Spatial Knowledge Acquisition from Maps and Virtual Environments in Complex Architectural Spaces

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INTRODUCTION

It has often been suggested that due to its inherent spatial nature, a virtual environment (VE) might be a powerful tool for spatial knowledge acquisition of a real environment, as opposed to the use of maps or some other two-dimensional, symbolic medium. While interesting from a psychological point of view, a study of the use of a VE in lieu of a map seems nonsensical from a practical point of view. Why would the use of a VE preclude the use of a map? The more interesting investigation would be of the value added of the VE when used with a map. If the VE could be shown to substantially improve navigation performance, then there might be a case for its use as a training tool. If not, then we have to assume that maps continue to be the best spatial knowledge acquisition tool available.

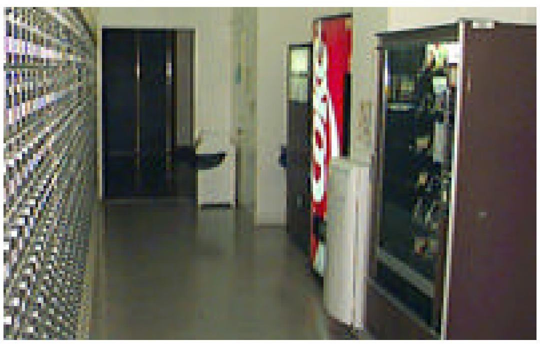
An experiment was conducted at the Naval Postgraduate School to determine if the use of an interactive, three-dimensional virtual environment would enhance spatial knowledge acquisition of a complex architectural space when used in conjunction with floor plan diagrams.

There has been significant interest in this research area of late. Witmer, Bailey, and Knerr (1995) showed that a VE was useful in acquiring route knowledge of a complex building. Route knowledge is defined as the procedural knowledge required to successfully traverse paths between distant locations (Golledge, 1991). Configurational (or survey) knowledge is the highest level of spatial knowledge and represents a map-like internal encoding of the environment (Thorndyke, 1980). The Witmer study could not confirm if configurational knowledge was being acquired. Also, no comparison was made to a map-only condition, which we felt is the most obvious alternative. Comparisons were made only to a real world condition and a symbolic condition where the route is presented verbally.

A study was recently completed, on which this current work is based, that investigated the utility of a virtual environment when used with a map for navigation tasks in a large, complex natural environment (Darken & Banker, 1998). This study showed that the virtual environment was effective in training spatial knowledge (specifically route knowledge) for this environment but only for users in an intermediate skill level category. Both very advanced orienteers and beginners showed no significant improvement in using the virtual environment over use of the map alone. There were two items of interest in this work that instigated this second study. First, how does navigation in natural environments (non-man-made) differ from that of architectural or urban environments? Second, how is spatial knowledge acquisition effected by exposure duration? That is, how long does one need to view a map and/or a virtual environment before training transfer occurs?

METHOD

Sixteen individuals (five female, eleven male) volunteered as participants in this experiment. All were junior enlisted military personnel with an average age of 19. There were two experimental conditions in the study. One group (the map group) was given a set of floor plan diagrams of the seven-story building to study for thirty minutes. We had predetermined a path through the building with a designated starting point and four subsequent target locations dispersed over six floors. Participants were to study the floor plans such that they would be able to walk the path when taken to the building immediately after the training phase. The second group (the virtual environment group) was also given these same floor plan diagrams and was simultaneously exposed to a virtual environment of the building. The virtual environment is a very high fidelity and accurate model of the actual building (Figures 1 and 2). The virtual environment was displayed on three projection screens creating a 145^{o} field of view. To avoid performance confounds based on vastly differing maneuvering ability, we eliminated the interface to the virtual environment by having each participant in that group give verbal movement commands to the experimenter.



(Figure 1. Mail Room – Real World)

(Figure 2. Mail Room - VE)

All participants were given the Guilford-Zimmerman Spatial Orientation Aptitude Survey (Guilford & Zimmerman, 1981). Participants were divided such that each of the two experimental conditions had an even distribution of spatial abilities. Upon completion of the training phase, participants were taken to the real venue to begin the testing phase.

The testing phase consisted of navigating from an entry point on the ground level through a sequence of four target locations. Participants would be informed within five paces when they made an error but were never given directions to remedy that error. We measured the time it took to negotiate the path as well as the number of errors made during each leg of the route. In between the second and third targets, each participant was stopped and asked to point to the other target locations using a wheel device (we call this the egocentric-pointing task). These bearings were measured and the task continued. Upon arrival at the fourth and final target, participants were given a final unprimed task. They were asked to construct and navigate a path to the entry point from which the testing phase began. This was done to determine if they had acquired only knowledge of the predetermined route or if they had a more thorough sense of the space.

Finally, in debriefing, we asked each participant to estimate the relative distances and bearings between each target by placing numbered magnets on a metal whiteboard (we call this the exocentric target placement task). This allowed us to determine how accurate each participant's mental model of the space was in a manner we considered better than map drawing (Lynch, 1964) or free recall (Roenker, Thompson, & Brown, 1971).

RESULTS

The results show that under these conditions, floor plan study is significantly more effective than the added use of a virtual environment. This is in direct contrast to several resent experiments that indicate spatial knowledge could be acquired from virtual environments and transferred to real world environments (Bliss, Tidwell, and Guest 1995, Darken and Banker 1998). Darken and Banker's (1998) research indicated that under certain situations, exposure to a virtual environment for an hour improved navigational performance in a complex natural environment. Bliss et al (1995) showed that fire fighters exposed to a virtual environment of an office building improved their navigation abilities through the building when conducting search and rescue operations. However, these results are not universally applied for more complex environments or for limited exposure times. In fact, the combination of more complex environments and short exposure time may even be counter productive.

The floor plan group made fewer errors than the virtual environment group (P=.0919, F(1,14)=3.274, See Figure 3). There was no significant difference in angular error in either the egocentric pointing task or the exocentric target placement task but the map group did tend to be more accurate. The angular errors on the egocentric pointing task were roughly twice that of the exocentric task. It is also interesting that angular error between the egocentric and exocentric tasks do not correlate. This suggests that the two tasks are fundamentally different and that they involve somewhat different cognitive skills. These results support research by Aretz and Wickens (1992) which demonstrated a lack of correlation between "inside-out" (egocentric) and "outside-in" (exocentric) frames of reference.

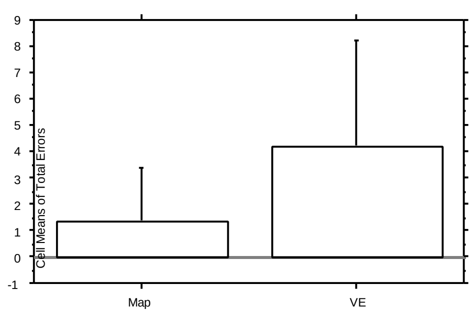


Figure 3. Total Errors

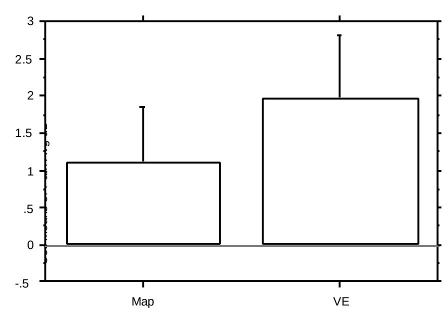


Figure 4. Distance Estimation

Results indicate that the map group was significantly more accurate in estimating distances in the target placement task (P=.0495, F(1,14)=4.623, See Figure 4). While all legs in the planned route were not identical in terms of navigational complexity as defined by Best (1969), error rates did not correspond to the expected difficulty of each leg. This leads us to believe that the method described by Best is either incomplete or erroneous. Best's method of calculating route complexity fails to take into account several characteristics of a route that may potentially play a factor in its complexity. Some of these factors include the degrees of rotation at each turn, route segments that have been revisited, and segment length. We are continuing our research into this area to better refine a route complexity model.

DISCUSSION

We cannot conclude from this experiment that a virtual environment is not useful for gaining spatial knowledge of architectural spaces since it has been shown by Witmer, et al (1995) and others that it can be useful. We do, however, believe that short exposures to complex environments such as this one are at least not helpful and at worst detrimental to subsequent navigation performance in that environment.

In order for a virtual environment to assist in spatial knowledge acquisition, its user must be able to resolve the egocentric perspective of the virtual environment with the exocentric perspective of the map. However, even with an extremely high fidelity virtual environment such as ours has significant differences between it and the real world. Consequently, this perspective transformation can never be exactly the same in virtual and real space. Given a short exposure time on such a complex task, each participant attempted to maximize the amount of spatial knowledge acquired during the training phase, regardless of what group they were in. Participants in the map group were better able to focus on the paths to be learned without having to deal with all the "noise" that the virtual environment offered. Not knowing what was important or essential to the execution of the task, participants in the virtual environment group failed to filter out nonessential information and where quickly saturated in facts, much of which was superfluous to the task. The greatest use of a virtual environment for spatial knowledge acquisition, as shown by Darken and Banker (1998), is to provide redundant information for route selection and disambiguation at junctions. The virtual environment can be used to see what a particular junction looks like when approached from a particular hallway, for example. But the detail between that junction and the next can be a distraction.

Map group participants typically learned the paths in egocentric terms such as "take the third right turn" but did not attempt to visualize the environment during the training phase. The virtual environment group concentrated on recognizing distinct features such as a grandfather clock or fountain by which to assist them in navigating in the actual building. Consequently, as was the case with our earlier study in a natural environment, scaling of the environment was an issue. Most participants in both groups had an incorrect conception of the size of the building. This had to be resolved during the testing phase. We might alleviate this problem by providing a familiar cue at the onset such that the size of the environment could be gauged by the size of the cue. There is anecdotal evidence that this may help but further investigation is needed.

Further studies are required to determine how long a participant must be allowed to view the virtual environment before there is substantial benefit in spatial knowledge acquisition. Furthermore, it has not been shown that the virtual environment is useful for gaining configurational knowledge. This will also demand further study. These studies will need to take into account model fidelity and navigational complexity, as well as exposure times.

CONCLUSIONS

We have shown that there are circumstances where the use of a VE not only fails to help in the development of mental representations of complex architectural environments, but may actually hinder this development. This is an important result in that, for short exposure durations, a map should be used without the VE for best results. For longer durations and for situations demanding extremely high navigation performance, a VE may be useful. Further studies will be required to determine how long a participant must be allowed to view the VE before there is substantial benefit. Also, it has not been shown that the VE is useful for gaining configurational knowledge. This will also demand further study.

Thus far, there have been no published studies illustrating any negative performance characteristics of the use of VEs in navigation. This clearly shows that there can be negative effects and that we need to better understand how spatial knowledge is acquired to avoid these effects in training systems.

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