet or 457 m in length) wound along corridors on three floors of the building leading to six destinations in two office suites. There were 41 directional changes and 47 two-choice decision areas along the route. While space does not allow for illustrating the entire route, the numbered sequence in Figure 1 shows the most difficult section of the route.

The U.S. Army Research Institute and the University of Central Florida Institute

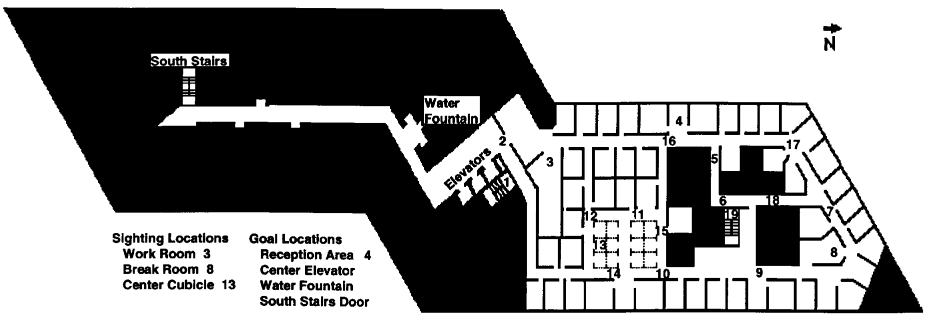

FIGURE 1. Third floor route with sighting and goal locations.

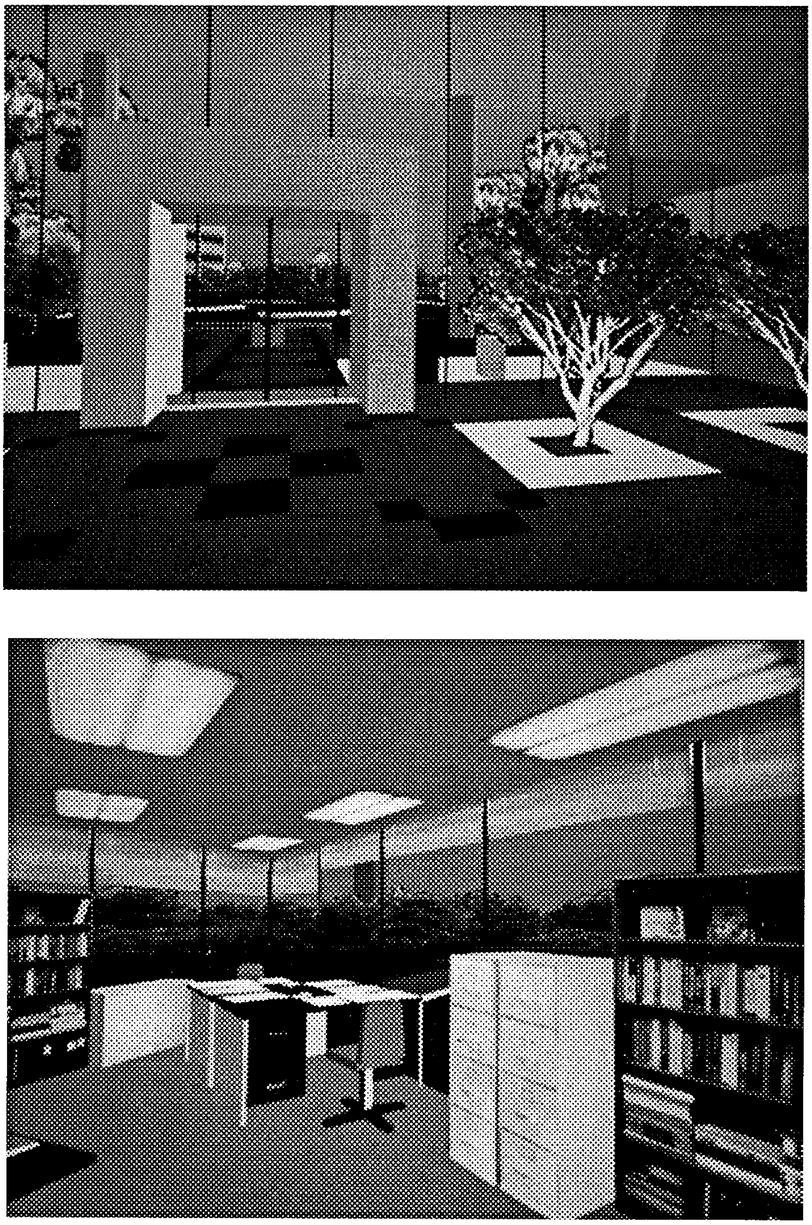

FIGURE 2. Building model interior views of a first floor foyer and a second floor office.

for Simulation and Training collaborated to develop a high fidelity computer model of the office building. Corridors and common spaces on three floors and office suites on the second and third floors were modeled. Figure 2 shows examples of the building model interior spaces.

Office furnishings were included in the building model, as were prominent landmarks. The model also included functional staircases and the out-the-window views. Modeled details included fluorescent lights, wall paintings, and exit signs. Doors to accessible areas automatically opened when approached.

The structural model of the building and all texture maps were generated using Multigen by Software Systems. Texture maps were derived from photographs of objects and were overlaid onto the modeled objects to provide detail and realism. The building model was rendered in real time by a Silicon Graphics Crimson Reality Engine Computer and displayed on a Fakespace Lab BOOM2C display. The Crimson Reality Engine ran with a single processor and two raster managers. The run-time software used in rendering and displaying the building model was WorldToolKit by Sense8 Corporation.

The BOOM2C is a stereoscopic display, that presents approximately 1280×492 pixels per eye in the pseudo-color mode. The pseudo-color mode produces images that contain mixtures of two primaries, red and green. The display field of view is 140 degrees horizontally and 90 degrees vertically. A mechanical arm counter-balances the display and allows users to move their head and body to change their viewpoint or change direction. Users move in the direction they are facing or backward at a constant speed by depressing buttons on the display control handles. The user's head position and orientation are tracked in three dimensions by position sensors located at six joints on the mechanical arm. The tracking update rate of the BOOM2C display is 60Hz with almost no latency, but the effective update rate dropped below 30Hz in some areas of the building because of heavy demands on the graphics generating engine.

Symbolic training materials included written step-by-step route directions with accompanying color photographs of landmarks and destinations. The directions specified distances between destinations or intersections, identified landmarks near them, and indicated the direction of turns. Large maps of each floor displayed the route and showed the locations of destinations.

2.3. DESIGN AND PROCEDURE

Participants were assigned randomly to either a VE rehearsal group, a building rehearsal group, or a symbolic rehearsal group, with an equal number of men and women assigned to each group. Half of the men and half of the women in each group studied a map before rehearsal. For discussion purposes, this research is divided into four phases: (1) Individual Assessment phase; (2) Study phase; (3) Rehearsal phase; and (4) Transfer Test phase.

2.3.1. Individual assessment phase

All participants received an overview of the research that described procedures and cautioned them regarding simulator sickness symptoms. Next, they answered questions about themselves to include a question about their sense of direction (Kozlowski & Bryant, 1977); they then took the Building Memory Test (Ekstrom, French, Harmen & Dermen, 1990), which requires them to recall the location of different-shaped buildings on a map.

After rehearsal, the VE group received the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum & Lilienthal, 1993) and a Presence Questionnaire (PQ) (Witmer & Singer, 1994). The SSQ asks participants to rate the severity of their sickness symptoms, while the PQ asks them to rate factors thought to be associated with feeling present in the VE.

2.3.2. Study phase

All participants studied a designated route through the building for 15 min using study aids. Study aids included written step-by-step route directions, color photographs of landmarks, and for map study participants, a map of each floor of the building. Participants were permitted to divide their study time as they wished among the study materials.

2.3.3. Rehearsal phase

Participants then rehearsed the route three times. The symbolic group verbally rehearsed the directions aloud, recalling information about turns and landmarks that purposely had been deleted (for rehearsal purposes) from the materials that they had studied earlier. This group viewed the landmark photos as they rehearsed. The VE group rehearsed the route by practicing the route in the virtual building model. The building group rehearsed the route by practicing in the building itself. All participants were required to stop at and identify each of six destinations along the route. When participants made a wrong turn or misidentified a destination, they were corrected immediately. Time to complete each rehearsal trial, number of wrong turns, and number of collisions were recorded.

2.3.4. Transfer test phase

Following their rehearsals, all participants completed a route knowledge test in the building. Participants were asked to traverse the route, stopping to identify each destination. We followed the participants along the route, recording wrong turns, route traversal times, and misidentified destinations. A pedometer attached at the participant's waistband recorded the number of steps taken along the route. Distance traveled was computed by multiplying the number of steps by the participant's average stride length. These measures were used as indicators of how well the participants had learned the route.

Participants demonstrated their knowledge of the building configuration by estimating the distance and direction from three third floor sighting locations (Breakroom, Workroom, Center Cubicle) to four goal sites (Elevator, South Stairs, Water Fountain, Small Reception Area) on the same floor (see Figure 1). As required by the projective convergence technique (Siegel, 1981), participants drew a line from their known location, represented by a dot on a piece of paper, to another point that they believed to be the location of the goal site.

Measures derived from this technique include consistency, accuracy, average distance error, and average miss distance. Consistency is the perimeter of the triangle formed by linking the endpoints of the vectors drawn from each sighting location to each goal. Accuracy is the distance from the geometric center of the triangle to the goal. Average distance error is the difference of the length of a drawn vector and the actual, accurate vector averaged across three sighting locations. Average miss distance is the distance from the endpoint of each drawn vector to the target averaged across sighting locations.

2.4. ANALYSES

Four participants assigned to the VE group voluntarily withdrew from the experiment because of severe simulator sickness. Unless otherwise noted, all analyses were based on the remaining 60 participants. An alpha level of 0.05 was used for all statistical tests.

Changes in performance during rehearsal were analyzed using repeated measures ANOVAs with trial as the repeated variable and training medium as the between subjects measure. Significant ANOVAs were followed by Newman–Keuls *post hoc* contrasts.

Differences in transfer were evaluated using a MANOVA with rehearsal medium, map, and gender as the independent measures. Dependent measures were route traversal time, number of wrong turns, and total distance traveled in completing the route.

A MANOVA was also used to assess differences in the amount of configuration knowledge as a function of rehearsal medium, map use, and gender. Consistency, accuracy, average distance error, and average miss distance were the dependent measures.

3.Results

3.1. ROUTE LEARNING

Route learning is indicated by decreasing rehearsal times and decreasing errors across rehearsal trials. Route rehearsal times plotted across trials suggest differences in the rate of learning for the various rehearsal media (see Figure 3). A repeated measures ANOVA or rehearsal time with trial as the repeated factor revealed both a signficant trial effect, $F(2, 114) = 141.11$, $p < 0.01$, and a significant training media effect, $F(2, 57) = 128.79$, $p < 0.001$. Route rehearsal times for the VE group were slower on each trial than those of the symbolic and building groups, ps < 0.001, as

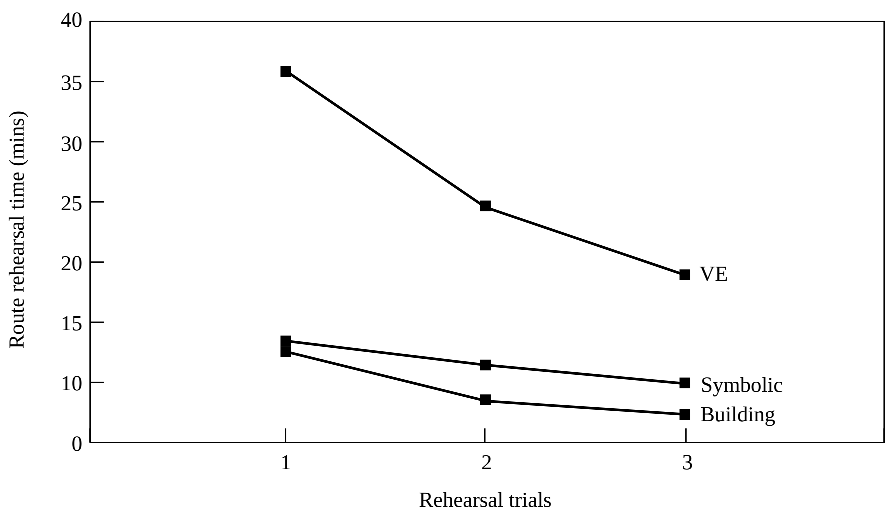

FIGURE 3. Mean route rehearsal time as a function of number of rehearsal trials and training medium.

revealed by Newman–Keuls contrasts, while the building and symbolic groups did not differ significantly. The trial by media interaction was also significant, $F(4, 114) = 35.53$, $p < 0.001$, reflecting the steeper learning curve of the VE group. Learning how to maneuver in the VE may account for the poor initial performance and steeper learning curve of the VE group.

3.1.1. Differences in training time

When comparing different training regimens, either the amount of time that each regimen requires or the number of training trials are almost always different. Failure to control for these differences does not indicate a flawed experimental design because the amount of training time is inherent in the regimen. However, training time differences can make it difficult to determine whether observed differences in training regimen effectiveness are purely due to differences in the amount of training time, or due to other qualitative aspects of the regimens that are usually of interest. The longer rehearsal times of the VE group could prove to be an advantage on the route learning test, but only if longer rehearsal times produce better test performance. Our results, reported below, suggest that longer rehearsal times, with number of trials fixed, did not lead to better test performance.

Pearson correlations between rehearsal time and transfer test measures of route learning for the entire sample were not significant, but there were significant positive correlations between rehearsal time and number of wrong turns on the transfer test for the building group, $r(20) = 0.53$, $p = 0.016$ and VE group, $r(17) = 0.49$, $p = 0.043$, when considered separately. Hence, longer rehearsal times were associated with poorer performances on the route transfer test for participants who rehearsed in the VE.

3.1.2. Route traversal errors during route rehearsal

Figure 4 shows decreases in the number of wrong turns across rehearsal trials.

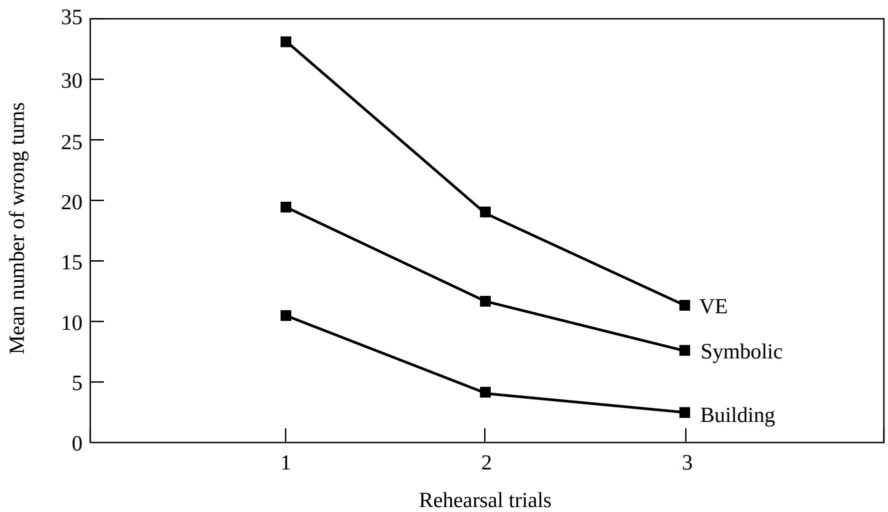

FIGURE 4. Number of wrong turns in rehearsal as a function of number of rehearsal trials and training medium.

Similar to the time data, the VE-trained participants made more wrong turns during rehearsal, but their performance improved more rapidly than that of the other two groups. A repeated measures ANOVA of wrong turns with trial as the repeated factor revealed both a significant trial effect, $F(2, 114) = 172.40$, $p < 0.001$, and a significant training media effect, $F(2, 57) = 39.18$, $p < 0.001$. Newman–Keuls contrasts revealed that the VE group made more wrong turns on each trial than the symbolic group, $p < 0.05$, who, in turn, made more wrong turns than the building-trained group, $p < 0.001$. The trial by media interaction was also significant, $F(4, 114) = 14.10$, $p < 0.001$, reflecting the steeper learning curve of the VE group. Some participants in the VE group became disoriented, typically following a collision, and made the same wrong turn repeatedly. This may explain the large number of wrong turns made by the VE group during rehearsal relative to the other two groups.

3.1.3. Training transfer

A MANOVA evaluating the effects of rehearsal medium, map, and gender on the transfer of route learning to the actual building revealed a significant main effect for rehearsal medium, Wilks $F(6, 92) = 11.16$, $p < 0.001$, but not for gender, while an apparent increase in performance due to map use was not significant, $p = 0.21$. An ANOVA indicated that rehearsal medium significantly affected each of the dependent measures: route traversal time, $F(2, 48) = 26.54$, $p < 0.001$; number of wrong turns, $F(2, 48) = 35.69$, $p < 0.001$; and total distance traveled, $F(2, 48) = 3.63$, $p < 0.05$. Newman–Keuls contrasts showed that participants who rehearsed in the building made fewer wrong turns, $p < 0.05$, than did those who rehearsed in the VE. VE participants, in turn, made fewer wrong turns, $p < 0.01$, and took less time to traverse the route, $p < 0.01$, than did participants who rehearsed symbolically. Figure 5 summarizes these results. Symbolic group participants also traveled further in completing the route than did the building-rehearsed group, $p < 0.05$. Other *post hoc* contrasts were not significant.

Although building-rehearsed participants made fewer wrong turns on the transfer test than those who rehearsed in the VE, the low number of wrong turns made by the VE group, relative to the number of possible wrong turns, indicates strong positive transfer. During route rehearsal and on the transfer test, wrong turns were recorded if participants turned the wrong way at an intersection, tried to enter a room other than a designated destination, or back-tracked along the route. Along the route there were more than 100 places where a wrong turn could be made. The number of wrong turns actually attempted could be much larger due to backtracking and repeatedly attempting to make the same wrong turn. The symbolic group made the highest number of wrong turns (Mean = 9.15, S.D. = 4.77). The building group made the fewest wrong turns (Mean = 1.10, S.D. = 1.33), followed by the VE group (Mean = 3.30, S.D. = 2.72). Clearly both the VE and symbolic groups exhibited transfer of training to the actual building.

Inspection of the route completion times on the transfer test yields further evidence for transfer from VE to the real world. The mean completion times (with standard deviations in parentheses) for the symbolic, VE, and building groups were 11.55 (2.36), 8.09 (1.23) and 7.44 (2.02), respectively. Route completion time differences between participants who rehearsed in the VE and those who rehearsed

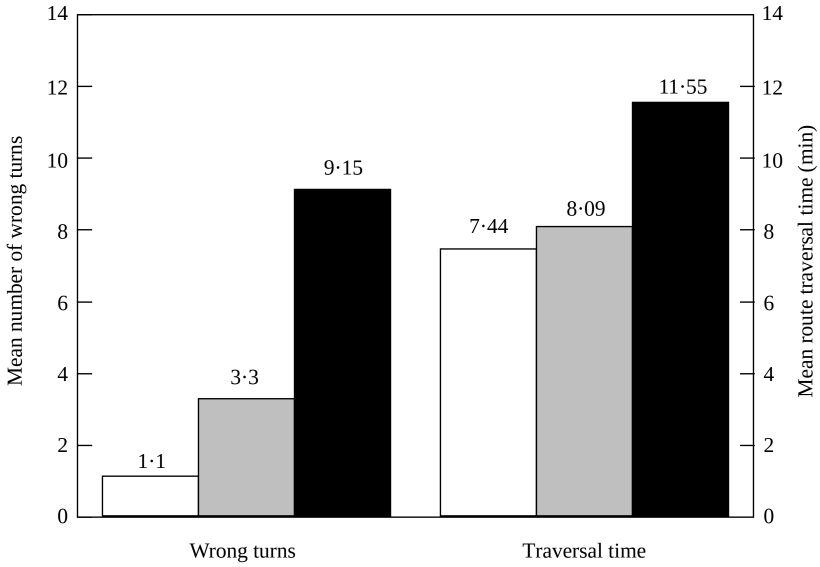

FIGURE 5. Wrong turns and route traversal time on transfer test as a function of training medium. □: Building; ▩: VE; ■: symbolic.

in the real building were small and not significant. However, the times of each of these groups were faster than the symbolic rehearsal group times (ps < 0.01).

A significant correlation between landmark recall and number of wrong turns made on the route transfer test was found, $r(60) = -0.84$, $p < 0.001$. Also, the number of wrong turns on the route transfer test was correlated significantly with the number of collisions with objects in the VE, $r(20) = 0.45$, $p < 0.05$.

3.2. CONFIGURATION LEARNING

Configuration knowledge was not affected significantly by training medium, Wilks $F(12, 86) = 0.67$, $p = 0.135$, or by map use, $F(6, 43) = 0.87$, $p = 0.384$, but men outperformed women on the configuration knowledge measures, Wilks $F(6, 43) = 3.03$, $p < 0.05$. No significant interactions were found. Significant predictors of configuration knowledge, using Pearson correlations, were gender, building memory test scores, and landmark recall, ps < 0.05.

3.3. SIMULATOR SICKNESS

Some participants reported simulator sickness symptoms after VE exposure, and four female participants were unable to continue the experiment due to nausea. The severity of reported symptoms varied from no symptoms to severe sickness. SSQ Total Severity scores for the 20 VE group participants who completed the experiment ranged from 0 to 130.9 ($M = 32.35$, S.D. $= 40.63$), and did not vary significantly with gender, $t(18) = 1.46$, $p = 0.161$.

The SSQ Total Severity scores of the four participants who voluntarily withdrew from the experiment ranged from 48.6 to 82.3 (Mean $= 65.45$, S.D. $= 13.83$). When these four participants were included in the analysis ($n = 24$), significant differences between men and women were obtained, $t(22) = 2.07$, $p < 0.05$. Simulator sickness did not correlate significantly with scores on tests of route or configuration knowledge.

3.4. PRESENCE

PQ item scores, averaging 4.6 on a 7-point scale, suggest that the VE rehearsal group experienced presence. Although higher PQ scores were associated with better performances on the route and configuration tests, correlations were not significant. A significant negative correlation between the SSQ Total Severity scores and the PQ scores, $r(20) = -0.60$, $p < 0.01$, was obtained. Possibly, participants who focus on feelings of discomfort due to simulator sickness may feel less presence in the VE than individuals who are not feeling sick and can focus on other aspects (e.g. images, task requirements) of the VE.

4. Discussion

If VE technology is to be used for training, it is essential that skills learned in a VE transfer to real world settings. Our research demonstrates that a VE can be almost as effective as real world environments in training participants to follow a designated route. In learning the route, little configuration knowledge was acquired, regardless of the training medium used. It should be noted, however, that no special effort was made to train configuration knowledge; rather we thought it might be acquired incidentally in learning the route. It should also be noted that configuration knowledge is typically acquired through repeated exposure to an environment over an extended period of time. Determining the relative effectiveness of VEs in training configuration knowledge will require further research.

Transfer of training of route learning skills from the virtual building to the real building was demonstrated despite using VE technology that developmentally is still in its infancy. The VE that we used was primarily visual and did not allow participants to manipulate objects or explore the environment through touch, nor did it provide aural cues. However, it did allow participants to move through the virtual building, while looking in whatever direction and at whatever objects they wished to view. As VE technology matures, providing higher fidelity environments, its effectiveness relative to real world training alternatives should increase. Maturation of VE should also reduce its costs, which are currently quite high.

The use of a map during the 15-min study phase had no significant effects on measures of route or configuration knowledge. Given a complex route and other materials to study (photos, written directions), participants may have been unable to devote enough time to map study to boost their performance.

4.1. POTENTIAL PROBLEMS

Colliding with walls in the VE and the ensuing loss of task focus and disorientation was clearly a problem in this research. This may have been less of a problem if the research participants had been given extensive practice in using the BOOM2C controls before beginning the route rehearsals. The reduced field of view provided by the BOOM2C, relative to what individuals enjoy in the real world, may have also contributed to the disorientation.

Another problem with the VE used in this research is that it induces simulator sickness in susceptible individuals. The simulator sickness reported following exposure to the virtual building was more severe than had been reported for the typical aircraft simulator (Kennedy *et al.,* 1993). The mean SSQ Total Severity score for ten aircraft simulators in Kennedy's study was Mean = 9.8, S.D. = 15.0, and the highest score was Mean = 18.8. Despite the relatively high Total Severity scores reported by our participants, correlations between simulator sickness Total Severity scores and measures of spatial knowledge were not significant. Given the severity of sickness reported, we might expect a greater impact on spatial learning than was observed.

Our data show that participants who experience simulator sickness in the VE experience less presence in that environment. The high negative correlation between PQ scores and SSQ scores may indicate that experiencing simulator sickness can decrease the amount of presence experienced in a VE. Conversely, participants who experience a greater sense of presence may be less likely to notice their simulator sickness symptoms.

In contrast to previous research (Witmer & Singer, 1994), significant correlations between PQ scores and performance were not obtained in this experiment. Further research is necessary to clarify the role of presence in spatial learning.

4.2. IMPLICATIONS OF RESEARCH FOR VE AS A TRAINING MEDIUM

We have shown that a route through a real building can be learned by rehearsing the route in a VE model of that building. Hence, soldiers can use relatively safe virtual spaces for rehearsing missions that they will later perform in a perilous environment. If knowledge of a complex building configuration is needed to accomplish the mission, it is recommended that the soldiers be allowed to explore the building model repeatedly until it is clear that they have acquired complete knowledge of the building configuration. Other military applications might be to teach ground forces the layout of a city or an airport, or to provide detailed spatial knowledge of other hostile territory.

Civilian applications might include teaching routes to mail carriers, package delivery personnel, or bus drivers. Civil defense planners and disaster relief agencies could use models of cities to plan escape routes and rescue procedures to handle natural or man-made disasters and practice these procedures for a simulated disaster. Police or firefighters could use VE models to practice emergency entry and rescue procedures for large public or government buildings, where many lives could depend on a timely response. Alternately, architects could use VE models to refine their designs to promote easy access and way finding prior to building construction.

While we tried to provide an effective symbolic training regimen, it did not train participants to navigate the complex route as well as did the VE. Compared to symbolic training media (e.g. maps, verbal directions), a VE better preserves real world spatial relations, and, unlike symbolic media, but similar to the real world environment, VE provides the opportunity to interact directly with a particular environment. Perhaps for very simple spatial tasks, symbolic training may be nearly as effective as VE, and far less expensive.

Real world environments may not be available for training, particularly if they are geographically remote or are located in enemy territory. Even when real world sites are available, real world training may entail risks (e.g. firefighters exposed to heat and smoke) that could be simulated in VE. Training in the real world can also be very expensive, particularly when travel to a remote site is required. In such cases, VE can be an effective tool for training route knowledge, and hence is applicable to a variety of real world situations.

We thank John P. Gildea and Daniel P. McDonald for the many hours they spent in assisting us in data collection and reduction. We also appreciate the contributions of Mike Goslin, Greg Wiatroski and Trenton Tuggle who made this research possible through their fine work in creating the virtual building model and developing the software. Finally we thank Steve Goldberg for his helpful comments in reviewing the draft manuscript. The research described by this manuscript has been reported, in part, in papers delivered at the Human Factors and Ergonomics Society 38th Annual Meeting and at the 16th Interservice/Industry Training Systems Conference. The views, opinions and findings contained in this article are those of the authors and should not be construed as the official position of the U.S. Army Research Institute or the Department of the Army.

REFERENCES

Appleyard, D. (1970). Styles and methods of structuring a city. *Environment and Behavior,* **2,** 110–118.

Best, G. (1969). Direction-finding in large buildings. In D. V. Canter, Ed. *Architectural psychology,* pp. 72–75. Cambridge: W. Heffer & Sons Ltd.

Bliss, J. P., Tidwell, P. D. & Guest, M. A. (in press). The effectiveness of virtual reality for administering spatial navigation training to firefighters. *Presence.*

Ekstrom, R. B., French, J. W., Harmen, H. H. & Dermen, D. (1990). *Manual for the kit of factor-referenced cognitive tests.* Technical Report, Office of Naval Research Contract N00014-71-C-0117), Educational Testing Service, Princeton, NJ, USA.

Evans, G. W. (1980). Environmental cognition. *Psychological Bulletin,* **88,** 259–287.

Evans, G. W. & Pezdek, K. (1980). Cognitive mapping: knowledge of real-world distance and location information. *Journal of Experimental Psychology: Human Learning and Memory,* **6,** 13–24.

Evans, G. W., Skorpanich, M. A., Garling, T., Bryant, K. J. & Bresolin, B. (1984). The effects of pathway configuration, landmarks, and stress on environmental cognition. *Journal of Environmental Psychology,* **4,** 323–335.

Goldin, S. E. & Thorndyke, P. W. (1981). *Spatial learning and reasoning skill.* Technical Report R-2805-ARMY. Santa Monica, CA: The Rand Corporation.

Golledge, R. G. (1991). Cognition of physical and built environments. In T. R. Garling & W. Evans, Eds. *Environment, Cognition, and Action: An Integrated Approach,* pp. 35–62. New York: Oxford University Press.

Held, R. & Durlach, N. (1992). Telepresence. *Presence,* **1,** 109–112.

Johnson, D. M. & Wightman, D. C. (1995). *Using virtual environments for terrain familiarization.* ARI Research Report 1686. U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, USA.

Kennedy, R. S., Lane, N. E., Berbaum, K. S. & Lilienthal, M. G. (1993). A simulator sickness questionnaire (SSQ): a new method for quantifying simulator sickness. *International Journal of Aviation Psychology,* **3,** 203–220.

Kozak, J. J., Hancock, P. A., Arthur, E. J. & Chrysler, S. T. (1993). Transfer of training from virtual reality. *Ergonomics,* **36,** 777–784.

Kozlowski, L. T. & Bryant, K. J. (1977). Sense of direction, spatial orientation and cognitive maps. *Journal of Experimental Psychology: Human Perception and Performance,* **3,** 509–598.

LAMPTON, D. R., KNERR, B. W., GOLDBERG, S. L., BLISS, J. P., MOSHELL, J. J. & BLAU, B. S. (1994). The virtual environment performance assessment battery (VEPAB): development and evaluation. *Presence,* **3,** 145–157.

LOFTIN, R. B., KENNY, P. J., BENEDETTI, R., CULBERT, C., ENGELBERG, M., JONES, R., PAIGE, L., MCRAE, S., MENNINGER, M., MURATORE, J., NGUYEN, L., PUSCH, L., SAITO, T., SAVELY, R. T. & VOSS, M. (1994). Virtual environments in training: NASA's Hubble Space Telescope mission. *Proceedings of the 16th Interservice/Industry Training Systems and Education Conference,* pp. 2–12.

LYNCH, K. (1960). *The Image of a City.* Cambridge, MA: MIT Press.

PEPONIS, J., ZIMRING, C. & CHOI, Y. K. (1990). Finding the building in wayfinding. *Environment and Behavior,* **22**, 555–590.

REGIAN, J. W., SHEBILSKE, W. L. & MONK, J. M. (1992). Virtual reality: an instructional medium for visual–spatial tasks. *Journal of Communication,* **42,** 136–149.

SAMURÇAY, R. & ROGALSKI, J. (1993). Cooperative work and decision making in emergency management. *Le Travail Humain,* **56,** 53–77.

SIEGEL, A. W. (1981). The externalization of cognitive maps by children and adults: in search of ways to ask better questions. In L. S. LIBEN, A. H. PATTERSON, N. NEWCOMBE, Eds. *Spatial Representation and Behavior Across the Life Span: Theory and Application.* pp. 167–194. New York: Academic Press.

SIEGEL, A. W. & WHITE, S. H. (1975). The development of spatial representations of large-scale environments. In H. REESE, Ed. *Advances in Child Development and Behavior,* Vol. 10, pp. 10–55. New York: Academic Press.

STREETER, L. A., VITELLO, D. & WONSIEWICZ, S. A. (1985). How to tell people where to go: comparing navigational aids. *International Journal of Man–Machine Studies,* **22,** 549–562.

THORNDYKE, P. W. & HAYES-ROTH, B. (1980). *Differences in spatial knowledge acquired from maps and navigation.* Technical Report N-1595-ONR. Santa Monica, CA: The Rand Corporation.

WITMER, B. G. & SINGER, M. J. (1994). *Measuring presence in virtual environments.* ARI Technical Report 1014. U.S. Army Research Institute for the Behavioral and Social Sciences. Alexandria, VA, USA.

Paper accepted for publication by Associate Editor, Dr. G. Sundstrom.