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Comparison of performance measures in the virtual environment and real world land navigation tasks

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THESIS

COMPARISON OF PERFORMANCE MEASURES IN THE VIRTUAL ENVIRONMENT AND REAL WORLD LAND NAVIGATION TASKS

By

Saltuk Buğra Karahan

September 2000

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Barry Peterson

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13. ABSTRACT *(maximum 200 words)*

Spatial knowledge acquisition is an integral part of navigation related studies. With the improvement of technology, the researchers gained the capability of testing the spatial ability in a virtual world as well. However, little research has been conducted to understand whether VE performance can predict Real World performance or not and amongst the measures used what measures are most predictive.

This thesis research addresses the validity of performance measures used in virtual and real environments. Ten subjects have participated in two experiments. The first experiment was a navigation task in a building type virtual environment. With some modifications, Herman Hall model was used for this experiment. The second experiment was a navigation task in a real building. For this experiment Middle East school in DLI was used. Measures of landmark, survey and route knowledge were taken for each participant.

The results did not suggest a correlation in overall performance measures. However a correlation is observed in the performance for the landmark knowledge. The acquisition of survey knowledge by time is also seen in the results of the study.

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COMPARISON OF PERFORMANCE MEASURES IN THE VIRTUAL ENVIRONMENT AND REAL WORLD LAND NAVIGATION TASKS

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ABSTRACT

Spatial knowledge acquisition is an integral part of navigation related studies. With the improvement of technology, the researchers gained the capability of testing the spatial ability in a virtual world as well. However, little research has been conducted to understand whether VE performance can predict Real World performance or not and amongst the measures used what measures are most predictive. This thesis research addresses the validity of performance measures used in virtual and real environments. Ten subjects have participated in two experiments. The first experiment was a navigation task in a building type virtual environment. With some modifications, Herman Hall model was used for this experiment. The second experiment was a navigation task in a real building. For this experiment Middle East school in DLI was used. Measures of landmark, survey and route knowledge were taken for each participant. The results did not suggest a correlation in overall performance measures. However a correlation is observed in the performance for the landmark knowledge. The acquisition of survey knowledge by time is also seen in the results of the study.

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I. INTRODUCTION

A. PROBLEM STATEMENT

The main question that this thesis will attempt to answer is whether or not there is a correlation between performance in a real world building interior navigation task and a virtual world building interior navigation task. The thesis will analyze and compare an individual's performance in both environments and draw conclusions about the measures we have been using by looking at the results of their performance in these two environments. The research intends to question a frequently implied assumption that the same performance measures are appropriate in virtual and real world environments. If a correlation is found, further research might investigate if it's also valid in other types of environments (such as forests and other natural spaces). If disproved in the building environment, the relationship can still be investigated for natural environments. The lack of a correlation will suggest the causes to be either that the sensitivity of the measures was too low or that the characteristics of the virtual environments interface or fidelity inhibited natural spatial knowledge acquisition.

B. MOTIVATION

1. Applications for Spatial Knowledge Acquisition

Spatial knowledge acquisition is used in a wide range of jobs and activities. In our daily lives we happen to use our spatial knowledge acquisition capability to find an address, to go to an office in an unfamiliar building, or to find the quickest route in an emergency. When we think of certain jobs like policemen, firemen, and paramedics, their need for the possession of this kind of knowledge becomes more clear. A policeman who gets into a building for the first time and attempts to take a certain route in the building will have to acquire the information about the routes, landmarks and general map of the building. Similarly, a fireman will need acquisition of this spatial knowledge to maneuver in an environment where there are flames and smoke. A taxi driver needs spatial knowledge to take the shortest route in a city and not cause any delay in his customer's schedule.

When it comes to the military, the acquisition of spatial knowledge gets even more important. Spatial knowledge acquisition is the main issue for the navigation of dismounted soldiers. Spatial knowledge is not limited to soldiers, but must also be acquired by tank drivers, pilots, and members of any maneuver unit. Knowledge of the environment is the basic knowledge needed to accomplish any of the military missions whether it is to attack, retreat, or reconnoiter. Even in defense, when there is no movement, acquisition of spatial features of the environment is essential.

So, spatial awareness of the environment is a requirement for the accomplishment of even relatively static tasks. And it gets even more important when movement is involved in the specific task.

2. Army and DOD Relevance

Traditional methods of training and mission preparation may be enhanced by virtual environment (VE) augmentation. Mock-ups or other representations of the training environments were used as training methods, but these had many disadvantages. Considering only the costs associated, they were expensive, and it took a lot of time to build them. Furthermore, they used to occupy a large area and it was not so easy to modify them according to the changes in the structure of the mission. The likely need for the replacement of these methods by VE technology has generated the issue of using virtual environments in training or mission preparation.

The representation of the real environment by a virtual environment has its own assumptions. One major postulate is that the performance measures in a virtual world would be equally sensitive to performance in the real world. Spatial knowledge acquisition in the virtual world has been evaluated with the same criteria which is used in the real world. However, there is no concrete basis for this assumption. The army, using virtual environment in its navigation studies, would like to know if there is a positive correlation between the measures used in these two different environments.

Additionally, army recruiters need to assess the capabilities of applicants for the army. Since the spatial knowledge has been proved as having significant importance in Army activities, it would be useful if the spatial knowledge ability of recruits could be assessed in a virtual environment navigation task. When we use such a task, for an accurate evaluation we want to make sure that the measures we use for the virtual environment do represent the same measures in the real world. In addition, we would like to know if there are some measures which do not necessarily apply to the real world and vice versa. All these assessment efforts will require a deep analysis of the measures used in virtual environments.

3. Existing Shortcomings of Research

Computer based training is gaining more popularity every day. However, except for the cost savings, there is not much proof of the advantage gained from using computer based systems. Furthermore, when these systems are used, we want to make sure that our evaluation of the capabilities is a realistic evaluation, and it assesses the individual capability on land navigation. So far, there has not been a study specifically investigating this correlation; rather the measures of real and virtual worlds have always been assumed to be related. Furthermore, while this study is not a transfer study, it does contribute to the transfer study literature by evaluating an assumption used in this kind of study.

C. THESIS ORGANIZATION

This thesis is organized as follows. Chapter I is the introduction to the area, describes the problem that the thesis tries to solve, gives an explanation of the motivation points for the thesis, and the organization of the thesis. Chapter II covers the background and previous work in the area. Mainly, the second chapter tries to introduce the existing measures of performance in land navigation, compares them, and identifies the main measures to be used in this study. Chapter III discusses the virtual and real environments used in this thesis. It also gives a detailed description of the experiments used for the study and the methodology of the experiments. Chapter IV analyzes the data collected from the two experiments, and discusses the results. Chapter V draws conclusions from the results of the experiments and discusses the impact of the conclusions to the studies in the area. Chapter V also lays out future research lines in this subject.

The thesis has several appendices which show the instructions to the participants, maps of the buildings used for the study, briefing forms, and the data sheets collected from the study. The appendices will help the reader to understand the nature of the experiments better, and will help researchers trying to replicate this work.

II. BACKGROUND AND PREVIOUS WORK

A. GENERAL DESCRIPTION OF THE CHAPTER

This chapter is a literature review on performance measures in a land navigation task. After an introduction to the subject, the author describes the concept of spatial knowledge with its three components: Landmark Knowledge, Route Knowledge and Survey Knowledge. Throughout the review of the literature, the author handles the measures of these three levels separately, and examines the advantages and disadvantages of each technique in measuring the performance level. Finally, four performance measures that can be used in a study to understand the correlation of the measures in virtual and real environments are determined considering the efficiency and applicability of the measures: landmark recognition, route replication (number of wrong turns), pointing, and map sketching.

B. INTRODUCTION TO THE BACKGROUND AND PREVIOUS WORK

Spatial knowledge acquisition has always been an integral part of navigation related studies. With the improvement of technology, researchers gained the capability of testing spatial ability in a virtual world as well. Researchers have been using different measures to assess spatial ability either in a real world or a virtual world land navigation task. However, there is no concrete evidence that supports the idea that the performance measures used in a real world task should necessarily correlate with the performance measures used in a virtual task. Anybody doing a study on land navigation of real and virtual environments should naturally be aware of the measures that are pretty much applicable in a real world, but do not correlate to the virtual world and vice versa. This chapter, firstly examines the issue of spatial awareness, and reviews the performance measures that are commonly used in navigation tasks. Finally, from the most common performance measures, the author determines the five best measures for investigating real and virtual world performance.

C. SPATIAL KNOWLEDGE

In the widely accepted theorization, there are three levels of spatial knowledge: *landmark knowledge, route knowledge and survey knowledge.* (SIEGEL & WHITE, 75)

1. Landmark Knowledge

Landmark knowledge is defined as the ability of the navigator to recognize distinctive features or locations at specific locations in the navigated area. When an outdoor navigation task is considered, landmark knowledge is the ability to recognize the features in an environment, such as a hilltop, a bridge, an intersection, or a building. Likewise, in an indoor navigation task, landmark knowledge would be the ability to recognize places where some certain objects are located. Although landmark knowledge can be gained through photographs or sketches of the area, generally the best way to gain landmark knowledge is direct exposure to the area. A performance success in landmark knowledge is assessed by evaluating the ability to recognize distinct locations or unique objects in the area, but not by knowing where they are.

2. Route Knowledge

Route Knowledge is defined as the ability of the navigator to navigate along a route or path between landmarks or distant locations [GOLLEDGE 91]. It expands landmark knowledge to a larger, more complicated arrangement of linking those objects or locations by a path or route. Route knowledge can be gained by repeated exposure to the environment, by maps or through a simulated exposure to the environment [GOLDIN 82]. Route knowledge is based on an egocentric viewpoint. Evaluating the ability to move from one landmark to another along a prescribed path assesses route knowledge. It requires the knowledge of the order between landmarks as well. The level of route knowledge gives no indication about the navigator's ability to find or follow alternate routes between landmarks.

3. Survey Knowledge

Finally, the highest level of spatial knowledge, *survey (or configurational) knowledge* represents a map-like or top down mental encoding of the environment and is based on a geocentric viewpoint. Survey knowledge is considered the most valuable part of the navigator's spatial knowledge. Because a person with survey knowledge has a mental map of the area, and can easily figure out alternate ways in that area. Sometimes, it's even a basis for making a distinction between a route learner and a navigator [HUNT & WALLER 99]. In survey knowledge, the navigator not only recognizes the specific locations or landmarks but also has a mental representation of them and can accurately place them in the environment even if he or she can not see them. The navigator can also traverse through the area without having to pre-plan the routes, because they know the area and they can devise new routes between landmarks [BANKER 97].

D. PERFORMANCE MEASURES

A review of the literature on spatial knowledge will result in the selection of five main performance measures to be tested for future work on the correlation between the measures in real and virtual worlds. These measures should be the measures pointing to the three main components of spatial knowledge. It's also expected that the measures identified in the review can be related to more than one component of spatial knowledge.

PERFORMANCE MEASURES	SPATIAL KNOWLEDGE TYPE
Landmark Recognition	Landmark
Order of Landmarks	Landmark, route
Number of Wrong Turns	Route, survey
Verbal Recollection of Spatial Experience	Landmark, route, survey
Number of People Losing Their Way	Route, survey
Sketch Map	Survey
Whiteboard Test	Survey
Projective Convergence	Survey
Map Placement	Survey
Pointing Test	Survey

Table 2.1 Spatial Knowledge type for each Performance Measure

1. Measures of Landmark Knowledge

Landmark recognition is almost the only measure in evaluating a navigator's landmark knowledge. It is assessed by asking observers to recognize or recall the landmarks that they have seen along the route [EVANS, 1980]. Recognition and recall have been evaluated through different types of tests. One way to test landmark recognition is getting the pictures of landmarks existing along the route, mixing these with some irrelevant landmark pictures, and asking the observer to choose the landmarks that he or she has seen throughout the navigated route. Assigning a positive weight to the correct and negative weight to the false response forms the scale for that particular individual's landmark recognition score.

2. Measures of Route Knowledge

There are several measures of route knowledge. One of these is the verbal recollection of spatial experiences [LYNCH, 1960]. By using the verbal recollection of experiences, it's possible to determine the way the navigator connects the landmarks in his or her memory. This recollection of experiences in fact shows the mental route that the navigator thinks he or she has followed. This measure is not an easily quantifiable measure, but will give a good idea about a certain individual's route knowledge.

Other measures used to evaluate the route knowledge of the navigator are the number of wrong turns and route traversal times [STREETER, et al.]. This is a rather quantifiable measure when compared to verbal recollection. A participant having his or her second traversal in the environment after a first exposure (or map study, VE exposure) is observed to assess the wrong turns he or she makes and the time he or she spends in the virtual environment. Obviously, time will differ in the real and virtual environments, since the factors affecting the time in a real environment are not necessarily effective in a virtual environment (e.g. travel methods). However, these factors don't necessarily have a relation with spatial ability either. To clarify this, we can think about the rate of movement in navigation. A fast walker in a virtual environment moves at the same rate as a slow walker, and walking fast or slow does not necessarily have any relation with a person's spatial ability.

In larger group studies, the number of people who lose their way [BEST, 1969] is also a measure used to determine the route knowledge acquisition for that environment. However, in a study to determine the spatial ability or performance level of each participant individually, this measure cannot be used. However whether or not one person is lost would be a measure for that individual's performance. When we think about the percentage of people getting lost in an environment, that would not be an appropriate measure for a particular person in that group.

One other measure for route knowledge is the arrangement of photos of route segments and landmarks in their correct order [EVANS, SKORPANICH, GARLING, BRYANT & BRESOLIN, 1984]. As it is expressed in previous pages, some of the measures being mentioned in this chapter can evaluate different levels of spatial knowledge at the same time. The last mentioned measure is a measure that assesses landmark knowledge as well as route knowledge.

3. Measures of Survey Knowledge

The highest level of spatial knowledge, survey (or configurational) knowledge, is the main factor that makes the difference between a route learner and a navigator. However, survey knowledge is difficult to measure. The mental map in each navigator's mind cannot be quantified easily.

Generally, configuration knowledge is measured by asking the participants to draw a sketch map of the navigated environment [LYNCH, 1960; APPLEYARD, 1970]. However, the maps drawn are difficult to score, and may underestimate the knowledge acquired [SIEGEL, 1981].

A measure used by Goerger was the "Whiteboard Test" which measures the exocentric survey knowledge of the participant [GOERGER, 1998]. This measure was able to overcome the effect of drawing abilities between different individuals.

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. A technique very similar to this one is the pointing technique which simply calculates the angular error between the pointed direction and the actual direction of an unseen object in the environment.

E. SELECTED MEASURES

A consideration of the measures mentioned in previous sections requires the selection of the most efficient ones among them. Without any doubt, a landmark recognition task, which is the only exclusive way to determine landmark knowledge should be included in a performance measure study. The correct order of the landmarks will provide information about the navigator's route knowledge. A route replication task to get a measures of the number of wrong turns will provide a good basis on the person's route knowledge. Then, for the survey knowledge, a pointing task and a sketch map will be used. The sketch map provides input on the route knowledge as well.

F. SUMMARY OF THE CHAPTER

In summary, the human performance measures used in either virtual or real environments is a broad area. Spatial knowledge itself has three components, which have their own effect on environmental knowledge acquisition. Some of the measures used in the previous studies are applicable in certain cases, but not in some others. Likewise, these measures might be evaluating just one aspect of spatial knowledge or different aspects of spatial knowledge. Therefore each of the measures has its own efficiency and applicability level.

For a further study of land navigation performance level correlation analysis, the author has selected five performance measures as the most efficient applicable ones due to their advantages or disadvantages. These measures are, landmark recognition, landmark sequence, route replication (number of wrong turns), pointing, and map placement. Table 2.2 shows the list of the selected measures and the spatial knowledge types they measure.

SELECTED PERFORMANCE MEASURES	SPATIAL KNOWLEDGE TYPE
Landmark Recognition	Landmark
Order of Landmarks	Landmark, route
Number of Wrong Turns	Route, survey
Map Placement	Survey
Pointing Test	Survey

Table 2.2 Selected Measures and the Spatial Knowledge Type they measure

Any study using human performance measures in a virtual or real world navigation task should expose and address the power of the measures to evaluate the performance levels, and the applicability of the measure for that particular study. Even indoor and outdoor navigation tasks might require quite different types of these measures. Furthermore, none of the components of spatial knowledge mentioned in this study should be neglected in an evaluation task. The most important measures, which are at the same time the most commonly used ones, should be examined for a comparison study. Thus, the results of further studies should be evaluated on a concrete basis.

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III. METHODOLOGY

A. EXPERIMENT OVERVIEW

An experiment was conducted in order to determine whether or not the performance measures in real and virtual worlds are correlated. The succeeding sections will describe the tools, phases and procedure of the experiment in more detail. This section will provide an overview for the experiment conducted in two different environments. The general sequence of the experiment was the in-briefing, model familiarization (VE only), walking through the course, route replication, landmark recognition, free exploration of the environment, finding alternate routes, map placement and debriefing.

Upon the arrival of the participant, the research monitor read the basic in briefing, and they filled out and signed basic consent forms. The in brief is shown in Appendix C. The consent forms are in Appendix D.

In the virtual environment condition, the subject was initially told how to operate the Flybox. Forward and backward movement switches and the usage of the joystick in order to face different directions or look down or up were also explained in the familiarization phase. A common error detected in the pilot experiment and previous attempts was trying to get a rolling effect. Each participant was told that the Flybox does not have such a function. After the verbal instructions of the Flybox, a trial model was started. In this model, the participant took a very short walk in the building, and this route was a part of the building excluded from the experimental building. In the trial model, the participant started from a specified point and moved as instructed by the research monitor. Throughout the trial he was allowed to move forward or backward, make necessary turns, in some narrow aisles, go down and up the stairs. All the movements in the trial model were as difficult as the real model. In the trial model, the participants replicated the route and were given pointing tests. Each participant had an idea of what he was supposed to do in the real experiment. There was no time limit for the trial model, but all participants reported that they felt comfortable with Flybox at the end of the trial task.

After the familiarization, each participant started to walk on the predetermined route according to the instructions given by the research monitor. At a certain point, (referred as point A) the participant was stopped and asked to face the starting point. In the virtual model, the degree was taken by a keystroke, and in the real building a pointing tool was provided to allow the participant point to the starting place while taking a measurement. (Figure After the first pointing test, the participant was asked to walk according to the instructions until the end point. At the end point, two more pointing tests were conducted. In these two tests, the participant was asked to point to the starting place and to point A.

Upon the completion of the route, the participant was told to follow the same route in reverse order to the starting point. This was the route replication task for the experiment. In the route replication task, the participant was allowed to look around to determine the route to take, but whenever he decided on a route and started to walk it, if the direction was incorrect, he was directed to the correct path. In each of these cases the wrong turn was recorded by the research monitor. By making the required turns, the participant reached the starting point. At this point, a fourth pointing task was conducted. The participant was asked to point to the end point.

When the route replication task was completed, a landmark recognition test was conducted. In this task, the participant was shown ten different landmarks, some of which had existed in the original route. For this test, color printed pictures of the landmarks were used and the number of correct landmarks were recorded. When the participant selected the landmarks he had recognized, he was asked to put them into correct order from the starting point to the end point. The order of the landmarks for each participant was also recorded for further analysis.

Upon the completion of the landmark recognition test, each participant was asked to explore the environment himself for 10 minutes. For the virtual building, at the end of the allowed time, the research monitor exited the program wherever the participant was. For the real building, in the last ninety seconds, the research monitor led the participant to the starting point in order to make sure that everybody uses the same amount of time.

After the free exploration of the environment, a task of finding alternate routes was conducted. The participant was told to take the exact route he took from the starting point to the end point. At a certain place in this route he was given a scenario. In the scenario, a stairway was blocked due to construction and the participant was asked to find an alternate route he thinks will reach the end point. Then he was instructed to take that alternate route. Whenever he realizes that his alternate route was not correct, he was asked to determine a new alternate route until he reaches the end point. In each of these, his level of confidence was also recorded.

When the participant completed the task of finding alternate routes, he was given the landmarks that he had recognized in small pictures. Then, he was asked to locate them at the appropriate points on a given map. The map was a rough design of the building just showing the outer lines and the starting point. The places of the landmarks were recorded with the map.

After the completion of the experiments in both environments, the subjects were debriefed about the experiment. They were thanked and reminded not to talk to anyone about the specifics of the experiment.

B. EXPERIMENTAL DESIGN

The participants were divided into two groups. The first group experienced the real building first, and then the virtual building. The second group had the reverse order.

1. Participants

The subjects for this experiment consisted of 10 male individuals ranging in age from 24 to 27 with an average of 25. All were active duty Turkish Army officers. None of the subjects was colorblind. Since a certain level of experience in navigation was not required in this experiment, they ranged in different levels of experience and spatial ability. None of the subjects had prior knowledge of the testing area. Data was collected from 28 June 2000 to 17 July 2000.

2. Order of Test Environments

The participants were tested in two groups. The first group participated first in the virtual environment, then in the real world. The second group followed the reverse order. However, this should not be taken as two different treatments. The reason for the order of exposure to the two different environments was not to test the difference. We wanted to avoid errors that could be caused by a learning effect.

Performance in landmark recognition, landmark sequencing, route replication, pointing, and map placement were the five performance measures used in this study.

C. APPARATUS

1. Test Environments

Two environments were used for the experiment. One of them was the Middle East School at the Defense Language Institute in Monterey, CA (See Figure 3.1). The other was a modified version of Herrmann Hall at the Naval Postgraduate School, Monterey, CA.

We never invented for the two environments to be exactly the same, because this could cause a learning effect. However, so as not to have a completely different level of performance in these two environments, we looked for similar properties in these two buildings.

Figure 3.1 Middle East School in DLI

These two buildings had similarities which made it possible to think of a correlation between the performance measures in these two environments. The first similarity was the complexity level of the two buildings as defined by the features that make the navigation more difficult. There were some features shared by both buildings. One feature was the location of the stairways. There were many stairways in different parts of both buildings. A second feature was the presence of partial floors in these buildings. The Herrmann Hall model has a mezzanine level. In the Middle East School, there were three buildings connected to each other, and the connection to a different building was provided by a passage off the halfway of the stairs. So, for example, the second floor of one building was between the first and second floors of another building. This made it possible to lose the concept of vertical location throughout navigation inside both buildings. Both of the buildings were closed environments and it was not possible to get much reference from the outside. Neither the Herrmann Hall model nor the Middle East School has sufficient windows to view outside. Since the classrooms in the Middle East School were not accessible throughout the experiment, it was not possible to get a sense of location by looking outside. In Herrmann Hall, there were rare windows through which to view outside.

2. Virtual Model

The virtual model is a modified form of the Herrmann Hall model created by John Locke at the Naval Postgraduate School. The model was created in Creator, by Multigen Paradigm and the motion model for it was developed by Brian Christianson and Andrew Kimsey at NPS. The model itself runs on an SGI machine with four 194 MHZ IP25 processors and 384 Mbytes main memory size.

The interface uses Flybox (see figure 3.2) as the interaction device. Flybox allows the user to face right or left, or look up or down. The speed of walking was also designated by the user by moving a lever into forward and backward positions. When the lever was kept in the center, there was no forward or backward motion.

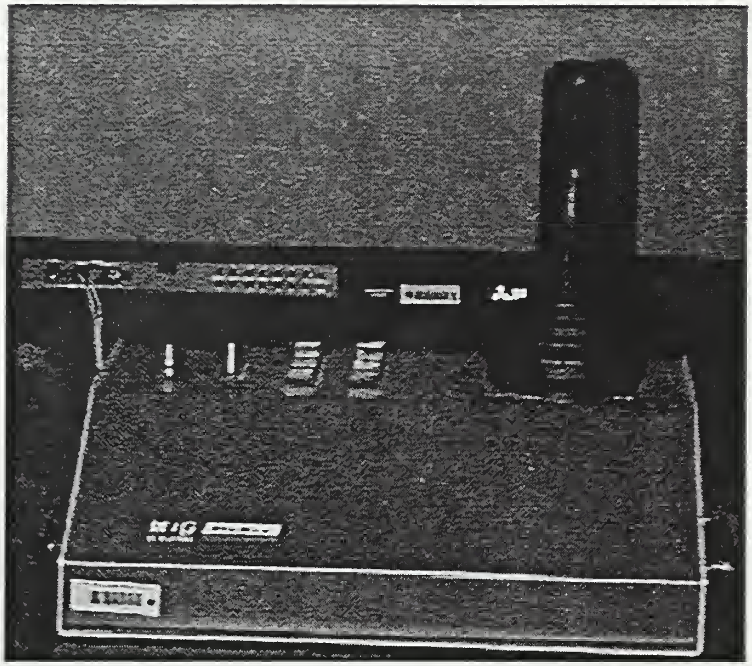

Figure 3.2 Flybox

The table 3.1 shows the effects of Flybox.

FLYBOX OPERATION	FUNCTION
Left Switch "Forward"	Increase forward speed
Left Switch "Backward"	Increase backward speed
Left Switch "Center"	Stop
Move Joystick to the "Left"	Turn the body to the left
Move Joystick to the "Right"	Turn the body to the right
Move Joystick "Forward"	Look Down
Move Joystick "Backward"	Look Up

Table 3.1 Functions of the Flybox

For the visual display, a three-screen configuration with 103 – degree FOV was used. (See figure 3.3) These three 40 inch screens were set up exactly 67 inches from the subject to ensure that 103 degrees were provided. The measurement for the visual display was based on the previous study made by Goerger [GOER 98].

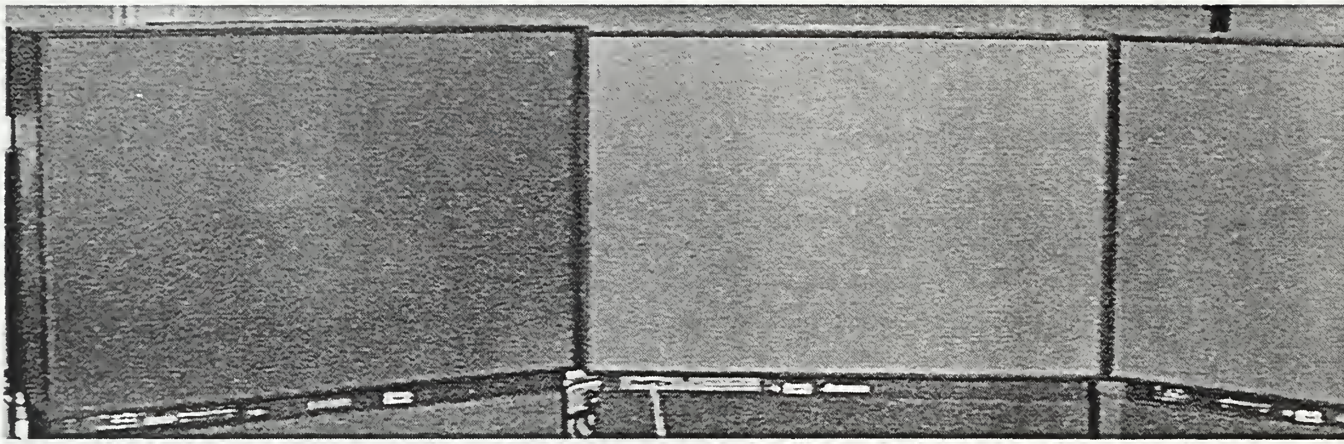

Figure 3.3 Three screen visual display

In summary, the model was set to make sure that the participants were provided the comfort and ability they needed to navigate in a virtual building.

3. Route

The route for the task was a route including the same level of vertical motion and approximately the same number of turns for both real and virtual environments.

In the Herrmann Hall model, there were 9 turns throughout the navigation, and the user was navigating in three floors of the building. One of the floors was a mezzanine, which had an entrance halfway up the stairway. The route for Herrmann Hall is shown in Figure 3.3. The oval shapes in the graph indicate the stairways.

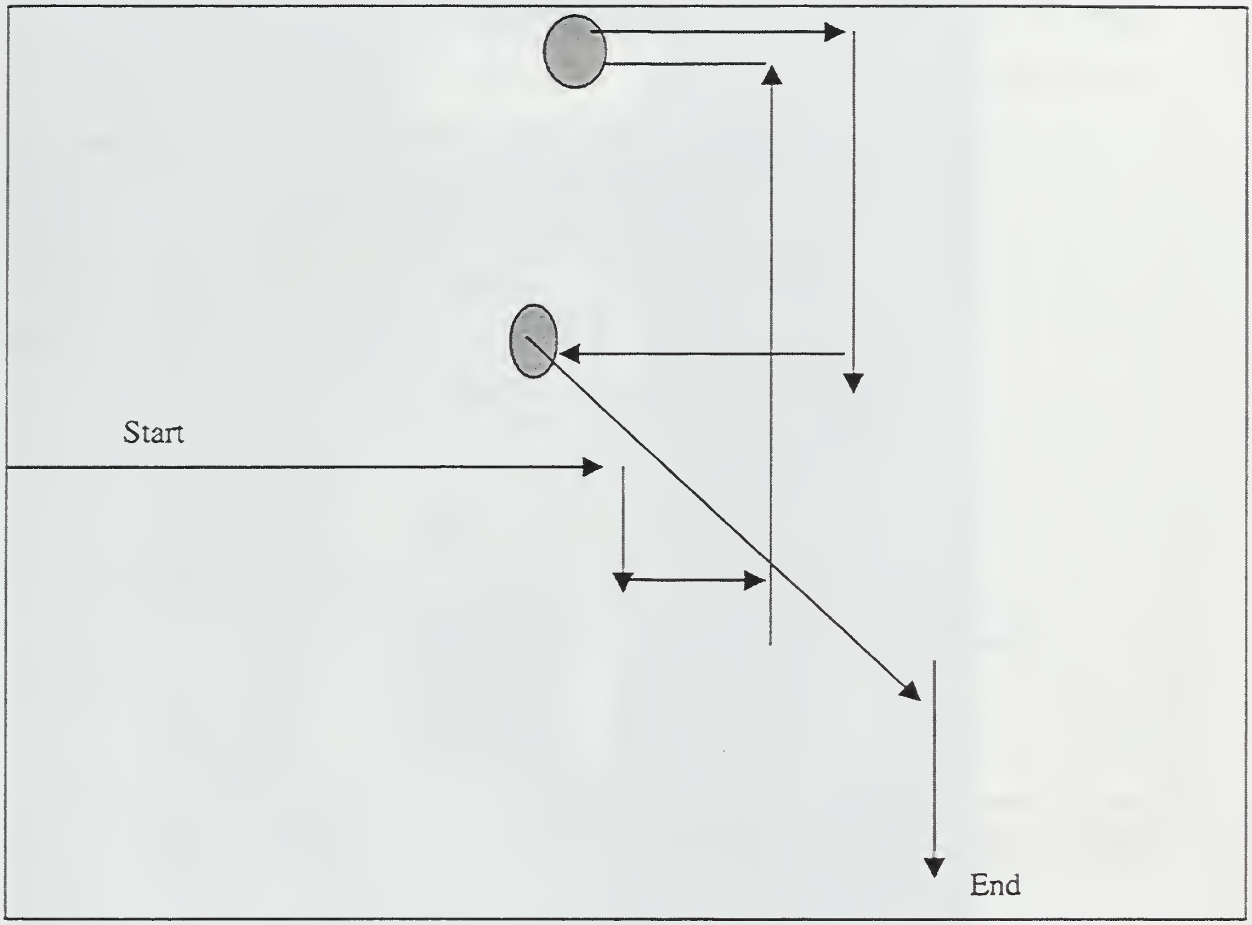

Figure 3.4 Plan View of the Route for the Herrmann Hall model

The real building route was similar to the Herrmann Hall model with respect to the number of turns and floors in the building. The route in the Middle East School had 8 turns and three floors throughout the navigation. This building consisted of three distinct parts connected by stairways. (The stairways were connecting one floor to the other. See figure 3.6) Consequently, the second floor of one building was vertically located at a level between the first and second levels of the other building. This feature of the real building was similar to the mezzanine of Herrmann Hall. A graph of the route for the real building is in Figure 3.4. In this figure the oval shapes indicate the stairways, as in the previous figure. The routes themselves are seen in Appendix E.

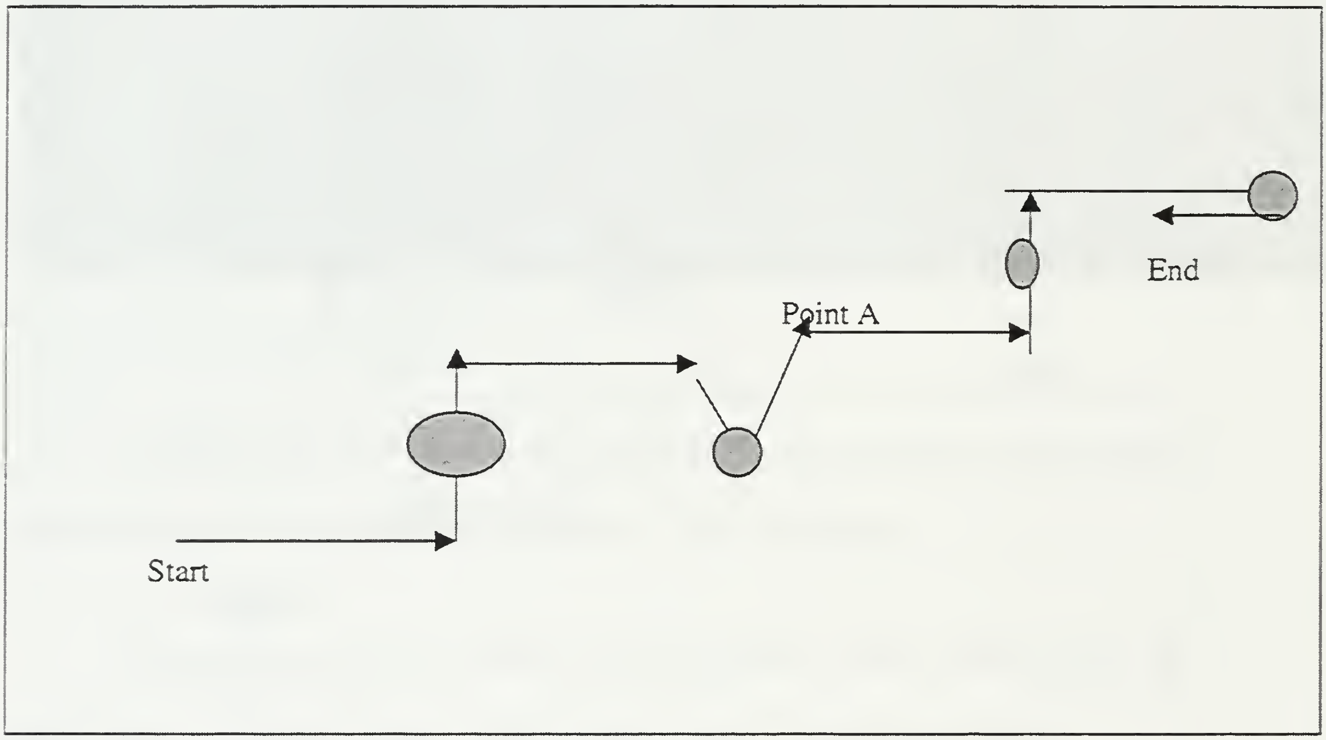

Figure 3.5 Plan View of the Route for the Real Building

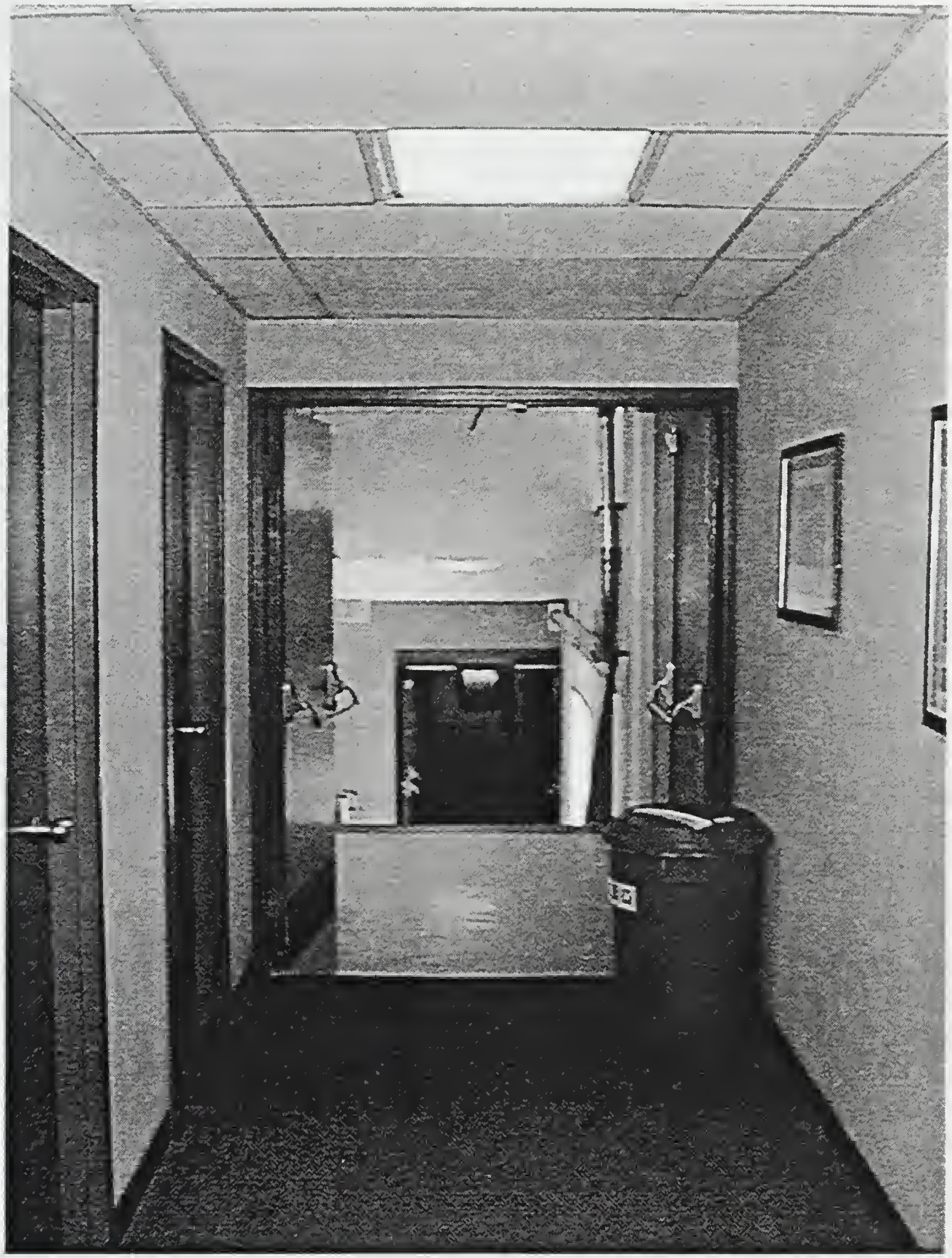

Figure 3.6 Stairways in DLI

D. PROTOCOL

1. Walking Through the Course

The first task was to walk through the course upon the instructions of the research monitor. From the starting point, the subject was asked to walk straight ahead or turn a direction by the research monitor. The walking speed of the subject was controlled by the research monitor, and he was warned if he either walked too slowly or too fast. The normal walking speed was determined as the speed of the monitor, and the subject was asked to keep that rate.

In the virtual environment, the speed of the participant was limited with the motion model, so the participant could not walk faster than a certain level. In addition to this, to prevent slower walking, the participants were verbally warned not to walk slower than a walking rate.

In the real building, since the participant and the research monitor were walking together, the participant was asked to keep pace with the research monitor's walking speed. This made it possible for each participant to have equal time for observation.

2. Route Replication Task

Once the subject walked from the starting point to the end point upon the instructions of the research monitor, a route replication test was started from the end point. At this point, the subject was asked to take the same route back to the starting point. In the route replication, although the subject was allowed to look around to make decisions on the necessary turn, once he decided and started to proceed on a route, that decision was recorded. If the subject has chosen a wrong way and started on that route, he was corrected, and that turn was recorded as a wrong turn. Each time the subject made such a wrong turn, the wrong turn was recorded. In this way, the subject walked from the end point to the starting point in the same path.

3. Landmark Recognition Test

Upon the completion of route replication, the subjects were given ten pictures of certain landmarks and were asked to select the ones they recognized. The landmarks used in the experiment are in appendix F. Once the subject chose the landmarks that he had recognized, he was asked to put them into the order that he had seen them from the starting to the end point. The number of correct landmarks that the subject recognized and the order of landmarks were recorded by the research monitor.

4. Pointing Tests

Throughout the first route from starting point to the end point, and at the end of the route replication, a series of pointing tests were conducted. The first pointing test was conducted halfway from the starting point to the end point. This place was referred to as point A throughout the experiment. At point A, the subject was asked to point the starting point.

In the virtual environment, pointing was done by facing that direction, at which time, the research monitor recorded the location and the bearing of the subject to a file. Two other pointing tests were conducted at the end point. In these test, the subject was asked to point to the starting point and point to A from the end point. Besides these, at the end of the route replication test, the subject was asked to point to the end point from the starting point. This was the fourth and last pointing test for the experiment.

In the real building, this test was conducted by directing a paper arrow on a board to the starting point. At certain points of the building, rather than facing a direction, the participant was asked to direct the arrow on the paper to the location asked. The angular degree was recorded at the time of the test conduction.

Pointing test results were used as a measure of survey knowledge of that subject. The degree of error in these tests were used as a clue to understand the survey knowledge of the participant in that environment.

5. Free Exploration

In the free exploration phase, the participant was allowed to explore the environment himself for ten minutes. Throughout this phase, the research monitor walked with the participant, and recorded the routes he took. This was done, so that if a specific route that can affect the results was taken, this could be noted.

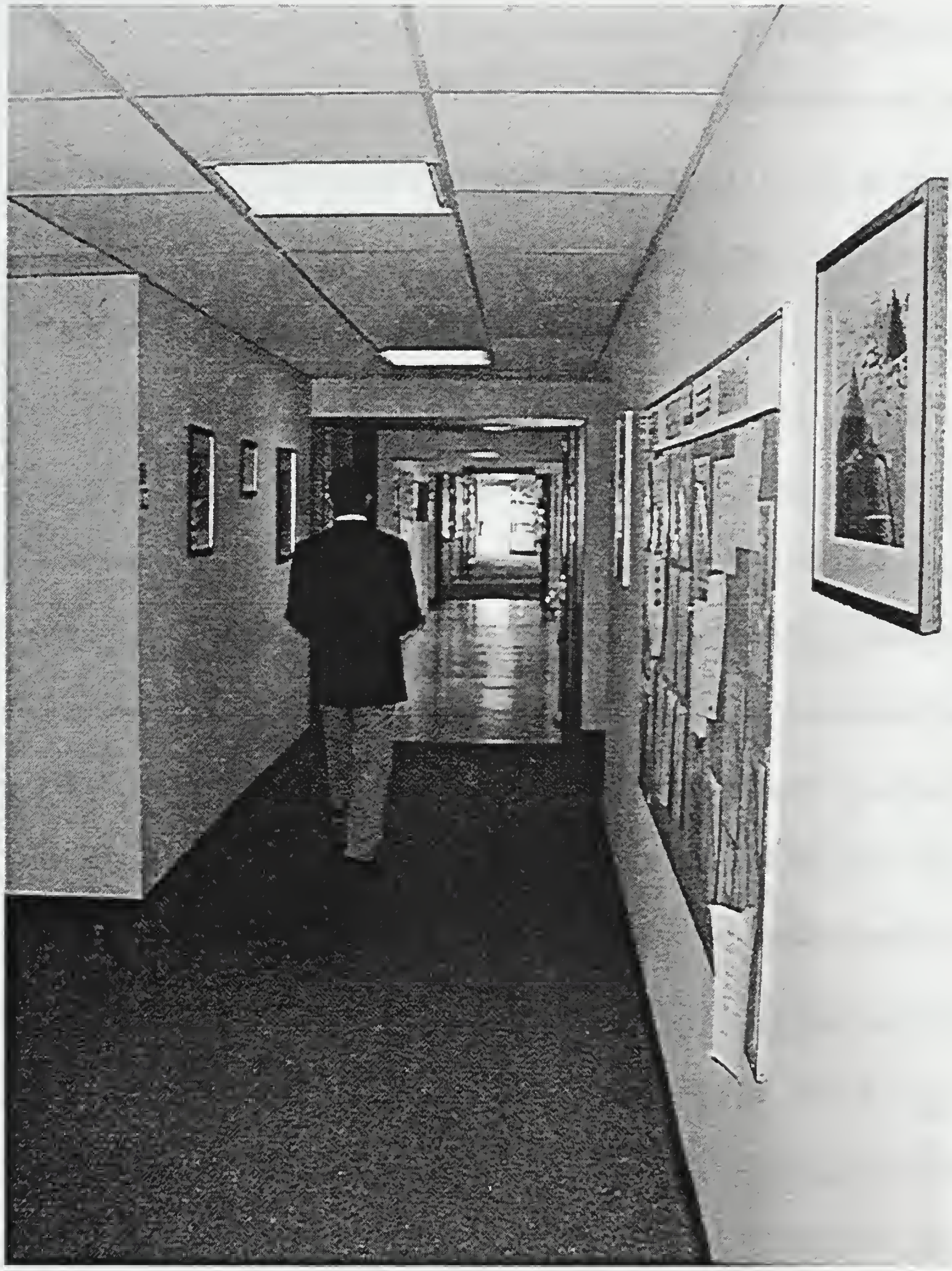
Figure 3.7 Free Exploration

In the virtual model, when the participant used the allowed time, the research monitor exited the program simply by hitting the escape key. This had been told to the participant prior to the free exploration task. Thus, the allowed time for each participant was same in the virtual environment.

However, it would not be this simple in the real world. In the real world, some participants could be close to the starting point at the end of the allowed time, and some could be far. This could result in extra time for the participants who are in the farthest location to the starting point. We wanted to avoid such a difference between the participants. For this reason, at the last 90 seconds of the free exploration, the research monitor evaluated how far the participant is from the starting point, and led the participant to the entrance of the building where he started. This was done by leading the participants via the shortest route, so the same amount of time would be used by each participant. Throughout the experiment, each participant was warned about the remaining time in one minute intervals.

6. Alternate Routes

After the free exploration of the environment, the subjects were asked to walk from the starting point to the end point in the same route they took in the first task. When they reached a certain point on this route they were given a scenario. According to the scenario, a stairway was blocked due to a construction in the building, and the subjects were asked to think about alternate routes to reach the end point. Before taking an alternate route, the subjects were asked to describe the route and their description of the alternate route was recorded by the research monitor. Besides describing their route, they were also asked to say the level of confidence they felt for this route. The confidence level for each alternate route was also recorded. The confidence level was a number between 1 and 9 from the least confidence to the highest. When the subject reached a point where he saw that his alternate route does not go to the end point, he was asked to describe a new alternate route and rate his confidence level for this new alternate route. Each of these routes and the confidence levels were recorded until the subject found his way to the end point.

7. Map Placement

Upon the completion of all tasks in the experiment, the subject was asked to place the landmarks he had seen throughout the navigation on a rough map of the building. The rough map used for this test showed only the outer line of the building and the starting point. The subjects were given small pictures of the landmarks that they had seen, and were asked to place them into proper locations of the building. The maps that they had built this way were recorded as another measure of survey knowledge. Once the exact points they had located were recorded, these maps were compared to a map which has 1/2 inch diameter (corresponding to 9 feet tolerance) circles in the places of the landmarks. The difference between the subject's landmark and that circle was taken as a measure. We did not require exact precision. If the subject was not able to remember that landmark, he was penalized by the biggest error made by any subject for that specific landmark.

This test should not be confused with the whiteboard test used by previous researchers (GOERGER, 1998). In the whiteboard test, a blank white board was used, but the map provided in this experiment used a rough design of the building. Although the rooms and the details of the building were not provided in this map, the walls and the entrance were indicated, so the participants had a better idea of where to locate the landmarks.

IV. ANALYSIS

A. RESULTS

1. General Information

The experiment is designed to test a primary hypothesis concerning the correlation between the navigational performance of a particular participant in a virtual and real environment. To determine overall performance, participants were evaluated on their landmark, route and survey knowledge of the environment, while going through a series of tasks in the target environments.

a. Primary Hypothesis

A participant's navigation performance in a real world environment will be correlated to their performance in a similar but distinct virtual environment.

b. Sub Hypotheses

1. Landmark Knowledge

a) A participant who has the spatial ability of keeping landmarks in his memory in a virtual environment, will have the spatial ability of keeping landmarks in his memory in a real world environment.

2. Route Knowledge

a) A participant who can recall the order of the landmarks he had seen in a virtual environment navigation task, will be able to recall the landmarks he had seen in a real world navigation task.

b) A participant who can form a route of a course in a virtual environment will also be able to form a route of a similar course in the real world environment.

3. Survey Knowledge

a) Given a certain time to get familiar with the environment, a navigator who can point to unseen objects accurately in a virtual environment will also be able to point to unseen objects accurately in a real world environment, after being exposed to that real environment for an equal period of time.

b) A participant who can form a mental map of a virtual environment that he or she has learned can also form the mental map of a real environment after being exposed to that real environment for a period of time.

2. Power Analysis

The results of the experiment are presented as scatter plots and histograms. The primary analysis was based on the correlation between the virtual and real treatment groups, but other possible factors were analyzed and discussed in Section B. An α value of 0.1 was used to determine significance. A post hoc power analysis for large effect, $\alpha = 0.1$ was made. The resulting power $(1 - \beta)$ was 0.5102. Due to the low sample size, it may be incorrect to draw conclusions based solely on the failure to determine a positive correlation.

3. Normalization of Data

Most of the measurements used for analysis in this experiment occurred over time and distance. Some participants were not able to locate certain landmarks just because they had not remembered the landmarks themselves. To make participant data comparable, measurements were modified with penalties. This allowed us to place each participant's data in a rational format for correlative analysis.

4. Landmark Knowledge

Landmark knowledge is assessed by analyzing the landmarks recognized by the participant and sequence of landmarks formed by the participant.

a. Number of Landmarks Recognized

After going through the environment for a certain period of time and a certain distance, each participant was shown ten landmarks, six of which had existed in the environment. From these landmarks, the participants were asked to select the ones that they had seen throughout the navigation exercise.

The general spatial ability to recall the landmarks in a virtual environment was not much different from the ability to recall them in a real world. Figure 4.1 shows the comparison of the general ability of landmark recognition for each participant in these two different environments.

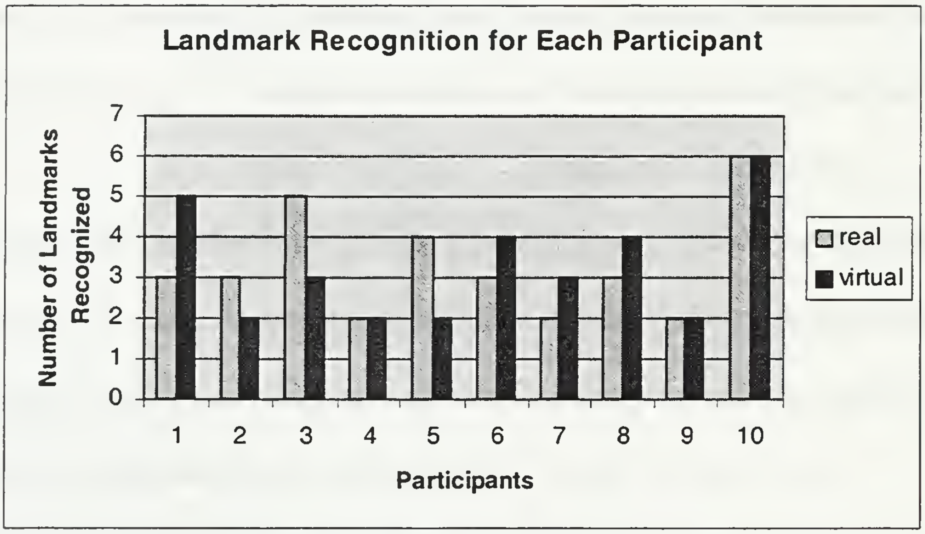

Figure 4.1 Histogram for Landmark Recognition Test

When we consider each individual's spatial ability on landmark recognition, we saw that the participants who performed better in the real world performed better in the virtual world as well. Figure 4.2 shows a scatter plot on the performance of the participants in landmark recognition.

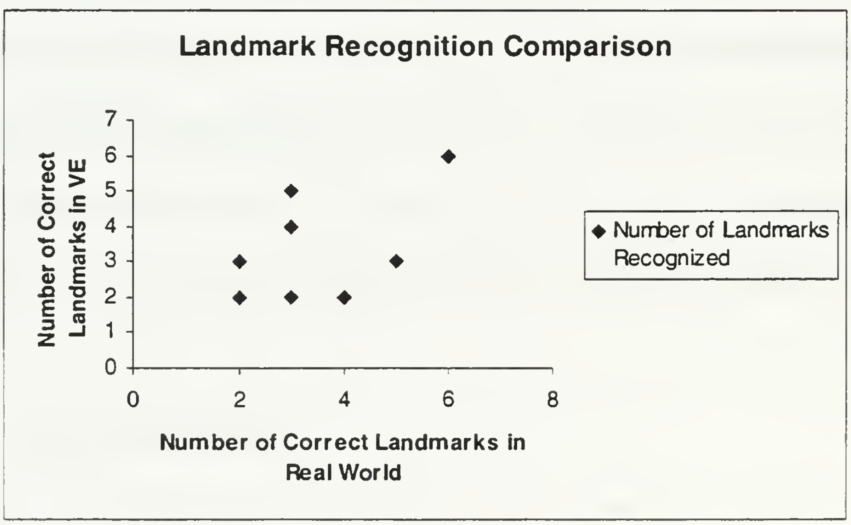

Figure 4.2 Landmark Recognition Comparison

The correlation coefficient for the comparison is calculated as 0.533 and this does not give a certain sign about the existence of a correlation. However, even in such a small group the performance comparison shows that in landmark recognition better navigators in a real world tended to be better in a virtual world as well.

b. Sequence of Landmarks

Just after selecting the landmarks that he had recognized, each participant was asked to put the landmarks into correct order. This order was measuring the participant's route knowledge and landmark knowledge. The landmarks that the participant could accurately put into order helped to understand about which landmarks the participant was more confident. The results of a scatter plot for the participants' performance in the sequence of the landmarks showed that the correlation between the ability to put the landmarks into correct order in a real and virtual world was not as strong as the correlation to recall them in these two environments. Figure 4.3 shows the scatter plot graph for the order of landmarks in these two environments. Figure 4.4 shows the histogram for the comparison of each individual's performance in both environments.

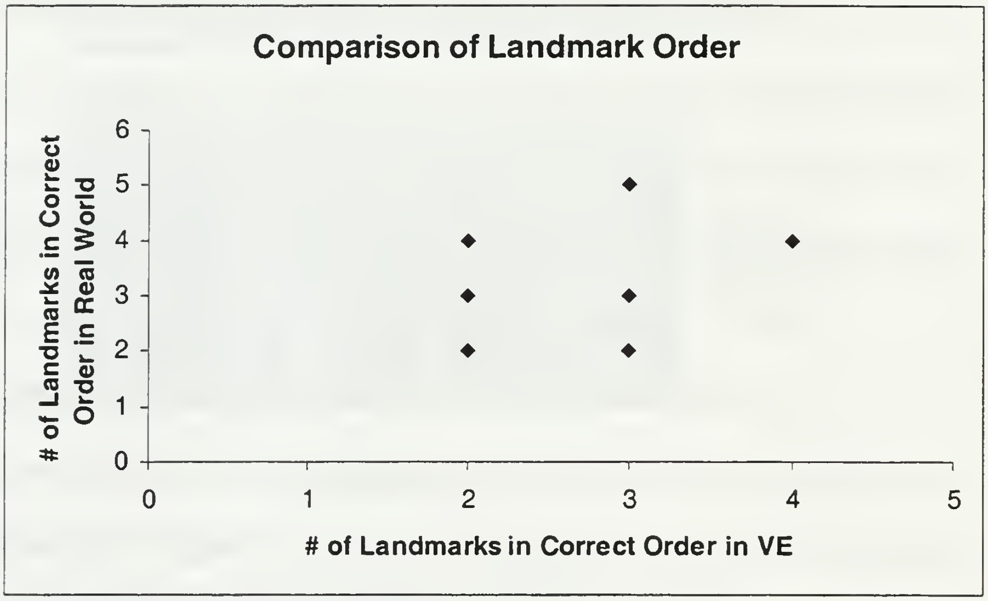

Figure 4.3 Comparison of Landmark Order

5. Route Knowledge

Route knowledge is assessed by analyzing the order of landmarks in correct order and the number of wrong turns in the route replication task. Sequence of the landmarks which had been used as a measure of landmark knowledge can also be used as a measure of route knowledge. The general picture of the route knowledge presents less correlation in the performances in real and virtual worlds.

a. Sequence of Landmarks

The sequence of landmarks, as stated above, did not present a correlation as strong as landmark recognition. However, there were still matching good and poor performances. A histogram of performance level for each participant is seen in Figure 4.4. The scatter plot for the landmark sequence is seen in Figure 4.3.

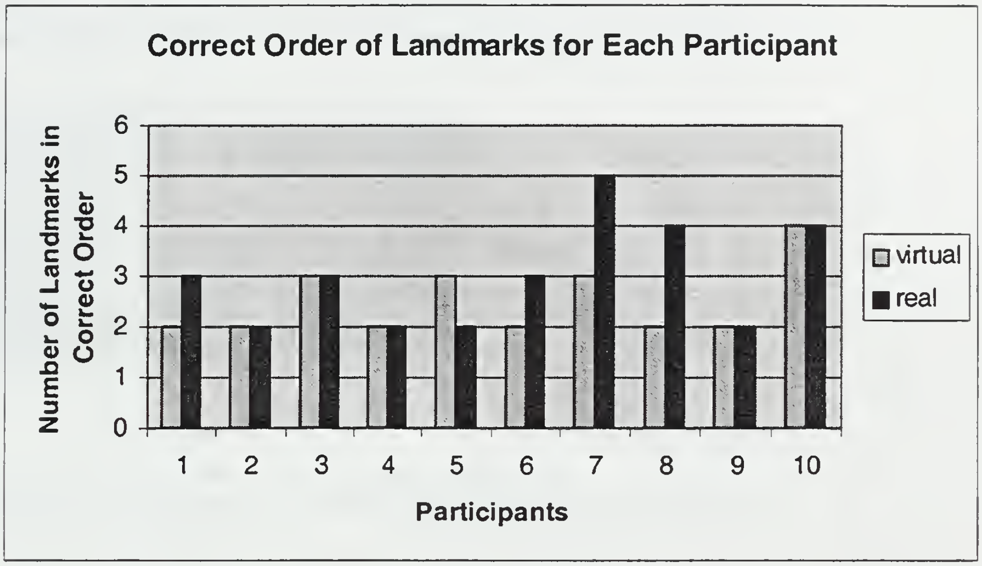

Figure 4.4 Histogram for Landmark Sequencing Test

In general, the performance of correct order in the real world tended to be mostly close to and in some cases better than the performance in a virtual world. The correlation coefficient for the correct order of landmarks was 0.447.

b. Number of Wrong Turns

The second important measure for route knowledge was the number of wrong turns in the route replication task. A navigator who has learned the route in an environment should make the correct turns when going through a route which he had taken before. A significant correlation could not be detected in the analysis of the number of wrong turns. Since there was a big difference between the performances in the real and virtual worlds, the errors in the virtual world were almost evenly distributed. The correlation coefficient for the number of wrong turns was –0.08. Figure 4.5 shows the scatter plot graph for the number of wrong turns in these two environments.

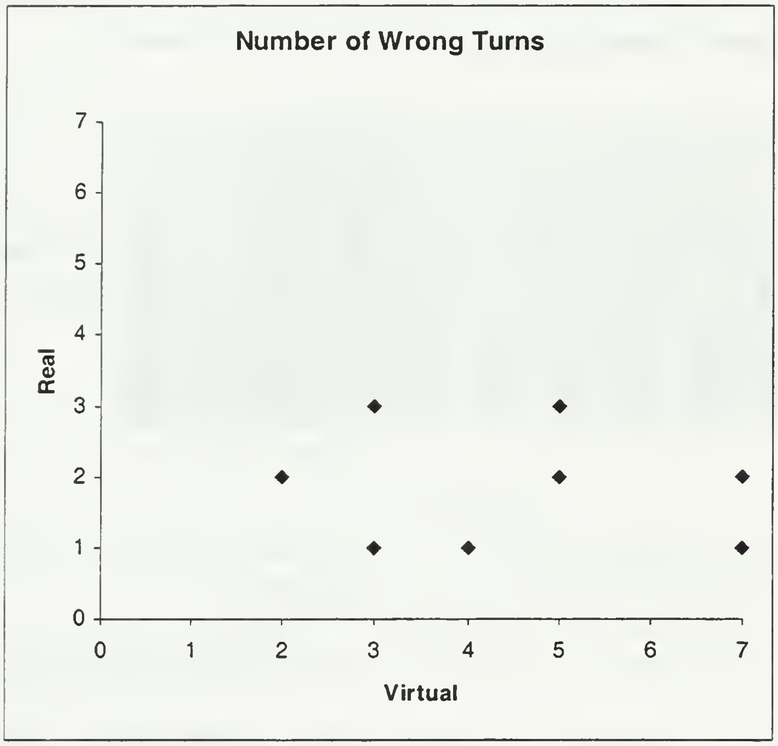

Figure 4.5 Scatter Plot for the Number of Wrong Turns

The participants made more wrong turns in the virtual than the real world. And the variance was also very little. This was probably because of the fact that the participants did not have enough time to get survey knowledge in the virtual environment. This fact prevented us from drawing conclusions on the route knowledge based on the results of performances in this test. The histogram below (Figure 4.6) shows the difference more clearly.

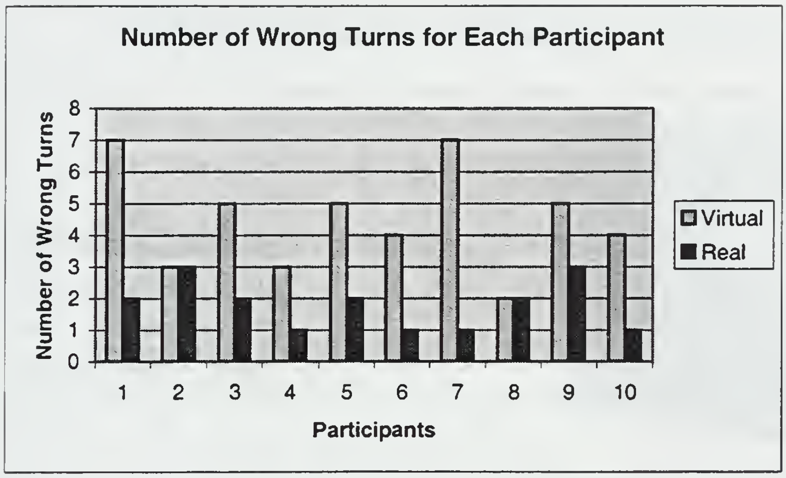

Figure 4.6 Histogram for the Number of Wrong Turns for each Participant

c. *Aggregated Route Knowledge Evaluation*

The correlation we had seen in the landmark knowledge was not seen in the performance measures of the route knowledge. So, we decided to aggregate the two measures of the route knowledge, and analyze these aggregated scores.

When we look into the aggregation and consider the score as a number between 0 and 1, the performance of determining the correct turns in a virtual environment is obviously less than any other performance measure. Figure 4.7 shows a 3D representation of the performance measures for the route knowledge.

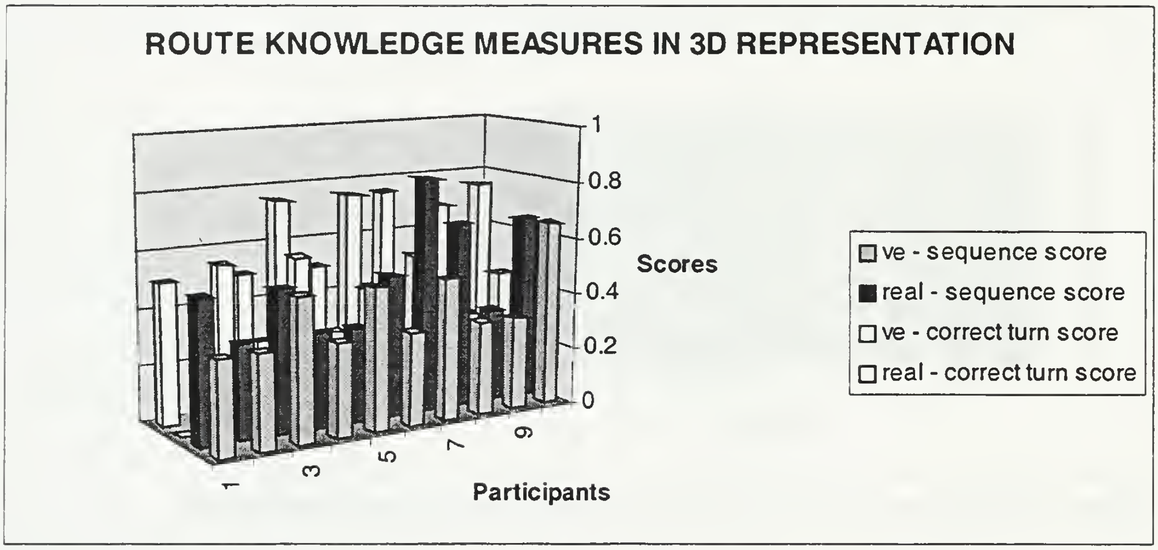

Figure 4.7 3D Representation of the scores for the route knowledge

Likewise, when we get an overall value for an individual's route knowledge in a virtual or real environment, we get the scatter plot graph below.

In an aggregated form, the performance of landmark recognition was given a value between 0 and 1. So, any participant who had recognized 4 of the 6 landmarks that had existed in the environment had a score of 4/6 = 0.66 in this model. Another value between 0 and 1 was also used for the number of wrong turns. This time, the number of wrong turns was divided to the maximum number of wrong that could be made. A greater value for this fraction would mean a poor performance, so the result from this division was subtracted from 1, and we still obtained a value between 0 and 1 for the performance level in the number of wrong turns. Thus, for an aggregated model, we had two values between 0 and 1 to indicate the performance level in these two tests. These two values were added, and we obtained a performance value in route knowledge between 0 and 2.

Figure 4.8 shows the slight correlation between the aggregated performances in virtual and real environments. In this graph, the values for each measure are added in the above way, and a score between 0 and 2 was obtained for each participant in a certain environment.

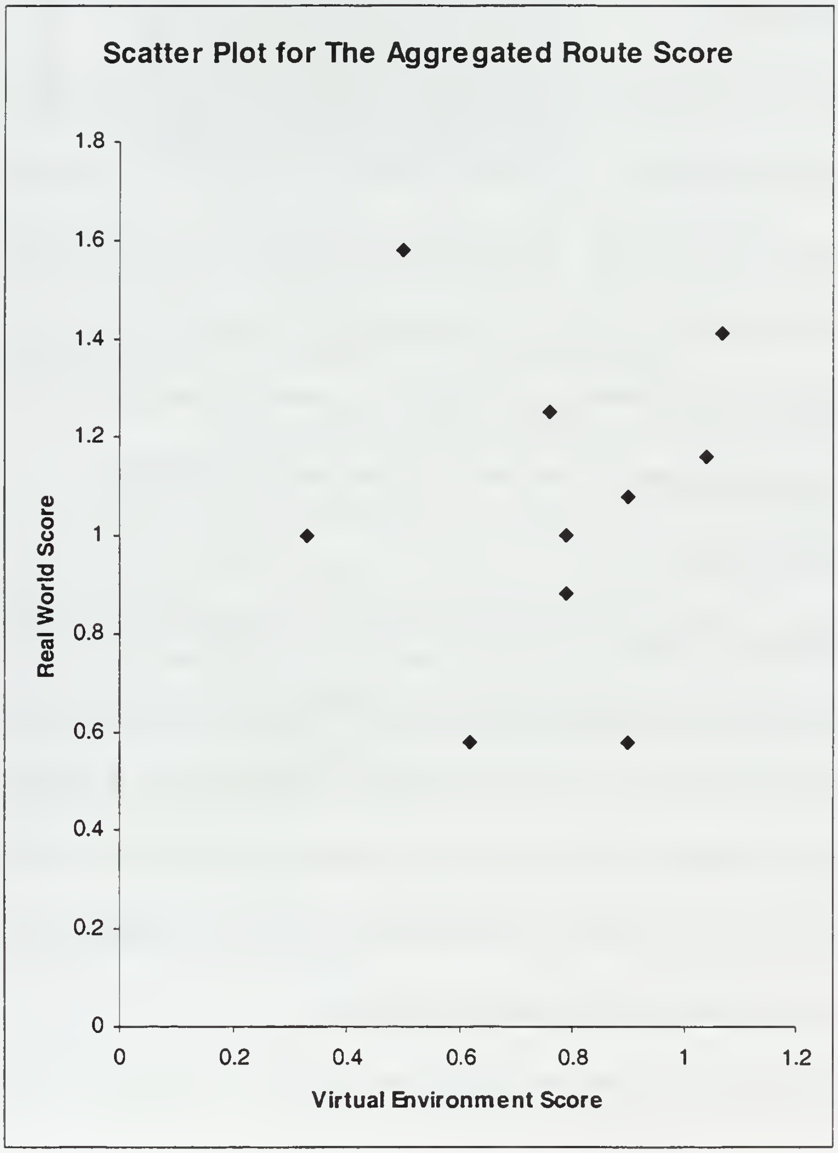

Figure 4.8 The Scatter Plot for Aggregated Route Knowledge Score

In the aggregated evaluation, the number of wrong turns has obviously affected the slight correlation in the sequence, and the graph we have in an aggregated form has the low coefficient of 0.04. The possible reasons for this effect will be discussed in the discussion section.

6. Survey Knowledge

Survey knowledge has been assessed by analyzing the results of the pointing tests and the maps built by the participants. Participants had built maps by putting the landmarks into certain points on the map. Although it had not been considered as a measure, the number of alternate routes tried by the participant have also been analyzed. Normally, survey knowledge is the hardest level of spatial knowledge, and can only be acquired in a longer time when compared to the route and landmark knowledges.

a. Pointing Tests

Four different pointing tests in three locations were conducted to measure survey knowledge. The results of the pointing tests have shown that there was a big difference between the performances in the real world and the virtual world. In addition to this, the range of degree of error in the real world was less than that in the virtual environment. Figures 4.9, 4.10, 4.11 and 4.12 indicate the scatter plot graphs for the comparison of these two environments for the four pointing tests.

The first pointing test came with quite big errors in estimation of the direction.

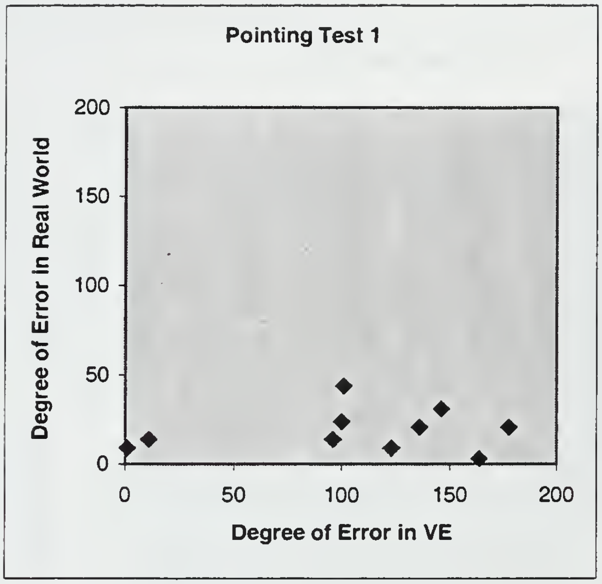

Figure 4.9 Scatter Plot graph for the first pointing test.

In this first test, for the virtual environment, most of the participants have also expressed that their pointing was mostly based on estimation, and they had reported poor confidence levels. The correlation coefficient for the first pointing test was 0.157. Two participants have performed very well in both environments for the first task. But those participants were not confident about their survey knowledge while pointing to the points.

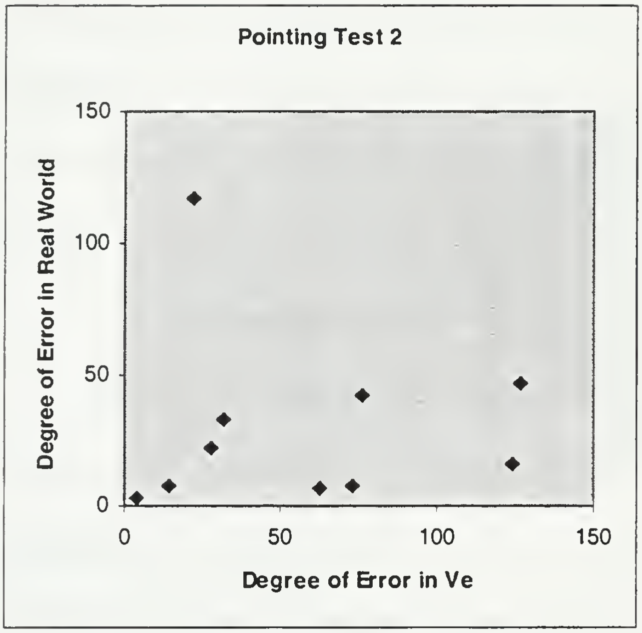

Figure 4.10 Scatter Plot graph for the second pointing test.

The second pointing test which had been conducted at the end point of the navigation gave better results in the virtual environment. The correlation coefficient for the second pointing test was –0.038. When one participant who performed very poorly in the real world was removed, the correlation coefficient became 0.474. However, no particular reason was observed for this participant's big error.

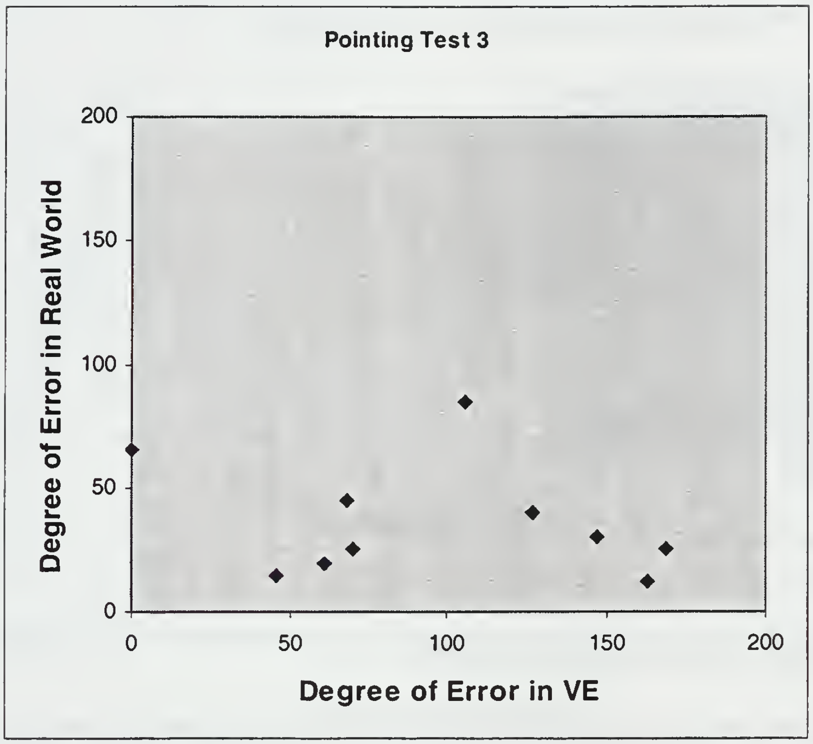

Figure 4.11 Scatter Plot graph for the third pointing test.

Results for the third pointing test were similar to the ones for the second, with the exception of the mentioned participant who made a big error in the real world. The correlation coefficient was –0.278.

For the fourth pointing test, the errors in the virtual environment were still existing, but the real world performance was better than the previous pointing tests. The correlation coefficient for the fourth pointing test was –0.315.

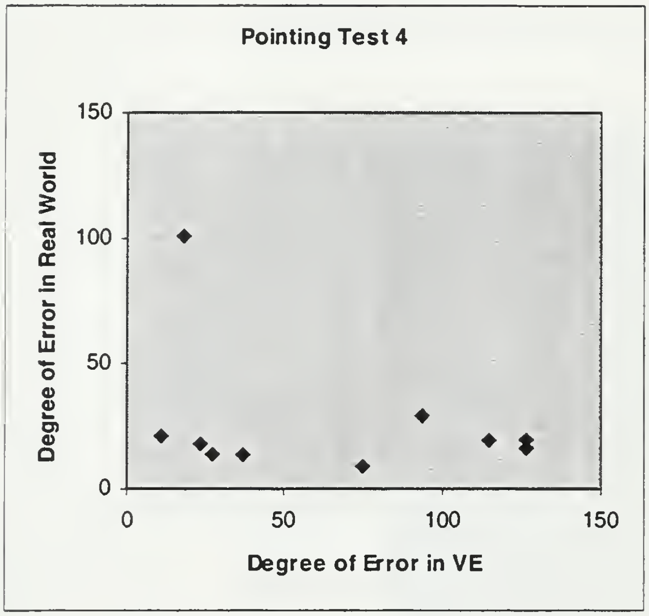

Figure 4.12 Scatter Plot graph for the fourth pointing test

When we consider the overall pointing tests, we see the same difference of performance and the lack of correlation. The one big error in one of the pointing tests affects the results in the overall performance too. This error was made by the same participant who made a big error in the second pointing test. Figure 4.13 shows the scatter plot graph for the overall evaluation of performances in pointing tests.

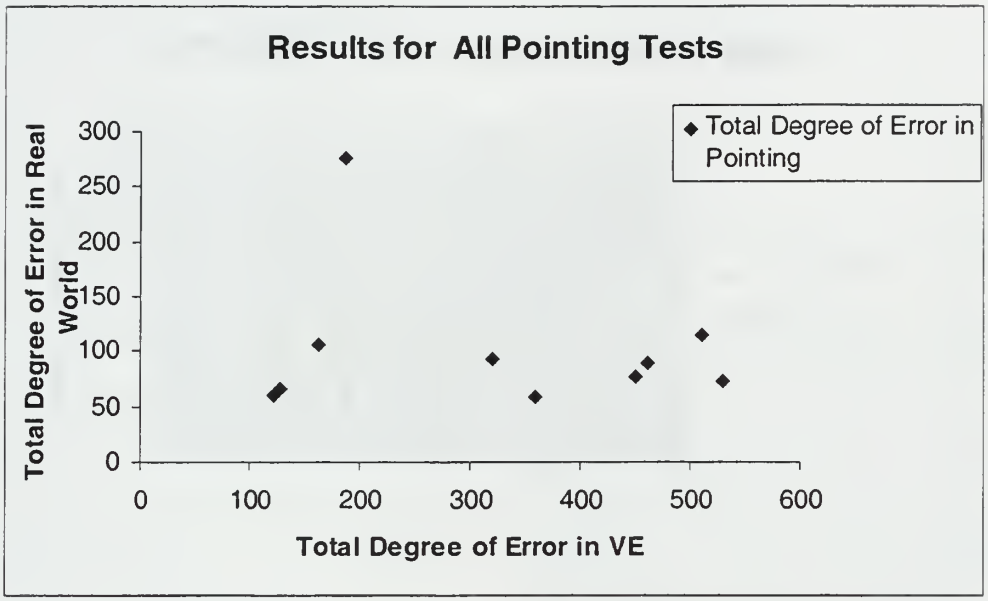

Figure 4.13 Scatter Plot graph for the overall performance in pointing tests

b. Map Placement Tests

Another way to analyze the survey knowledge is the map placement test results. The results in map placement indicated similarity to the pointing tests in the poorness of correct placements. So, the results of the map placement tests did not tell us anything about the existence of a correlation.

Figure 4.14 shows a scatter plot graph for the map placement test. The correlation coefficient for this test was –0.15 of negative correlation.

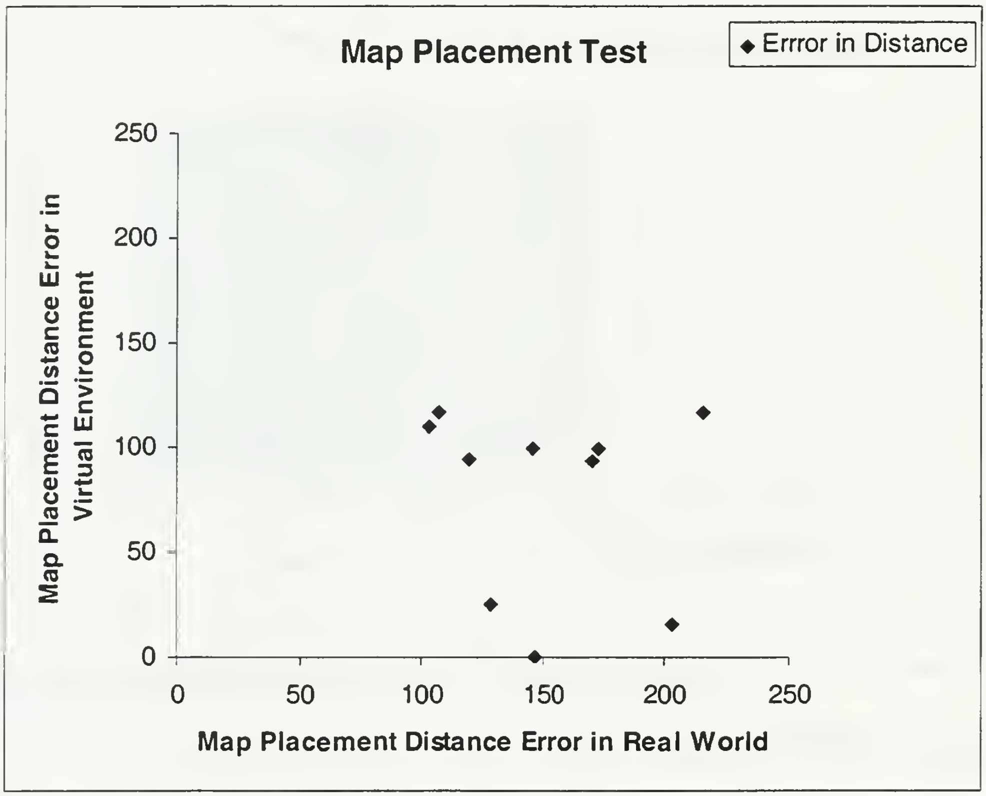

Figure 4.14 Scatter Plot graph for the map placement test

In the map placement tests, the group performance in the real world was still better than the performance in the virtual world. Figure 4.15 shows the histogram comparing each individual's performance in these two distinct environments. As it's seen in the histogram one participant made zero errors in the real world.

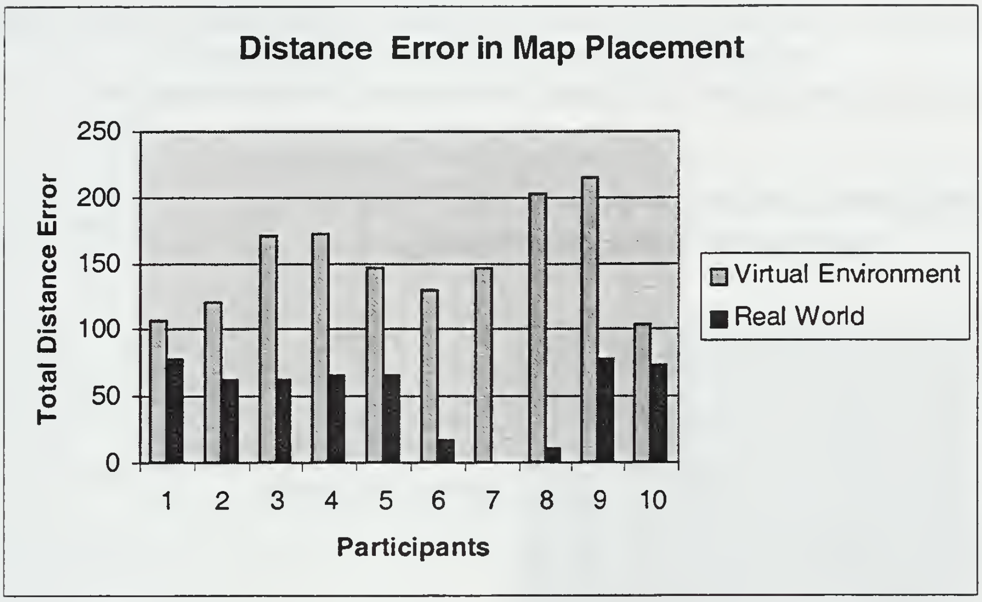

Figure 4.15 Comparison of Map Placement Test in Real and Virtual Environments

c. *Aggregated Evaluation*

An aggregated evaluation of the pointing tests and the map placement test gives a better idea about the survey knowledge of the participant. However, the aggregation does not indicate a correlation either. To aggregate these two measures, we have given a value between 0 and 100 to the pointing performance of the participant, simply by dividing his total error in degree by the highest error and multiplying the result by 100. Likewise, the distance error in map placement test was divided by the highest error and the result was multiplied by 100 to get a value between 0 and 100 for the map placement test. The addition of these two performance scores has provided a performance score for each participant. This score was a number between 0 and 200, and indicated the overall survey knowledge performance of an individual. The aggregated results showed that the performance in the real world was better than the performance in the virtual world for the sample group. Figure 4.16 shows the histogram for this comparison.

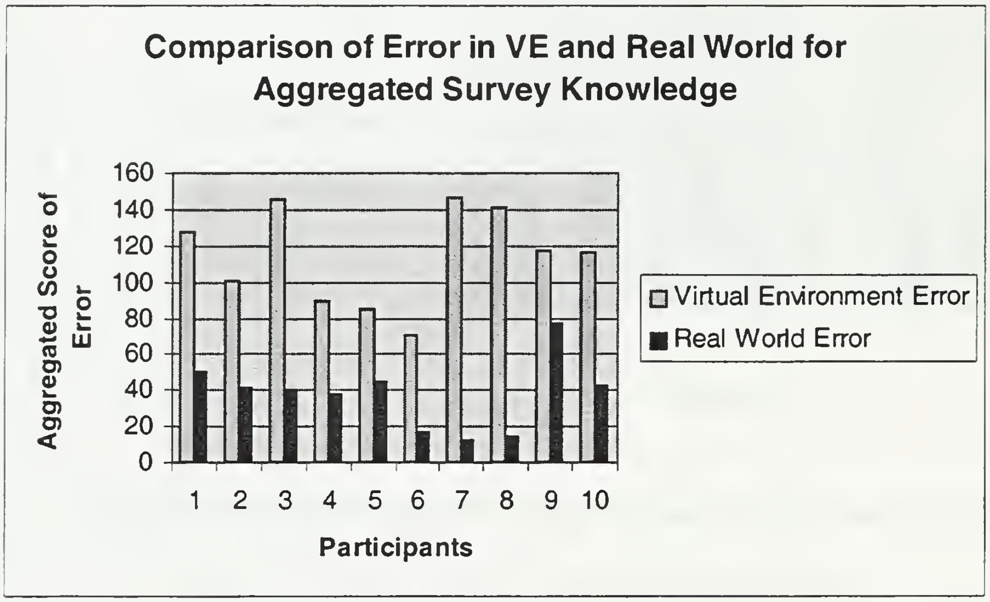

Figure 4.16 Comparison of Aggregated Results for Survey Knowledge

When the results for the survey knowledge were aggregated, it was still not possible to find a positive correlation. The scatter plot for the correlation is shown in figure 4.17, and the correlation coefficient for the aggregated results was –0.104.

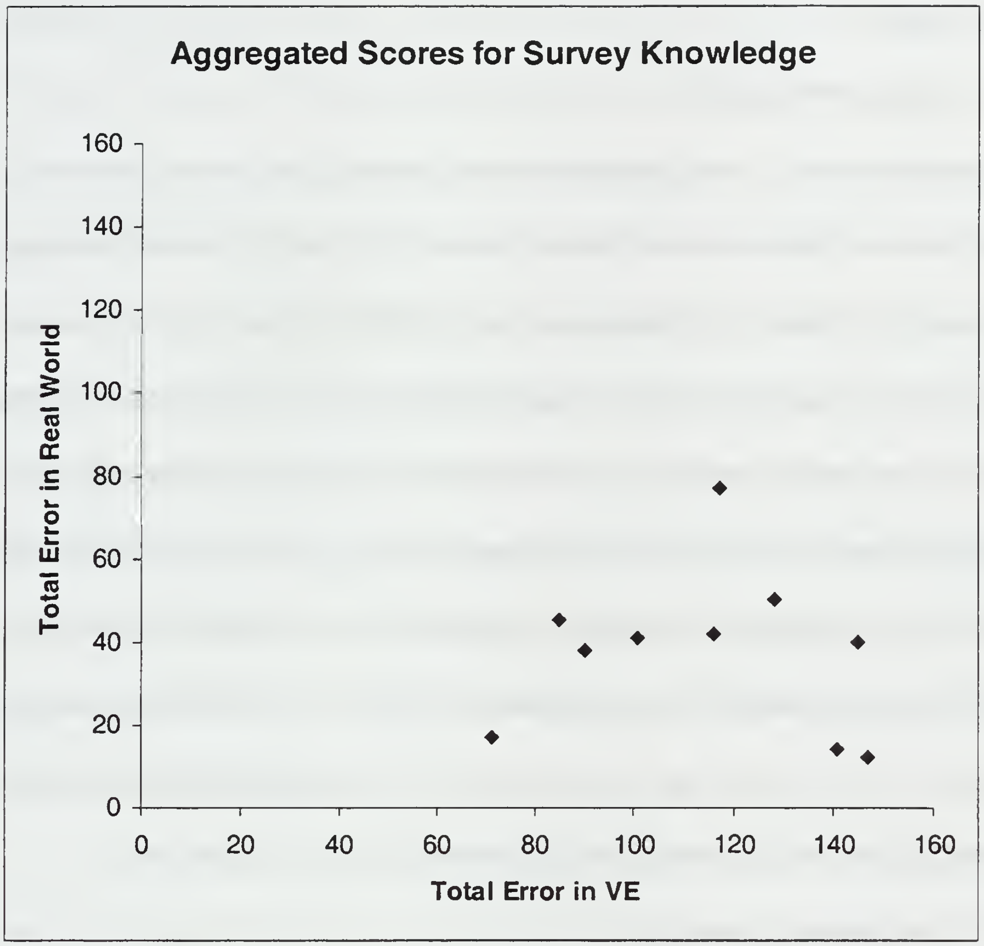

Figure 4.17 Scatter Plot Graph for the Aggregated Survey Knowledge

The overall analysis of the survey knowledge gave little information about the performance and the existence of a correlation.

B. DISCUSSION

1. General Discussion

The general results of the experiment did not indicate a correlation in all of the performance measures. There was a difference between the types of spatial knowledge. Landmark knowledge, being the type acquired in a relatively short time, has shown a positive correlation for performance in real and virtual environments. Route knowledge was a type that is not acquired so easily, and the results for route knowledge indicate that there was a big difference between the performances in the real and virtual worlds. The environmental factors that might have had an effect are discussed under the sections of these types of spatial knowledge. It's not possible to think of a virtual environment apart from the interface. The interface that has been used for the experiment also had some effects on the results, and these are also discussed under the following sections.

2. Landmark Knowledge

The landmark knowledge scores have indicated a correlation between performances in real and virtual environments. Since the spatial ability in landmark knowledge is mostly a memory process, this is reasonable. The participants who had the ability to keep certain landmarks in his memory could do so regardless of the environment. One participant who did the best in the group performed as the best performer in both of the environments. Likewise, two participants who performed poorly in the real world did the same way in the virtual environment. However, there were two others who performed at a medium level in the real world, but poorly in the virtual environment. In an overall evaluation, it was seen that the landmark recognition in a virtual environment was harder than the landmark recognition in a real world. This might be due to less frequent checks in a virtual environment. The participants seeing the landmark from one direction were not able to recognize the same landmark when they had seen it from another direction. This happened in a few cases for the candy machine. For landmark recognition, the verbal reports of the participants throughout the experiment have shown that some details are observed in a virtual world, but the bigger picture was generally lost. For instance, a participant was paying attention to the change of design in the horizontal and vertical faces of the stairways in the Herrmann Hall model, but was missing the Grandfather's clock in a hall. Despite these differences, it can be said that there is a positive correlation between the landmark knowledge performance measures in the real world and virtual environment land navigation.

It should also be noted that the objects we identified as landmarks may have not been meaningful landmarks to some of the participants. The concept of a landmark is always relative to the subjectivity of the individual.

3. Route Knowledge

The route knowledge performance measures did not give a level of confidence as much as landmark knowledge. We have used two measures to assess route knowledge. The first one was the order of landmarks, and the second one was the number of wrong turns in a route replication task.

While the correlation coefficient for the landmark sequencing was 0.447, it was –0.08 for the number of wrong turns. When we aggregated these two results, we have seen that the results in the number of wrong turns have affected the aggregation, and the coefficient was still as low as 0.04.

One experimental observation that might have affected the results in the number of wrong turns and has been observed in the experiment was the ability of the participants in making checks in the navigation. While frequently looking over their shoulder and checking locations in the real world was quite simple, it was not that easy in the virtual environment. Since learning a route is a memory process, the checks made in the real world have probably helped this memory process. One other reason for the difference might be the fact that there were more choices in the decision points in the virtual environment. While a participant had three or four choices to go to in a virtual world, there were generally only two choices in the real world navigation. Thus the scores in the real world were less than the ones in the virtual world and were closer to each other. It's also known that the order of development for the types of spatial knowledge acquisition is landmark knowledge, route knowledge, and survey knowledge. Thus, the learning of route knowledge itself requires more time than landmark knowledge.

4. Survey Knowledge

The results of the tests on survey knowledge provided very poor information. Since the survey knowledge is the type of spatial knowledge which requires the most amount of time, it is understandable that the participants were not so successful in forming a mental map of the buildings. However, we still asked them to provide us with the answers even if those were just an estimate of the location. In these estimates, coincidences might have caused some of them to show good performance, and the results should be evaluated from this perspective. Obviously, the results did not show any correlation in the pointing tests and the map placements. Especially, in the pointing tests, there was a big difference between the results of the virtual environment and the real world. The real world results were much more accurate than the results of the virtual environment. One reason for this might be the locations of the starting point, Point A, and the end point. In addition to this, the way the pointing test is conducted in a virtual environment might have also affected the results. In a virtual environment test, since people do not turn with their whole body, they don't have full confidence in pointing. This result is similar to the results of the study made by Peterson et al. In that study, the participants' ability to form a mental map and to use it to find alternate routes was significantly better with a full-body controller than a joystick. (PETERSON et al, 1998) The observed behavior of the participants' frequently changing position in a pointing test was a sign of this. While the participants performed the pointing in a real world just by directing the arrow, in a virtual environment they were turning their body a few times to make sure they face the location they intended.

All the coefficients for the pointing tests were close to zero. It is therefore unwise to draw conclusions in favor of a correlation or lack of a correlation from these results. In the process of travel, pervious studies have shown that pointing as a traveling technique is more advantageous than gaze-directed steering, and this helped us to rely on a more comfortable way of traveling. However, it's also been stated in previous studies that, it requires more time to become an expert to be able to perform this test (BOWMAN et al. 1997).

In the map placement test, there were still more errors in the virtual environment. The fact that the participants performed relatively well in the real world for these two tests indicate that there was an obvious difference of performance in survey knowledge.

Since the map placement test is also an indication of survey knowledge, it was not formed so easily. Having toured in the environment for a short time, the participants were not confident while placing the landmarks into correct locations. So, the results of the map placement tests did not tell us anything about the existence of a correlation.

5. Interface Issues

The interface for the experiment can always be questioned. The Flybox that we have used gave the freedom to move in all directions, but did not provide the ability to look around without turning the entire body. Although it may seem to developers that there's no need for such a motion, this behavior was frequently used by the participants in the real world. Throughout navigation, the participants were frequently looking at the places they walked through and checking the points. This would bring an extra burden in a virtual environment, and the participants used this very rarely. The lack of multimodal stimulation while turning the body was another disadvantage of the interface. The participants were not able to get the sense of the direction they were turning. They were using only visual cues, and this largely affected their performance in the pointing tests.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. General Conclusion

The thesis experiments studied the existence of a correlation between performance measures in the real world and virtual environment land navigation tasks. Participants of the experiment navigated in a virtual and a real world building. For each participant, his performance was assessed through a set of performance measures in the three types spatial knowledge. The results of the experiments were then analyzed in order to understand the existence of such a correlation, and it's level in different measures. The following conclusions are drawn from the qualitative and quantitative results that have been presented in the previous chapters.

a. Subjects who had the ability to keep certain landmarks in their memory in a virtual environment had the ability to keep landmarks in their memory in a real world as well.

b. Types of spatial knowledge are formed through time, and the survey knowledge is the type of spatial knowledge that takes the most amount of time to form.

c. The interface in a virtual environment becomes much more important when directional orientation is involved.

2. Landmark Knowledge

The results suggest that there is a positive correlation between the performance measures in landmark knowledge in a virtual environment and a real world. A landmark recognition in a virtual environment can give an idea about the performance of the same individual in a real world. Although not as strong as the landmark recognition, this correlation is seen in the sequencing of the landmarks.

3. Route Knowledge

The correlation in landmark knowledge was not seen in route knowledge. This study did not provide evidence that route knowledge performance of an individual in a virtual environment can give an indication about the performance of the same individual in a real world.

4. Survey Knowledge

A correlation was not seen on survey knowledge either. With the relatively very poor performance of the participants and the short time period spent in each environment, this study also supported the fact that survey knowledge is the type of spatial knowledge acquired over time.

B. RECOMMENDATIONS

1. Different Interfaces

This study can be replicated with different interfaces to assess the effect of the interfaces on the results, and further comparison can be investigated with these interfaces. Interfaces taking kinesthetic approaches into account will be a helpful in a better evaluation of the virtual environments.

2. Different Environments

The correlation can also be analyzed for a natural terrain outdoor environment. This study has mainly focused on the spatial knowledge acquisition in a building type environment. However, the acquisition of spatial knowledge in an outdoor environment, such as a forest, has its own features. Further studies can be made to investigate a correlation in these environments.

3. Bigger Sample Size

This study suggests that there may not be a correlation between the performance measures in real and virtual environments. A further study can be made with a bigger sample size. Researchers of navigation in virtual environments need to know if the lack of correlation is significant.

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APPENDIX A. EXPERIMENT OUTLINE

1) In Brief /Consent Form
   a) Time – 5 Min.
   b) Location-MOVES graphics Lab.
   c) OIC – Lt. Saltuk B. Karahan
   d) Materials –Consent Form, Privacy Act Statement , Minimal Risk Consent Form, pen, Briefing Scripts
2) Interface Familiarization (VE Only)
   a) Time – 5 Min.
   b) Location- Graphics Lab.
   c) OIC – Lt. Saltuk B. Karahan
   d) Materials – SGI Machine, Herrmann Hall Trial Model, Flybox, Flybox Instructions, Virtual Environment Briefing Script
3) Testing in Virtual Environment
   a) Time – Varies
   b) Location- Graphics Lab.
   c) OIC – Lt. Saltuk B. Karahan
   d) Materials – SGI Machine, Herrmann Hall Trial Model, Flybox, Flybox Instructions, Virtual Environment Briefing Script, Landmark Pictures, Building Maps, pencils, Footprint pictures of Landmarks

e) Tasks:

(1) Task 1. Walking from the Starting point to the End Point (Perform the pointing tests on route)

(2) Task 2. Route Replication (Measure the number of wrong turns on route, perform landmark recognition and landmark sequencing tests at the end.)

(3) Task 3. Free Exploration

(4) Task 4. Finding Alternate Routes

4) Testing in Real World

a) Time – Varies

b) Location- Middle East School

c) OIC – Saltuk B. Karahan

d) Materials –Real World Briefing Scripts, Compass, Landmark Pictures, Building Maps, pencils, Footprint pictures of Landmarks, Pointing Board

e) Tasks:

(1) Task 1. Walking from the Starting point to the End Point (Perform the pointing tests on route by using the pointing board)

(2) Task 2. Route Replication (Measure the number of wrong turns on route, perform landmark recognition and landmark sequencing tests at the end.)

(3) Task 3. Free Exploration (Lead the participant to the starting point before the end of the allowed time)

(4) Task 4. Finding Alternate Routes

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APPENDIX B. TASK LISTING

Task 1. Move from starting point to the end point along designated route. (Measure the bearing from the first control point (point A) the starting point at point A. Measure the bearings from the end point to point A and the starting point at the ending point.)

Task 2. Move from the end point to the starting point following the route in the first task in reverse order. (Measure the number of wrong turns and the locations for those wrong turns on route. Measure the number of landmarks correctly recognized and in correct order at the end of the route replication)

Task 3. Explore the environment yourself for 10 minutes. (Record the routes the participant takes, perform map placement test at the end of the free exploration)

Task 4. Find the alternate routes from the second control point (the blocked location) to the end point. (Record the alternate routes the participant takes)

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APPENDIX C. BRIEFING SCRIPTS

BRIEFING SCRIPTS FOR REAL BUILDING

IN BRIEFING

Welcome to the Naval Postgraduate School's MOVES Department. My name is Lt. Bugra Karahan. Thank you for participating in this experiment. This experiment deals with navigation in Building Type environment.

This experiment does not test your intelligence or performance in this type of an environment. It rather tests the measures that have been used for VE Building Type land navigation. Your performance will be used only for research purposes, and it will not be used in you records. Prior to starting the experiment you'll be asked to read and sign a series of consent forms. Our experiment will take approximately 45 minutes. Upon completion of the task, you'll be given a short debriefing

If you don't have any question, please read and sign this consent form.

EXPERIMENT BRIEFING

Meet the participant in the Graphics Lab.

Take the participant to the Hachiya Hall in DLI.

"As I have expressed, it'll be approximately 45 minutes experiment. We will have four different tasks: a route following, a route replication, free exploration and finding alternate routes. At the beginning of each task you'll have a brief description of the task. When you reach to the end point in the last task, it'll be the end of the experiment too.

If you don't have any questions we can start the experiment."

COURSE BRIEFING

TASK 1: STARTPOINT TO ENDPOINT.

Take the participant to the side door of the building 623(next to room 164).

Task: "As the requirement of the first task I'll ask you to follow a predetermined route in this building. In this phase, what you're expected to do is just to follow the verbal instructions to make the necessary turns in the spots I tell. We'll have two tests on this first task. This is the starting point of the building. Your first task is to follow the verbal instructions for your navigation."

(Throughout the navigation, note down the number of times the participant turns his head to look at where he came from)

(At the start point) -Please turn left at this spot and, go up the stairs.

(At the room 153) - Please go straight ahead.

(At the room 238) – Please turn right and go straight ahead on this hallway.

(When he reaches 232) – Please turn right to the EXIT sign.

(When he passes the door to the stairways) – Please go down the stairways.

(When he goes one floor down) – Please turn left.

(When he reaches the stairway in a few meters) – Please go out of the stairway.

(When he comes out of the stairway on the first floor of Building 621) – "Now we'll perform a pointing task. Now face any direction you want, and make your heading stable. And use this marker to direct the start point." *(Note down the participant's heading by using the compass, and write down the angle he directs as well.)* "Thank you, now Please turn right, and go straight ahead on this hallway."

(When he comes to 123B) " Please turn left and go up the stairs."

(When he reaches the Building 619, Rm 210) – Please turn right, and go straight ahead on this hallway.

(When he reaches the end of the hallway, Rm 201) – Please turn left to the stairways.

(When he passes the door to the stairways) – Please go up the stairs.

(When he reaches the third floor of Building 619) – Please go out of the stairways.

(When he goes out of the stairways, and sees room 301) - Please turn right and go straight ahead on this hallway.

(When he reaches the endpoint, Room 306) – "Please stop here. Now we'll perform a second pointing task. Now face any direction you want, and make your heading stable. And use this marker to direct the start point. ." *(Note down the participant's heading by using the compass, and write down the angle he directs as well.)* Now we'll perform a third pointing task. Please face any direction you want, and make your heading stable. And use this marker to direct the spot where we made the first pointing task. ." *(Note down the participant's heading by using the compass, and write down the angle he directs as well.)* "Thank you, this is the end of the first task"

TASK 2: ENDPOINT TO STARTPOINT (ROUTE REPLICATION).

Task:

"Now, we'll perform the second task. The second task is just to follow the exact route back to the starting point. At any point, if you make a wrong turn, I will not make any comment, but as soon as you start proceeding on that route, I'll show you the right turn, and will ask you to continue from then on.

If you don't have any questions, now please follow the route back to the starting point.

(On this task, write down all the wrong turns made by the subject and their locations. Use the Map 1 for this task. And throughout the navigation, note down the number of times the participant turns his head to look at where he came from)

(At the end of the task.) *"Thank you. This is the end of the second task. Now I'll show you 10 landmarks and some of them have been on your route. Please tell me, which* *of these landmarks you have seen on your route."* (Note the number of correct landmarks)

"Now, please put the landmarks into order from the start point to the end point." (Write down the order he has put the landmarks)

TASK 3. FREE EXPLORATION

Task:

"Now, we'll have 10 minutes of free exploration. On this free exploration, I'll not help you in any way, but will just follow you on the path. When you get close to the end of the allowed time, I'll lead you to the starting point. Please walk in a regular walking pace, and do not feel rushed. Please tell me when you're ready for a free exploration of the environment."

(When the participant tells that he is ready, start the free exploration and the time as well. On the route, draw the path that the participant follows on a different map for further analysis.)

TASK 4. ALTERNATE ROUTES

Task:

"Now, we'll perform the last task. Before proceeding, please point the end point. *(Note down the participant's heading by using the compass, and write down the angle he directs as well.)* "Thank you. Now, please proceed to the end point."

(When he comes to the passage to the building 621) "This passage is blocked due to construction. Now, please show the end point, and please tell me the alternate route that you think of." *(Draw the alternate route on a map, but do not show that map to the participant. Make sure that the route you drew is exactly the same as what the participant told. If the route goes out of boundaries, pretend to be drawing, but just cut drawing at that point.)* "Now, please move on your alternate route." *(If he ever wants to change the route, remind that this is not the alternate route he told, and ask why he has changed the route. If he just understood that the route he told was wrong, this is acceptable, but note the incident.)*

"Thank you, we have reached at the end point. Now please place the landmarks you have seen on this white-board."

(At the end of the task, give the participant a white-board showing the exterior lines of the building, and make him place the landmarks that he correctly recognized on appropriate points.)

"This is the end of our experiment in the Real Building. Thank you for participating in this experiment. I'll debrief you on the details of this experiment after the completion of the whole experiment."

BRIEFING SCRIPTS FOR VIRTUAL BUILDING

IN BRIEFING

Welcome to the Naval Postgraduate School's MOVES Department. My name is Lt. Bugra Karahan. Thank you for participating in this experiment. This experiment deals with navigation in Building Type environment.

This experiment does not test your intelligence or performance in this type of an environment. It rather tests the measures that have been used for VE Building Type land navigation. Your performance will be used only for research purposes, and it will not be used in you records. Prior to starting the experiment you'll be asked to read and sign a series of consent forms. Our experiment will take approximately 45 minutes. Upon completion of the task, you'll be given a short debriefing

If you don't have any question, please read and sign this consent form.

EXPERIMENT BRIEFING

Meet the participant at the Main Gate.

Bring the participant to the Graphics Lab.

"As I have expressed, it'll be approximately 45 minutes experiment. You'll first get familiarized with the VE interface that we use for this experiment. At any phase of this familiarization, please feel free to ask any question. After the familiarization phase, you'll have four tasks to perform in the virtual environment. Prior to each task, I'll give the instructions for that specific task. When you reach to the end point in the last task, it'll be the end of the experiment too.

If you don't have any questions we can start the experiment."

COURSE BRIEFING

Brief the participant on familiarization.

"In front of you is a three screen monitor, which you'll use throughout your navigation in the experiment building. You'll use this flybox to move in the virtual environment. The flybox gives you the capability of moving forward, moving backward, turning right, tuning left, looking down and looking up. The speed is controlled as on or off, from this button on the keyboard.

If you don't have any questions, you can try the flybox for five minutes to familiarize with the interface."

TASK 1: STARTPOINT TO ENDPOINT.

Task: "In this phase, what you're expected to do is just to follow the verbal instructions to make the necessary turns in the spots I tell. We'll have two tests on this first task."

(At the start point) -Please go down the stairs.

(At the base floor) - Please go straight ahead.

(When he reaches the elevator) – Please turn right.

(When he reaches the end of the mailboxes) – Please turn left.

(When he gets out of the mailboxes) – Please turn left and go straight ahead.

(When he reaches the end of the hallway) – Please turn left.

(When he reaches the stairway in a few meters) – Please turn left, and use the stairway.

(When he comes out of the stairway on the first floor) – "Now we'll perform a pointing task. Now face any direction you want, and make your heading stable. And use this marker to direct the start point." *(Hit the key P on the keyboard to get the exact heading. Note the degree that the subject shows.)* "Thank you, now Please turn right, and go straight ahead."

(When he comes to the elevators) " Please turn right and use the stairs you see."

(When he climbs the first part of the stairs) – Please turn left, and use the stairs up.

(When he reaches the mezzanine) – "Please turn left, and go straight ahead."

(When he reaches the end of way) – "Please turn left, and go straight ahead."

(When he reaches the end of way) – "Please turn right, and go straight ahead."

(When he reaches the endpoint) – "Please stop here. Now we'll perform a second pointing task. Now face any direction you want, and make your heading stable. And use this marker to direct the start point. ." *(Hit the key P on the keyboard to get the exact heading. Note the degree that the subject shows.)* Now we'll perform a third pointing task. Please face any direction you want, and make your heading stable. And use this marker to direct the spot where we made the first pointing test. ." *(Hit the key P on the keyboard to get the exact heading. Note the degree that the subject shows.)* "Thank you, this is the end of the first task"

TASK 2: ENDPOINT TO STARTPOINT (ROUTE REPLICATION).

"Now, we'll perform the second task. The second task is just to follow the exact route back to the starting point. At any point, if you make a wrong turn, I will not make any comment, but as soon as you start proceeding on that route, I'll show you the right turn, and will ask you to continue from then on.

If you don't have any questions, now please follow the route back to the start point.

(On this task, write down all the wrong turns made by the subject their locations. Use the Map 1 for this task.)

(At the end of the task.) *"Thank you. This is the end of the second task. Now I'll show you 10 landmarks and some of them have been on your route. Please tell me, which of these landmarks you have seen on your route."* (Note the number of correct landmarks)

"Now, please put the landmarks into order from the start point to the end point." (Write down the order he has put the landmarks)

TASK 3. FREE EXPLORATION

"Now, we'll have 10 minutes of free exploration. On this free exploration, I'll not help you in any way, but will just follow you on the path. When you complete the allowed amount of time, I'll exit the program. Please tell me when you're ready for a free exploration of the environment."

(When the participant tells that he is ready, start the free exploration and the time as well. On the route, draw the path that the participant follows on a different map for further analysis.)

TASK 4. ALTERNATE ROUTES

"Now, we'll perform the last task. Before proceeding, please point the end point. *(Hit the key P on the keyboard to get the exact heading. Note the degree that the subject shows.)* "Thank you. Now, please proceed to the end point. Along this route I'll just follow you and."

(When he comes to the stairways) "This stairway is blocked due to construction. Now, please show the end point, and please tell me the alternate route that you think of." *(Draw*

the alternate route on a map, but do not show that map to the participant. Make sure that the route you drew is exactly the same as what the participant told. If the route goes out of boundaries, pretend to be drawing, but just cut drawing at that point.) "Now, please move on your alternate route." *(If he ever wants to change the route, remind that this is not the alternate route he told, and ask why he has changed the route. If he just understood that the route he told was wrong, this is acceptable, but note the incident.)*

"Thank you, we have reached at the end point. Now please place the landmarks you have seen on this white-board."

(At the end of the task, give the participant a white-board, and make him place the landmarks on appropriate points.)

"This is the end of our experiment in Virtual Environment. Thank you for participating in this experiment. I'll debrief you on the details of this experiment after the completion of the entire experiment."

APPENDIX D. CONSENT FORMS

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

MINIMAL RISK CONSENT STATEMENT

Subject: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN : Navigation in Virtual Environments and Real Buildings

I have read, understood and been provided "Information for Participants" that provides the details of the below acknowledgements.

I understand that this project involves research. An explanation of the purposes of the research, a description of the procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

I have been informed of any benefits to me or to others that may reasonably be expected from the research.

I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

I understand that my participation in this project is voluntary; refusal to participate will involve no penalty or loss of benefits to which I'm otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

I understand that the individual to contact should I need answers to pertinent questions about the research is Rudy Darken, Ph. D., Principal Investigator, and about my rights as a research subject or concerning a research related injury is the Modeling Virtual Environments and Simulation Chairman. A full and responsive discussion of the elements of this project and my consent as taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

Signature of Principal Investigator Date

Signature of Volunteer Date

Signature of Witness Date

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

MINIMAL RISK CONSENT STATEMENT

Subject: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN : Navigation in Virtual Environments and Real Buildings

I have read, understood and been provided "Information for Participants" that provides the details of the below acknowledgements.

I understand that this project involves research. An explanation of the purposes of the research, a description of the procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

I have been informed of any benefits to me or to others that may reasonably be expected from the research.

I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

I understand that my participation in this project is voluntary; refusal to participate will involve no penalty or loss of benefits to which I'm otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

I understand that the individual to contact should I need answers to pertinent questions about the research is Rudy Darken, Ph. D., Principal Investigator, and about my rights as a research subject or concerning a research related injury is the Modeling Virtual Environments and Simulation Chairman. A full and responsive discussion of the elements of this project and my consent as taken place.

____

Signature of Principal Investigator Date

____

Signature of Volunteer Date

____

Signature of Witness Date

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

PRIVACY ACT STATEMENT

Authority: Naval Instruction

Purpose: Spatial Cognition information will be collected to enhance knowledge, or to develop tests, procedures, and equipment to improve the development of virtual environments.

Use: Spatial Cognition information will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

Disclosure/Confidentiality:

I have been assured that my privacy will be safeguarded. I will be assigned a control or code number which thereafter will be the only identifying entry on any of the research records. The principal investigator will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

I understand that a record of the information contained in this Consent Statement or derived from the experiment described here in will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

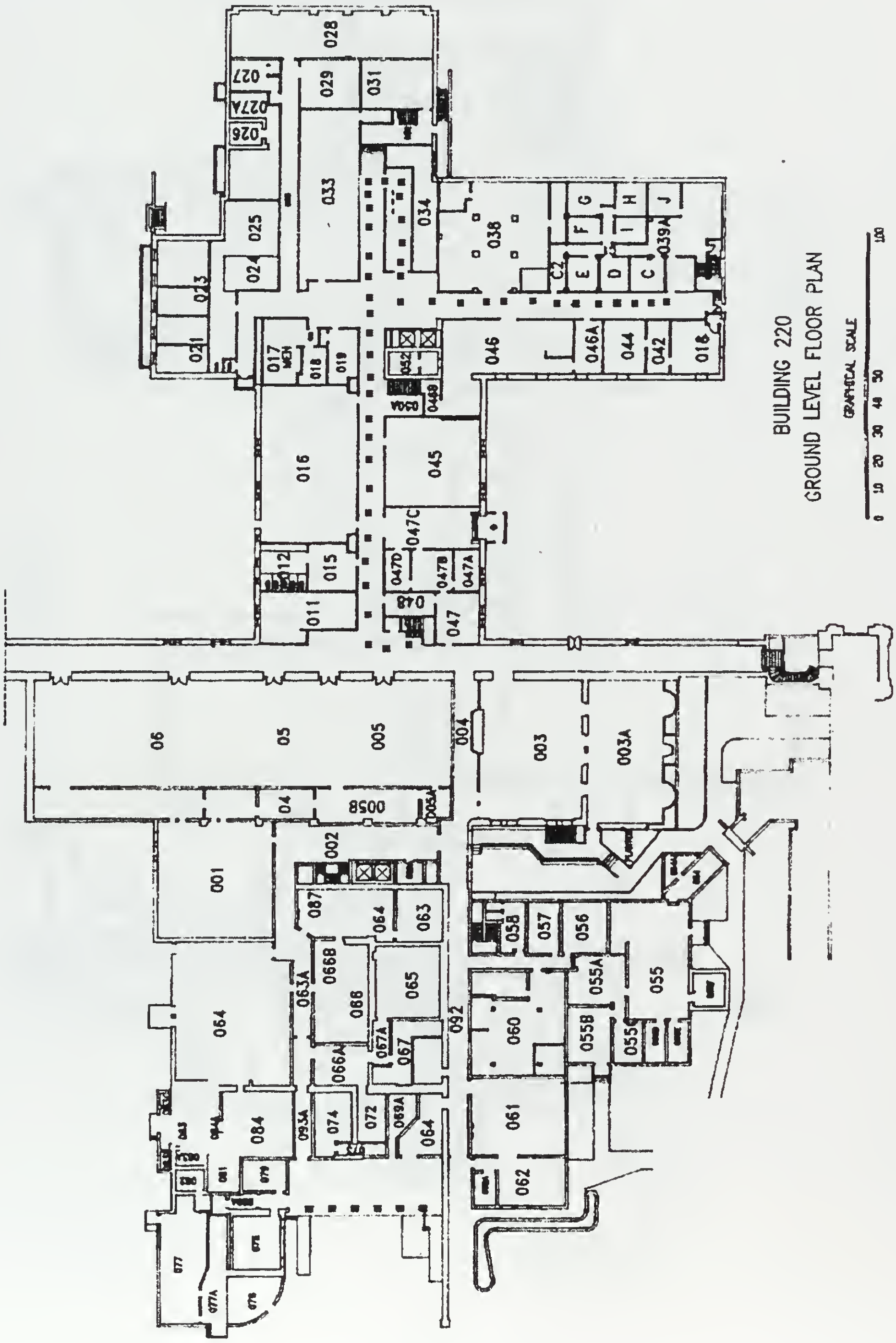
Signature of Volunteer   Print Name, Grade/Rank (if applicable)   DOB   SSN   Date

---

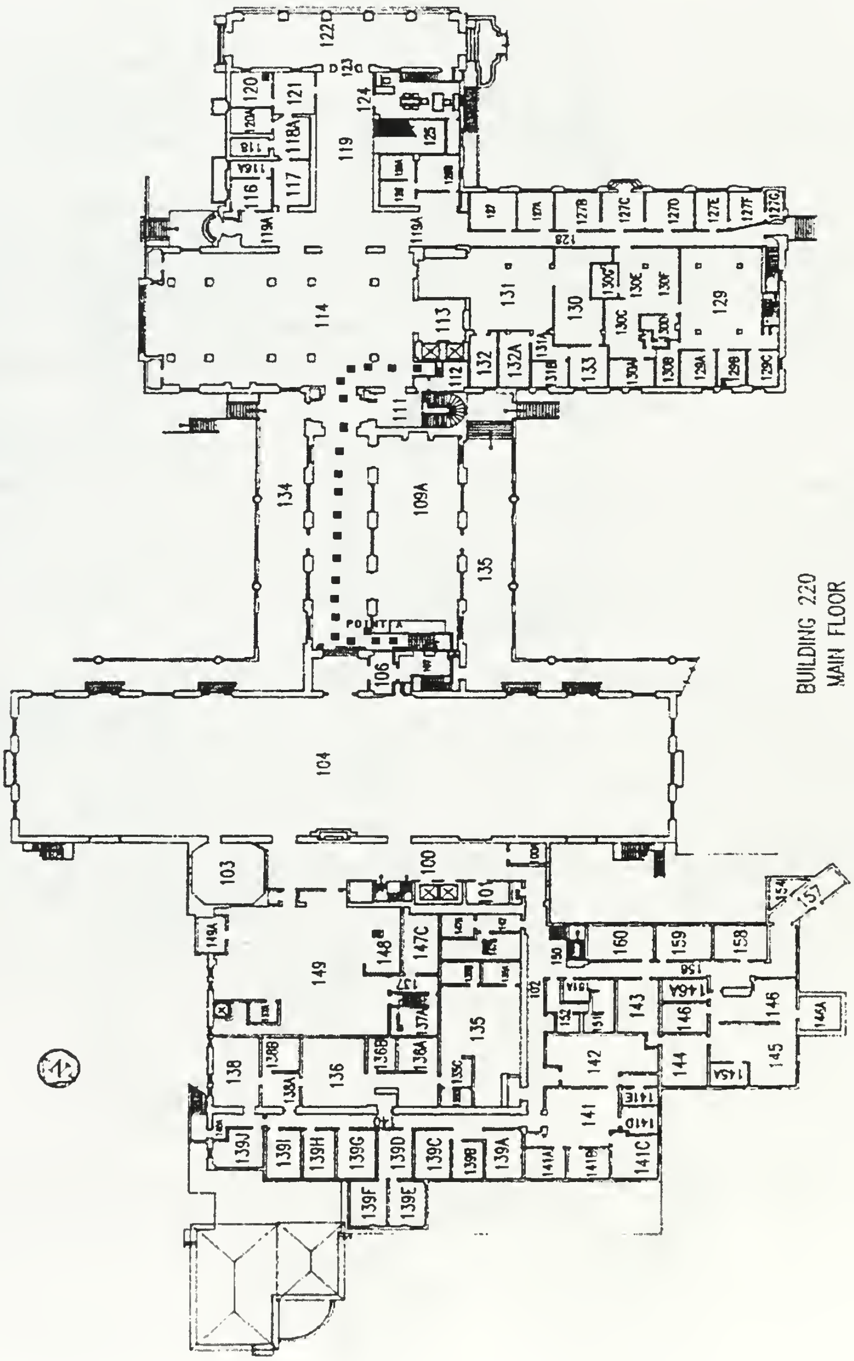
Signature of Witness   Date

APPENDIX E. BUILDING MAPS AND ROUTES

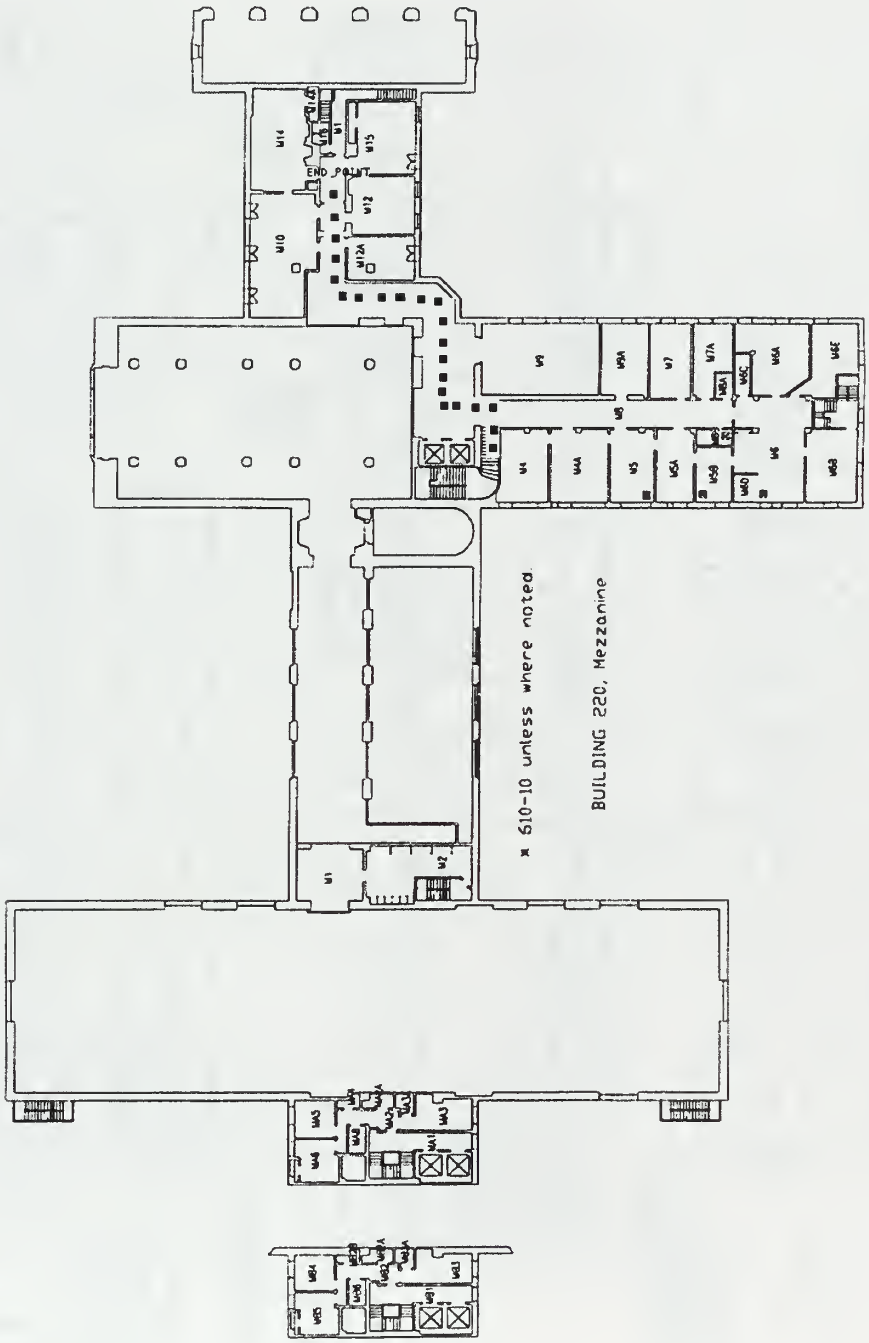
Herrmann Hall First Floor



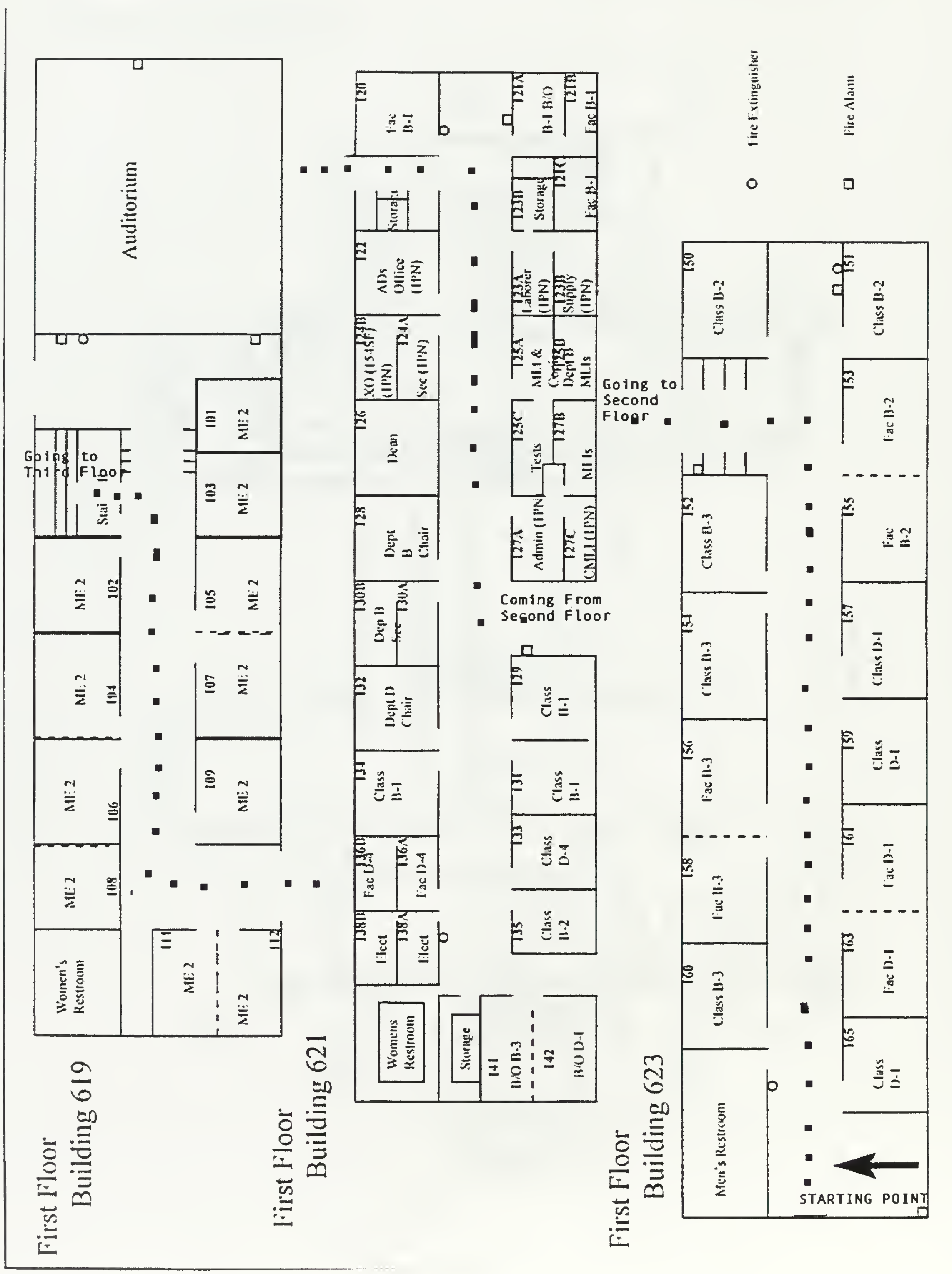
Herrmann Hall Second Floor



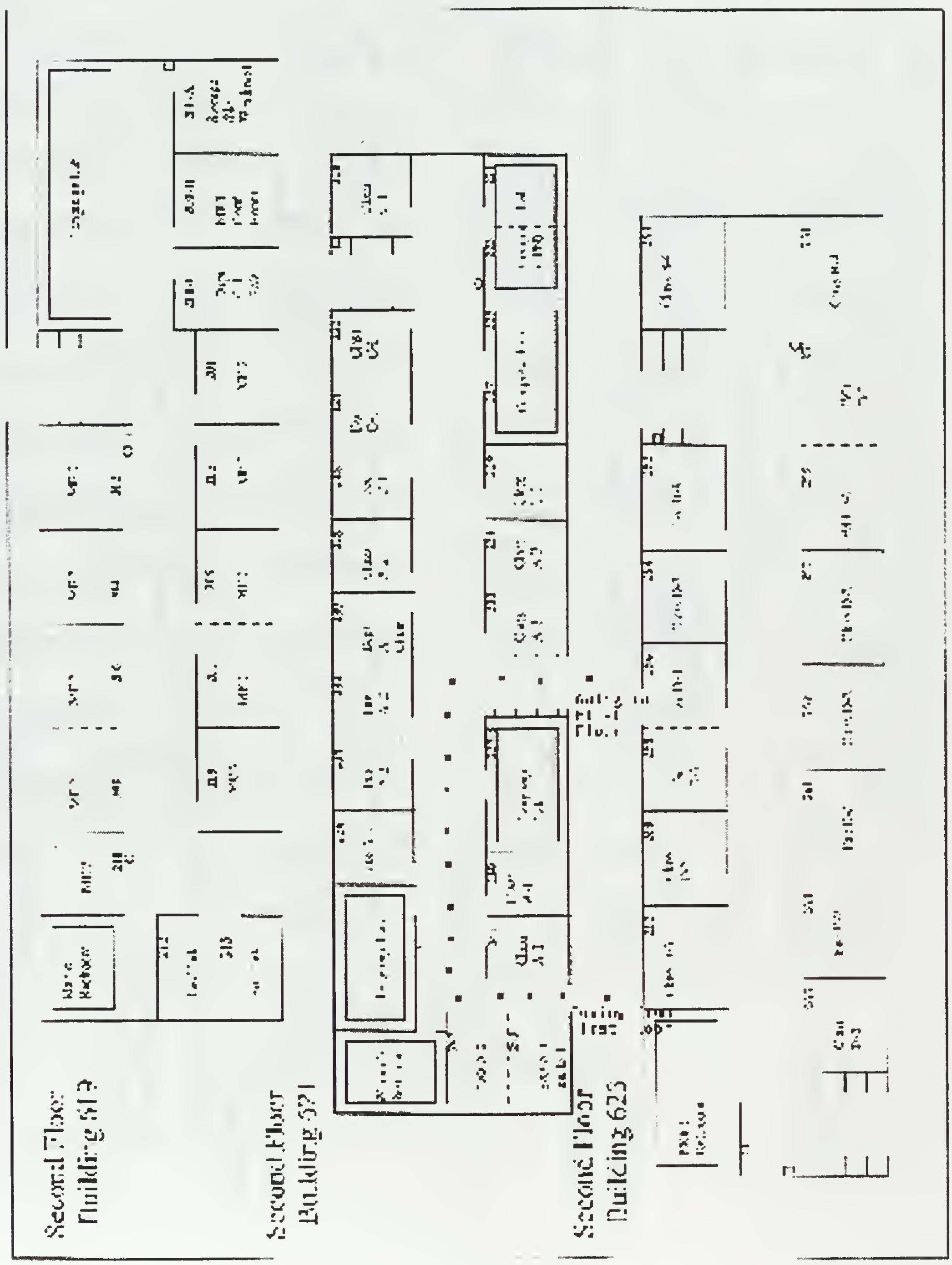
Herrmann Hall Third Floor



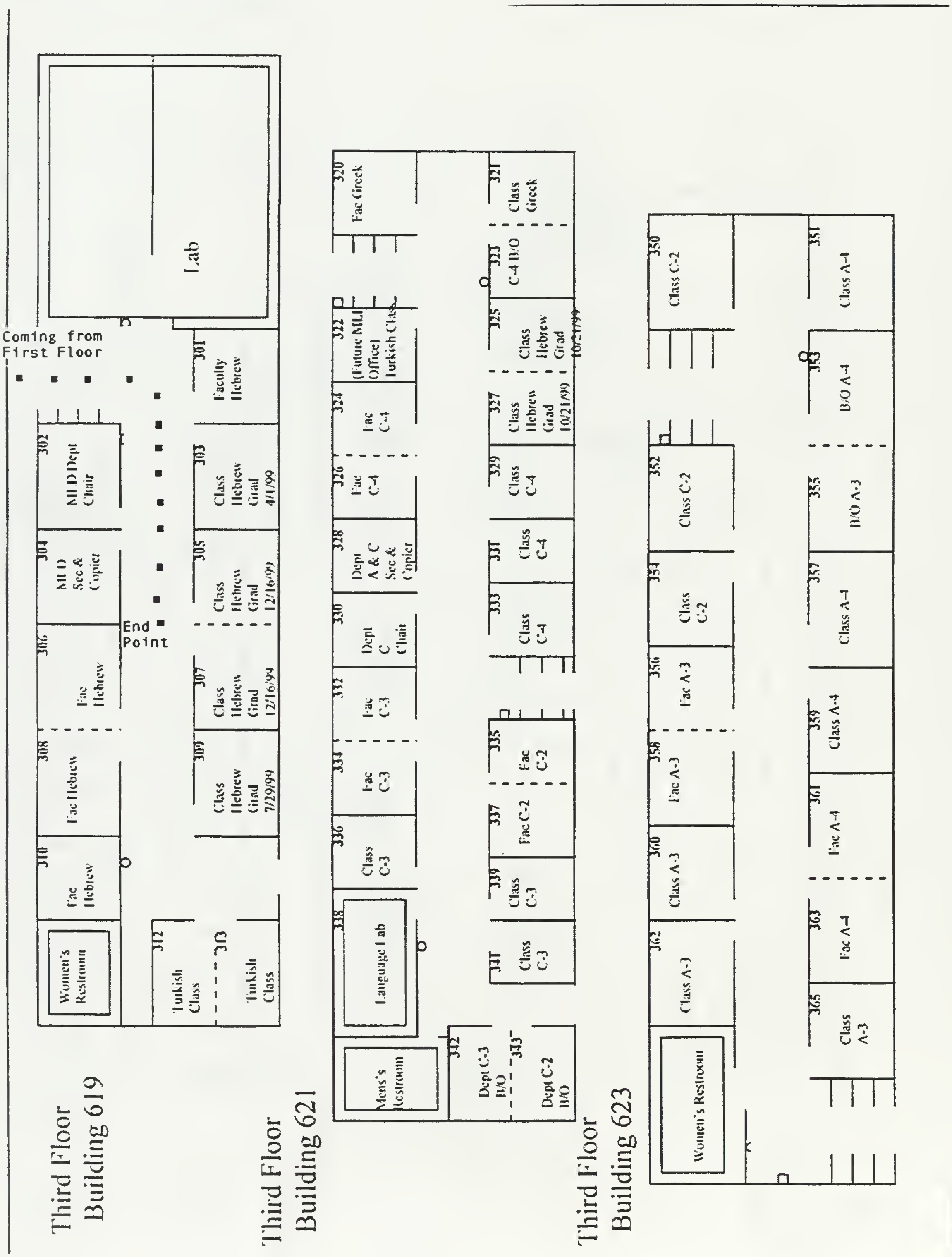
Real Building First Floor



Real Building Second Floor



Real Building Third Floor



APPENDIX F. DATA COLLECTION WORKSHEETS

		PT1 V	PT1 R	PT2 VIR	PT2 REAL	PT3 VIR	PT3 REAL
SUBJECT 1		100	24	127	47	169	25
SUBJECT 2		178	21	63	7	68	45
SUBJECT 3		96	14	124	16	147	30
SUBJECT 4		1	9	28	22	61	20
SUBJECT 5		136	21	4	3	0	65
SUBJECT 6		11	14	14	8	70	25
SUBJECT 7		164	3	76	42	163	12
SUBJECT 8		146	31	32	33	106	85
SUBJECT 9		101	44	22	117	46	15
SUBJECT 10		123	9	73	8	127	40

APPENDIX F. DATA COLLECTION WORKSHEETS

PT4 VIR	PT4 REAL	L.M. SEQ(VR)	L.M.SEQ (REAL)	# OF WRONG TURNS (VIR)	# OF WRONG TURNS (REAL)
115	9	2	3	7	2
11	1	2	2	3	3
94	9	3	3	5	2
37	4	2	2	3	1
23	8	3	2	5	2
27	4	2	3	4	1
127	6	3	5	7	1
75		2	4	2	2
18	01	2	2	5	3
127	9	4	4	4	1

APPENDIX F. DATA COLLECTION WORKSHEETS

# OF CORRECT LANDMARKS		# OF ALTERNATE ROUTES	
REAL	VIRTUAL	REAL	
3	5	2	6
3	2	2	3
5	3	2	4
2	2	1	2
4	2	2	4
3	4	3	4
2	3	1	1
3	4	2	3
2	2	4	3
6	6	2	5

SKETCH MAP	
virtual	real
107	78
120	63
171	63
173	66
146	66
129	17
147	0
203	10
215	78
103	73

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