Effects of Active Exploration and Passive Observation on Spatial Learning in a CAVE

Brian Melanson bmelanso@vt.edu
John Kelso kelso@vt.edu
Doug Bowman bowman@vt.edu

Department of Computer Science, Virginia Tech

Abstract

This experiment was a modification of Paul N. Wilson's 1999 study entitled "Active Exploration of a Virtual Environment Does Not Promote Orientation or Memory for Objects." It was hoped that changing the immersion level from a standard desktop monitor to a more immersive CAVE environment would change the results of this experiment.

All subjects explored a three-dimensional virtual environment in a CAVE. Active subjects were given controls to choose their own path and explore the environment. Passive subjects watched a playback tour through the virtual environment. A unique active subject determined the tour for each passive subject. Each subject was asked to remember the objects they saw, their locations, and the floor plan of the environment.

Afterward, subjects were asked to indicate the direction to another location that was not visible from the current location. Other object memory tests required recalling the location of each object and indicating it on a plan view of the environment. Similar to Wilson's experiment, this experiment yielded no significant indication that active exploration or passive observation changes the level of spatial learning.

1 Introduction

According to Bowman et al. (1999), it is often difficult for users of a Virtual Environment (VE) to maintain a good understanding of their spatial orientation while immersed in a virtual environment. Spatial orientation is important to the effectiveness of a VE. Sensory inputs are required for spatial orientation to be maintained while a user is immersed in a VE (Lackner and DiZio, 1998).

Spatial orientation refers to the information extracted from an environment, and how it is recalled from memory (Darken et al., 1998). This information is commonly referred to as a mental, or cognitive map. This does not pertain specifically to virtual environments, but is an issue to ensure the effectiveness of a VE.

In order for VEs to be effective in areas like education and training, and design evaluation and testing, the user must have good spatial orientation (Bakker et al., 1998). Without knowing where they are in the environment, users cannot make good use of the visual information they are observing.

It is also known that proprioceptive references can add to the spatial orientation of users of a VE. Bakker et al. (1998) also found that an absolute reference, such as keeping one foot stationary while turning, can greatly add to a subject's knowledge of their orientation.

This experiment was largely based on a previously completed experiment by Paul N. Wilson entitled "Active exploration of a virtual environment does not promote orientation or memory for objects." In this study, Wilson was unable to conclude that spatial orientation was affected by active exploration or passive observation. This experiment modified the original in hopes that conclusive results will follow.

The main change from Wilson's original experiment was the level of immersion in the VE. The original experiment used a standard computer screen, whereas this experiment utilized the CAVE at Virginia Tech. It was hypothesized that the higher level of immersion would add proprioceptive references for the subjects and show a clearer difference in the spatial learning done by active and passive subjects.

One conclusion of a study by Chance et al. (1998) was that in devices with a larger field of view then a head-mounted-display, perhaps a CAVE, real rotation and translation are important to promote better spatial orientation. They indicated that if spatial orientation is important, these additions to the controls might be beneficial. For this reason, it is believed the CAVE will produce different results then the desktop in Wilson's study.

Another change from the original study was separating the active and passive subjects. Originally, two subjects were run at the same time; the passive subject observing while the active subject explored the environment. The subjects were not allowed to talk to each other, and were evaluated separately after the experiment. The change was made to have the subjects run separately to make the experiment run more smoothly. This way, only one subject was required for each time slot, and it was easier for the evaluator to observe one subject at a time.

2 Method

This experiment was done in the between-subjects format; groups defined as the active or passive subjects. All subjects were volunteers and were evaluated individually. No subjects will have previous knowledge of this experiment, and are not required to have used a VE previously.

2.1 Experimental Design

This experiment examined the differences in spatial learning done using active exploration and passive observation in a CAVE virtual reality system. The experiment investigated the following research question: Does active exploration or passive observation of a VE change the level of spatial learning?

This question was investigated by performing an experimental research study utilizing a CAVE to deliver the three-dimensional information. This experiment was done in the between-subjects format. The only independent variable was the different groups; active and passive. Subjects explored the virtual environment using two methods. Following the exploration, subjects were tested in three different ways to support the following hypothesis.

H_1: Test scores for the orientation tests will be higher for the active group then the passive group.

H_2: Test scores for the object memory tests will be higher for the passive group then the active group.

H_3: Test scores for the object recognition tests will be higher for the passive group then the active group.

2.2 Measures of Spatial Learning

The first measurement in the experiment was the time the subject spent exploring the environment. This value was recorded for each active subject. For passive subjects, the time was duplicated from the time recorded for the active subject who created the path.

The next measurement was to measure the subject's orientation within the environment. Each subject was placed inside three rooms they had explored; the Start Room, the Game Room and the Animal Room. The subject pointed toward the other two rooms from their current location, and a measurement was recorded.

The third measurement tested the subjects' memory for the locations of objects. Each subject was given a map of the environment and asked to indicate the locations of all objects they remembered on the map. Points were given, to a maximum of 46, as follows: 2 points for each correct object in the correct location, 1 point for each correct object in an incorrect location, and 1 point for each incorrect object in a correct location.

The final measurement was the subjects' recognition of objects in the environment. A stack of flash cards was comprised of the 23 actual objects from the experiment, and 23 additional "distracter" objects. Subjects were asked to look at each picture and indicate if they saw the object in the environment.

2.3 Subjects

These were 22 people affiliated with Virginia Tech: 15 undergraduate students, 5 graduate students and 2 staff members. Of the subjects, 7 were female. The average age was 20.7, with a range of 18 to 26.

2.4 Apparatus

The virtual environment was created on a Windows NT computer using Discreet software's 3D Studio Max. The objects were downloaded off 3D-Cafe, a website where individual users can post 3D models they have created. The objects were manipulated using the DIVERSE software system, developed at Virginia Tech (Kelso et al., 2001).

The 3D model was based on the same environment used in Wilson's experiment. The model consisted of 6 rooms, all connected via openings to a common hallway. (See Figure 1) The overall environment measured 60 x 60 units, where each unit was equal to 1 meter in the CAVE. The Animal Room measured 20 x 12 units, containing a Kangaroo, a Camel, a Cow, and a Dog. The Music Room measured 20 x 30 units, containing a Coca-Cola can, Lounge Chair, Electric Piano, and a Harp. The Bedroom measured 30 x 10 units, containing a Bed, Wardrobe, Blimp and Couch. The Start Room measured 17 x 10 units, containing a Globe, Gazebo and Windmill. The Toy Room measured 30 x 20 units, containing Mr. Potato Head, a Red Car, Army Truck, and Tux, the Linux Penguin. The Game Room measured 30 x 20 units, containing a Ping-pong table, a Roulette Wheel, a Television, and a Dart Board. A perspective view is in Figure 2.

Figure 1: Top view of the environment. Rooms: (clockwise from top-right) Animal Room, Music Room, Bed Room, Start Room, Toy Room, Game Room.

Figure 2: Perspective view of the environment

The completed model was displayed to the subjects in the Virginia Tech CAVE. The computer used was an SGI Onyx with 8 processors, 1.5 GB system memory, and 3 Infinite Reality graphics pipes. The CAVE consists of 4 projected surfaces: front, left and right walls, and the floor, and was designed by Fakespace. Positional tracking and user interface was provided via an Intersense IS900 tracking system. The only software used in this experiment was the diversifly program in the DIVERSE suite. The diversifly program allows for the display and manipulation of spatial data in any format supported by SGI's OpenGL Performer.

The active subject controlled the manipulation of the environment using an Intersense Wand, a device that measures 6 degrees of freedom, and has buttons and a joystick. The subject utilized the thumb-joystick on the wand to travel forward or rotate the world around them. Moving the joystick forward or backward moved the subject in the direction they were pointing the wand; moving it left or right rotated the world around them.

Collision detection and terrain following were enabled for the experiment using loadable modules of the DIVERSE software. Collision detection required that subjects navigate around walls and objects, rather then walk through them. Terrain following kept the subject at a constant 2 meters above the terrain making it impossible to see over the 5 meter walls.

2.5 Procedure

Each subject signed up for a thirty-minute time slot, and was presented with a consent form and questionnaire upon arrival to the test site. Subjects were designated as either active or passive on an alternating basis. This method was chosen so that each passive subject would watch the tour created by the previous active subject. This method also ensured an even number of active and passive subjects, should the experiment be stopped early.

The active subjects were given time to explore another environment so that they could become familiar with the controls for the CAVE. This exploration was not part of the recorded results, but merely a way to give practice time with the controls. The subject was then placed inside the start room of the environment and instructed that they would be able to explore the environment until they felt familiarized with the environment. They were reminded to concentrate on the objects, their locations, and the floor plan of the environment. The subjects were instructed to tell the experiment operator when they felt ready to continue to the next step.

The passive subjects were not given time inside another environment because they would not be navigating. They were given similar instructions, noting that they would be taken on a tour by the computer through the environment. They were also asked to concentrate on the objects, their locations, and the floor plan of the environment. Upon completion of the tour, the experiment continued to the next step.

The first test for all subjects consisted of orientation tests in the environment. The controls were modified so that the subject could only rotate their position around a preset location by moving the joystick left or right. The position in the environment was switched back to the initial location in the start room. The subject was asked to rotate the environment and point the wand in the direction of the Game Room, and then the Animal Room. The subject indicated to the experiment operator when they were pointing toward the requested room, and a measurement of heading was recorded. This procedure was repeated in the Game Room, pointing toward the Animal Room and the Start Room, and in the Animal Room, pointing toward the Start Room and the Game Room. Following these orientation tests, other memory tests were conducted.

The next test was an object memory test. Subjects were presented with a map of the environment and asked to recall any objects they could, and indicate their position on the map. Subjects were instructed to indicate locations of objects they could not identify with a question mark. This test was not timed. The map score (as described above) was determined from this test. An object recognition test followed this memory test.

Subjects were presented with a stack of 46 flash cards. Pictured on these cards were the 23 objects located in the environment, as well as 23 additional distracter objects. Subjects were asked to flip through the cards and indicate on a table if they remembered seeing the object in the environment.

3 Results

Analysis of the resulting data was completed by entering it into SPSS. Correlations, Analysis of Variance (ANOVA) and general statistics were run on all data. The results from SPSS were reviewed and conclusions drawn.

The mean pointing errors for the active group were 32.5, 34.1 and 21.0 degrees for the Start, Game, and Animal rooms respectively. The errors for the passive group were 31.0, 33.1, and 29.7 degrees for the Start, Game and Animal rooms respectively. The errors were not significantly different between groups, however a pattern between locations was noticed. The errors indicate that subjects were oriented best in the Animal room, second best in the Start room, and oriented the least in the Game room. These pointing errors did not support the first hypothesis that the scores for the active group would be higher then the passive group. The analysis of the results did not find a significant difference between the groups in all of the pointing tests.

The results for the first object memory test were also very close between groups. The mean map score for the active group was 32.1, and 28.4 for the passive group. This result did not support the second hypothesis that the passive group would score higher then the active group. No significant difference between the groups existed.

The recognition test also yielded very similar results. The average number of objects from the study incorrectly identified for the active group was 2.4, and 2.0 for the passive group. The number of distracter objects incorrectly identified for the active group was 0.3, and 0.9 for the passive group. No significant difference between groups existed for the actual object error score. However, the difference between groups for the distracter objects error score was marginally significant, $F(1,20) = 3.403$, $p < 0.01$.

There were two correlations identified by SPSS relating to the group directly. The correlation data indicated that the age of the subject, and their declaration of how often they used a computer for work were correlated to the group. This indicated unbalanced grouping, and might have slightly skewed the results.

A correlation also existed between time spent exploring the environment and the number of objects identified incorrectly in the memory test section. This is expected because less time immersed in the environment means less time examining the objects and committing them to memory. The average time spent by active subjects exploring the environment was 7.2 minutes, with a range of 6-8 minutes.

Another logical correlation is the subjects' map score, and the number of objects identified incorrectly in the memory test section. If a user could not remember which objects were in the environment, it makes sense that the score of their map would be lower, and vice versa.

Locations with higher mean pointing errors also showed correlations. In the Start and Game rooms, the errors for the two pointing measurements in each room were correlated to each other. This reinforced the idea that subjects did not have good spatial orientation in either of these rooms. It makes sense that if they did not know where they were in the environment, both measurements were incorrect. It is interesting to note that the mean pointing errors in the Animal room were not correlated, indicating that subjects knew, or guessed, the correct direction to one other location, but not both.

From analyzing these results, it can be determined that changing the immersion level of the Virtual Environment does not change the results Wilson's study on spatial learning. The previous findings hold, in that active exploration and passive observation do not change the spatial learning enough to be determined statistically different.

4 Discussion

The results of this study do not support any of the hypotheses tested. There are many reasons why these hypotheses failed. Most of these reasons relate to the subjects and the data for the study.

The subject-base was probably much too small to yield useful results. In order to get good quality, unbiased data, the study should have been run with as many as 50 subjects. This higher number of subjects could have reduced the variance in the data.

The concept of passive observation was also not quite true. Due to the ability of the subjects to move their head, the active and passive subjects did not receive the exact same perspective of the environment. This contributes to the different proprioceptive inputs received by each subject.

Several passive subjects expressed an interest for more time in the environment after their preset tour had ended. This indicated the different learning methods used by different subjects. Other subjects indicated that they were focusing on different aspects of the environment, and had not devoted enough attention to the aspects on which the evaluation was based.

Reversing the order of the object memory tests might have changed the results. Several subjects had trouble recalling objects, but knew things were there. After seeing the pictures of objects, several subjects wanted to return to the previous step and make modifications to their map.

5 Conclusions and Future Work

In this paper, we have reported on the results of an experiment comparing the effects of active exploration and passive observation on spatial learning. The experiment was unable to show a significant difference in the spatial learning of active and passive subjects. It was thought that due to the extra proprioceptive feedback provided by the CAVE, results would differ from the similar experiment using a desktop.

Increasing the number of subjects could change the results of this experiment. A larger subject base would add different characteristics into the group to get a better sample of the population. More people could help reduce the variance in the data. The evaluation methods chosen for this study could also be changed. Different methods of evaluation would yield different results because other methods would focus on different aspects of the process of spatial learning.

References

Bakker, N., Werkhoven, P., & Passenier, P. (1998). Aiding Orientation Performance in Virtual Environments with Proprioceptive Feedback. *Proceedings of IEEE Virtual Reality Annual International Symposium, Atlanta, Georgia, 28-35.*

Bowman, D., E. Davis, L. Hodges & A. Badre. (1999). Maintaining Spatial Orientation during Travel in an Immersive Virtual Environment. *Presence 8(6), 618 - 631*.

Chance, S., Gaunet, F., Beall, A., & Loomis, J. (1998). Locomotion Mode Affects the Updating of Objects Encountered During Travel. *Presence, 7(2), 168-178.*

Darkin, R., T. Allard & L. Achille. (1998). Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces: An Introduction. *Presence, 7(2), 101-107.*

Kelso, J., L. Arsenault, S. Satterfield & Ron Kriz. (2001). DIVERSE: A Framework for Building Extensible and Reconfigurable Device Independent Virtual Environments.

Lackner, J. & Paul DiZio. (1998). Spatial Orientation as a Component of Presence: Insights Gained from Nonterrestrial Environments. *Presence 7(2), 108-115*.

Wilson, P. (1999). Active Exploration of a Virtual Environment does not Promote Orientation or Memory for Objects. *Environment and Behavior 31(6), 752-763.*