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The effects of natural locomotion on maneuvering task performance in virtual and real environments

Unguder, Eray

Monterey, California. Naval Postgraduate School

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THESIS

THE EFFECTS OF NATURAL LOCOMOTION ON MANEUVERING TASK PERFORMANCE IN VIRTUAL AND REAL ENVIRONMENTS

by

Eray Unguder

September 2001

Thesis Advisor:	Rudy Darken
Thesis Co-Advisor:	Barry Peterson

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This thesis investigates human performance differences on maneuvering tasks in virtual and real spaces when a natural locomotion technique is used as opposed to an abstraction through a device such as a treadmill. The motivation for the development of locomotion devices thus far has been driven by the assumption that a "perfect" device will result in human performance levels comparable to the real world. This thesis challenges this assumption under the hypothesis that other factors beyond the locomotion device contribute to performance degradation. An experiment was conducted to study the effects of these other factors.

The experiment studied sidestepping, kneeling, looking around a corner, and backward movement tasks related to a building clearing exercise. The participants physically walked through the environment under all conditions. There were three treatments: real world (no display, physical objects present), virtual world (head-mounted display, no physical objects), and real and virtual world combined (head-mounted display, physical objects present). The results suggest that performance and behavior are not the same across conditions with the real world condition being uniformly better than the virtual conditions. This evidence supports the claim that even with identical locomotion techniques, performance and behaviors change from the real to the virtual world.

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THE EFFECTS OF NATURAL LOCOMOTION ON MANEUVERING TASK PERFORMANCE IN VIRTUAL AND REAL ENVIRONMENTS

Eray Unguder
1st Lieutenant, Turkish Army
B. S., Turkish Army Academy, 1996

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September 2001

Author: ______________________
Eray Unguder

Approved by: ______________________
Rudolph Darken, Thesis Advisor

____
Barry Peterson, Thesis Co-Advisor

____
Rudolph Darken, Academic Associate
Modeling, Virtual Environments, and Simulation Academic Group

____
Michael Zyda, Chair
Modeling, Virtual Environments, and Simulation Academic Group

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I. INTRODUCTION

A. PROBLEM STATEMENT

The question that this thesis attempts to answer is to determine if the locomotion and maneuvering performance and behaviors of people in virtual environments (VE) are the same as in the real world, assuming that the designers are able to build a “perfect locomotion device”. “A perfect locomotion device” is defined to be the device that allows indistinguishable actions from the real world. It is hypothesized that even if the perfect locomotion device has been built, because of other limitations of virtual environments, the behavioral characteristics of the people will not be the same as that of the real world. To investigate this issue, a real and a virtual model of the same environment was built. A perfect locomotion device cannot provide a performance level better than actual walking. Assuming that it has been built, such a device can only be as good as actual walking in terms of performance and behaviors of its users. Therefore, the participants were required to actually walk in a real and a simulated virtual environment. The maneuvering behaviors of the participants were observed and their performance levels in achieving the maneuvering tasks were measured. If there is a decrease in the performance level of people in a virtual environment, then it can be stated that other factors play an important role in maneuvering performance. “Natural” interaction in and of itself does not solve the problem. If there is not any significant difference, then it can be suggested that if the designers can build a perfect locomotion device, then people will be able to maneuver in the virtual environments as they do in the real world.

B. MOTIVATION

Whenever a small physical space, as is typical of most laboratories, must be mapped to a much larger virtual space (often many orders of magnitude larger), a mechanism must be provided to allow users to move over large distances in the virtual world without actually moving far in the physical space (Darken & Cockayne, 1997).

One of the major problems in current virtual environments is the difficulty associated with human locomotion in virtual spaces. Virtual locomotion techniques allow the user to move and maneuver in the virtual environments.

All of the locomotion devices developed so far are based on one implicit assumption. The designers of such devices assume that if they allow people to walk naturally on various locomotion interfaces while performing all kinds of small movements and maneuvering tasks, then the performance of the user in the virtual world will be the same as in the real world. They assume that solving the problems associated with walking will solve problems preventing users from attaining the same performance level from virtual worlds. However, natural locomotion is not only based on walking. Locomotion involves a wide variety of other actions such as looking (directing both the head and the eyes), manipulation (typically involving the hands, as in pointing a rifle), posturing (moving parts of the body for purposes other than looking, manipulation, or locomotion), and thinking (Templeman, Denbrook, and Sibert, 1999). No matter how good the walking interface that is being used, there are still other important issues to consider because of the nature of the virtual environments.

People naturally maneuver in real life using sensory cues such as vision, the vestibular apparatus, the haptic and proprioceptive senses, and audition. When the environment limits one or more of these cues, as is common in virtual environments, the interpretation of that environment can become inaccurate and simple tasks may become complex. As a consequence, user's performance level may degrade. Because of the nature of the virtual environments, there will be some differences between virtual worlds and real worlds in the way people perform actions such as looking, manipulation and even thinking. In real life, people have a much wider field-of-view (FOV) than in virtual worlds. No matter what type of visual display mechanisms are being used, because of the limitations in FOV, there will be some differences between the ways people look at objects in virtual environments. Manipulation is another example; hand operations will be different from the real world even if we have the most recent hands-free interface for walking. People need to turn their body for a number of reasons while they are moving. While people are turning their body, they sense through the visual, aural, haptic and vestibular systems. The feedback from these sensory cues will be different in virtual and real worlds. When users are required to manipulate objects in the virtual environments, no matter how perfect the interface technique is, they will not be able to sense the feeling of actual touching, thereby creating an obvious difference from the real world. When the users are using a head-mounted-display (HMD) in a virtual environment, the weight of the HMD will affect the balance of their body causing them to act differently than in the real world. Another important issue is maneuvering tasks. People usually use their body and hands while they are performing maneuvering tasks like sidestepping or kneeling. Nobody walks backwards in the same way as they walk forward. Usually people have a tendency to use their hands to feel if there is a wall or another object behind them while they are walking backwards. This is a common situation, especially if the people are trying to see what is in front of them, but trying to move backwards at the same time. No matter how perfect the locomotion device is, the behaviors of people will not be the same in the virtual environment as in the real world. Whenever there is a virtual environment experiment that is used to test some kind of human locomotion task, there is always some artificiality caused by the cables, the limitations of visual displays, and the limitations of the trackers, etc. When the person using a HMD is walking, somebody else in the environment has to take care of the cables coming from the HMD, or he is in danger of stepping on those cables whenever he needs to change his direction of motion. Another limitation of current virtual environments is that the user's movement must be within the range of the tracker, which is not very wide using today's technology.

These are only a few of the examples of situations that are inevitably different from the real world. The question being asked here is what effect, if any, do these factors have on maneuvering performance and behavior? All of these derivations may affect human locomotion altering the performance level of the people. Considering the factors mentioned above, it would be interesting to know if the user's performance level in the VE will be the same as in real life in terms of locomotion, assuming that the designers are able to build a perfect locomotion device. There is a strong possibility that even if a perfect locomotion device is used, because of the constraints of the current VE systems and the nature of the VE, the performance level of people will not be the same as that of the real world. However, there is no study that verifies this hypothesis. On the other hand, there are no data to verify the alternative hypothesis either. It is possible that when people have the right interface, they will be able to perform as they do in the real world. These questions are highly important for VE designers in that knowing the answers to these problems will have a direct effect on future virtual locomotion design studies and their evaluations.

C. THESIS GOALS

The overall goals of this thesis are:

- Develop a virtual and a real model of the same environment that allow people to perform actual walking and maneuvering tasks.
- Specify the tasks and observe the people in each of the environments while they are performing the maneuvering tasks.
- Analyze the data and draw conclusions about the behavioral characteristics of the people in the real and virtual world.

D. THESIS ORGANIZATION

Six chapters comprise this research:

- *Chapter I – Introduction*: Identifies the purpose and motivation behind conducting this research. Establishes the goals for the thesis.
- *Chapter II – Background and Previous Research*: Provides information on virtual locomotion devices and the previous research conducted in this area.
- *Chapter III – Task Analysis of Building Clearing*: Introduces basic concepts and the individual maneuvering tasks during a building clearing operation. Explains the selection of tasks to be used in the experiment.
- *Chapter IV - Methodology*: Describes the process and methodology employed during the development of the experiment.
- *Chapter V – Experiment Results and Discussion*: Analyzes the data and discusses the observed maneuvering behaviors of the people.
- *Chapter VI – Conclusions and Future Work*: Explains the conclusions and gives recommendations about possible future work.

II. BACKGROUND AND PREVIOUS RESEARCH

A. GENERAL DESCRIPTION OF THE CHAPTER

This chapter is a literature review on locomotion devices and interfaces in virtual environments. After an introduction to the concept of locomotion, the author describes the previous research on locomotion devices and discusses the current problems of virtual environments associated with human locomotion and maneuvering.

B. INTRODUCTION

One of the major problems in current virtual environment systems is the difficulty associated with human locomotion in virtual spaces. When there is a need to allow the user to move around the virtual environment, a mechanism must be provided, either with viewpoint control mechanisms, or with some special devices that let the users actually walk. In addition to locomotion, there must be a mechanism for maneuvering, - fine movements over short distances.

C. PREVIOUS RESEARCH

1. Natural Locomotion

The American Heritage Dictionary, Second College Edition, defines locomotion as “the act of moving or the ability to move from place to place.” Based on this definition, everything from crawling to traveling in a plane can be considered locomotion. Darken and Cockayne make a distinction between these two vastly different classes of locomotion. The first class of locomotion is called active locomotion, whereas the second class is called passive locomotion (Darken & Cockayne, 1997). Active locomotion is based on the use of the person’s physical exertion relying on the person’s body for transport. While the user is moving, no device is involved in the process. On the other hand, passive locomotion relies on the transportation of a person using a vehicle. The major human abilities required for active locomotion are the human’s use of limb movement, balance, coordination, and other physical traits of walking. Passive locomotion relies on more cognitive, or abstracted models of control. Both classes of locomotion are used in daily life, however this thesis focuses on active locomotion and refers to “active locomotion” by the term “locomotion”.

2. Virtual Locomotion

Virtual locomotion techniques allow the user to move and maneuver in virtual environments. Whenever a small physical space, as is typical of most laboratories, must be mapped to a much larger virtual space (often many orders of magnitude larger), a mechanism must be provided to allow users to move over large distances in the virtual world without actually moving far in the physical space (Darken & Cockayne, 1997). This is the virtual locomotion mechanism. Ideally, with these mechanisms people should be able to perform actions and move in virtual environments in the same manner as they do in the real world. Unfortunately, the ideal has not been achieved yet.

In virtual environments, the ideal locomotion technique or device should be able to allow the user to move over vast distances with reasonable accuracy and control. It has to be so transparent that the users can move automatically, without consciously being aware of locomotion input. There is an implicit assumption about the use of locomotion devices in virtual environments, particularly for training applications, that the users are being trained for other primary tasks. It is inevitable that there will be an adaptation period with the device, but spending time to train people in order to use the device is usually unacceptable.

As Templeman and his colleague state, virtual locomotion plays a role in many applications:

Training and Rehearsal in executing skills, tasks, strategies, and navigation that involves moving through an environment on foot,

Planning activities that involve moving through a target environment,

Evaluating the ergonomics or aesthetics of structures designed for human habitation, or of devices intended for use by people while walking,

Communications between people at different locations when they want to relate to each other in a way that involves locomotion, and

Entertainment experiences that involve moving through a VE. (Templeman, Denbrook, Sibert, 1999).

Virtual locomotion allows building realistic training systems, especially for the military. Dismounted infantry soldiers must be able to walk over long distances and maneuver in narrow areas on different terrains. Virtual locomotion is an essential and critical factor for individual infantry combatants when they are being trained in a VE. They need to be able to interact directly with the environment, but without an easily usable virtual locomotion mechanism. This is hardly possible. Developing such a virtual locomotion device to support all infantry tasks is quite difficult. In order to build a realistic virtual locomotion mechanism, the actions that the user has to perform in the virtual environment have to be considered first (Templeman, Denbrook, Sibert, 1999). These actions need to match their real world counterparts. Then, the sensory feedback received in response to the user's actions has to be considered. The user should be able to pick up the same information as he would in the real world. A virtual locomotion control influences how the user moves through the VE, which in turn shapes the user's perceptions, producing a simulated experience (Templeman, Denbrook, Sibert, 1999). So, observing how users perform actions in the VE in comparison to the actions performed in the real world is a good way to determine the realism of the virtual system.

3. Simulating a Natural Capability

Templeman and his colleague state that when trying to develop a virtual locomotion control technique that is as similar to actual locomotion as possible, it is useful to divide the control technique into two parts: the control action made by the user and the controlled effect produced by the computer system (Templeman, Denbrook, & Sibert, 1999). They describe simulating a natural capability in four requirements. The goal of simulated locomotion is to provide a control for moving through a VE as naturally as possible. We now have the terms to state this requirement more formally, in terms of action, component actions, interaction, and effect.

- The control action should be similar to the natural action with respect to its intrinsic properties (constraints on movements, caloric energy expenditure, and so on).
- The components of the control action (steering and speed control) should interact with each other as the components of the natural locomotion interact.

- The control action should interact with other actions (looking, manipulation, posturing, and thinking) in a similar manner to the way the natural locomotion interacts with other actions (for example, freeing the hands for manipulation and allowing a normal level of coordinated head, arm, and leg movements). It should also be compatible with actual locomotion over short distances.
- The controlled effect should be similar to the natural effect. The rate and precision of movement should match, and there should be no inappropriate side effects (such as having to be careful to avoid falling over).

This is clearly a tall order for any virtual locomotion control to meet, but it provides a basic set of criteria with which to evaluate all candidate techniques. These criteria are summarized in Table 2.1 (Templeman, Denbrook, & Sibert, 1999)

Similarity of Natural and Control Actions
1. Actions - Part of body performing action - Attributes of action: orientation, motion, force, etc. Motion attributes: direction, extend, timing - Effort and caloric energy expenditure
2. Interaction between Component Actions (A) - Steering: turning and sidestepping - Speed control
3. Interaction with Other Actions (B) - Look: pointing the head and eye - Manipulate: free hands for manipulation - Think: cognitive load - Move: compatibility with other body motions One and two-footed pivots: to quickly turn Actual steps: to local displacement of body Special purpose motions: bending, crouching, etc.
4. Effects - Rate and precision of movement - Trajectories taken - Constraints on movement
(A) implies the components of motion control interact with each other as the components of natural motion interact. (B) implies the motion control interacts with other actions as natural motion interacts with other actions (coordinated head, arm, and leg movements)

Table 2.1. Summary of Requirements for the Interactive Realism of Virtual Locomotion. “From Ref [2].”

4. Virtual Locomotion Mechanisms

Walking is a key element of fully immersive virtual environments. However, there are severe problems in terms of human factors issues associated with virtual walking. It is a natural thing that people take for granted in real life. However, it becomes very complicated to achieve in virtual environments. This is due to the fact that the sensory cues used for maneuvering and walking are different in virtual environments than in real life. A number of sensor-based techniques are used to control movement in VE, then mechanical devices such as Uniport, Treadport or Omni-Directional Treadmill (ODT), have been proposed to solve the problem. They have serious side effects and drawbacks in terms of human abilities to locomote.

In general, there are two major different approaches to the problem of locomotion control in virtual environments. The first approach is more conventional motion controls that use sensors attached to the upper body of the user. The second approach is the use of mechanical devices that try to simulate actual walking.

a. Sensor-Based Controls

These control techniques use sensors that are attached to the user's body. Sensor-based controls are often used to steer and set the speed of motion through the virtual environment (Templeman, Denbrook, Sibert, 1999). There are a variety of techniques for steering control. The most common steering techniques are pointing and head-based steering. In the pointing technique, the users point the steering direction and while they are moving in the virtual world, they can steer at any direction. However, the hand is occupied, so it conflicts with the manipulation tasks. The head-based steering technique, allowing the user to use their hands for object manipulation, is more economical since the same tracker can be used for determining both the field-of-view (FOV), and the direction of the motion. The drawback is that looking and moving is no longer independent. The users cannot turn their heads to look in other directions while they are moving. A widely used speed control technique is using fingers with some buttons on a hand control. This technique is easy and inexpensive to implement. It works independently of head and leg movement allowing physical motions of the body. On the other hand, this technique interferes with using fingers for manipulation tasks.

b. Mechanical Locomotion Devices

There are a variety of mechanical locomotion devices in the virtual environments. This thesis discusses three generations of locomotion devices developed for the United States Army Dismounted Infantry Training Program. It then describes their problems in terms of human factors issues, according to a usability study performed by Rudolph Darken in 1997.

UNIPORT (Figure 2.1) was one of the first devices built for lower body locomotion and exertion (Darken, Cockayne, & Carmein, 1997). The metaphor of this device is pedaling a unicycle rather than actually walking. The users can move forward and backward, and turn left or right with the device. The direction of motion is uncomfortable and awkward and is controlled by its seat. Small motions and maneuvering such as sidestepping are almost impossible to perform.

Figure 2.1. Soldier on a Uniport. “From Ref [3].”

TREADPORT (Figure 2.2) was the successor of the Uniport. The initial goal of the Treadport was to overcome the difficulties associated with the Uniport. The Treadport has a standard treadmill and the user is monitored from behind a mechanical attachment that is attached to the user’s waist. The mechanical attachment gives feedback to the system and provides force-feedback to the user. The major improvement with this device is that it allows the users to walk instead of pedaling. However, it does not solve all of the problems associated with the Uniport. The users turn their waists to specify the direction of movement. Physical movement is constrained to one direction and fine movements are awkward if not in the direction of the treadmill.

Figure 2.2. Treadport**.** "From Ref [3]."

Omni-Directional-Treadmill (ODT) is the last and the most recent of these three successive locomotion devices. Figures 2.3 and 2.4 show a person using ODT in a virtual environment. ODT is a major breakthrough in that it actually allows the people to walk in any direction. However, there are also major problems with this device in terms of human factors issues. Mechanically, it consists of two treadmills one inside of the other. There are two belts, -upper and lower belts- controlled by their own servomotors. ODT responds to the user's motions and maneuverings with the servomotors. The user wears a harness for safety reasons. The harness prevents the users from falling to the ODT platform when they lose their balance. In cases when the users completely lose their balance, a switch is triggered to stop the ODT. The tracking arm is used to locate the user's position and orientation relative to the platform. When the user moves off the center of the ODT, servomotors attempt to drive the user back to the center. Therefore, there are two fundamental types of movement associated with the use of the ODT:

- **User initiated movement:** The user attempts to walk from the ODT center to some position.
- **System initiated movement:** The ODT attempts to return the user to its center. (Darken & Carmein, 1997)

Figure 2.3. ODT. "From Ref [3]."

Figure 2.4. ODT. "From Ref [3]."

Although ODT is the most recent device and seems to be the most elegant solution to the problem, a usability analysis performed by Darken and Carmein (1997, Naval Postgraduate School) shows that there are a number of problems yet to be solved. First, the users must learn how to walk on the ODT, indicating that there is a big difference compared to real life in terms of walking and maneuvering. The biggest problems are the maneuvering and small movement tasks. There is almost no way to remove the side effects with these tasks. Whenever users try to maneuver, such as turn in place or side step, ODT responds to the users and tries to drive them to the center. Even if there is no motion with a maneuvering task, the ODT responds to the user as if there is a motion, consequently causing the users to stumble or lose their balance. Another big problem is latency. When the user tries to accelerate and change direction of movement rapidly, there is very little time for ODT to respond. If the ODT cannot keep up with the pace of the user's movements, a misalignment occurs and the users lose their balance. This situation may cause the user to move off the edge of the ODT platform.

D. SUMMARY

This chapter introduced the basic issues and previous research on virtual locomotion. The important terms like natural locomotion and virtual locomotion have been discussed to construct a basic understanding. A review of significant virtual locomotion studies was also included. It can be concluded that the locomotion devices that have been developed so far are not good enough to provide realistic movements and maneuvering capabilities for their users.

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III. TASK ANALYSIS OF BUILDING CLEARING OPERATIONS

A. INTRODUCTION

One application for virtual locomotion devices is in the area of Military Operations on Urban Terrain (MOUT) training. Combat skills are difficult to acquire as they require an individual combatant to make time-critical decisions and responses. As part of a simulator, locomotion interfaces would allow individual combatants to practice the techniques that they use in real operations. Soldiers perform numerous fine movements and maneuvering tasks while they are conducting MOUT operations. Therefore, the locomotion interface plays a highly important role in a simulator or a virtual environment that is used for training individuals for MOUT operations.

The author conducted a task analysis of clearing building operations in order to determine the maneuvering and locomotion tasks to be used in the experiment. After an understanding of how individual combatants behave in a tactical situation, the author specified the maneuvering tasks that can be used for the purpose of this research. This analysis was made based on the tactical documents and the military manuals that are cited in the reference section of the thesis.

Sections B, C, D, and E of this chapter describe the basics of MOUT operations. They introduce the principles of the clearing building operations and present clearing building techniques. Section F presents the individual tasks in a clearing building operation. Section G presents the maneuvering tasks that are used in the experiment.

B. BASICS OF CLEARING BUILDING OPERATIONS

1. Definitions

Military operations on urbanized terrain (MOUT) is defined as all military actions planned and conducted on a topographical complex and its adjacent terrain where manmade construction is the dominant feature. It includes combat in cities, which is that portion of MOUT involving house-to-house and street-by-street fighting in towns and cities. (Marine Corps Reference Publication (MCRP) 5-2A, 1997)

A **built-up area** is a concentration of structures, facilities, and populations, such as villages, cities, and towns, which form the economic and cultural focus for the surrounding area. (MCRP 5-2A, 1997)

Urbanized terrain is a complex environment. It includes the characteristics of natural landscape and manmade construction. The requirements for urban combat cause a variety of problems with maneuvering, command, and control of the troops. There is a requirement for a larger operational focus, a slower pace of operations, a longer duration of commitment and a continuous communication between soldiers. Therefore, the methods of conducting operations in such environments are different than the methods of natural landscape operations. Tactical doctrine states that urban combat operations are conducted only when required, since they involve high risks and time-consuming procedures. Urban operations are usually conducted to capture or control a place, which provides a strategic or tactical advantage over the enemy. The attack or defense of a built-up area should be undertaken only when significant tactical or strategic advantage accrues through its seizure or control (FM-90-10, 1979).

2. General Characteristics of Urban Warfare

The general characteristics of urban warfare make it more difficult to apply basic tactical fundamentals and to maintain control. Combat operations might be limited by the presence of civilians in the area. There might be a need to insure the minimum collateral damage within the urban complex's built-up areas, causing a constraint on firepower of the unit. Weapons employment and target acquisition ranges are reduced in the urban areas. Visibility usually extends to less than 1200 meters. These limitations cause a violent combat between opposing forces, requiring the use of automatic weapons, hand grenades, rocket launchers and close quarter combat skills.

Operating from, within or through urban areas isolates and separates units (FM-90-10, 1979). Operations take place as a series of small-unit battles. Thus, the individual skills of the soldiers are greatly depended upon. The communication in urban areas is very difficult to maintain. There is continuous close combat and a high casualty rate. This causes severe psychological strain and physical overload among soldiers.

C. ATTACKING AND CLEARING BUILDINGS

Regardless of a structure's characteristics or the type of built-up area, there are four interrelated requirements for attacking and clearing a defended building (FM-90-10-1, 1993). These are:

- Fire Support
- Movement
- Assault
- Reorganization

When these requirements are properly applied to the situation, casualties can be reduced and the mission can be accomplished more easily.

1. Fire Support

A support force provides fire support. The goal of fire support is to assist to the advance of the assault force. This assistance includes suppressing and obscuring enemy gunners within the objective buildings, preventing enemy withdrawals, destroying enemy positions and breaching walls en route to the objective building. The size of the support force is determined according to the type and the size of the buildings to be cleared.

2. Movement

The assault force minimizes enemy defensive fires during movement by:

- Using covered routes
- Moving only after defensive fires have been suppressed or obscured
- Moving at night or during other periods of reduced visibility
- Selecting routes that will not mask friendly suppressive fires
- Crossing open areas quickly under the concealment of smoke and suppression provided by support forces. (FM-90-10-1, 1993)

3. Assault

The assault force quickly and violently executes the assault and clearing operations. The individual close quarter combat skills play an important role in an assault to a built-up area since a large portion of the combat takes place at very close quarters. Each individual in the team must understand the basic principles of close quarter combat: *surprise, speed, and controlled violent action.* During their action in clearing the building, team members must move quickly and silently, eliminating all enemies within the room by use of fast, accurate, and discriminating fires.

Normally, close quarters combat clearing techniques are designed to be executed by the standard four-man fire team. The space available for the clearing operations is limited, so the units larger than squads can become unwieldy. Ideally a top-to-bottom method is preferred for room clearing operations. When the upper floor or rooftop is accessible, this method should be used since it provides an advantage for the assault team when throwing hand grenades and moving from floor to floor. However, entering a building from the top is not usually easy, so a bottom-to-top method is more common than a top-to-bottom method. In this method, the assault team clears each room on the ground floor and progresses clearing each room one by one systematically.

4. Reorganization

It is a very critical task for the assault team to cover the potential enemy counterattack routes to the building after securing a floor. Some of the team members are assigned to this task after the clearing process. These soldiers guard against the enemy mouseholes connecting adjacent buildings, covered routes to the buildings, underground routes into the building, and approaches over adjoining roofs (FM-90-10, 1979).

D. WEAPONS HANDLING TECHNIQUES

During MOUT, soldiers have to engage targets at very close distances. Being too slow to shoot at an enemy or too fast to shoot at a noncombatant is not a desirable situation in a MOUT operation. Avoiding these situations requires using proper weapon carry techniques. The Marine Corps Warfighting Publication (MWCP) 3-35.3 states four major techniques used in MOUT operations.

1. Tactical Carry

This technique is used when no immediate threat is present. The control of the weapon is easy and it allows a quick engagement of the enemy. The barrel of the weapon is angled upward approximately forty-five degrees in the general direction of the enemy. Figure 3.1 shows a soldier using the “Tactical Carry” technique.

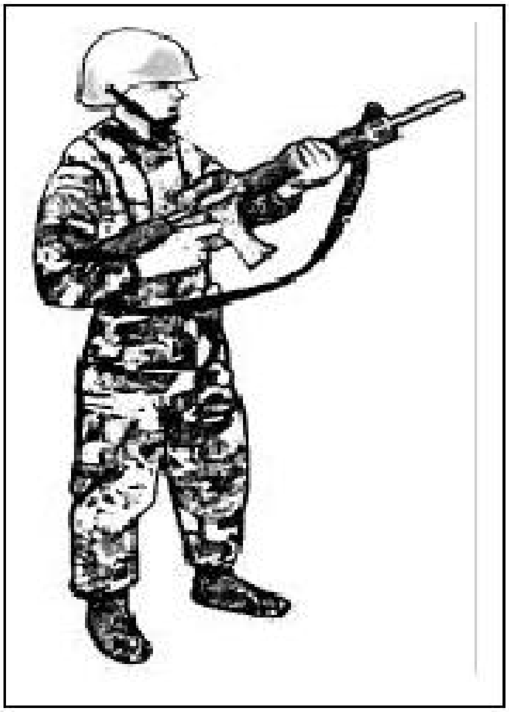

Figure 3.1. Tactical Carry. “From Ref. [7]”.

2. Alert Carry

When an enemy threat is likely, the alert carry technique is used. The muzzle angles down approximately forty-five degrees and is pointed in the likely direction of the enemy. Figure 3.2 shows a soldier using the “Alert Carry” technique.

Figure 3.2. Alert Carry. “From Ref. [7]”.

3. Ready Carry

This technique is used when an enemy contact is about to occur. It allows engaging a target immediately. The muzzle of the rifle points in the direction of the enemy. Figure 3.3 shows a soldier using the “Ready Carry” technique.

Figure 3.3. Ready Carry. “From Ref. [7]”.

4. Short Stocking

This technique is used in enclosed areas to increase the maneuverability of the weapon while reducing its exposure to the enemy eyes. The stock is positioned so that the pistol grip is behind the soldier's head. The soldier uses his index finger or thumb to manipulate the trigger. Figure 3.4 shows a "Short Stocking" technique.

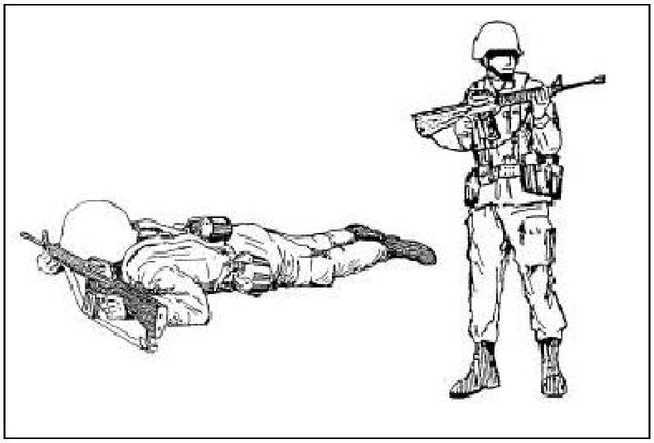

Figure 3.4. Short Stocking. "From Ref. [7]".

E. CLEARING TECHNIQUES

MCWP 3-35.3 states that clearing techniques are conducted as at least two-man teams. However, there may be times when a single person has to conduct a clearing operation. The techniques described in this analysis are based on the two-man clearing team conducting the operation.

1. Clearing a Room From Stacked Positions

The positioning of the team is given in Figure 3.5. This position is the same, no matter if the door is already open or nonexistent. The team forces the door open by using automatic fire through the door. The team members should beware of booby traps and enemy fires. The team member close to the door is referred to as Shooter Number One, and the other is referred as Shooter Number Two.

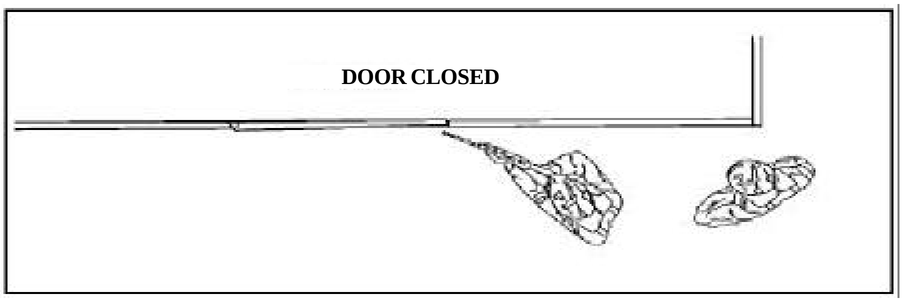

Figure 3.5. Clearing a Room, Door Closed. “From Ref. [7]”.

Once the door is open, Shooter Number Two throws a hand grenade into the room. The positioning of the team is shown in Figure 3.6.

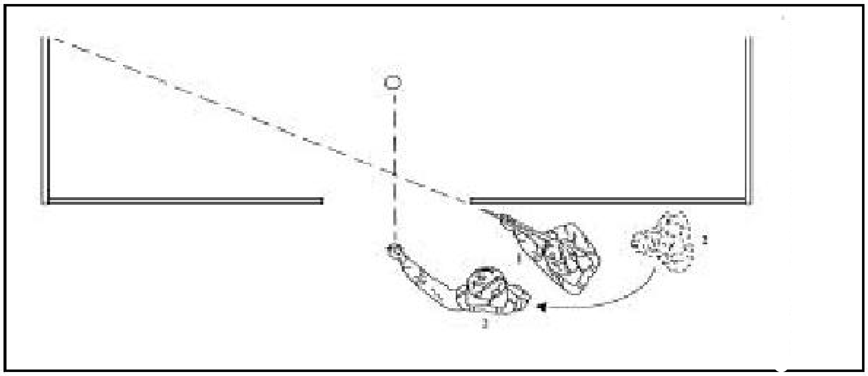

Figure 3.6. Throwing a Grenade Into a Room. “From Ref. [7]”.

After the grenade explodes, Shooter Number One enters the room and clears his immediate area. Then, as shown in Figure 3.7, Shooter Number Two enters the room and clears his area.

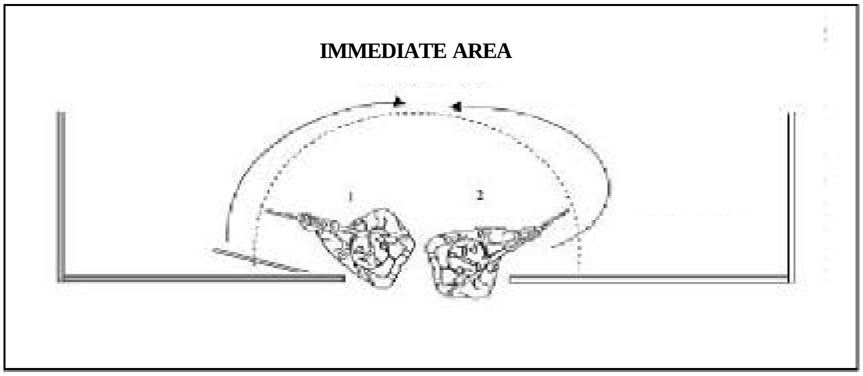

Figure 3.7. Shooters Enter The Room. “From Ref. [7]”.

Both shooters then establish a dominant position in the room so that they clear the entire room. The positioning of the team is shown in Figure 3.8.

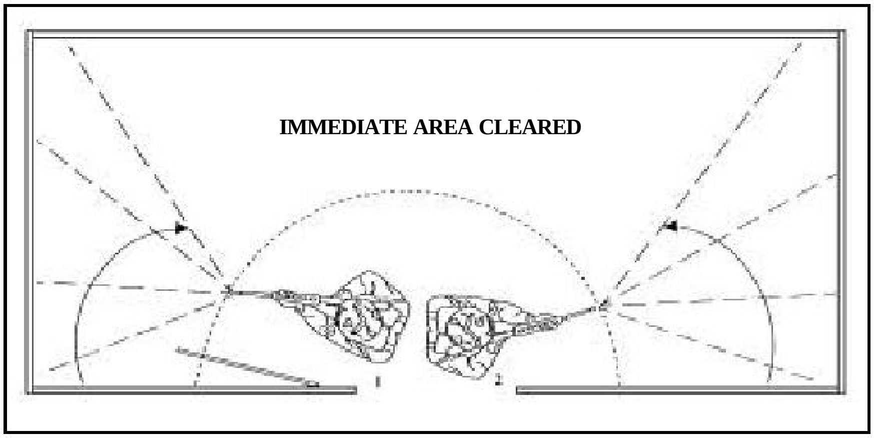

Figure 3.8. Clearing a Room. "From Ref. [7]".

2. Clearing a Room From Split Positions

The team members position themselves on the other side of the door and away from the wall in a safe position allowing Shooter Number One to shoot the door. The poisoning of the team is shown in Figure 3.9.

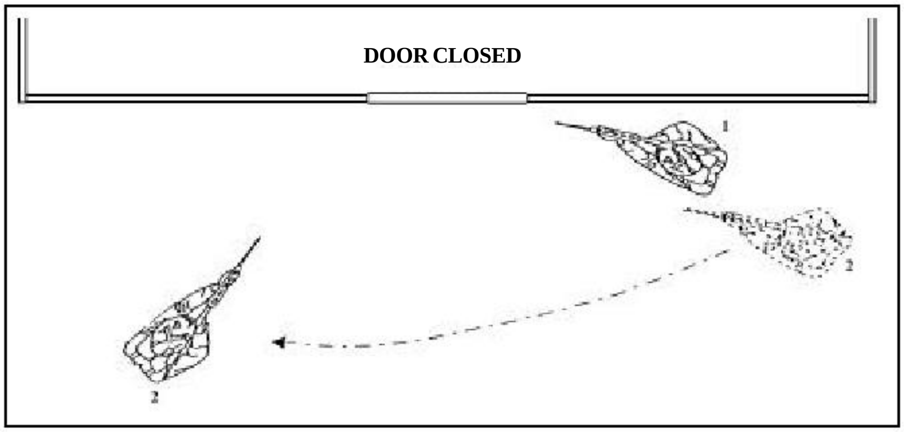

Figure 3.9. Positioning to Open a Door. "From Ref. [7]".

After Shooter Number One shoots the door open, Shooter Number Two moves to a kneeling position against the wall. Figure 3.10 shows the positioning of the team.

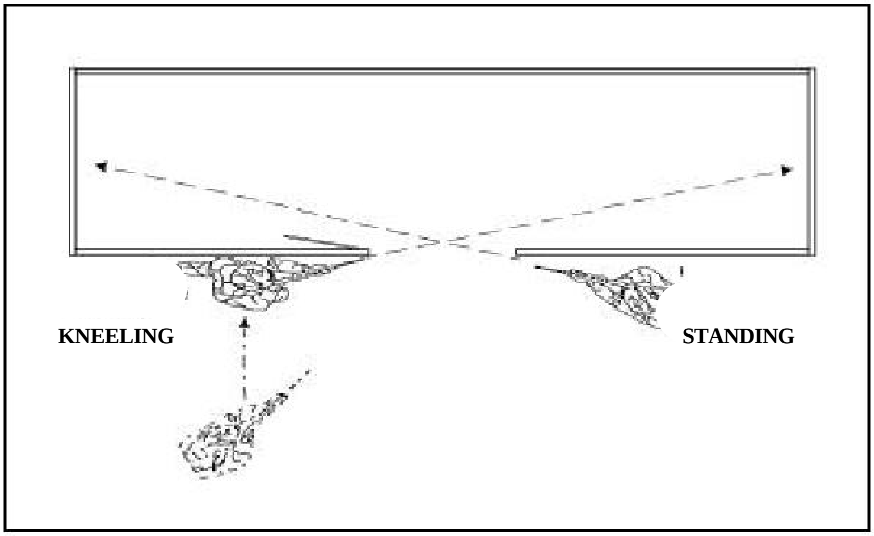

Figure 3.10. Positioning to Enter a Room. “From Ref. [7]”.

Shooter Number Two throws a hand grenade into the room. Then, both shooters pass through the doorway together and enter into the room. Then a clearing operation is performed. Figure 3.11 shows the “Entering the Room” operation.

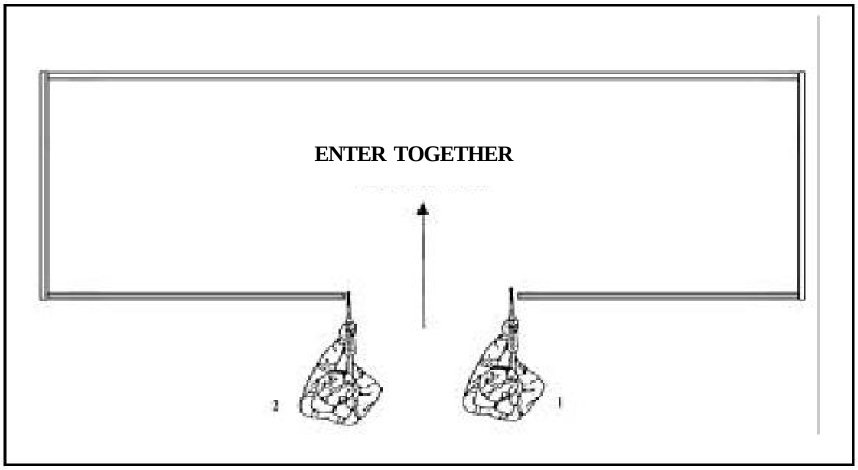

Figure 3.11. Shooters Enter The Room Together. “From Ref. [7]”.

3. Cross Method

The team members position themselves on either side of the door. Each member faces into the room covering the opposite corners. Then, they enter the room with a predetermined signal. Each member crosses quickly to the opposite corners of the room. The Cross Method is shown in Figure 3.12.

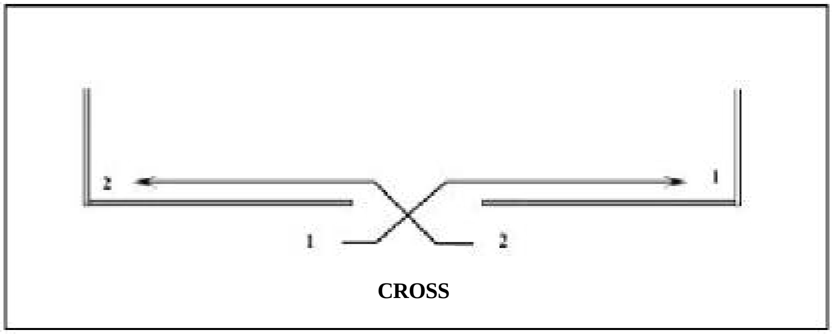

Figure 3.12. Cross Method. “From Ref. [7]”.

These techniques describe the correct way of conducting a clearing building operation according to the doctrine. In reality, the correct method just happens.

F. INDIVIDUAL MOVEMENTS DURING CLEARING BUILDING

Individual soldiers move differently in the urban operations than they do in normal field operations because of the special nature of the combat area. In urban operations, individual soldiers face many obstacles that must be breached or bypassed.

1. Individual MOUT Tasks or Skills

FM-90-10-1 states four major tasks and their related subtasks that need to be performed during an urban operation:

a. Clearing Building

This requires the following tasks or skills:

- Clear a room
- Vary clearing techniques
- Reorganize after clearing a room

b. Select Hasty Firing Positions in Urban Terrain

This requires the following tasks or skills:

- Fire around a building or wall
- Fire from a window
- Fire from an unprepared loophole

c. Enter a Building

This requires the following tasks or skills:

- Select point(s) to enter a building

- Enter a building
- Select use of hand grenades
- Clear the entry point
- Check for and clear booby traps

d. Move in Urban Terrain

This requires the following tasks or skills:

- Follow general rules of MOUT movement
- Move across an open area
- Cross obstacles

2. Subtasks of Individual MOUT Tasks or Skills

The aforementioned four major tasks were divided into the very low-level subtasks based on FM-90-10, FM-90-10-1, MCWP 3-35.3, MOUT ACTD Handbook #3 by Omega Training Group, Inc, and a training study by U.S. Army Research Institute for The Behavioral and Social Sciences: Analysis of Mission-Based Scenarios For Training Soldiers and Small Unit Leaders in Virtual Environments.

a. Clearing Building

- Take position to one side of a doorway
- Move quickly through doorways
- Take a tactical position within a room
- Scan the room quickly for hostile combatants
- Engage targets within a room
- Identify non-combatants within a room
- Move past furniture in a room
- Maneuver past other personnel within a room
- Understand verbal commands
- Identify sector of responsibility
- Communicate spot reports to squad leader

b. Select Hasty Firing Positions in Urban Terrain

- Fire from a window (Figure 3.13)
    - Avoid firing from the standing position
    - Prevent the muzzle flash from being seen

    - Kneel to limit exposure when needed

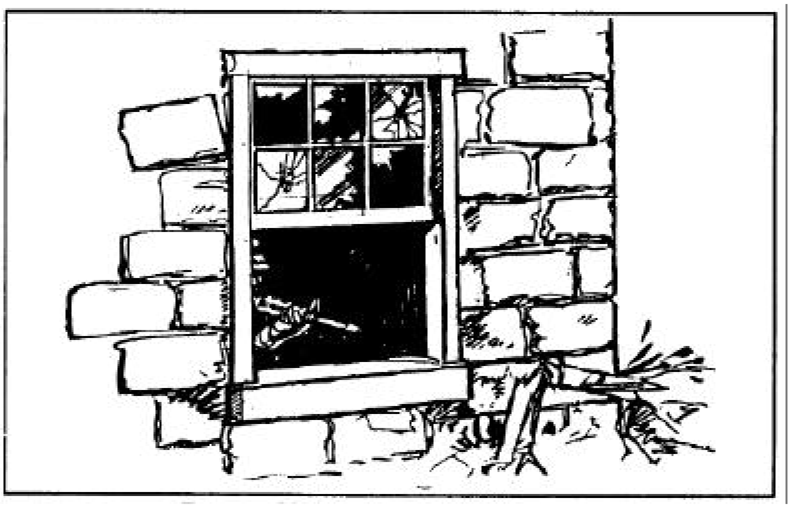

Figure 3.13. Firing From a Window. “From Ref. [6]”.

- Fire around a building or wall (Figure 3.14)
    - Be able to fire the weapon both right-and-left handed to be effective around the corners.

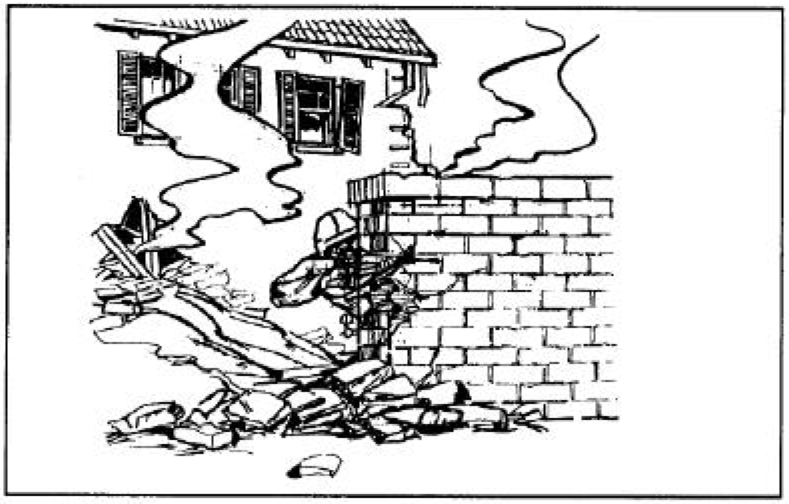

Figure 3.14. Firing Around Cover. “From Ref. [2]”.

    - Fire from an unprepared loophole
    - Fire when no position available
        - Lie prone as close as possible to a building
        - Avoid silhouetting

    - Make maximum use of available cover and concealment
    - Avoid firing over cover; when possible, fire around it
    - Avoid silhouetting against light-colored buildings
    - Keep exposure time to a minimum
    - Carefully select a new firing position before leaving an old one

c. Enter a Building

- Select entry point(s)
    - Avoid windows and doors
    - Use smoke to conceal the advance
- Use hand grenades before entering. (Figure 3.15)

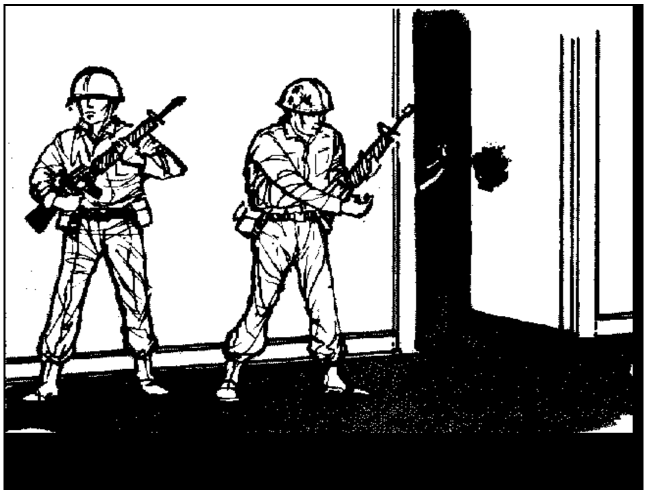

Figure 3.15. Use Hand Grenades. “From Ref. [5]”.

- Clear the entry point
- Use automatic fire when entering
- Do not open the doors by hand or attempt to kick them open
- Shoot the door open by firing several rounds through the lock. Figure 3.16 shows the positioning of the team while shooting the door open.

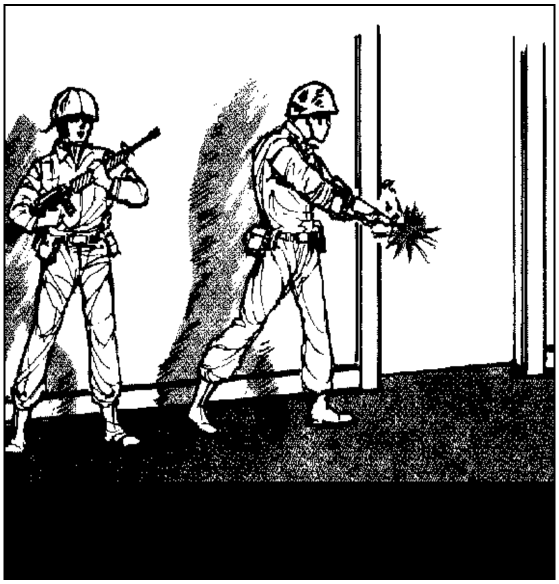

Figure 3.16. Shoot The Door. "From Ref. [5]".

- Use voice alerts
- Check for and clear booby traps:
    - Be constantly alert for them in doors, windows, halls, stairs, and concealed in furniture
    - Do not attempt to deactivate them; mark for later disarming by trained engineers
    - Use previously cleared routes where possible
    - If untrained personnel must remove the booby trap, evacuate building; destroy in place with explosives, re-clear the building

d. Movement in Urban Terrain

- Avoid open areas such as streets and alleys, when possible
- Take care not to be silhouetted
- Make a visual reconnaissance of the next position before moving
- Take advantage of all cover and concealment
- Stay alert all the time
- Observe around corners
    - Use the pie method to observe around a corner or barrier to expedite movement. Figure 3.17 shows the "Pie Method".

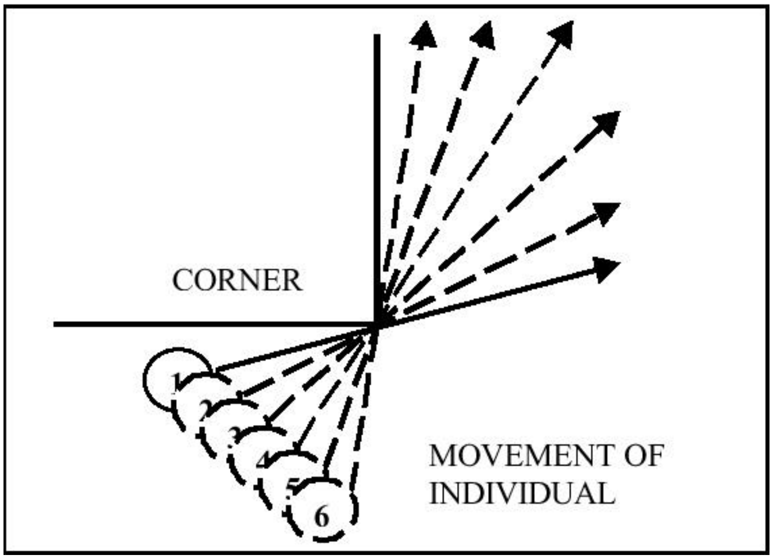

Figure 3.17. Pie Method. “From Ref. [8]”.

- Move across open areas.
    - Run the shortest distance between the buildings and move along the far building to the next position
    - Make a visual reconnaissance before moving to select position for the best cover and concealment
    - Move in the most direct route to the selected position
    - Move from position to position without masking covering fires
    - When the next position is reached, be prepared to cover the movement of other members of the fire team or squad
- Move parallel to buildings
    - “Hug” the side of the building
    - Stay in the shadow
    - Present a low silhouette
    - Move rapidly to the next position
- Move past the first floor windows. (Figure 3.18)
    - Don’t expose the head (kneeling may be required)
    - “Hug” the side of the building

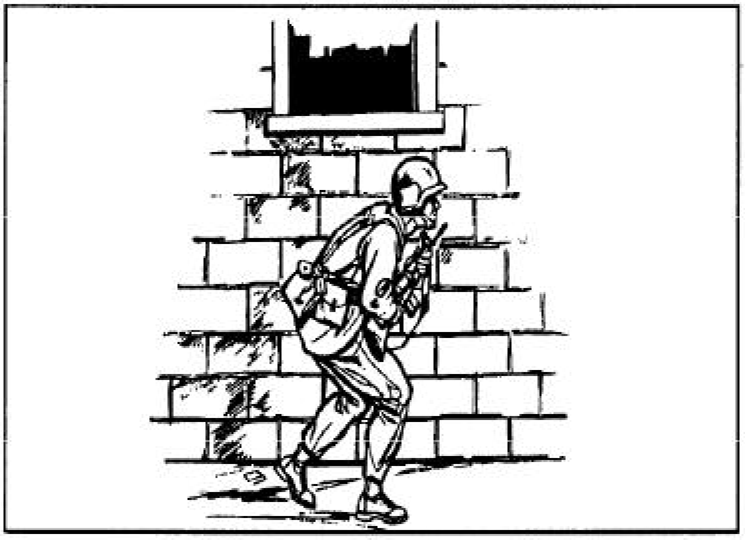

Figure 3.18. Moving Past Windows. “From Ref. [5]”.

- Move past basement windows. (Figure 3.19)
    - Stay close to the wall of the building
    - Step or jump past the window
    - Do not expose the legs

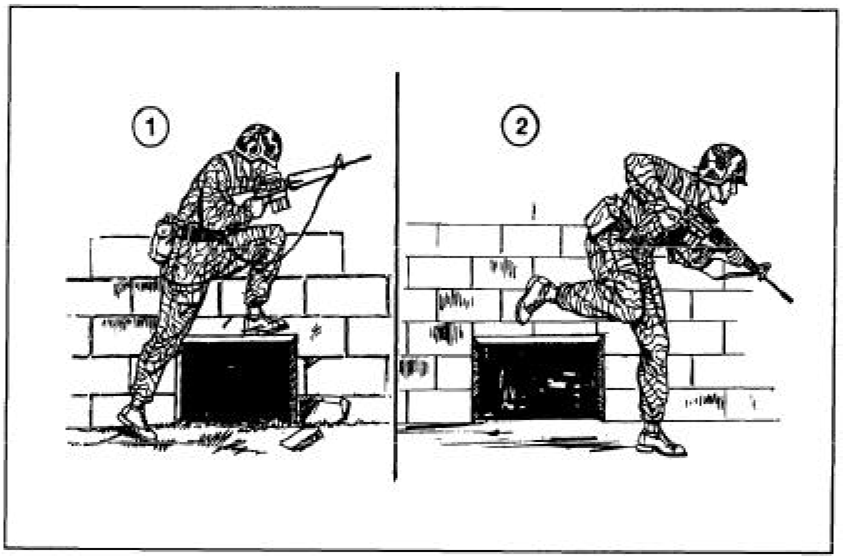

Figure 3.19. Passing Basement Windows. “From Ref. [6]”.

- Cross the obstacles (walls, fences, and rooftops). Figure 3.20 shows a soldier crossing an obstacle

- Correctly reconnoiter the other side
- Quickly roll over the wall, or fence keeping a low silhouette

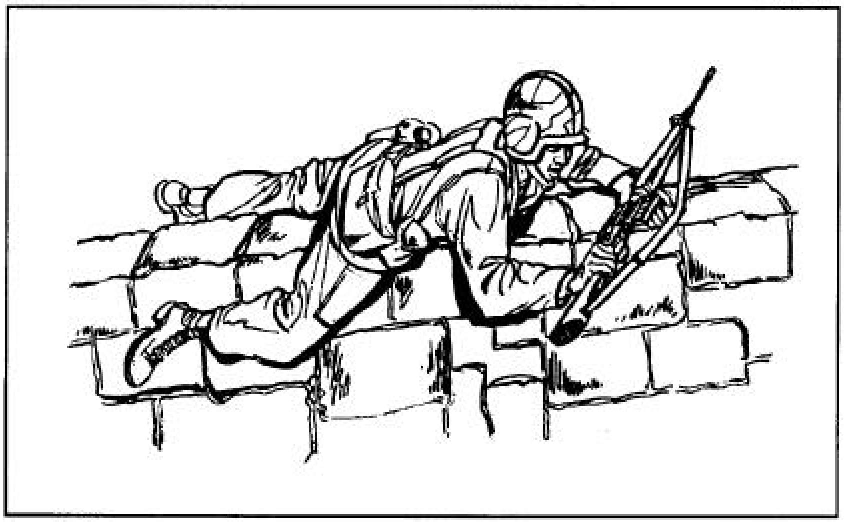

Figure 3.20. Soldier Crossing A Wall. "From Ref. [5]".

- Use proper weapon carrying techniques
    - Hold the muzzle of the weapon in the direction of travel
    - Avoid "flagging" or leading with the weapon
- When the weapon malfunctions, drop to one knee and conduct immediate action to reduce malfunction

G. SELECTION OF TASKS FOR THE EXPERIMENT

Based on the maneuvering tasks described above, the author determined the tasks that represent the general characteristics of a clearing building operation. It was very difficult, if not impossible, to perform the entire aforementioned maneuvering tasks using natural locomotion with current virtual environment technology. Obviously, there are many issues to be considered such as the range of trackers, the HMD capabilities, and the latency problems. Therefore, the author selected a representative set of maneuvering tasks, which can be applied to a virtual environment.

1. Maneuvering Tasks

The maneuvering sub-tasks that comprise the MOUT soldier's maneuvers are listed below:

- Walking
- Sidestepping
- Kneeling
- Crawling
- Jumping
- Rolling
- Running
- Looking around the corner
- Backward movement
- Lie prone

2. Selection

Among these maneuvering tasks, a representative subset of tasks was chosen for this research based on the ability to perform them in our lab-space. ‘Crawling’ was difficult to perform, since the range of the tracker was not long enough to cover the entire room from the ceiling to the floor. Also, the short length of the cables constituted a big problem for this task. Cables and the weight of the HMD did not allow us to include ‘jumping’ and ‘rolling’ in the study. ‘Running’ was impossible to perform, since the range of the tracker was too short. Finally, ‘lie prone’ was excluded from the study for the same reasons described above. The range of the tracker and the cables made it impossible to perform this maneuvering task.

The following maneuvering tasks were selected from the list, since they can be performed within current VEs: ***sidestepping, kneeling, look around the corner, and backward movement.*** In an experiment, the participants were required to perform these four maneuvering task set within appropriate scenarios. The methodology used in the research is described in the next section.

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IV. METHODOLOGY

A. EXPERIMENT OVERVIEW

An experiment was conducted in order to see whether or not people are able to perform the maneuvering tasks in VE as in the real world, when locomotion is factored out. This section provides an overview of the conduct of the experiment, while succeeding sections describe the tools, phases, and methodology of the experiment in more detail. The general sequence of the experiment was the in-briefing, head-mounted-display (HMD) and model familiarization, kneeling task, looking around the corner task, sidestepping task, backward movement task, and debriefing.

The experiment consisted of three conditions. Participants performed the same tasks in each of these conditions. The first condition was real world only and was a room in which some objects were placed. There was no interface or display mechanism in this condition. The second condition was the virtual world only. The participants saw the virtual objects with a HMD, and they walked through the empty room. The third condition was the real and virtual world together (VE+Real). The exact same room with the first condition was used, however they used a HMD while walking through the room. In the virtual conditions, the positions and the head orientations of the participants were tracked with an electromagnetic tracker. The difference between the second and third conditions was that the VE+Real condition provided the participants haptic feedback, since the real objects were placed at their exact locations as they were seen in the HMD. A detailed explanation of the conditions will be discussed later in the chapter.

Upon the arrival of the participants, the basic in-briefing was given to the participants and they filled out and signed consent forms. The in-brief is shown in Appendix B. The consent forms used are in Appendix C.

After the in-briefing, the participants were familiarized with the HMD. A scene similar to the ones used in the experiment was displayed and the participants were asked to turn their head and walk inside the room. Pilot studies indicated that a familiarization phase was necessary to assure the proper use of HMD due to the participants' varying levels of past experiences with virtual environments. Also, this familiarization phase allowed us to see if any of the participants had physical problems associated with using the HMD.

After the familiarization phase, the participants performed the kneeling task. In this task, the participants were asked to read the letters written on the bottom faces of the cube-shaped objects. The objects were placed in the environment so that the participants needed to kneel down in order to read the letters. The kneeling behaviors of the participants were observed in each of the three conditions. Also, the time to complete the task was measured.

Upon the completion of the kneeling task, the participants were asked to perform a "look around the corner" task within a scenario. They were told to reconnoiter the other side of a room separated by a wall. They were also told that the scenario was a tactical situation in which they needed to minimize their exposure while trying to see the enemy forces as much as they could. The only option for them to successfully complete the task was to look around the corner of the wall. A number of cube-shaped objects were used as the representative of the enemy forces to be explored. The task ended when the participants indicated that they had seen the objects. The behavioral characteristics of the participants were observed. The time to complete the task was measured and the number of correctly recognized objects was recorded for further analysis.

After the look around the corner task was completed, a sidestepping task was performed. The participants were asked to walk through the narrow paths. Some objects were placed inside the environment so that the participants needed to sidestep in order to pass them. Sidestepping behaviors of the participants were observed and the time to complete the task was measured. The number of collisions with the objects was measured categorically. In those conditions with physical objects (Real only, and VE+Real), the number of collisions with the objects could be observed easily, however there was no practical way of achieving this in the VE only condition, since it required the tracking of the whole body as well as the need for using an avatar. Therefore, collisions with objects were measured categorically as described later in this chapter.

The last maneuvering task required the participants to move backwards. The environment consisted of a chair in front of the participants' starting point and a box at the end of the room. The chair was placed in the environment as an obstacle so that participants had to take it into consideration during their movements. The participants first walked to a certain point in the room where they saw the box and a letter "A" on top of it. Then, they were told that the letter would change into "B" at any time while they were moving back to the starting point, and they were asked to report any changes as soon as possible. The only way for the participants to see the letter during their movement was moving backwards. The backward movement of the participants was observed and the time to complete the task was measured in each of the conditions. The collisions with the objects were measured categorically as in the previous task. Also, after the completion of walking backwards, the error distance to the starting point was measured for further analysis.

The tasks were performed in each of the three conditions. After the completion of the experiment, the subjects were debriefed about the experiment. They were thanked and were reminded not to talk to anyone about the specifics of the experiment.

B. EXPERIMENTAL DESIGN

A within-subject design was used. All of the participants performed the tasks in each of the conditions. Each participant performed the tasks in the same order. However, the order of the conditions was randomized for each task in order to minimize the learning effect.

1. Participants

The participants for this experiment consisted of 38 individuals (1 female and 37 male) ranging in age from 23 to 60 with an average age of 29. Five were civilian, and the rest were active duty officers. None of the participants had prior knowledge about the purpose of the study. The participants ranged in different levels of previous knowledge about HMD and head tracking. None of the participants were colorblind nor had a physical difficulty with walking and maneuvering. Data were collected from 28 June 2001 to 28 July 2001.

2. Independent Variables

The controlled variables were the environment types. Table 4.1 shows the three different conditions used in the experiment. The locomotion mechanism and the natural locomotion were used in all of the conditions.

- **Real World Only**. Walking in the room with no interface (actual walking in the room).
- **Virtual World Only.** Walking with a HMD in the empty room (no real objects).
- **VE+Real**. Walking with HMD in the room that is exactly the same as the one displayed.

CONDITIONS	HMD	Computer Generated Objects	Physical Objects
Real World Only	NO	NO	YES
Virtual World Only	YES	YES	NO
VE + Real	YES	YES	YES

Table 4.1. Independent Variables of the Experiment.

In the VE+Real condition the real objects were placed at their exact locations as they were seen on the HMD. This provided haptic feedback to the participants. In the virtual only condition, there was no real object inside the environment. Therefore, no haptic feedback was provided. The participants had seen the virtual objects on the HMD, but the objects were not physically placed on the environment, so the participants walked inside the empty room. The difference between the real only and the two virtual conditions was that the participants used their own eyes but not any display mechanism in the real only condition, whereas in the virtual conditions, they used a HMD as a display mechanism. The difference between the two virtual conditions was that one provided haptic feedback whereas the other did not.

3. Dependent Variables

The main goal of the experiment was to observe and describe user behaviors when they performed maneuvering tasks under varied conditions. A number of measurements were used in order to determine the difference in performance levels of people in different conditions. The participants were asked to perform each task twice. This allowed us to smooth the data by using the averages as our dependent measures. Table 4.2 shows dependent variables for each task used in the experiment.

TASK	**DEPENDENT VARIABLES**
KNEELING	Task Completion Time
	Observed Behavior
LOOK AROUND THE CORNER	Task Completion Time
	The Number of Correctly Recognized Objects
	Observed Behavior
SIDESTEPPING	Task Completion Time
	Collision Category • Category Zero • Category One • Category Two
	Observed Behavior
BACKWARD MOVEMENT	Task Completion Time
	Collision Category • Category Zero • Category One • Category Two
	Error Distance to Starting Point
	Observed Behavior

Table 4.2. Dependent Measures of the Experiment.

a. Kneeling Task Dependent Variables

The average time to complete the task was measured. The kneeling behavior of the participant was observed in each of the conditions.

b. Look Around the Corner Task Dependent Variables

The average time to complete the task and the number of correctly recognized objects were measured. The looking around a corner behavior of the participants was observed in each of the conditions.

c. Sidestepping Task Dependent Variables

The average time to complete the task was measured. The number of collisions with the objects was measured categorically for the following reasons:

In the VE only condition, in order to accurately represent the body of the participant, an avatar was needed. Even if an avatar was used, it had to be in the same shape and dimensions as the body of the participant, which was impractical. This would require adjustments for the avatar for every single participant. Also, a whole-body tracking system requiring multiple receivers was needed to accurately measure the number of collisions with the objects. However, we used only one receiver. For these reasons, we categorized the number of collisions into three groups:

- Category Zero (0): No hits
- Category One (1): Small bumps, but continuous walking
- Category Two (2): Major collisions that prevent walking

The sidestepping behaviors of the participants were observed in each of the conditions. Based on the observations, the participants were categorized into one of the above groups with respect to their collisions with the objects.

d. Backwards Movement Task Dependent Variables

The average time to complete the task and the average error distance to the starting point were measured. The number of collisions with the objects was measured categorically as described above. The backward movement of the participants was observed in each of the conditions.

C. APPARATUS

1. Test Environments

Three conditions were used for the experiment.

a. Condition 1 (Real World Only)

The first condition was the real world only condition. The objects inside the room varied depending on the task, but the same room was used in each of the tasks. The participants were asked to perform the tasks as they do in real life. No interface or display mechanism was involved in this condition.

b. Condition 2 (Virtual World Only)

The second condition was the same environment as in the first condition. However, there was no object inside the room. The participants used a HMD and they walked through the empty room. They saw the room and the objects virtually, but the objects were not placed inside the room. This condition was pure virtual condition in that the participants could see the objects inside the room. However, there was no way for them to obtain haptic feedback from the objects, because the room was actually empty. The position and the head orientations of the participants were tracked with an electromagnetic tracker.

c. Condition 3 (VE+Real)

The third condition was a combination of the first two environments. The environment was set to be the same as the first condition. However, the participants donned a HMD, and performed the maneuvering tasks with HMD. The difference from the first condition was that the participants used a HMD as a display mechanism. The difference between this condition and the second condition was that the participants were provided haptic feedback in this condition, because the objects were really placed inside the environment. The position and the head orientations of the participants were tracked with an electromagnetic tracker.

2. Virtual Model

The virtual model was built by the author, using Vega version 3.6 and Creator version 2.4 by Multigen Paradigm Incorporated. The model runs on an Intel Pentium III processor, with 256 Mbytes main memory size. The frame rate was fixed at 60 frames per second and the resolution was set to 640x480 pixels.

3. Head Mounted Display

A V8 HMD manufactured by Virtual Research Systems, was used as display mechanism. The display field-of-view was 45 degrees horizontally and the resolution was 640x480 pixels. The geometric field-of-view was set to 45 degrees. Figure 4.1 shows the HMD used in the experiment. Stereoscopy was not a research issue in this experiment, so stereo was not used.

Figure 4.1. 8 HMD.

4. Head Tracking

A Polhemus 3Space FastTrack^{TM} electromagnetic tracking system was used in the experiment. The system allowed six degrees of freedom. The transmitter was located on the ceiling of the experiment room, and the receiver was placed on the HMD. The tracker was calibrated manually. Figure 4.2 shows the tracker used in the experiment.

Figure 4.2. Polhemus Fastrak Tracker.

5. Safety Procedures

The experimenter handled the cables in order to prevent any possible accidents. The tasks never lasted longer than 30 seconds. Both measures were taken to prevent the participants from feeling dizzy or showing any other symptoms that could possibly cause them to fall or stumble.

D. PROTOCOL

1. Task Sequence

Upon the arrival of the participants, they were given an in-briefing, and then they were familiarized with the HMD and the model. Then, the tasks were performed in the following order: *kneeling, look around the corner, sidestepping, and backward movement*. The same sequence was used for each participant. Each participant performed the tasks in three different conditions. The order of the conditions for each participant was randomized. Table 4.3 shows the general protocol used throughout the experiment. Table 4.4 shows a sample protocol for a given participant.

SEQUENCE	TASK	ENVIRONMENT
1	Familiarization	VE Only
2	Kneeling	Random
3	Kneeling	Random
4	Kneeling	Random
5	Look Around The Corner	Random
6	Look Around The Corner	Random
7	Look Around The Corner	Random
8	Sidestepping	Random
9	Sidestepping	Random
10	Sidestepping	Random
11	Backward Movement	Random
12	Backward Movement	Random
13	Backward Movement	Random

Table 4.3. General Protocol.

SEQUENCE	TASK	ENVIRONMENT
1	Familiarization	VE Only
2	Kneeling	VE Only
3	Kneeling	VE+Real
4	Kneeling	Real Only
5	Look Around The Corner	Real Only
6	Look Around The Corner	VE+Real
7	Look Around The Corner	VE Only
8	Sidestepping	Real Only
9	Sidestepping	VE+Real
10	Sidestepping	VE Only
11	Backward Movement	VE+Real
12	Backward Movement	VE Only
13	Backward Movement	Real Only

Table 4.4. Sample Protocol For A Given Participant.

2. Familiarization

After having been given an initial briefing about the experiment, participants were familiarized with HMD and the model. First, they were taught how to adjust the HMD. Then, a scene that was similar to the ones used in the experiment was displayed on the HMD. The scene consisted of a wall in the middle of the room and the participants were asked to walk inside the room as well as walking through the wall. We asked them to walk through the wall purposely, so that if they walk through the wall again in the look around the corner task, we wanted to see whether or not they would stop walking though the wall. For the participants who use glasses, the familiarization phase also helped them to figure out if they would use the HMD with their glasses. Some of the participants decided to use their glasses, whereas some did not want to use them.

After the participants were familiarized with the HMD and the model, they were asked if they had any further questions or problems regarding the HMD or the model. Then, we proceeded to the implementation phase of the actual experiment tasks.

3. Kneeling Task

The first task required the participants to kneel down. Four cube-shaped objects were placed in the environment (Figure 4.3). The participants were told that there was a letter written on the bottom face of each of the objects and they were asked to read the letter to the experimenter. Appendix D shows the scenario used for the kneeling task. It was impossible for the participants to read the letter correctly unless they moved to a close distance to the object and kneeled. The participants were not allowed to move the objects. However, they were not told anything about whether or not they could touch it. Figure 4.4 shows a participant performing the kneeling task in the VE+Real condition. Figure 4.5 shows the first person view when a participant kneeled down to see the letters. The task started after the participant clearly understood the instructions, and it ended when the participant read the letters on the bottom faces of the desired boxes. Participant behaviors were observed and recorded in each of the conditions. The participants were required to perform the task twice in each of the conditions. The time to complete the task was measured using a manually operated stopwatch and the average time to complete the task was used as a dependent measure.

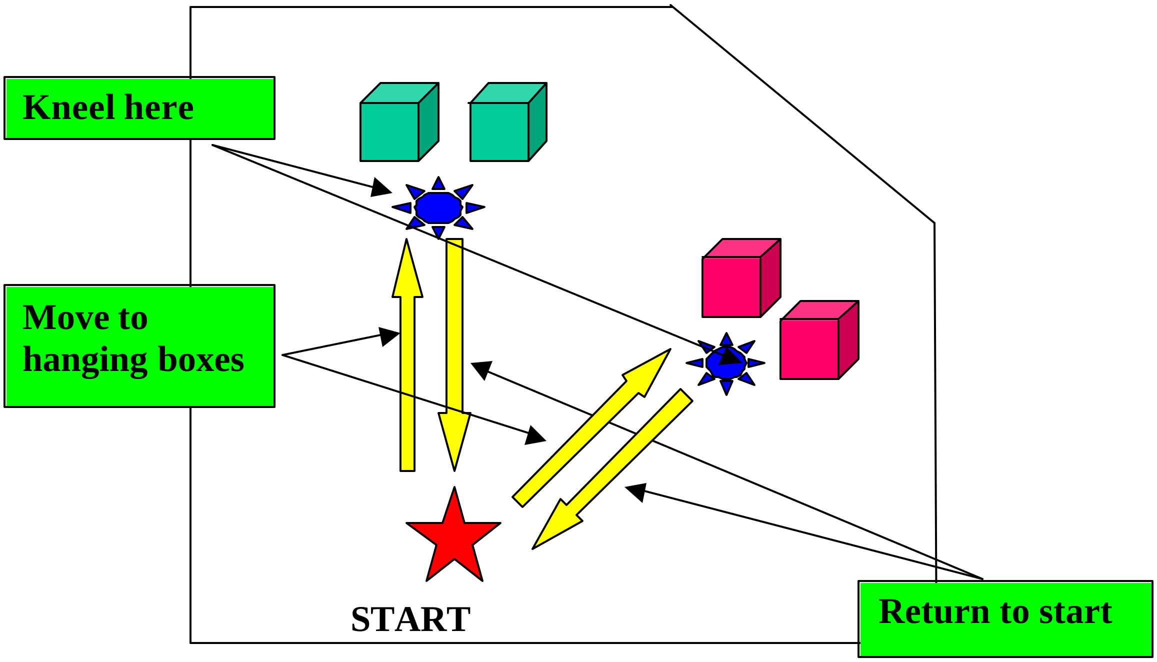

Figure 4.3. Plan View: Kneeling Task.

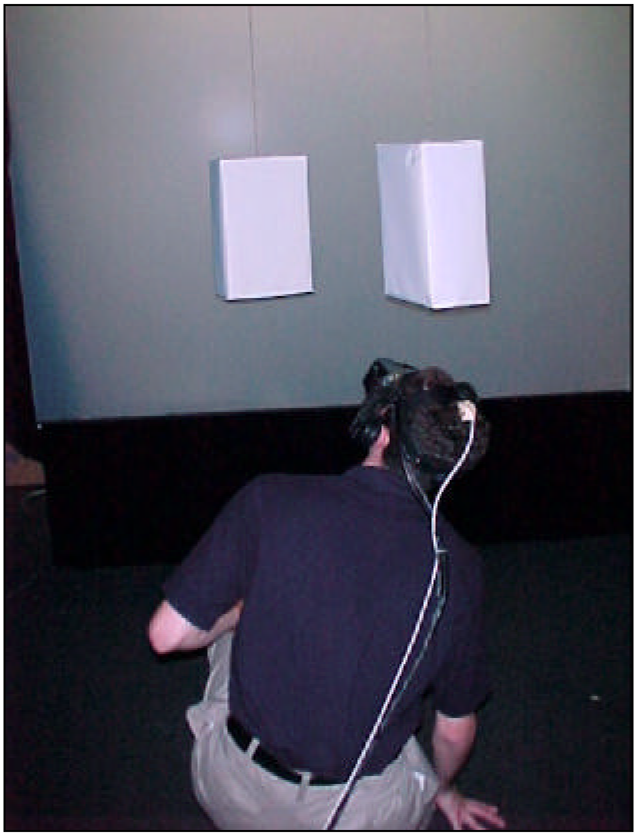

Figure 4.4. Kneeling Task in VE+Real Condition.

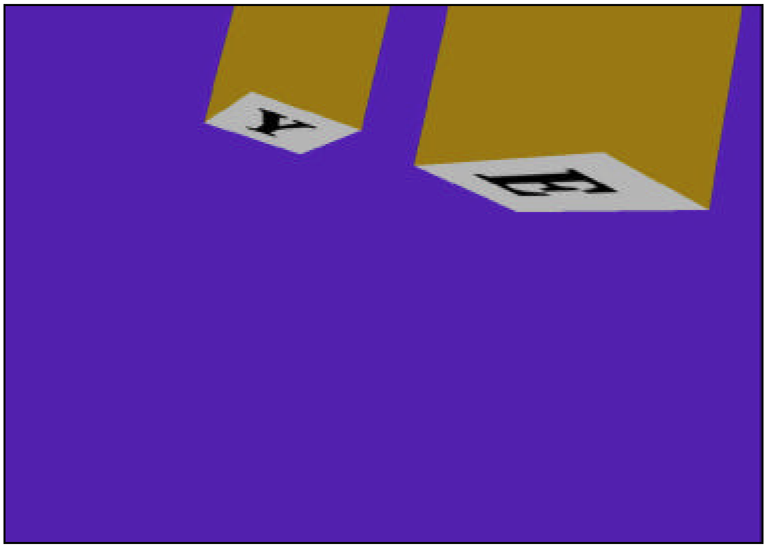

Figure 4.5. First Person View of Kneeling Task.

4. Look Around the Corner Task

The second task required the participants to look around the corner of a wall within a tactical scenario. The participants were told to explore the backside of a wall where they would see some enemy forces (see Figure 4.6). They were asked to report the number and the types of enemy forces on the other side. At the same time, they were required to minimize their exposure to the enemy forces. Enemy forces were represented by cube-shaped boxes. The only way for the participants to successfully complete the task was to look around one of the corners of the wall, which was placed in the middle of the room. Appendix E shows the scenario used for this task. The participants were not allowed to lie down due to the limited range of the tracker. They looked around the corner either from a standing position or by kneeling down. The task started after the participants clearly understood the task, and it ended when they indicated that they had seen the enemy forces. In the VE only condition, the scene turned into black when they walked inside the wall. This situation was shown to them in the familiarization phase so that when they walked through the wall again in this task, we wanted to see if they would stop walking though the wall or whether they would go through it. The time to complete the task and the number of correctly recognized objects were measured in each of the environments. Also, the behavioral characteristics of the participants were observed and recorded. Figure 4.7 shows a person performing the task in the third (real and virtual together) condition. Figure 4.8 shows the scene from HMD while looking around the corner.

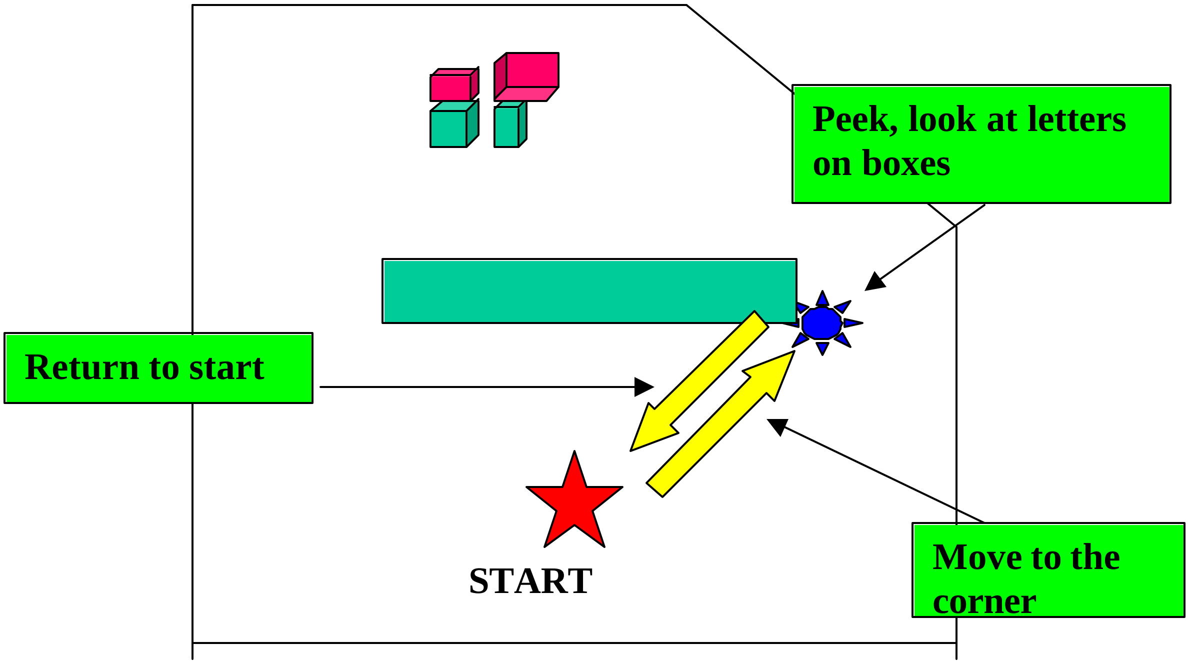

Figure 4.6. Plan View: Look Around The Corner Task.

Figure 4.7. Look Around the Corner Task in VE+Real Condition.

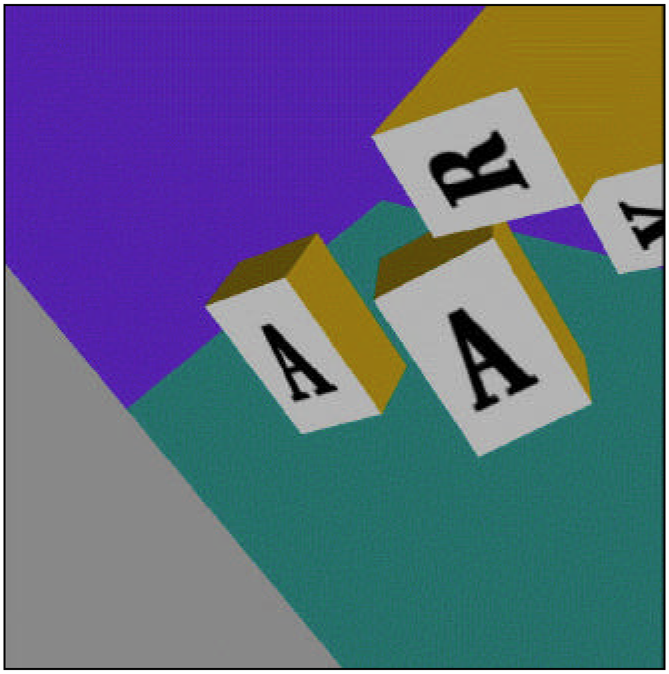

Figure 4.8. First Person View of Look Around Corner Task.

5. Sidestepping Task

In this task, the participants were asked to walk through narrow paths. The participants were told to walk to the end of the room. Some cube-shaped objects were placed inside the room close together forcing the participants to sidestep in order to complete the task (see Figure 4.9). Appendix F shows the scenario used for this task. The time to complete the task was measured. The number of collisions with the objects was measured categorically. In VE conditions, there was no way for the participants to see their feet since an avatar was not used. This was expected to cause an increase in the number of collisions in virtual conditions. However, because of the practical reasons described before, it was very difficult, if not impossible, to measure the number of collisions accurately in a VE only condition. So, the exact locations of the objects were marked on the floor and the participants were observed while they were performing the task. Based on the observations, they were categorized into one of the groups with respect to the collisions with the marks on the floor. Figure 4.10 shows the person performing the task in the third condition (real and virtual together). Figure 4.11 shows the task environment in VE conditions.

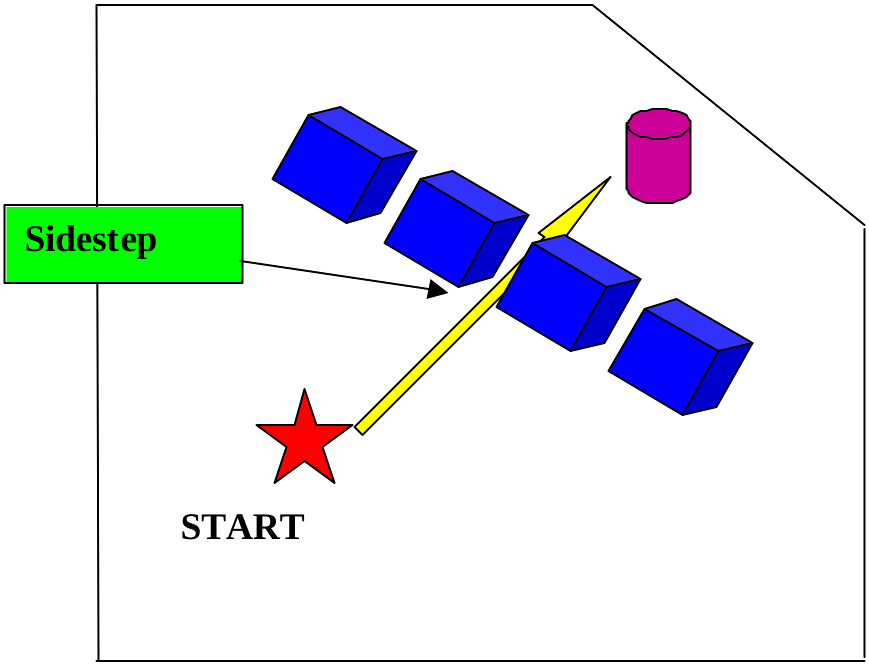

Figure 4.9. Plan View: Sidestepping Task.

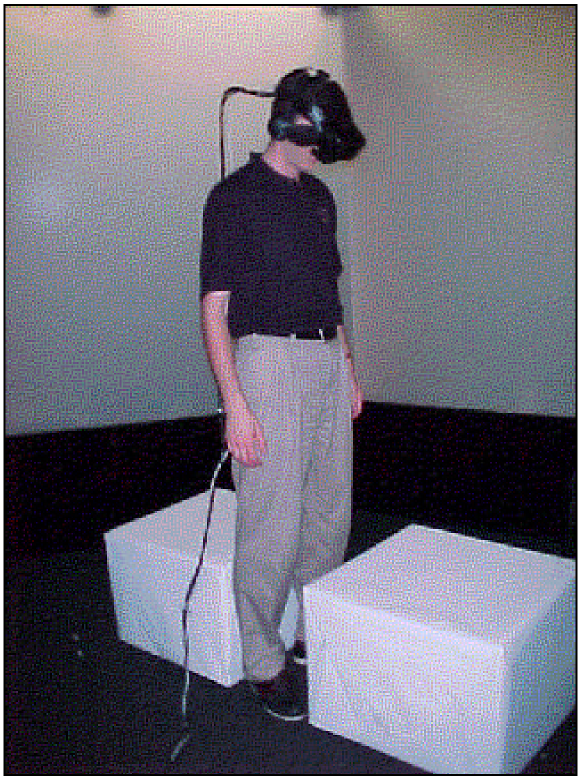

Figure 4.10. Sidestepping in VE+Real Condition.

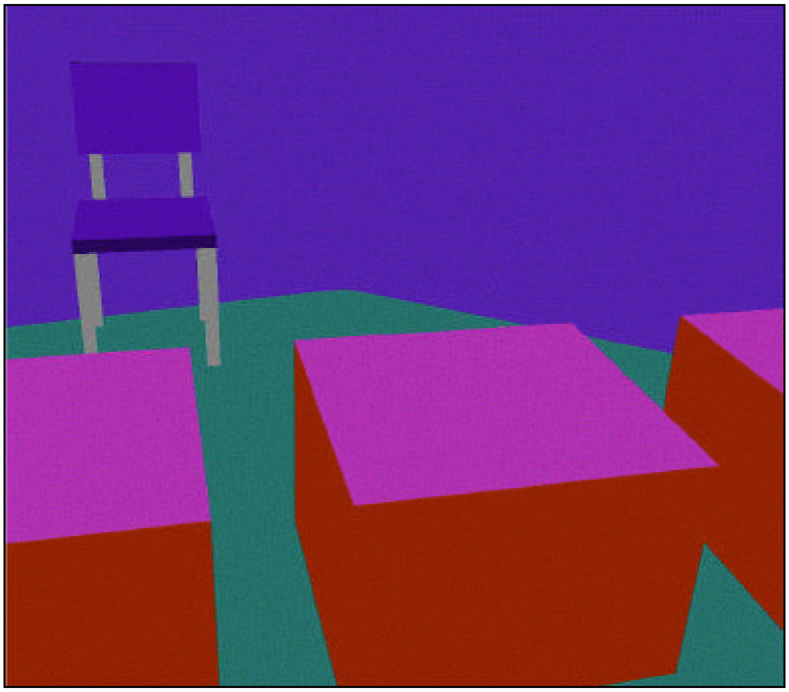

Figure 4.11. First Person View in Sidestepping Task.

6. Backward Movement Task

The last task required the participants to move backwards. The participants were first told that they were standing at the starting point. The environment consisted of a chair in front of the participant, and a box with a letter “A” on one of the walls of the room (see Figure 4.12). The chair was placed in the environment as an obstacle so that participants had to take it into consideration while they were moving backwards. It was possible for the participants to see the objects from the starting point. They were told to walk to a very close point to the box. After arriving at the desired location, they were stopped. They were then instructed to go back to the starting point while keeping their eyes on the box and the letter. The scenario used for this task is shown in Appendix G. The time to complete the task was measured. The time started when the participants started to move backwards, and ended when they indicated that they had reached the starting point. After the completion of the backward movement, the distance to the starting point was measured. The collisions with the objects (chair on their path) was observed and categorized as described in the previous tasks. Figure 4.13 shows a person moving backwards in the third (real and virtual together) condition. Figure 4.14 shows the task environment from a first person view when a participant is standing at the starting point. The backward movement behavior of the participant was observed and recorded.

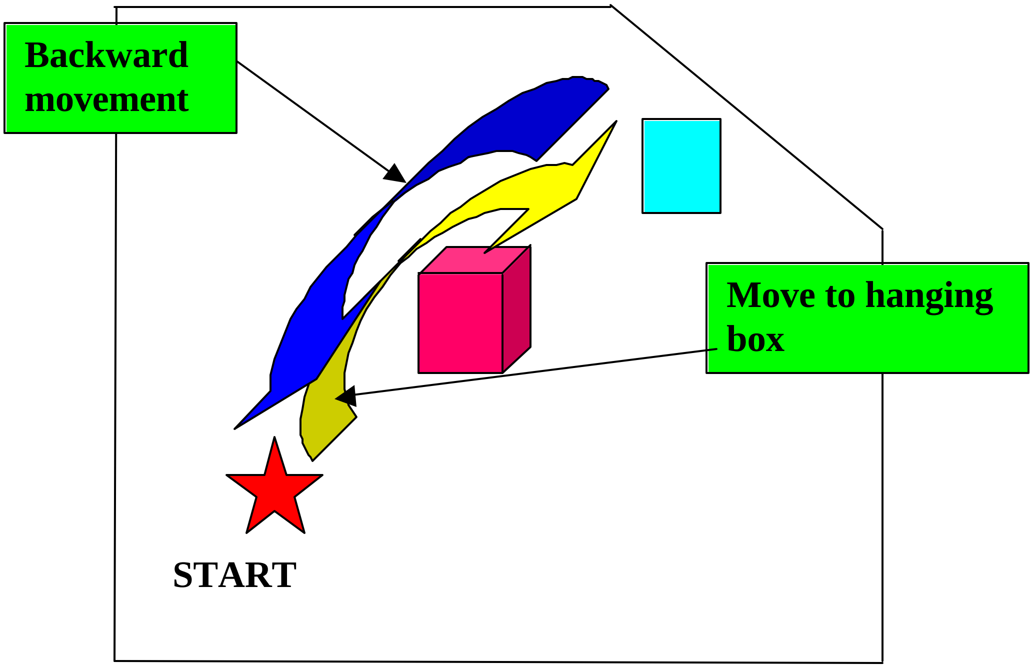

Figure 4.12. Plan View: Backward Movement Task.

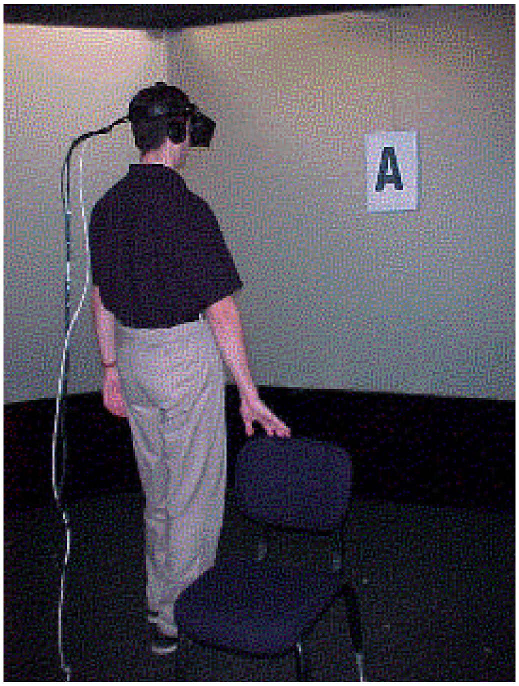

Figure 4.13. Backward Movement.

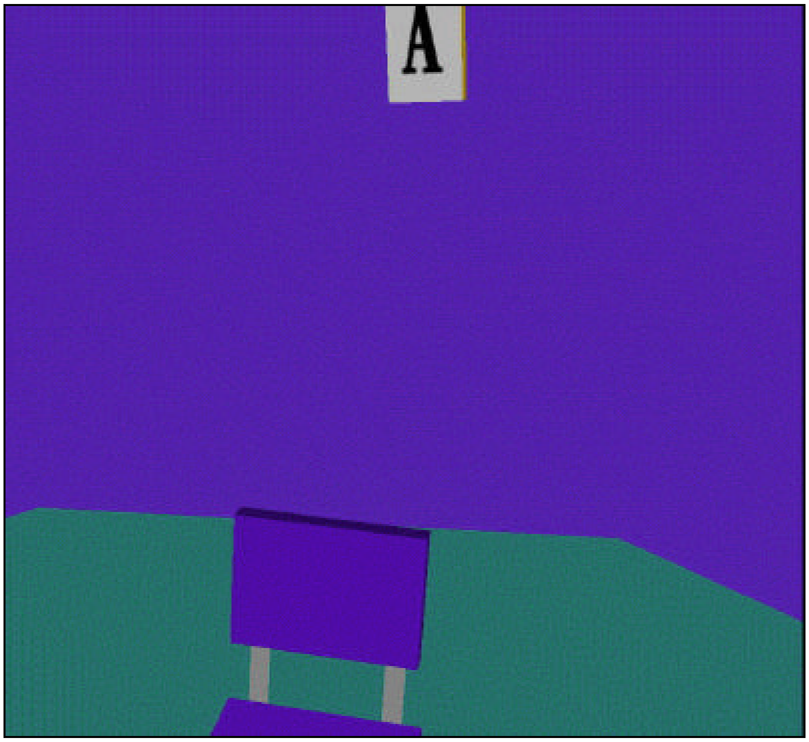

Figure 4.14. First Person View in Backward Movement Task

V. EXPERIMENT RESULTS AND DISCUSSION

A. GENERAL INFORMATION

The main goal of the experiment was to observe the behavioral characteristics of the participants. However, a number of quantitative data were collected to see the differences in the performance levels of participants in different conditions. This chapter first describes the data analysis and explains the results. Then, it discuses the observed behaviors of participants during the experiment.

1. Primary Hypothesis

The maneuvering performance of people in virtual environments will not be the same as the real world performance even if a perfect locomotion technique is used.

2. Primary Analysis

The results of the experiment were presented as boxplots. Participants performed each task two times. Primary analysis was based on the task completion times in three different conditions. Therefore the task completion times were analyzed separately for each trial. Other dependent measures were first averaged and then they were analyzed. A α value of 0.05 was used to determine significance.

B. RESULTS

1. Kneeling Task Results

a. Task Completion Times Trial-1

The time to complete the task was measured in each of the environments. We tried to see if there was any difference in the task completion times between the three conditions of the experiment. A One Way ANOVA test indicated that there was a significant difference between the treatments ($\underline{F}(2,111) = 26.13$, $\underline{p} < 0.0005$). A follow-on Tukey's Procedure showed that the Real Only condition was significantly different from the other two conditions at $\alpha = 0.05$. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only condition and the VE+Real condition. Figure 5.1 shows the task completion times in each environment. The mean and standard deviations for the time data is shown in Appendix H.

Figure 5.1. Kneeling Task Completion Times Trial 1.

Analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests indicated the same findings as the previous ANOVA test, yielding significant differences between the VE Only and Real Only conditions ($t(37)=7.95$, $p < 0.0005$), and significant differences between the VE+Real and the Real Only conditions ($t(37)=8.70$, $p < 0.0005$). There was not any significant difference between the VE Only and VE+Real conditions ($t(37)=0.63$, $p = 0.26$).

b. Task Completion Times Trial -2

A One Way ANOVA test indicated that there was a significant difference between the treatments ($F(2,111) = 24.19$, $p < 0.0005$). A Tukey's Procedure showed that the Real Only condition was significantly different than the other two conditions at $\alpha = 0.05$. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.2 shows the task completion times in each environment.

Figure 5.2. Kneeling Task Completion Times Trial 2.

Analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests indicated the same findings as the previous ANOVA test, yielding significant differences between the VE Only and Real Only conditions ($\underline{t}(37)=12.61$, $\underline{p} < 0.0005$), and significant differences between the VE+Real and Real Only conditions ($\underline{t}(37)=7.70$, $\underline{p} < 0.0005$). Although not significant, there was a difference between the VE only and VE+Real conditions ($\underline{t}(37)=-1.63$, $\underline{p} = 0.055$).

The results indicated that both of the trials yielded very similar findings. A further analysis to determine possible differences between trials is described later in the chapter.

c. Average Task Completion Times

In order to see the overall performance, we averaged the data from the two trials, and performed another test on this data. A One Way ANOVA test indicated that there was a significant difference between the treatments ($\underline{F}(2,111) = 24.93$, $\underline{p} < 0.0005$). A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.3 shows the average task completion times in each environment.

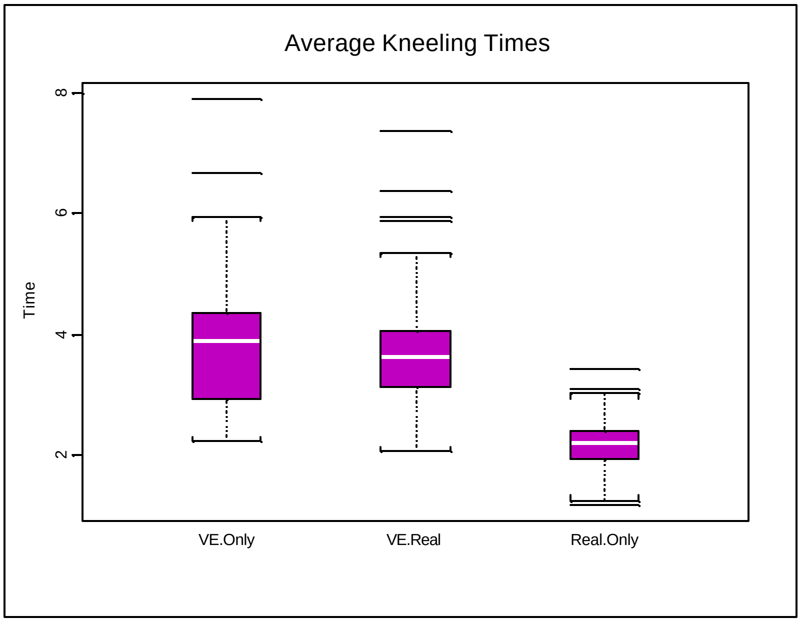

Figure 5.3. Average Kneeling Task Completion Times.

Analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests indicated similar findings as the previous AVNOVA test, yielding significant differences between VE Only and Real Only conditions (t(37)=9.87, p < 0.0005), and significant differences between the VE+Real and Real Only conditions (t(37)=8.92, p < 0.0005). There was not any significant difference between the VE Only and VE+Real conditions (t(37)=-0.45, p = 0.32).

2. Kneeling Task Observations

In this task, participants tended to behave similar in all three conditions. They usually kneeled down at a close point to the boxes and tried to read the letters. There was not any major behavioral difference between the virtual conditions. Most of the participants usually did not care if the boxes were physically placed in the environment, since the task did not require them to touch the boxes. However, in the virtual conditions, there were a few participants who wanted to hold the boxes and turn them over to read the letters. They were told that holding the boxes would not help them read the letters, since there was not any type of connection between the boxes and the virtual model.

a. Kneeling in the VE Only Condition

In virtual conditions, participants tended to get closer to the boxes than in the real condition. This can be explained by the limited FOV provided by the HMD. There were a few participants who walked inside the boxes in this condition. They did not do this intentionally, but they had difficulties in distance estimation. We did not use stereoscopy throughout the experiment since this might have a negative effect on the distance estimation capabilities of the participants. There was no way of reading the letters when the participants stepped inside the boxes. Thus, once they recognized that they were inside the boxes, they immediately stepped back to complete the task.

b. Kneeling in the VE + Real Condition

Some of the participants bumped into the boxes in this condition. An avatar was not used, so the participants could not see any part of their bodies. Stereoscopy was not used in the study either. These factors affected the distance estimation capabilities of the participants negatively, causing collisions with the objects. The most common case for the collisions was that the participants did not take into consideration the front part of HMD, which constituted an extension to their heads. In general, the behaviors of the participants in this condition were not so different from the VE Only condition, because the task did not require them to obtain any kind of haptic feedback from the environment.

c. Kneeling in the Real Only Condition

Most of the participants behaved similarly in this condition. They kneeled down at a close point to the boxes, and read the letters. There was no FOV limit on this condition. The participants did not have to get very close to the boxes. Thus, collision with the objects did not occur.

3. Kneeling Task Discussion

The findings suggested that participants had better performance levels in the Real Only condition, as was expected. There was not any difference between the VE Only and VE+Real conditions. This might be the result of the fact that Kneeling Task did not require participants to touch or interact with the objects. This made the VE Only and VE+Real conditions very similar to each other.

4. Look Around The Corner Task Results

a. Task Completion Times Trail-1

A One Way ANOVA test indicated that there was a significant difference between the treatments (F(2,111) = 5.06, p = 0.0078). A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.4 shows the task completion times in each environment.

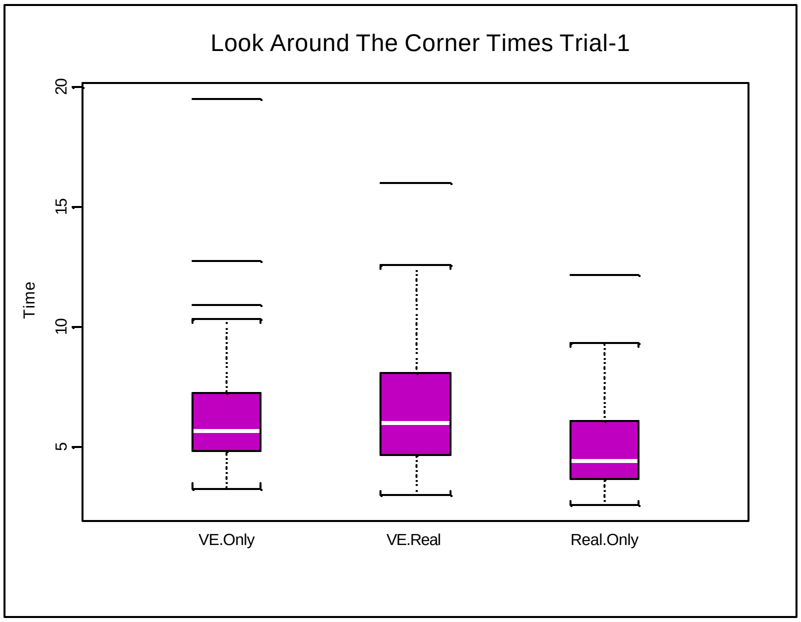

Figure 5.4. Look Around The Corner Task Completion Times Trial-1.

Analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests indicated similar findings as the previous ANOVA test, yielding significant differences between VE Only and Real Only conditions (t(37)=4.49, p < 0.0005), and significant differences between VE+Real and Real Only conditions (t(37)=4.64, p < 0.0005). There was not any significant difference between VE Only and VE+Real conditions (t(37)= -0.12, p = 0.45).

b. Task Completion Times Trail-2

A One Way ANOVA test indicated that there was a significant difference between the treatments ($\underline{F}(2,111) = 14.52$, $\underline{p} < 0.0005$). A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.5 shows the task completion times in each environment.

Analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests indicated the same findings as the previous ANOVA test, yielding significant differences between the VE Only and Real Only conditions ($\underline{t}(37)=6.35$, $\underline{p} < 0.0005$), and significant differences between the VE+Real and Real Only conditions ($\underline{t}(37)=6.01$, $\underline{p} < 0.0005$). There was not any significant difference between the VE Only and VE+Real conditions ($\underline{t}(37)= 0.80$, $\underline{p} = 0.21$).

The results indicated that both of the trials yielded very similar findings. A further analysis to determine any significant difference between the trials is described later in the chapter.

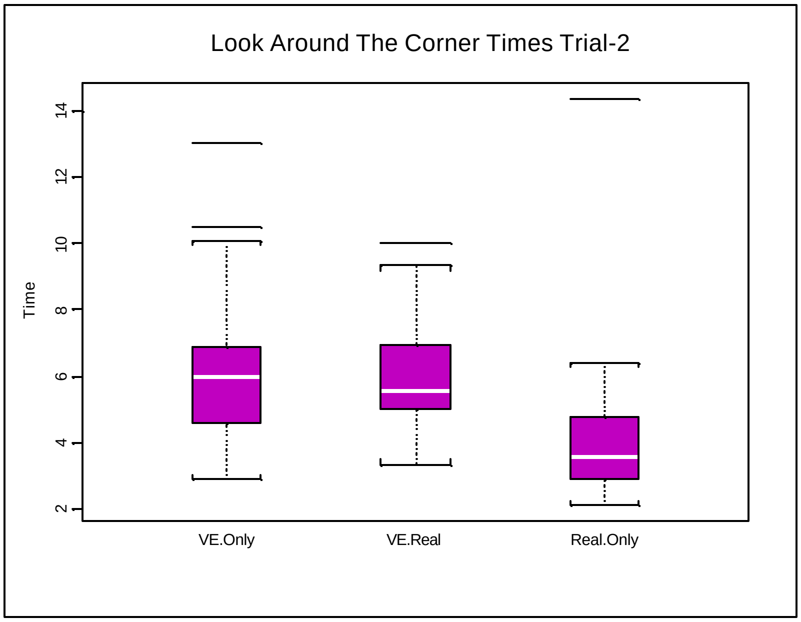

Figure 5.5. Look Around The Corner Task Completion Times Trial 2.

c. Average Task Completion Times

In order to see the overall performance, we averaged the data from the two trials, and performed another test on this data. A One Way ANOVA test indicated that there was a significant difference between the treatments (F(2,111) = 10.12, p < 0.0005). A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.6 shows the average task completion times in each environment.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests indicated the same findings as the previous ANOVA test, yielding significant differences between the VE Only and Real Only conditions (t(37)=6.79, p < 0.0005), and significant differences between the VE+Real and Real Only conditions (t(37)=7.53, p < 0.0005). There was not any significant difference between the VE Only and VE+Real conditions (t(37)= 0.35, p = 0.36).

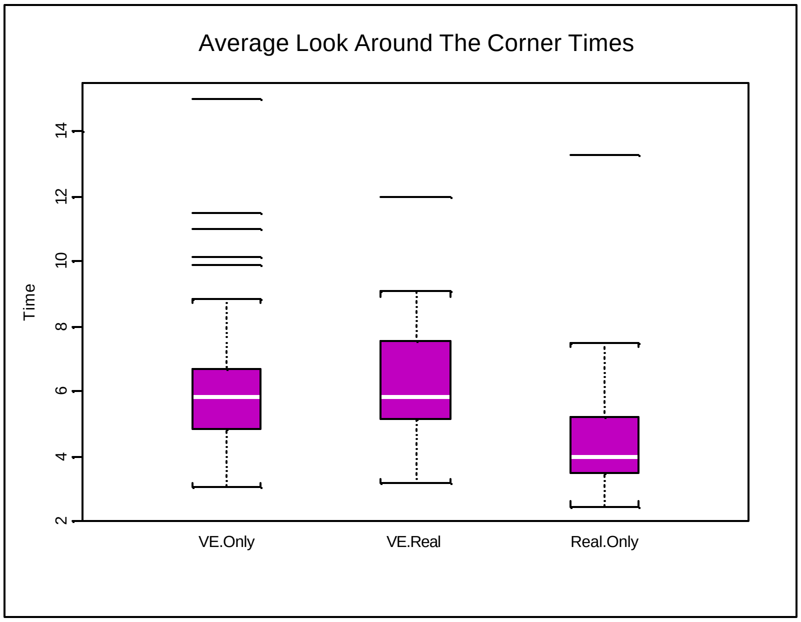

Figure 5.6. Average Look Around The Corner Task Completion Times.

d. Average Number of Recognized Objects

In order to see the overall performance, we averaged the data from the two trials, and performed tests on the averaged data. The results suggested no significant difference between the environments (F(2,111) = 0.085, p =0.91). Figure 5.7 displays the average number of correctly recognized objects in three different environments of the experiment.

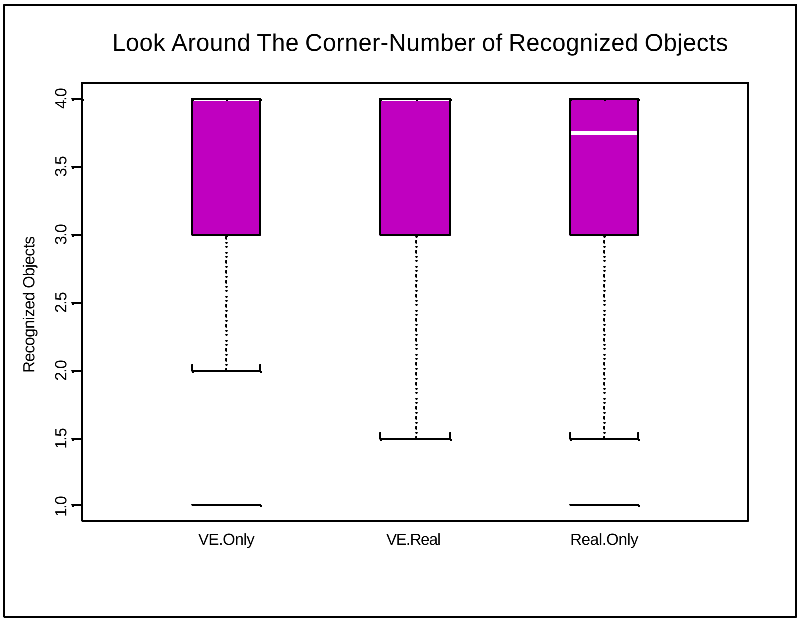

Figure 5.7. Look Around The Corner Task The Number of Recognized Objects.

5. Look Around The Corner Task Observations

In this task, we expected to observe many behavioral differences between the conditions. The participants usually seemed to be consistent with their behaviors between the conditions of the experiment. If they did not touch the wall in the first condition, then they seemed to be reluctant to touch the wall in the successive conditions. Some of the participants kneeled down to minimize their exposure levels, whereas some preferred to stand. The participants seemed to have higher exposure levels in virtual conditions. This can be explained by the limited FOV provided by HMD. The cables affected the maneuvering capabilities of people in virtual conditions in a negative way. Even though the experimenter handled the cables and minimized the effects of the weight of the cables, some of the participants complained about the cables.

a. Look Around The Corner in the VE Only Condition

In the VE Only condition, participants tried not to walk inside the wall. When they recognized that they were walking through it, they stepped back. This behavior was expected, because in the familiarization phase, we had displayed a similar wall to the participants and asked them to walk inside the wall in order for them to understand what "walking inside the objects" means in a virtual environment. The fact that the wall was not physically placed in the environment did not seem to have an important role on the performance levels of the people, since they usually tended not to touch the wall in both of the virtual conditions.

b. Look Around The Corner in the VE + Real Condition

In this condition, a lot of participants bumped into the wall thinking that it was not physically placed inside the real environment. More interestingly, after the first collision with the wall, they did not try to lean into or touch it to get haptic feedback. Since they had seen the object virtually, they hesitated to interact with the real object. This made their behaviors very similar to the VE Only condition. On the other hand, there were very few participants who tried to use the wall to get haptic feedback after they figured out that the wall was physically placed inside the environment. This made the task easier for them when compared to the VE Only condition.

c. Look Around The Corner in the Real Only Condition

In this condition, most of the participants used the wall to get feedback. There was no unintentional contact with the wall. The participants did not have any difficulty performing the task.

6. Look Around The Corner Task Discussion

When compared to the differences between the conditions in the Kneeling Task, the differences in this task were smaller, but large enough to suggest significance between the Real Only and two virtual conditions. The significant difference between the Real Only and two virtual conditions was what we expected to happen. There was not any significant difference between the two virtual conditions. This might be the result of the fact that participants usually behaved in similar ways in virtual environments no matter how the physical environment was set up. They seemed to be reluctant to interact with the real objects when they had seen them virtually. This might have resulted in yielding similar performance levels.

7. Sidestepping Task Results

a. Task Completion Times Trial-1

A One Way ANOVA test indicated that there was a significant difference between the treatments ($\underline{F}(2,111) = 33.35$, $\underline{p} < 0.0005$). A follow-on Tukey's Procedure showed that the Real Only Condition was significantly different than the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.8 shows the task completion times in each environment.

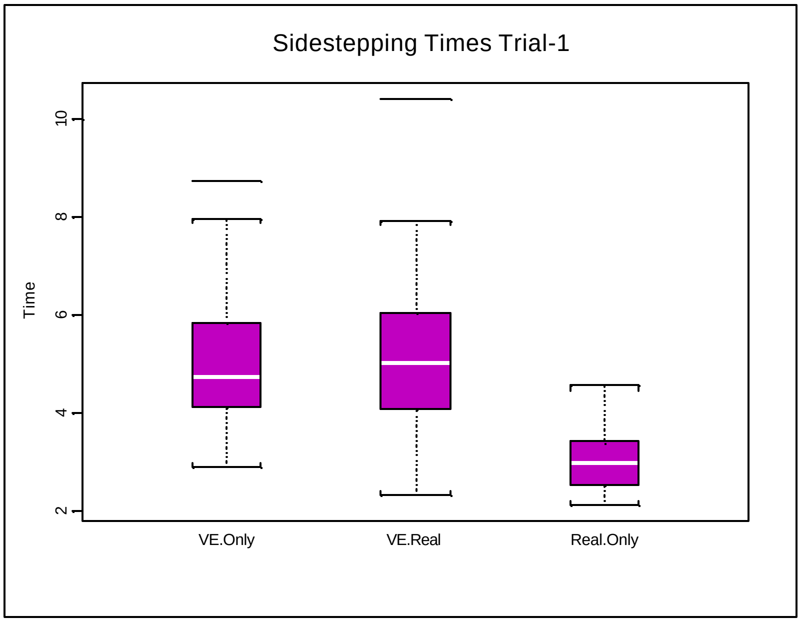

Figure 5.8. Sidestepping Task Completion Times Trial 1.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests yielded significant differences between the VE Only and Real Only conditions ($\underline{t}(37)=9.77$, $\underline{p} < 0.0005$), and significant differences between the VE+Real and Real Only conditions ($\underline{t}(37)=9.60$, $\underline{p} < 0.0005$). There was not any significant difference between the VE Only and VE+Real conditions ($\underline{t}(37)= 0.38$, $\underline{p} = 0.35$).

b. Task Completion Times Trial-2

The results suggested a significant difference between the treatments ($F(2,111) = 31.08$, $p < 0.0005$). A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.9 shows the task completion times in each environment.

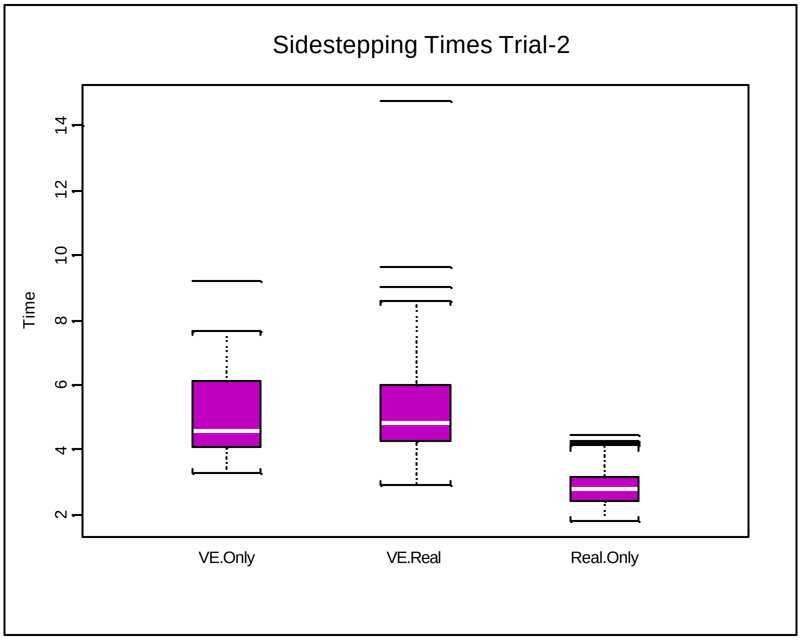

Figure 5.9. Sidestepping Task Completion Times Trial 2.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests yielded significant differences between the VE Only and Real Only conditions ($t(37)=12.59$, $p < 0.0005$), and significant differences between the VE+Real and Real Only conditions ($t(37)=7.77$, $p < 0.0005$). There was a difference between the VE Only and VE+Real conditions, but it was not significant at $\alpha = 0.05$ ($t(37)= -1.63$, $p = 0.056$.).

c. Average Task Completion Times

The results suggested a significant difference between the treatments ($F(2,111) = 37.55$, $p < 0.0005$). A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.10 shows the average task completion times in each environment.

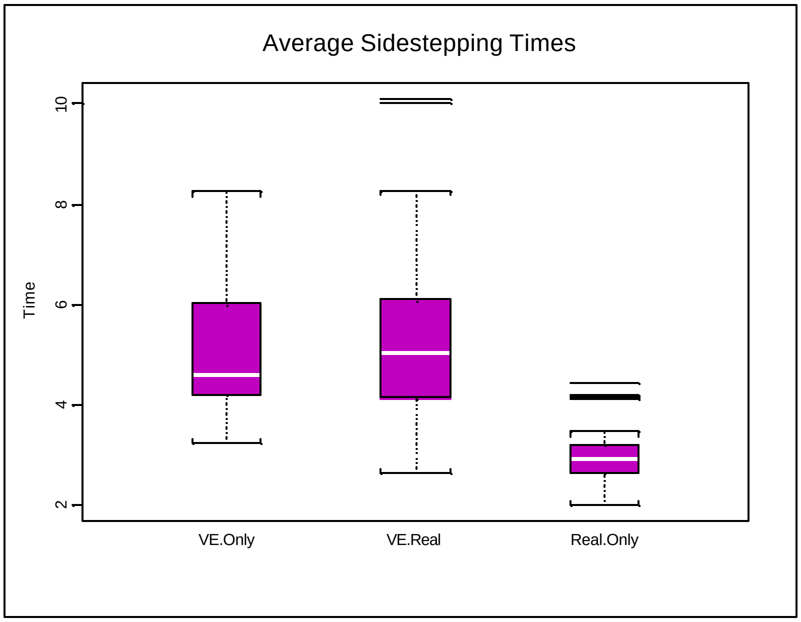

Figure 5.10. Sidestepping Average Task Completion Times.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests yielded significant differences between the VE Only and Real Only conditions ($t(37)=11.96$, $p < 0.0005$), and significant differences between the VE+Real and Real Only conditions ($t(37)=9.69$, $p < 0.0005$). There was a difference between the VE Only and VE+Real conditions, but it was not significant at $\alpha = 0.05$ ($t(37)= -1.56$, $p = 0.063$).

d. Collision Categories

We did not measure the collisions quantitatively. Instead, we categorized the collisions based on the observations as explained in the previous chapters. This prevented us from running statistics to determine if there was any difference between conditions. In order to see the difference between conditions, we averaged the data from the two trials, and plotted the data. Figure 5.11 displays the average collisions for each participant in each of the conditions. In the VE Only condition, most of the participants failed to recognize that they were walking through the objects. This resulted in higher collision levels in this condition.

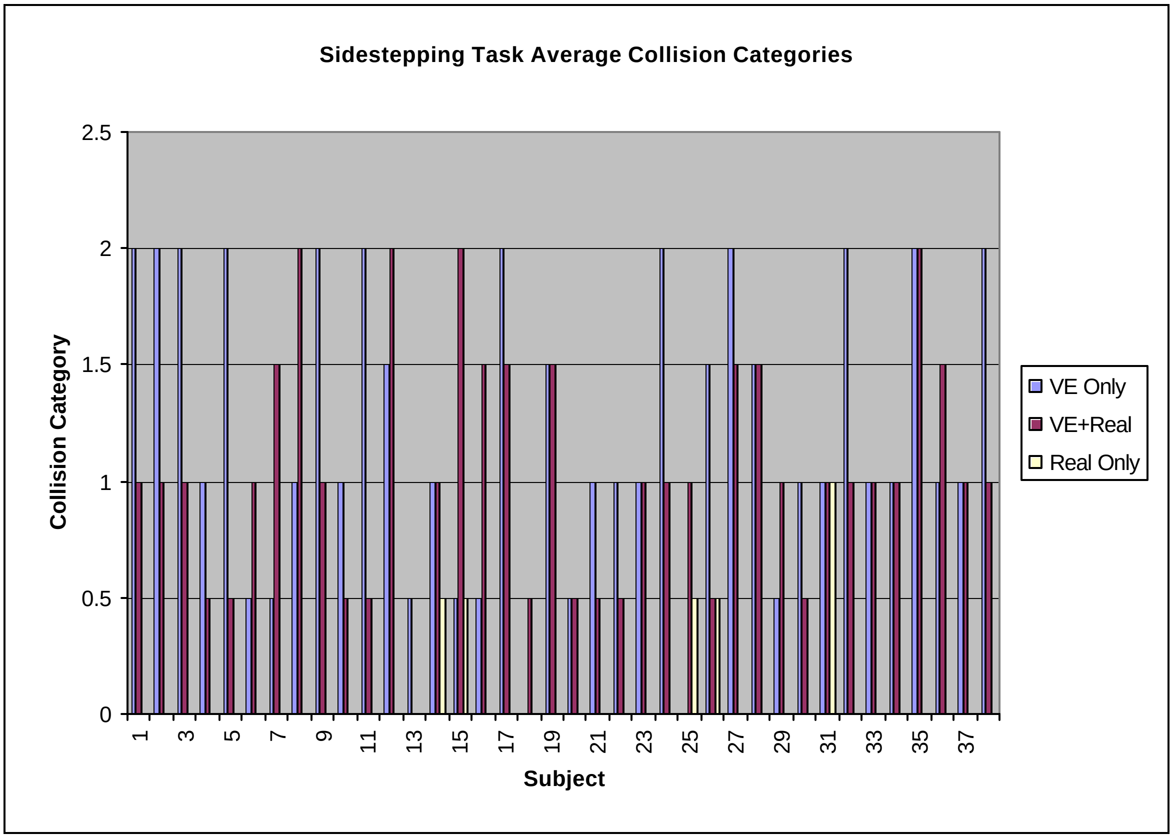

Figure 5.11. Average Collision Categories in Sidestepping Task.

8. Sidestepping Task Observations

This task was observed to be the most challenging among all four tasks. In general, the participants paid attention not to bump into the objects in all three conditions. The fact that an avatar had not been used throughout the experiment was the major cause of the difficulties associated with this task. The participants needed to see their feet in order to sidestep. An avatar would have been convenient for this purpose. This situation caused two major problems: First, in the VE+Real condition, there were a lot of major collisions with the objects causing an increase in the task completion time. Second, in the

VE Only condition, there were also a lot of major collisions, but this time the participants could not understand that they were colliding with the objects. They thought that they were walking properly while they were walking through the objects. This caused shorter task completion times in the VE Only condition.

We observed that in the virtual conditions, nobody sidestepped in the same way as they did when in the real condition. This can be explained by the limited FOV and the lack of an avatar. Also, the HMD weight and the cables affected the way participants sidestepped in virtual conditions. They were slower and more cautious while performing the task.

a. Sidestepping in the VE Only Condition

The participants sidestepped with very small steps and they paid much more attention to their movements in this condition. Some of the participants tried to understand if the objects were physically placed inside the real environment, and once they had recognized that the objects were not there, they simply did not pay attention to their movements and continued sidestepping with less attention. This caused them to walk through the objects. On the other hand, some of the participants were careful as needed, but they still failed to recognize that they were walking through the objects.

b. Sidestepping in the VE+ Real Condition

As in the VE Only condition, the participants sidestepped with very small steps and they were very careful during their movements in this condition. This can be explained by the limited FOV and the lack of an avatar in virtual conditions. This task did not require the participants to touch the objects. Therefore, there were no major differences between the virtual conditions. Despite the similarity, task completion times in this condition seemed to be longer than for the VE Only condition. The fact that there were a lot of physical collisions in this condition was the main reason for the higher task completion times. In the VE Only condition, they simply walked through the objects with or without being aware of it, and walking through an object required less time than walking with bumps.

In VE conditions, some of the participants had difficulties with estimating the distance to the objects from their bodies. This situation also increased the number of collisions which can be explained by the lack of stereoscopy in the virtual model. For the same reason, some of the participants were unable to estimate the distance between the objects correctly. Therefore, they did not think that they needed to sidestep to pass the narrow path between two objects. Even though they sidestepped in the previous Real Only condition, they failed to recognize that they needed to sidestep in the virtual condition. This caused them to either bump into the objects in this condition or to walk through the objects without being aware of it in the VE Only condition.

c. Sidestepping in the Real Only Condition

The way people sidestepped was different between the real and virtual conditions. In the Real Only condition, participants sidestepped with large steps and they were able to pass the narrow paths with paying less attention in a very short time. Participants had the ability to see their feet. This made the task easier compared to the virtual conditions.

9. Sidestepping Task Discussion

The significant difference between the Real Only condition and the virtual conditions was what we expected to happen due to the limitations of virtual environment. The difference between the VE Only and VE+Real conditions was the result of the fact that participants generally did not recognize when they were walking through the objects in the VE Only condition. This made the task completion times shorter. On the other hand, they bumped into the objects in the VE+Real condition which resulted in longer task completion times. In the VE Only condition, most of the participants failed to recognize that they were walking through the objects. This resulted in higher collision levels in this condition.

10. Backward Movement Task Results

a. Task Completion Times Trail-1

A One Way ANOVA suggested a significant difference between the treatments ($\underline{F}(2,111) = 36.28$, $\underline{p} < 0.0005$). A Tukey’s Procedure showed that all of the treatments were significantly different from each other. The Real Only condition yielded the best performance levels, followed by the VE+Real condition, and then the VE Only condition respectively. Figure 5.12 shows the task completion times in each environment.

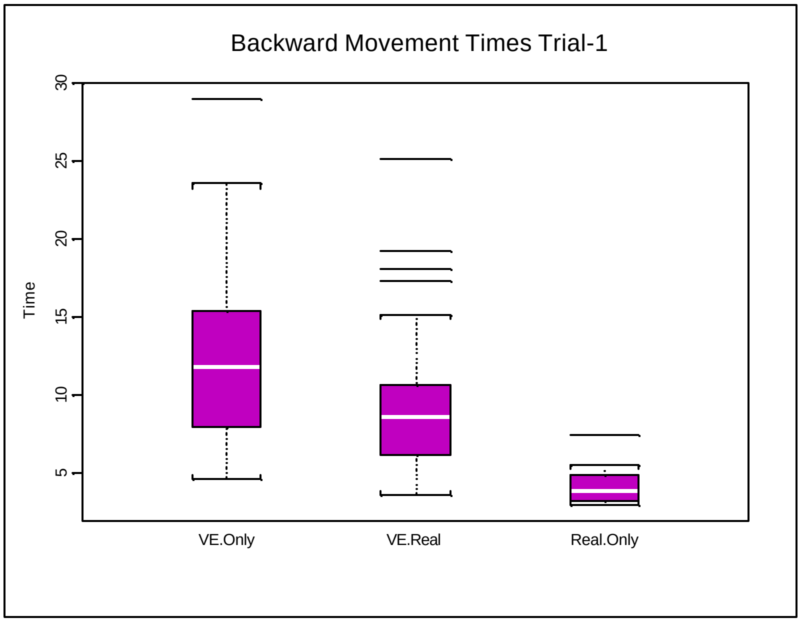

Figure 5.12. Backward Movement Task Completion Times Trial 1.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. These tests yielded significant differences between the VE Only and Real Only conditions ($\underline{t}(37)=9.45$, $\underline{p} < 0.0005$), and significant differences between the VE+Real and Real Only conditions ($\underline{t}(37)=7.67$, $\underline{p} < 0.0005$). Interestingly, the difference between the VE Only and VE+Real conditions was found to be significant at $\alpha = 0.05$ ($\underline{t}(37)= 3.66$, $\underline{p} < 0.0005$).

b. Task Completion Times Trail-2

A One Way ANOVA suggested a significant difference between the treatments, $\underline{F}(2,111) = 22.31$, $\underline{p} < 0.0005$. A Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant differences between the VE Only and the VE+Real conditions. Figure 5.13 shows the task completion times in each environment.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. Although the ANOVA test did not suggest a significant difference between the VE Only and VE+Real conditions, these tests yielded significant differences between all three environments. There was a significant difference between the VE Only and Real Only conditions (t(37)=7.33, p < 0.0005), between the VE+Real and Real Only conditions (t(37)=8.97, p < 0.0005), and between the VE Only and VE+Real conditions (t(37)= 3.02, p = 0.0022).

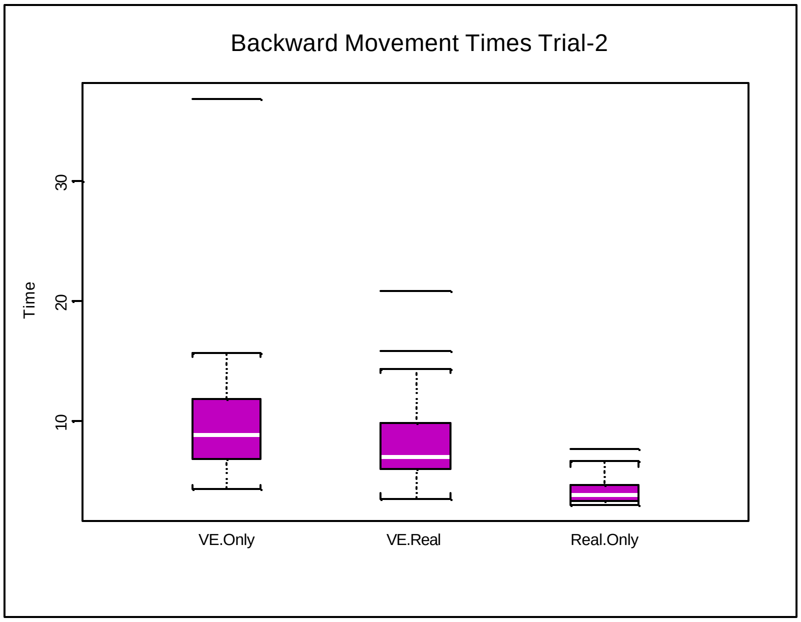

Figure 5.13. Backward Movement Task Completion Times Trial 2.

c. Average Task Completion Times

A One Way ANOVA suggested a significant differences between the treatments (F(2,111) = 32.31, p < 0.0005). A follow-on Tukey's Procedure showed that the Real Only Condition was significantly different from the other two conditions. This suggests better performance levels in the Real Only condition. However, there was not any significant difference between the VE Only and the VE+Real conditions. Figure 5.14 shows the average task completion times in each environment.

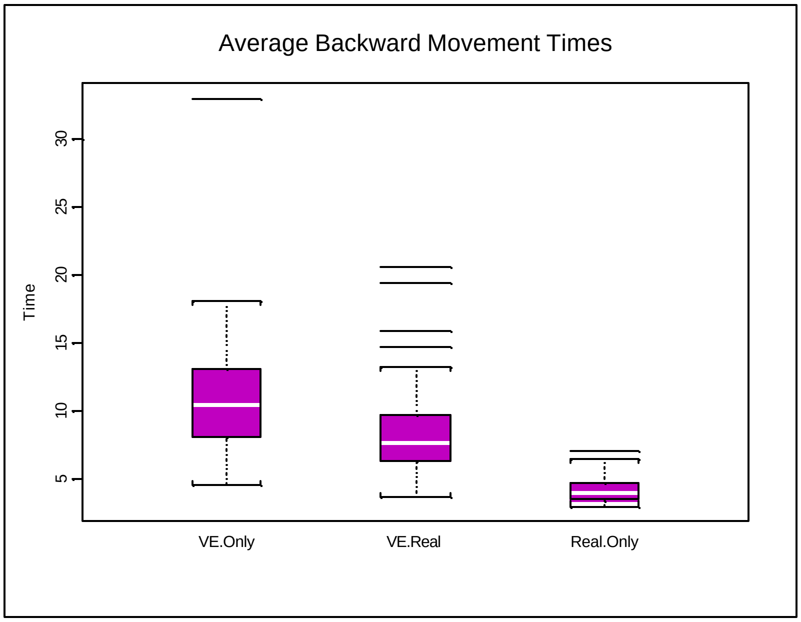

Figure 5.14. Average Backward Movement Task Completion Times.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. Although the ANOVA test did not suggest a significant difference between the VE Only and VE+Real conditions, these tests yielded significant differences between all three environments. There was a significant difference between the VE Only and Real Only conditions (t(37)=9.13, $p < 0.0005$), between the VE+Real and Real Only conditions (t(37)=8.90, $p < 0.0005$), and between the VE Only and VE+Real conditions (t(37)= 3.81, $p = 0.0020$).

d. Average Error Distances

A One Way ANOVA suggested a significant difference between the treatments, F(2,111) = 13.79, $p < 0.0005$. A Tukey's Procedure suggested that there was a significant difference between the VE Only and Real Only conditions and between the VE Only and VE+Real conditions. There was not any significant difference between the VE+Real and Real Only conditions. Figure 5.15 shows the average error distances in each environment.

A further analysis of the Paired Data (Paired T Test) was conducted to see the differences between the treatments. Although the ANOVA test did not suggest a significant difference between the VE+Real and Real Only conditions, these tests yielded significant differences between all three environments. There was a significant difference between the VE Only and Real Only conditions (t(37)=4.89, p < 0.0005), between the VE+Real and Real Only conditions (t(37)=2.46, p = 0.009), and between the VE Only and VE+Real conditions (t(37)= 3.05, p = 0.0020).

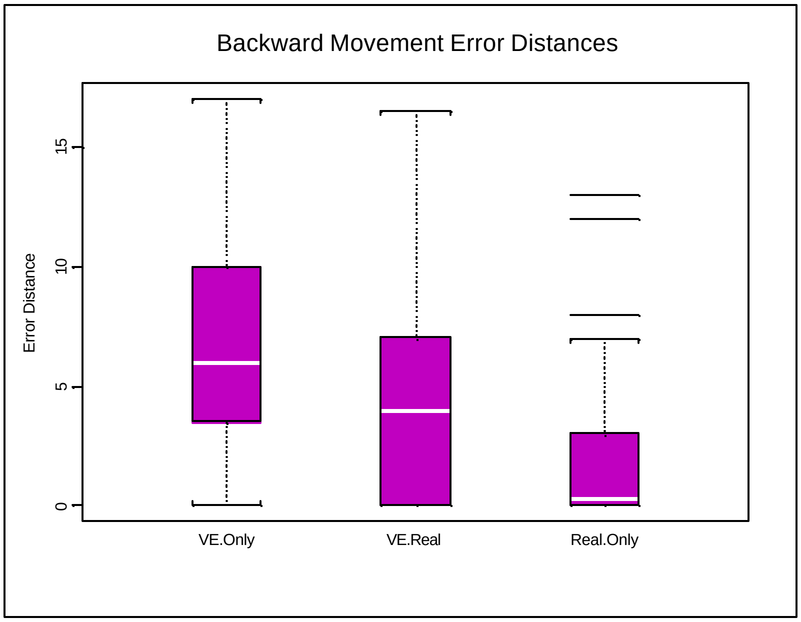

Figure 5.15. Backward Movement Task Average Error Distances.

e. Average Collisions

As in the Sidestepping task, we did not measure the collisions quantitatively. Instead, we categorized the collisions based on the observations as explained in the previous chapters. Figure 5.16 displays the average collisions of each participant in each of the conditions. Participants usually failed to recognize when they were walking through the objects in the VE Only condition, and this resulted in a higher level of collisions in this condition.

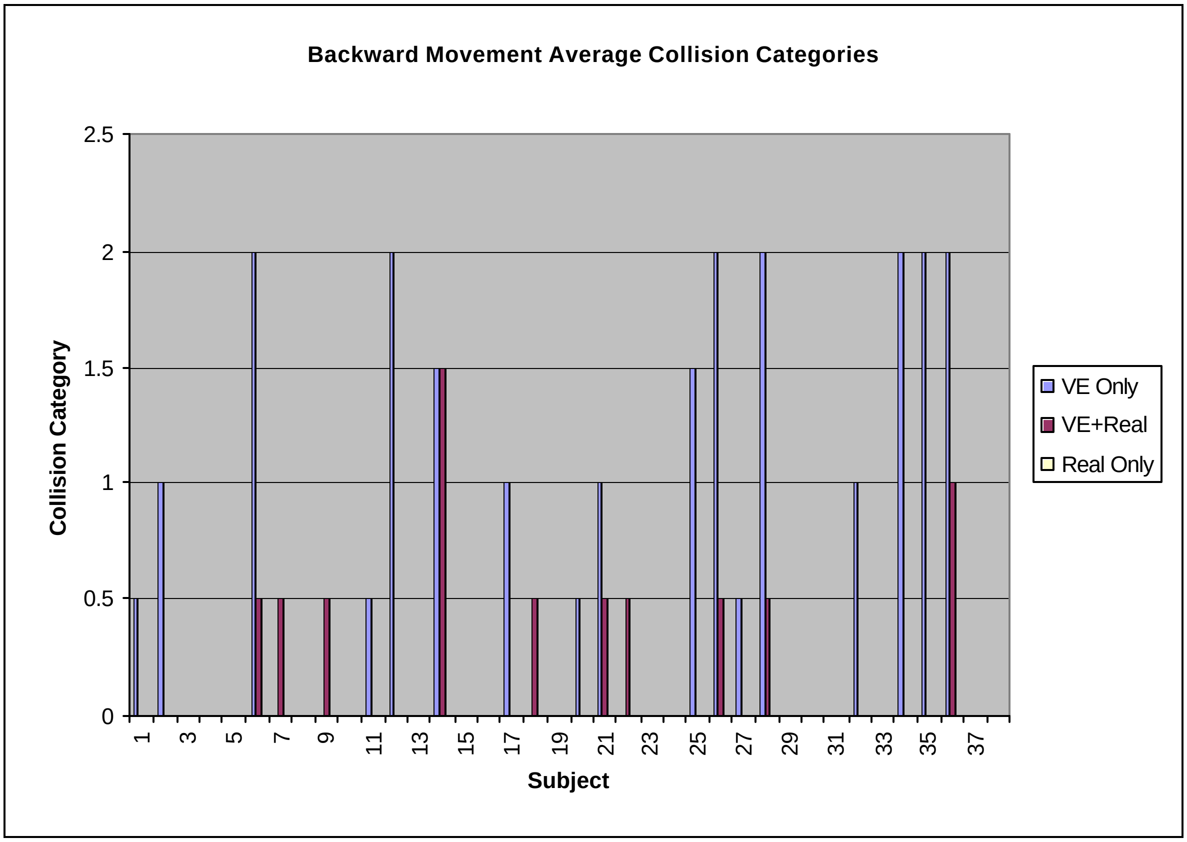

Figure 5.16. Backward Movement Task Average Collision Categories.

11. Backward Movement Task Observations

In general, none of the participants seemed to move the same way in virtual and real conditions. In the Real Only condition, the participants seemed to move fast with large steps. However, they seemed to behave slower, more carefully, and more suspiciously in virtual conditions. This was the cause of limited FOV in the virtual environment. We asked participants to look at only the letter and the box during their backward movements. This was more difficult to achieve in virtual conditions. They tended to look in other directions, especially at the chair in order to prevent collisions with it. The total distance traveled during the backward movement was longer in virtual conditions.

a. Backward Movement in the VE Only Condition

Once some of the participants recognized that the chair was not physically placed inside the room, and they walked through it without paying attention to collisions. They simply walked through the chair, and this decreased their task completion times., The task was more difficult to achieve in virtual conditions because of the limited FOV. The participants moved backward with very small steps, and made more attention. The total distance they traveled throughout the execution of the task was much longer than the distance traveled in the real world.

b. Backward Movement in the VE + Real Condition

Some of the participants tried to touch the chair while they were moving backwards in virtual conditions. They wanted to touch the chair in order to pass it without bumping into it. However, this condition did not yield different behaviors from the VE Only condition, since the task neither required nor did the participants want to obtain haptic feedback from the environment.

c. Backward Movement in the Real Only Condition

Participants walked fast with large steps in this condition. They usually did not try to touch the chair during their movements. There was a difference in the behaviors of the participants between the real and virtual conditions in that they were faster and more decisive in the real condition because FOV was wider.

12. Backward Movement Task Discussion

The significant difference between the Real Only condition and the virtual conditions was what we expected to happen due to the limitations of the virtual environment. The difference between the VE Only and VE+Real conditions was not what we expected to happen. The error distances in the Real only condition were less than in the virtual conditions. The collision level in the VE Only condition was greater than in the other conditions. Participants usually failed to recognize when they were walking through the objects in the VE Only condition. This resulted in a higher level of collisions in this condition.

C. DIFFERENCES BETWEEN TRIALS

We intended to determine if there was any significance difference between the two trials. This helped us to see the possible learning effects of the tasks.

1. Kneeling Task

There were significance differences between two trials in the VE Only and VE+Real conditions (for VE Only, $\underline{t}(37) = 3.25$ and $\underline{p} = 0.0012$, for VE+Real, $\underline{t}(37) = 2.16$ and $\underline{p} = 0.018$). However, there was not any significant difference in the Real Only condition ($t(37) = 1.04$, $p = 0.15$). Figure 5.17 shows the task completion times for each trial in the VE Only condition. Figure 5.18 shows the task completion times for each trial in the VE+Real condition. Figure 5.19 shows the task completion times for each trial in the Real Only condition.

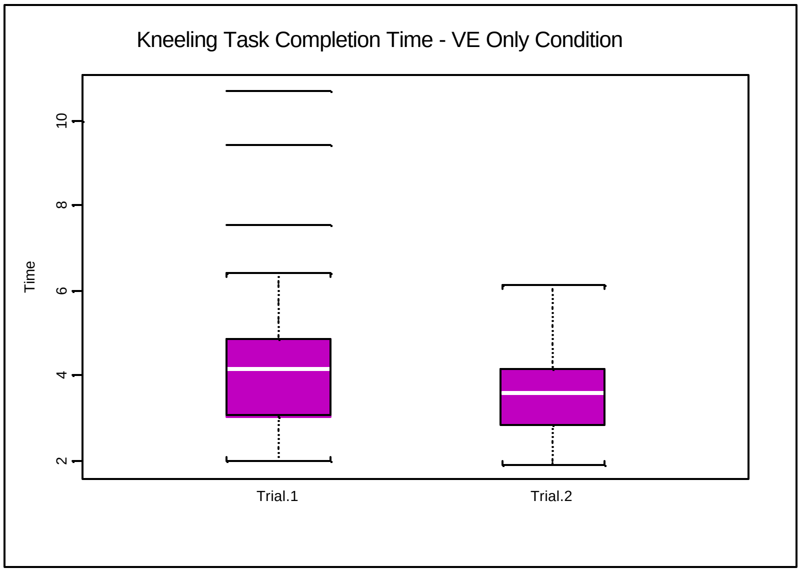

Figure 5.17. Kneeling Task Completion Times in the VE Only Condition.

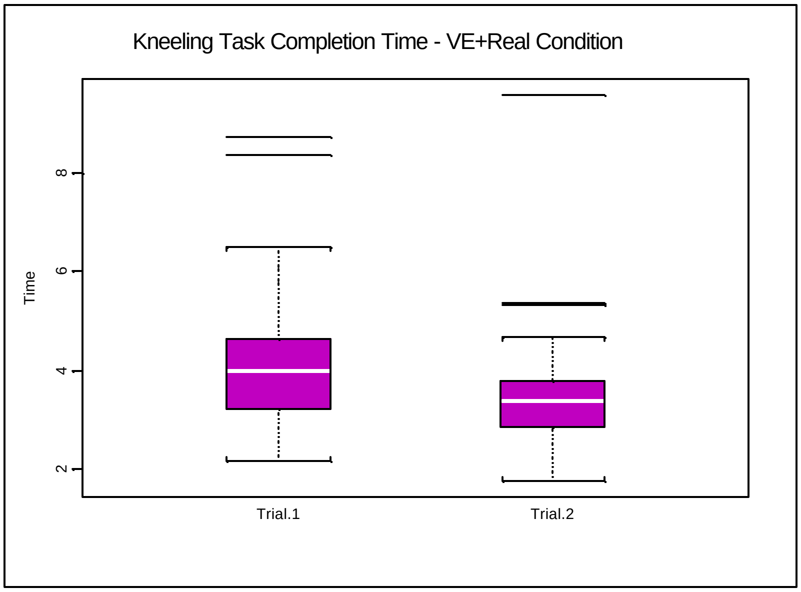

Figure 5.18. Kneeling Task Completion Times in the VE+Real Condition.

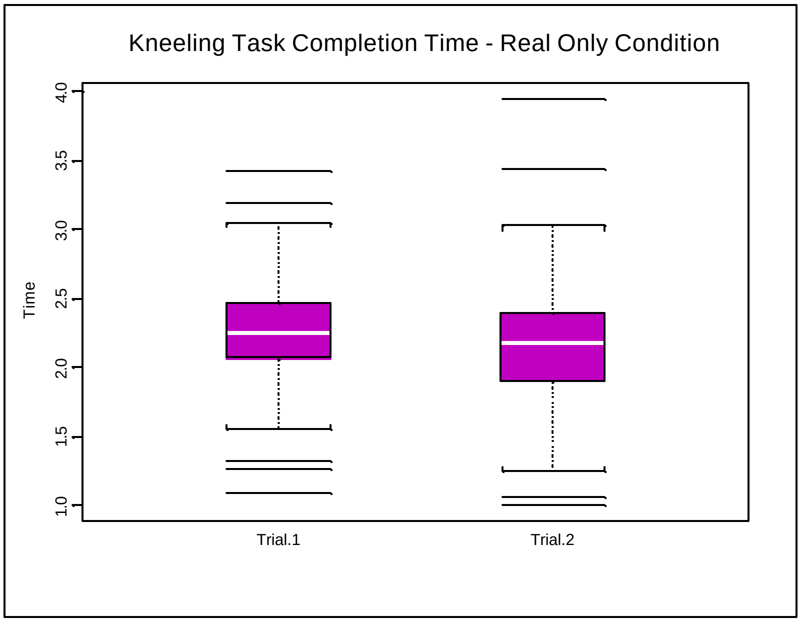

Figure 5.19. Kneeling Task Completion Times in the Real Only Condition.

2. Look Around The Corner Task

There was not any significance difference between two trials in VE Only and VE+Real conditions (for VE Only: $\underline{t}(37) = 1.47$ and $\underline{p} = 0.07$, for VE+Real: $\underline{t}(37) = 1.64$ and $\underline{p} = 0.055$). However, there was a significant difference in the Real Only condition ($\underline{t}(37) = 4.49$, $\underline{p} < 0.0005$). Figure 5.20 shows the task completion times for each trial in the VE Only condition. Figure 5.21 shows the task completion times for each trial in the VE+Real condition. Figure 5.22 shows the task completion times for each trial in the Real Only condition. These results indicate that there was not any learning effect on virtual conditions.

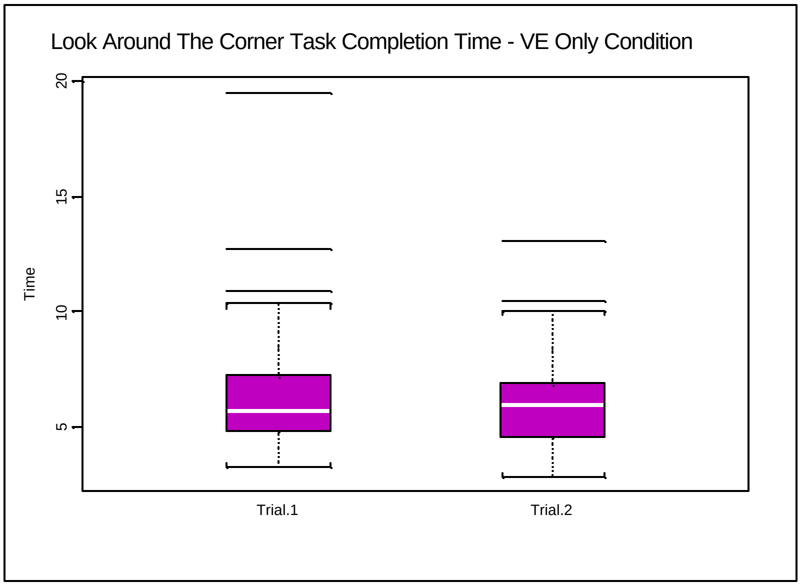

Figure 5.20. Look Around The Corner Task Completion Times-VE Only.

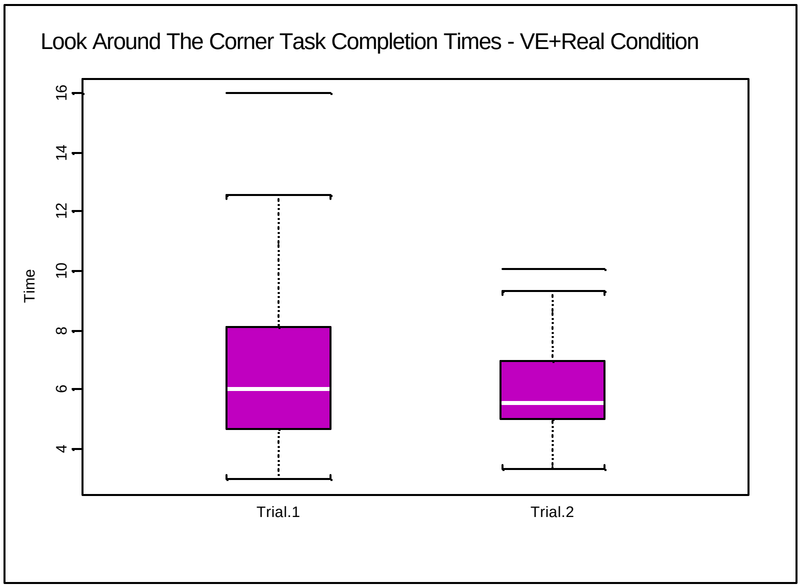

Figure 5.21. Look Around The Corner Task Completion Times-VE+Real.

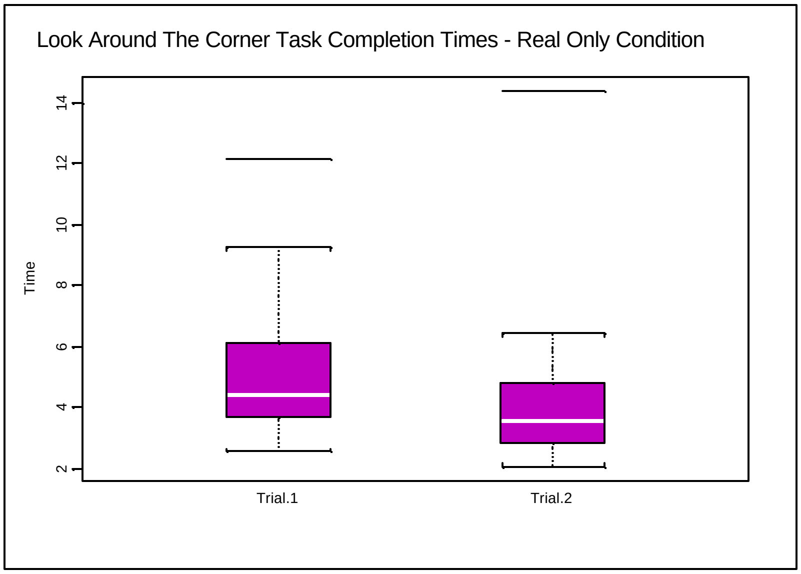

Figure 5.22. Look Around The Corner Task Completion Times-Real Only.

3. Sidestepping Task

There was not any significance difference between two trials in any of the environments (for VE Only: t(37) = 0.72 and p = 0.23, for VE+Real: t(37) = -0.83 and p = 0.20, and for Real Only: t(37) = 0.01 and p = 0.49). This suggests that there was not any learning effect in any of the environments. Figure 5.23 shows the task completion times for each trial in the VE Only condition. Figure 5.24 shows the task completion times for each trial in the VE+Real condition. Figure 5.25 shows the task completion times for each trial in the Real Only condition.

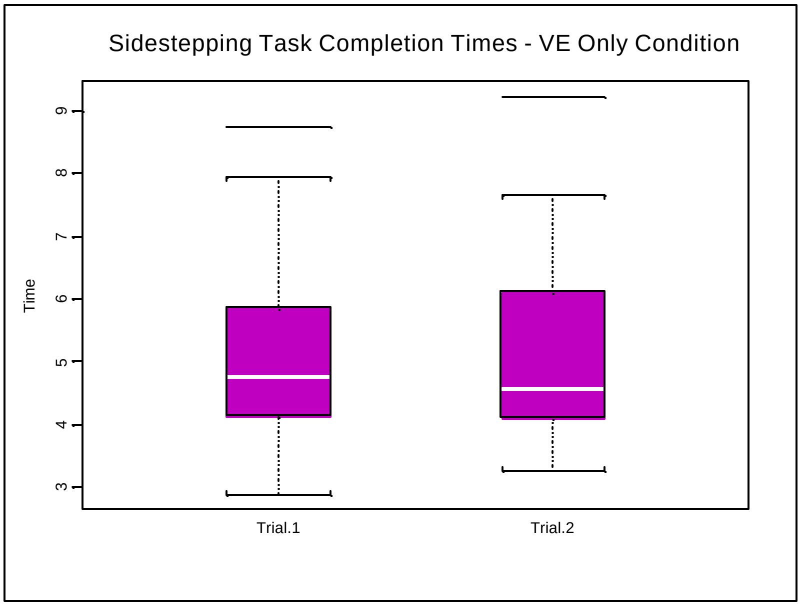

Figure 5.23. Sidestepping Task Completion Times in the VE Only Condition.

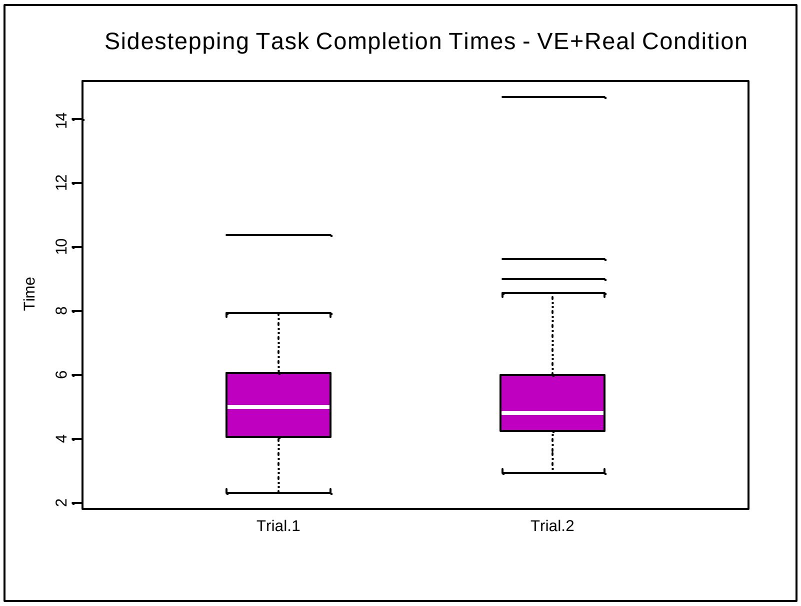

Figure 5.24. Sidestepping Task Completion Times in the VE+Real Condition.

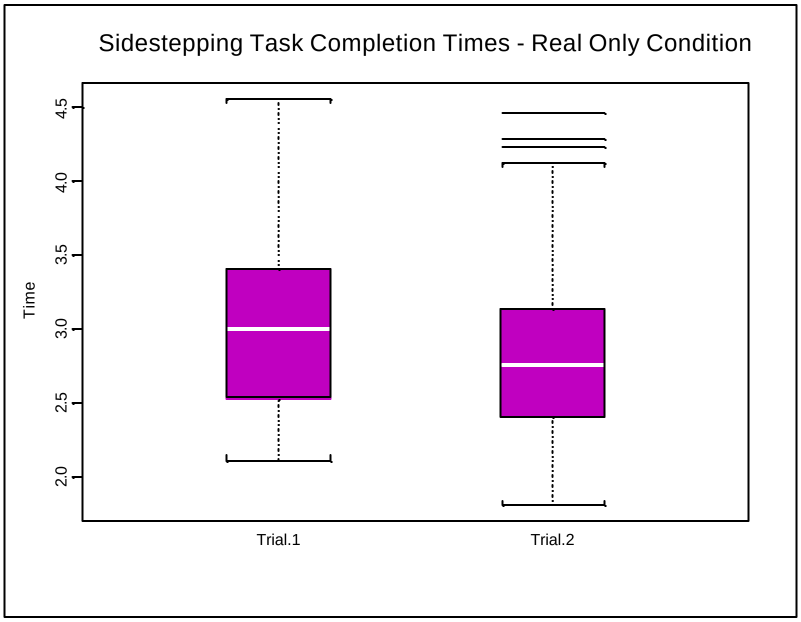

Figure 5.25. Sidestepping Task Completion Times in the Real Only Condition.

4. Backward Movement Task

There was a significance difference between two trials in the VE Only and VE+Real conditions (for VE Only: $\underline{t}(37) = 4.53$ and $\underline{p} < 0.0005$, for VE+Real: $\underline{t}(37) = 2.76$ and $\underline{p} = 0.004$). However, there was not any significant difference in the Real Only condition ($\underline{t}(37) = -0.026$, $\underline{p} = 0.48$). This suggests that participants seemed to have better performance levels on their second trials in virtual conditions, indicating a learning effect. Figure 5.26 shows the task completion times for each trial in the VE Only condition. Figure 5.27 shows the task completion times for each trial in the VE+Real condition. Figure 5.28 shows the task completion times for each trial in the Real Only condition.

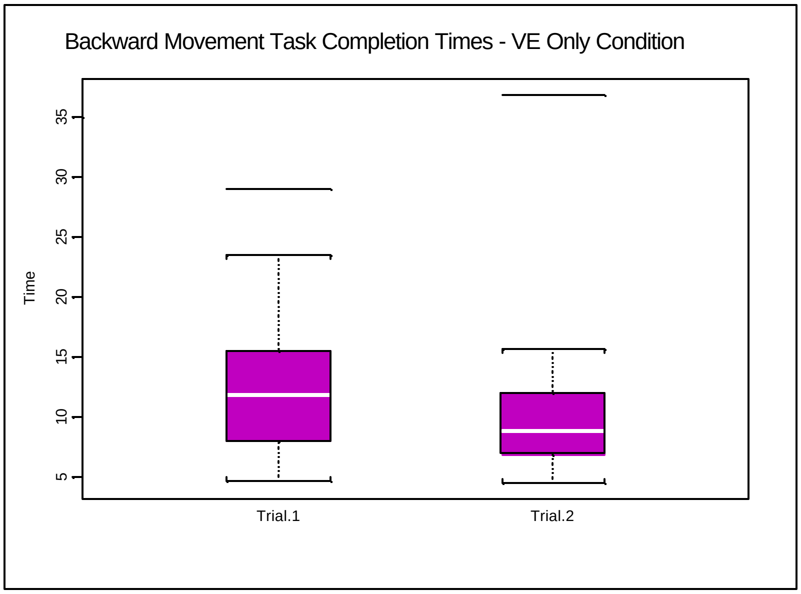

Figure 5.26. Backward Movement Task Completion Times- VE Only.

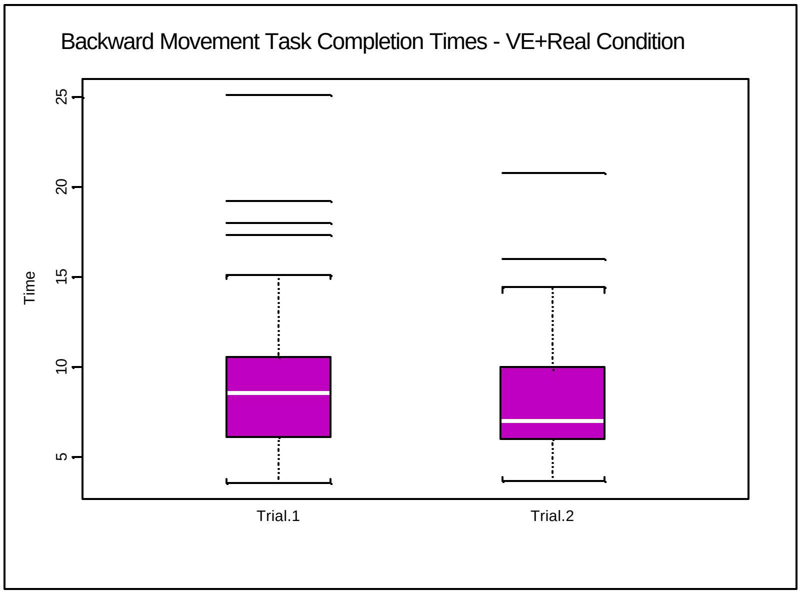

Figure 5.27. Backward Movement Task Completion Times- VE+Real.

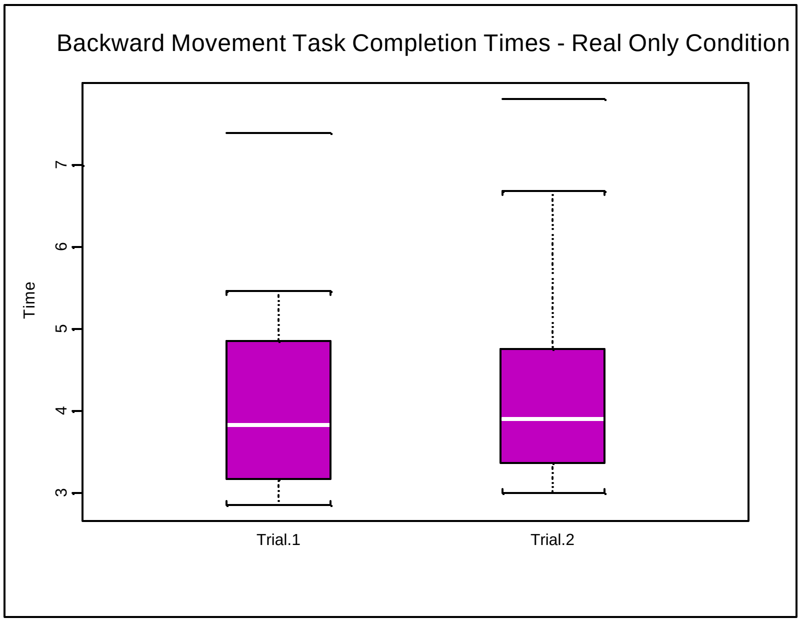

Figure 5.28. Backward Movement Task Completion Times- Real Only.

D. OVERALL ANALYSIS

We wanted to see the differences between treatments in all the tasks. For this reason, we conducted a 4-Way ANOVA test by using Environment Conditions, Trials, Subjects, and Tasks as factors. This helped to minimize the total amount of errors included in the error terms of the ANOVA formula. The 4-Way ANOVA test indicated that all four factors were significant at $\alpha = 0.05$. A further analysis of Multiple Comparisons using Tukey's Method indicated significant differences between three environment types. Figure 5.29 shows the 95% Confidence Intervals for the comparisons between the environments. It indicates that the difference between the VE Only and VE+Real conditions is significant at $\alpha = 0.05$.

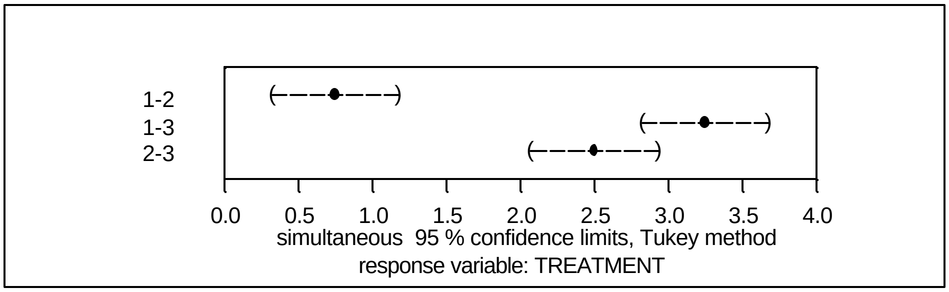

Figure 5.29. 95% CI Limits, Environment Types - 1:VE Only, 2:VE+Real, 3:Real Only.

E. GENERAL DISCUSSION

1. Discussion on Observations

The first goal of the experiment was to observe the participants' behaviors while performing maneuvering tasks. The observed behaviors of participants in a virtual environment were different than the behaviors in a real environment. The limitations of a virtual environment affected the behaviors of the participants and created differences in the real world.

a. VE Only Condition

Generally, participants seemed to behave slower and more carefully in this condition. Some of the participants tried not to walk through the objects. When they recognized a collision, they stepped back. However, there were a lot of participants at the opposite end of the spectrum. When they noticed that the physical objects were not placed, they walked through them without paying any attention to them. The way people maneuvered in this condition was different than the way they did in the real condition. Their behaviors were different especially in Backward Movement and Sidestepping Tasks. These tasks were affected the most by the limitations of the virtual environment. Limited FOV and the lack of an avatar were the main reasons for different behavioral characteristics in this condition.

b. VE+Real Condition

The most interesting behaviors were observed in this condition. We expected to observe that the participants would make use of the haptic feedback available in this condition. However, even when they knew the objects were physically placed inside the environment, they hesitated to touch them and did not obtain haptic feedback. They had seen the objects virtually. This made them think of the objects only in the virtual world, and as a consequence, they tended not to touch them, or they touched them slightly which was not enough to obtain passive haptic feedback. This might be a result of the fact that people usually try to get tactile feedback instead of haptic feedback in virtual environments.

The observations in this condition were similar to the ones in the VE Only condition. The participants seemed to behave slower and more carefully in this condition. The way people maneuvered in this condition was different from the way they did in the real condition. There were a number of collisions in each of the tasks. Limited FOV and the lack of an avatar were the main reasons for collisions and different behavioral characteristics in this task.

c. Real Only Condition

Participants performed the tasks in this condition as they do in real life. They were observed to be faster while performing the tasks. There was no problem associated with the interface, since no interface was involved in this condition. Participants tended to make use of the objects to obtain haptic feedback in this condition.

2. Discussion on Performance Levels

The general results of the experiment indicated a difference in the performance levels of people between the virtual and real environments. The Real Only environment yielded the highest performance levels in all of the tasks. Generally, there was not any significant difference between the VE Only and VE+Real conditions. Participants usually did not try to obtain haptic feedback from the virtual environment. This made the VE Only and VE+Real conditions very similar to each other. Participants usually performed equally well in these two conditions. However, their performance levels on these conditions were much lower than that of the Real Only condition.

VI. CONCLUSIONS AND FUTURE WORK

A. CONCLUSIONS

The thesis experiment studied the effects of natural locomotion on maneuvering tasks in the virtual and real world. The participants performed four maneuvering tasks in three different environments. The performance levels of each participant were assessed through a set of performance measures. The maneuvering behaviors of the participants were observed for comparison between the environments. The results of the experiment were then analyzed in order to determine if there exists a significant difference between the environments. The following conclusions were drawn from both the qualitative and quantitative results previously presented:

- Participants performed better in the real environment in all of the four tasks. This indicates that the maneuvering performances of people in virtual environments are not as good as their real world performances even if natural locomotion is used.
- Generally, there was not any significant difference in the performance levels of participants between the VE Only and VE+Real conditions. Participants usually did not try to get haptic feedback from the environment in virtual conditions. This caused the VE Only and VE+Real conditions to yield similar performance levels.
- The behaviors of the participants in the virtual environment were different from their behaviors in the real environment. This indicates that the limitations of the virtual environment have a big role in the maneuvering behaviors of participants no matter how good the locomotion device is. Participants usually tended to be more careful, more hesitant, and slower throughout their movements in the virtual environment.
- Besides the differences between the virtual and real conditions, there were differences in the behaviors of the participants between the VE Only and VE+Real conditions. Some of the participants did not pay attention to their movements once they recognized that the objects were not physically placed inside the environment. This created an artificial decrease in their task completion times since they walked through the objects.
- In the VE+Real condition, most of the participants did not touch the objects even after they recognized that the objects were physically placed inside the room because they had seen the objects virtually and recognized them only as virtual objects. Their visual systems dominated all other receptors, causing them to think only about virtual objects even if they knew the objects were physically placed inside the environment.

- Limited FOV and the lack of an avatar affected the behaviors and the performance levels of the participants in virtual conditions. These two factors were the main reasons for the differences between the real and virtual conditions.
- The lack of stereoscopy was observed to be one of the disadvantages in virtual conditions. Participants had experienced difficulties with distance estimation. This caused collisions with the objects.
- HMD cables and the weight of HMD were observed to be important issues affecting the behaviors and performance levels of participants in the virtual environment.

B. FUTURE WORK

While this thesis validated the behavioral and performance differences between virtual and real world, there remain significant areas for future work and exploration. This section focuses on some possible future enhancements and modifications to the experiment presented in this thesis.

This thesis indicated that the answer to the locomotion problem is clearly not in the device. However, there are still important issues to be explored to enhance the user's performance level in virtual environments. Using full-body avatars with high-resolution, low latency trackers may enhance the proprioceptive feedback of the user. This might yield better performance levels in virtual environments. Using wireless, very low-weight eye-worn displays may also enhance the performance levels of the users. We did not use stereoscopic displays in our study. Using stereoscopic displays may help increase the performance level of the users in virtual environments. The following sections discuss these issues.

1. Trackers with Longer Range

The experiment can be conducted using more improved tracker systems. With a long-range tracker, participants can walk and maneuver in a wider area, allowing better observations of their movements. In our current implementation, the participants could be tracked in a very limited area. Also, the electromagnetic tracker used throughout the experiment was subjected to metallic object interferences. Even if the large metallic objects inside the environment were removed, there was an inevitable interference caused by the metals used in the construction of the building frames, doors, etc. Using a high-resolution low-latency tracker would possibly yield better performances.

2. Stereoscopy

We did not use stereoscopy throughout the experiment. This affected the distance estimation capabilities of the participants in virtual conditions. The lack of stereoscopy affected the participants' behaviors as well as their performance levels. It affected the behaviors of the participants and caused them to be more hesitant and slower during their movements. It affected the performance levels of the participants which led to a lot of collisions with the objects due to the difficulties in distance estimation. Using stereoscopy could enhance the performance levels of participants in virtual conditions.

3. Field-of-view and HMD Resolution

Limited FOV was one of the biggest problems in the virtual environment. The participants had difficulties seeing the entire environment during their movements, whereas in the real environment, they did not have this problem. There is no existing technology that can provide the same FOV as the real world, but using more improved HMD with higher resolution and wider FOV may enhance the performance level of the participants.

4. Using an Avatar with Whole Body Tracking

We did not use an avatar during the experiment. If a whole-body tracking technology had been used, including every limb of the body, it would have been useless to have an avatar in the virtual environment. Current technological limitations did not allow us to achieve whole-body tracking. Therefore, we did not intend to use an avatar during the experiment. However, if an avatar can be used with a whole-body tracking system, then the prorioceptive cues of the users can be enhanced. This might yield better performances in virtual conditions.

5. Replications of Tasks

The participants performed each task twice in each of the environments. As explained in the previous chapter, some amount of learning occurred during the experiment. We tried to remove the learning effects by analyzing each trial separately between the conditions, and by averaging the data. We could not allow the participants to perform each task more than twice for practical reasons. We had four tasks to complete and each task was performed in three different environments. It took an hour for the participant to complete the entire whole experiment. If we had let them perform each task more than twice, it would have taken much longer to complete the experiment. This could have caused other problems such as participants quitting the experiment due to boredom. Despite these practical issues, if the number of replications for each task can be increased, we believe there is a strong probability of obtaining more valuable data by eliminating the learning effects. Maybe this can be achieved by performing only one or two maneuvering tasks a sufficient number of times each to eliminate any learning effect.

6. Using Complex Tasks

We selected four different maneuvering tasks based on the task analysis of clearing building operations. We happened to choose these four tasks. Our technical limitations prevented us from choosing more complex tasks such as crawling. If more tasks can be included in the study, there would be more opportunities to observe the differences between virtual conditions. We did not see significant performance differences between the VE Only and Ve+Real condition. Experimenting with more complex tasks can help determine the performance differences between two virtual conditions.

APPENDIX A. EXPERIMENT OUTLINE

1) In Brief/Consent Form

   a) Time – 5 Min
   b) Location – CAVE Lab - Spanegal 242
   c) OIC – 1st Lt Eray Unguder
   d) Materials – Consent Form, Privacy Act Statement, Minimal Risk Consent Form, pencil, In Briefing Script

2) HMD and Model Familiarization
   a) Time – 10 Min
   b) Location – CAVE Lab - Spanegal 242
   c) OIC – 1st Lt Eray Unguder
   d) Materials – A PC, HMD, Virtual Model, Tracker
3) Kneeling Task
   a) Time – 12 Min
   b) Location – CAVE Lab - Spanegal 242
   c) OIC – 1st Lt Eray Unguder
   d) Materials – A PC, HMD, Virtual Model, Tracker, boxes, pencil, data collection sheet, stopwatch

4) Look Around The Corner Task
   a) Time – 12 Min
   b) Location – CAVE Lab - Spanegal 242
   c) OIC – 1st Lt Eray Unguder
   d) Materials – A PC, HMD, Virtual Model, Tracker, boxes, separator, pencil, data collection sheet, stopwatch

5) Sidestepping Task
   a) Time – 10 Min
   b) Location – CAVE Lab - Spanegal 242
   c) OIC – 1st Lt Eray Unguder
   d) Materials – A PC, HMD, Virtual Model, Tracker, boxes, pencil, chair, data collection sheet, stopwatch

6) Backward Movement Task
   a) Time – 10 Min
   b) Location – CAVE Lab - Spanegal 242
   c) OIC – 1st Lt Eray Unguder
   d) Materials – A PC, HMD, Virtual Model, Tracker, pencil, chair, data collection sheet, a box, stopwatch

7) Debriefing

- a) Time – 2 Min
- b) Location – CAVE Lab - Spanegal 242
- c) OIC – 1st Lt Eray Unguder
- d) Materials –Pencil, chair, data collection sheet

APPENDIX B. IN BRIEFING

Welcome to the Naval Postgraduate School's MOVES Department. My name is Eray Unguder. Thank you for participating in this experiment. This experiment deals with locomotion and maneuvering in virtual environments.

This experiment does not test your intelligence or performance level in this type of an environment. Rather, it looks at how we behave in real world and virtual world. Your performance will be used only for research purposes, and it will not be used in any type of personal records. Prior to starting the experiment you will be asked to read and sign a series of consent forms. Please read them carefully and ask me if you have any questions. The experiment will take approximately 60 minutes. Upon completion of the tasks, you will be given a short debriefing. If you don't have any question, please read and sign the consent forms.

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APPENDIX C. CONSENT FORMS

1. GENERAL

The forms in the appendix appear in the same format utilized for the experiment and do not follow the standard thesis formats utilized in the chapters of this document. This appendix consists of three documents: Consent Form, Minimal Risk Consent Statement, and the Privacy Act Statement. Each participant is required to read and sign these documents before he is allowed to participate in the study.

2. CONSENT FORM

PARTICIPANT CONSENT FORM

1. **Introduction.** You are invited to participate in a study that requires performing maneuvering tasks in natural and virtual environment. With information gathered from you and other participants, we hope to discover insight on locomotion devices used to move through virtual environments during dismounted navigation of natural terrain and buildings. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you may have before signing.

2. **Background Information.** The Naval Postgraduate School NPSNET Research Group is conducting this study.

3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. There will be one session during which you will be expected to accomplish a number of maneuvering tasks. The total amount of experiment will not be more than one hour.

4. **Risks and Benefits.** This research involves no risks or discomforts greater then those encountered in an ordinary walking in a building. The benefit to the participants is contributing to current research in human-computer interaction.

5. **Compensation.** No tangible reward will be given. A copy of the results will be available to you at the conclusion of the experiment.

6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which could identify you as a participant.

7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.

8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, Dr. Rudolph P. Darken (831) 656-4072 darken@nps.navy.mil.

9. **Statement of Consent.** I have read the above information. I have asked all questions and have had my questions answered. I agree to participate in this study.

-- ---------------------------
Participant's Signature Date

-- ---------------------------
Researcher's Signature Date

3. MINIMAL RISK CONSENT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
MINIMAL RISK CONSENT STATEMENT

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: The Effects of Natural Locomotion on Maneuvering Tasks in Virtual and Real World

1. I have read, understand and been provided "Information for Participants" that provides the details of the below acknowledgments.

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

3. 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.

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

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

6. 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.

7. I understand that my participation in this project is voluntary, refusal to participate will involve no penalty or loss of benefits to which I am 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.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Professor Rudy Darken, Principal Investigator, and about my rights as a research participant 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 has taken place.

Medical Monitor: Flight Surgeon, Naval Postgraduate School

____

Signature of Principal Investigator Date

____

Signature of Volunteer Date

____

Signature of Witness Date

4. PRIVACY ACT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Authority: Naval Instruction

2. Purpose: Maneuvering and locomotion task performance data will be collected to enhance knowledge, and to develop tests, procedures, and equipment to improve the development of Virtual Environments.

3. Use: Data 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.

4. Disclosure/Confidentiality:
   a. 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.

   b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein 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.

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

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

Signature of Witness	Date

APPENDIX D. KNEELING TASK SCENARIO

There are four boxes in the room. If you look around the room, you will see two boxes on the left side, and two more on the right side. First, I want you to concentrate on the left side. There is a letter written on the bottom face of each box. I want you to read those letters to me. The order does not matter. You can read them in the order of your choice. I want you to read them as soon as you see them. After the completion of reading the left boxes, I will ask you to do the same thing for the boxes on the right side. If you have any questions, please let me know before we start.

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APPENDIX E. LOOK AROUND THE CORNER TASK SCENARIO

In this task, there are some enemy force units on the other side of the wall that you see in the middle of the room. Boxes (with letters on one side) represent the enemy forces. Your task is, with minimum exposure (but not lie prone) to the enemy, to see the enemy forces as much as you can. Please remember that I want you to minimize your exposure level to the enemy. Keep in mind that as long as you see the enemy forces, they can see you too. When you believe you have seen all of the enemy units, please say “OK” loudly, and raise your hand. The task ends when you inform me that you have seen the enemy units. If you have any questions, please let me know before we start.

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APPENDIX F. SIDESTEPPING TASK SCENARIO

In this environment, there are some boxes and a chair behind them. I want you to pass the obstacles and stop at a point where you can easily touch that chair. However, I don’t want you to try to touch the chair. I want you to use the shortest path and make sure that you pass the obstacles completely, before stopping. I do not want you to jump over the boxes. Also, please make sure that you attempt not to hit the objects, as you normally do in real life. If you have any questions please let me know before we start.

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APPENDIX G. BACKWARD MOVEMENT TASK SCENARIO

Now, you are standing on the starting point for this task. Please note that this is your starting point. If you look around the room, you will see a chair in front of you, and a box with a letter “A”, which is placed on the wall that you are facing. I want you to walk towards that letter. When you reach a close point to the box, please stop and wait. I will tell you to stop otherwise. I do not want you to touch to the box. First, please walk towards the box and stop there.

(After the participant arrives to the desired point) Now, I want you to go back to your starting point without looking anywhere other than the letter on the box. I want you to go back where you were before, while keeping your eyes on the letter. If the letter “A” changes into a “B” at some point during your movement, I want you to inform me about that change as soon as possible, so you should be always looking to the letter. When you believe that you have reached to the starting point, please let me know by saying “OK”. If you have any questions, please let me know before we start.

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APPENDIX H. TIME DATA

A. KNEELING TASK COMPLETION TIMES

KNEELING TASK	CONDITION	MEAN	STANDARD DEVIATION
TRIAL 1	VE ONLY	4.342	1.845
TRIAL 2	VE ONLY	3.567	0.929
AVERAGE	VE ONLY	3.798	1.064
TRIAL 1	VE+REAL	4.118	1.446
TRIAL 2	VE+REAL	3.535	1.322
AVERAGE	VE+REAL	3.914	1.433
TRIAL 1	REAL ONLY	2.256	0.521
TRIAL 2	REAL ONLY	2.177	0.602
AVERAGE	REAL ONLY	2.180	0.500

B. LOOK AROUND THE CORNER TASK COMPLETION TIMES

LOOK AROUND THE CORNER	CONDITION	MEAN	STANDARD DEVIATION
TRIAL 1	VE ONLY	6.606	2.985
TRIAL 2	VE ONLY	6.171	2.110
AVERAGE	VE ONLY	6.389	2.419
TRIAL 1	VE+REAL	6.640	2.716
TRIAL 2	VE+REAL	5.942	1.556
AVERAGE	VE+REAL	6.309	1.817
TRIAL 1	REAL ONLY	4.988	2.035
TRIAL 2	REAL ONLY	4.019	2.054
AVERAGE	REAL ONLY	4.502	1.933

C. SIDESTEPPING TASK COMPLETION TIMES

SIDESTEPPING	CONDITION	MEAN	STANDARD DEVIATION
TRIAL 1	VE ONLY	5.140	1.478
TRIAL 2	VE ONLY	5.049	1.335
AVERAGE	VE ONLY	5.092	1.356
TRIAL 1	VE+REAL	5.210	1.607
TRIAL 2	VE+REAL	5.460	2.218
AVERAGE	VE+REAL	5.325	1.726
TRIAL 1	REAL ONLY	3.057	0.631
TRIAL 2	REAL ONLY	2.879	0.647
AVERAGE	REAL ONLY	2.967	0.607

D. BACKWARD MOVEMENT TASK COMPLETION TIMES

BACKWARD MOVEMENT	CONDITION	MEAN	STANDARD DEVIATION
TRIAL 1	VE ONLY	12.382	5.726
TRIAL 2	VE ONLY	9.811	5.399
AVERAGE	VE ONLY	10.965	5.146
TRIAL 1	VE+REAL	9.338	4.657
TRIAL 2	VE+REAL	8.162	3.464
AVERAGE	VE+REAL	8.720	3.888
TRIAL 1	REAL ONLY	4.096	0.967
TRIAL 2	REAL ONLY	4.226	1.074
AVERGAE	REAL ONLY	4.163	0.940

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APPENDIX I. RAW DATA

A. KNEELING TASK COMPLETION TIMES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	4.75	3.97	4.05	3.79	3.19	3.03
2	5.01	3.61	2.63	3.62	2.47	2.19
3	4.45	3.1	3.74	3.54	3.03	3.01
4	4.62	3.63	3.59	2.95	2.5	1.72
5	6.25	4.65	4.39	2.6	2.17	1.4
6	4.82	3.8	3.56	4.57	2.36	2.68
7	5.61	3.82	4.23	2.93	1.97	2.15
8	9.41	3.94	2.63	2.05	2.27	1.06
9	4.87	3.38	4.37	3.4	2.19	2.18
10	4.15	4.16	2.7	3.04	1.63	1.93
11	6.42	5.06	8.73	4	2.88	1.69
12	2.59	2.62	2.7	3.35	2.19	2.18
13	3.59	2.93	3.97	3.42	2.57	2.74
14	3.93	2.87	3.32	1.75	2.09	2.07
15	2.49	2.53	2.17	1.97	1.33	1
16	3.29	2.49	3.13	3.57	2.27	2.18
17	4.37	2.7	2.75	3.43	1.56	1.54
18	4.22	4.92	3.22	2.49	2.27	2.25
19	7.55	4.33	4.67	4.37	3.05	2.19
20	10.69	5.1	5.09	9.6	3.42	3.44
21	4.84	3.28	2.99	3.79	2.17	2.15
22	4.1	3.66	3.23	4.46	2.37	2.35
23	4.05	3.77	4.18	3.07	2.07	2.05
24	4.19	4.52	6.42	5.36	2.95	2.93
25	3.03	2.84	3.94	3.23	2.29	2.25
26	2.53	2.82	3.33	2.72	1.65	1.6
27	3.23	3.24	8.37	2.33	2.45	2.44
28	2.12	2.41	4.41	2.64	2.41	2.4
29	2.77	2.18	2.35	2.84	1.69	1.6
30	3.74	3.77	4.77	3.47	1.99	1.9
31	5.07	6.12	6.51	5.34	2.88	3.95
32	2.56	1.9	4.84	2.37	1.27	1.25
33	3.04	4.57	4.73	3.34	2.39	2.1
34	1.97	2.97	4.39	4.38	1.09	2.27
35	3.19	3.17	4.05	3.63	2.13	2.01
36	4.53	3.54	4.45	2.96	2.1	2.03
37	4.53	4.5	4.63	4.67	2.25	2.43
38	2.42	2.69	3.29	3.31	2.17	2.4

B. LOOK AROUND THE CORNER TASK COMPLETION TIMES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	8.46	8.72	9.92	4.68	7.32	3.04
2	6.72	6.52	5.83	4.82	6.1	3.53
3	5.27	6.4	5	5.7	4.07	3.29
4	6.48	6.87	9.88	7.67	4.19	5.82
5	7.37	7.36	7.59	7.52	6.57	4.83
6	10.35	7.39	7.07	6.29	3.07	4.36
7	5.83	5.19	6.99	6.38	5.02	3.8
8	12.7	9.34	12.56	4.02	3.89	3.05
9	9.67	10.07	8.79	8.12	7.45	5.09
10	7.67	5.96	6.22	5.34	8.53	6.42
11	9.92	13.04	8.09	10.04	5.58	4.78
12	6.69	6.1	8.88	7.19	5.2	5.27
13	5.72	5.76	3.97	9.33	5.06	3.4
14	5.03	6.07	4.01	6.15	3.79	3.12
15	4.61	4.24	3.93	3.57	2.87	2.34
16	4.54	4.22	5.41	4.45	3.47	3.9
17	5.17	4.21	4.18	5.29	6.65	5.18
18	4.72	5.63	5.09	5.22	4.35	2.67
19	10.88	9.36	10.28	6.56	9.3	5.68
20	19.48	10.5	15.97	7.96	12.16	14.37
21	6	6.21	7.46	6.95	7.36	5.82
22	5.62	6.08	5.73	5.16	5.24	3.83
23	7.21	6	3.33	7.96	2.55	2.39
24	5.65	5.17	6.81	6.8	6.1	2.62
25	4.96	4.89	5.04	4.36	3.2	2.66
26	5.95	5.77	5.7	5.25	4.64	3.07
27	4.19	4.21	3.29	4.99	4.43	2.87
28	5.57	6.04	7.13	5.27	3.63	2.62
29	6.17	6.05	8.97	6.4	4.29	4.13
30	3.28	2.86	2.97	3.34	2.9	2.08
31	4.52	4.5	5.53	5.55	3.81	3.78
32	5.43	7.07	6.34	5.44	4.87	3.59
33	4.67	3.93	4.63	4	3.69	2.67
34	4.85	4.83	5.19	5.17	4.43	2.87
35	4.69	4.57	4.57	5.69	4.05	3.99
36	5.82	4.21	6.16	5.5	2.78	2.88
37	3.99	3.9	4.66	4.07	3.02	3.04
38	5.19	5.27	9.18	7.6	3.94	3.9

C. LOOK AROUND THE CORNER TASK - # OF RECOGNIZED OBJECTS

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	2	2	4	2	4	4
2	2	3	2	2	3	3
3	3	4	3	3	3	3
4	4	4	4	4	3	4
5	4	4	4	4	4	4
6	3	3	3	3	3	3
7	3	4	2	3	3	4
8	3	4	3	3	3	4
9	4	4	4	4	3	3
10	4	4	4	4	4	4
11	3	3	3	4	3	4
12	4	4	4	4	4	4
13	3	3	2	2	1	2
14	4	4	4	4	4	4
15	4	4	4	4	4	4
16	4	4	4	4	4	4
17	2	2	2	2	2	3
18	3	4	4	4	3	3
19	2	3	2	2	3	3
20	1	1	2	1	1	1
21	4	4	4	4	4	4
22	4	4	4	4	3	4
23	4	4	4	4	4	4
24	4	4	3	4	3	3
25	2	3	2	4	3	2
26	4	4	4	4	4	4
27	3	3	2	2	2	3
28	3	3	4	3	4	4
29	4	3	4	4	4	4
30	4	4	4	4	4	4
31	4	4	4	4	4	4
32	4	4	4	4	3	4
33	4	4	4	4	4	4
34	4	4	4	4	4	4
35	4	4	4	4	4	4
36	4	4	4	4	4	4
37	4	4	4	4	4	4
38	3	3	2	2	3	3

D. SIDESTEPPING TASK COMPLETION TIMES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	4.9	4.7	4.47	6	2.3	2.12
2	4.6	4.32	3.51	4.48	2.37	2.27
3	5.16	4.47	5.39	4.25	3.15	3.15
4	5.88	6.43	5.68	8.38	2.94	2.83
5	4.35	4.38	5.23	4.7	3.07	2.27
6	3.98	4.29	4.91	4.47	2.8	2.66
7	6.6	5.41	5.68	5.99	3.41	2.97
8	6.68	5.17	6.8	5.74	2.36	3.52
9	5.33	5.02	7.12	6.25	3.57	2.64
10	4.48	4.42	3.86	4.42	3.29	3.04
11	7.27	9.21	7.56	7.41	4.56	4.29
12	5.02	4	5.39	5.4	2.16	1.8
13	4.38	4.58	3.74	3.04	3.25	3.13
14	3.24	3.26	4.07	3.56	2.11	2.09
15	3.36	3.33	2.33	2.92	2.53	2.33
16	5.38	5.65	6.45	4.9	4.13	4.13
17	5.47	4.37	3.46	3.37	3.19	2.4
18	3.59	3.96	4.09	4.47	2.25	2.57
19	8.74	7.66	5.47	14.73	2.93	2.75
20	7.95	7.05	7.36	9.03	3.88	4.46
21	5.67	6.37	6.64	5.59	3	2.92
22	5.74	6.09	5.72	4.54	3.45	3.25
23	5.84	6.72	5.07	6.24	3.06	3.05
24	8.73	6.57	10.41	9.61	4.07	4.23
25	5.04	5.48	4.97	5.34	3.38	2.61
26	4.45	4.8	4.34	5.04	3.64	3.27
27	2.89	3.86	3.65	3.73	3.34	2.77
28	4.12	4.23	6.05	4.43	2.77	2.57
29	7.12	6.49	7.93	8.59	4.45	3.94
30	3.05	3.4	3.13	3.83	2.96	2.39
31	6.73	6.7	4.87	4.78	2.21	2.17
32	4.37	3.79	4.09	4.77	2.69	2.6
33	4.07	4.97	4.47	5.04	2.99	2.61
34	3.97	3.9	3.43	3.96	2.23	2.75
35	4.44	4.09	6.93	5.23	2.43	2.07
36	4.45	4.4	4.19	4.06	3.46	2.96
37	3.8	3.78	3.99	3.9	2.95	2.93
38	4.49	4.57	5.55	5.3	2.84	2.9

E. SIDESTEPPING TASK COLLISION CATEGORIES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	2	2	1	1	0	0
2	2	2	1	1	0	0
3	2	2	1	1	0	0
4	1	1	0	1	0	0
5	2	2	0	1	0	0
6	1	0	1	1	0	0
7	0	1	1	2	0	0
8	0	2	2	2	0	0
9	2	2	1	1	0	0
10	1	1	1	0	0	0
11	2	2	1	0	0	0
12	1	2	2	2	0	0
13	1	0	0	0	0	0
14	1	1	1	1	0	1
15	1	0	2	2	1	0
16	1	0	2	1	0	0
17	2	2	2	1	0	0
18	0	0	0	1	0	0
19	2	1	2	1	0	0
20	0	1	0	1	0	0
21	1	1	0	1	0	0
22	1	1	1	0	0	0
23	1	1	1	1	0	0
24	2	2	1	1	0	0
25	0	0	1	1	0	1
26	1	2	0	1	0	1
27	2	2	2	1	0	0
28	1	2	2	1	0	0
29	1	0	1	1	0	0
30	1	1	0	1	0	0
31	1	1	1	1	1	1
32	2	2	1	1	0	0
33	1	1	1	1	0	0
34	1	1	1	1	0	0
35	2	2	2	2	0	0
36	1	1	2	1	0	0
37	1	1	1	1	0	0
38	2	2	1	1	0	0

F. BACKWARD MOVEMENT TASK COMPLETION TIMES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	17.51	12.91	25.17	15.97	5.13	6.27
2	8.94	9.16	19.23	10.17	5.27	5.03
3	13.2	11.93	17.33	14.42	7.38	6.69
4	15.41	10.32	9.69	6.47	3.73	4.13
5	12.99	12.22	10.56	8.09	4.17	4.37
6	12.03	9.08	7.9	5.27	4.5	3.73
7	10.97	9.91	8.52	8.29	3.8	3.78
8	11.54	9.25	15.17	9.96	4.09	3.99
9	12.82	13.42	12.12	6.33	5.47	4.87
10	6.87	6.19	7.1	6.03	2.95	4.01
11	21.03	13.6	12.47	10.92	4.89	5.31
12	11.18	7.14	8.63	8.53	4.94	4.84
13	13.13	8.57	6.73	6.83	3.8	4.09
14	6.63	5.33	6.54	7.43	3.18	3.35
15	9.3	6.83	5.65	6.54	4.23	3.79
16	8.58	8.1	4.19	5.94	3.07	3.84
17	7.83	9.05	8.9	10.03	4.99	3.94
18	13.24	8.01	5.98	6.68	3.86	3.86
19	23.53	12.64	8.74	6.6	3.81	3.37
20	29	36.91	18.03	20.83	5.27	7.8
21	12.01	8.95	7.44	7.17	3.76	3.37
22	22.69	9.03	9.41	5.81	3.33	5.34
23	10.78	8.16	7.47	5.89	3.03	4.52
24	16.17	15.27	8.82	9.18	4.02	4.51
25	7.89	6.81	7.54	6.79	4.53	3.76
26	22.54	8.78	9.62	10.51	4.85	3.8
27	5.72	5.23	4.53	4.54	2.89	3.54
28	8.91	8.65	7.03	7.89	3.82	3.01
29	18.33	13.87	12.56	10.36	4.76	5.67
30	5.35	6.04	5.86	6.33	3.15	3.09
31	15.72	15.7	13.33	13.3	3.81	3.78
32	6.63	4.44	3.57	4.04	2.85	3.17
33	6.12	6.62	4.73	5.31	3.07	3.25
34	4.6	4.61	3.64	3.65	3.09	3.01
35	6.52	5.14	5.99	4.85	3.37	3.29
36	12.97	7.13	8.89	7.58	5.1	4.68
37	9.33	7.98	6.09	6.05	3.03	3.01
38	12.54	9.87	9.69	9.6	4.69	4.75

G. BACKWARD MOVEMENT TASK ERROR DISTANCES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	2	2	0	8	12	0
2	10	5	10	10	0	0
3	17	2	16	17	1	0
4	12	9	3	12	6	8
5	12	12	5	3	2	3
6	9	3	4	6	0	0
7	0	5	6	9	0	2
8	3	6	0	0	0	2
9	0	12	5	2	3	0
10	15	3	0	0	3	0
11	3	0	6	12	0	12
12	12	6	10	5	0	0
13	15	5	0	0	0	0
14	6	3	0	0	8	6
15	14	14	14	0	0	2
16	7	0	12	0	10	16
17	6	3	0	6	0	0
18	0	8	3	0	0	0
19	0	0	8	6	12	0
20	12	6	6	10	10	6
21	5	6	5	3	0	0
22	3	3	6	0	6	7
23	12	0	12	0	12	12
24	0	0	0	3	0	0
25	13	0	0	2	0	0
26	23	0	0	0	3	0
27	10	0	0	0	0	0
28	6	3	0	3	0	0
29	3	0	6	3	6	0
30	11	16	0	0	0	0
31	3	3	0	0	0	0
32	0	3	0	0	0	0
33	21	13	6	3	3	0
34	12	9	10	3	0	0
35	12	15	6	0	0	0
36	10	3	12	10	0	0
37	10	0	0	0	0	0
38	12	10	3	5	0	0

H. BACKWARD MOVEMENT TASK COLLISION CATEGORIES

SUBJECT NO	VE ONLY		VE + REAL		REAL ONLY	
	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2	TRIAL 1	TRIAL 2
1	0	1	0	0	0	0
2	1	1	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	2	2	1	0	0	0
7	0	0	1	0	0	0
8	0	0	0	0	0	0
9	0	0	0	1	0	0
10	0	0	0	0	0	0
11	0	1	0	0	0	0
12	2	2	0	0	0	0
13	0	0	0	0	0	0
14	2	1	2	1	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	2	0	0	0	0	0
18	0	0	0	1	0	0
19	0	0	0	0	0	0
20	1	0	0	0	0	0
21	1	1	0	1	0	0
22	0	0	0	1	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	1	2	0	0	0	0
26	2	2	1	0	0	0
27	1	0	0	0	0	0
28	2	2	1	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	0	0
32	2	0	0	0	0	0
33	0	0	0	0	0	0
34	2	2	0	0	0	0
35	2	2	0	0	0	0
36	2	2	1	1	0	0
37	0	0	0	0	0	0
38	0	0	0	0	0	0

LIST OF REFERENCES

1. Darken, R.P., Cockayne W.R., *A Classification of Active Human Locomotion in Virtual Environments*, Naval Postgraduate School, Monterey CA, 1997.

2. Templeman, J.N., Denbrook, P.S., Sibert, L.E., Virtual Locomotion: *Walking in Place through Virtual Environments*, Presence 8(6): 598-617, 1999.

3. Darken, R.P., Cockayne, W.R., Carmein, D., *The Omni-Directional Treadmill: A Locomotion Device for Virtual Worlds*, Proceedings of UIST: 213-221, 1997.

4. MCRP 5-2A Operational Terms and Graphics, US Headquarters Department of the Army, US Marine Corps, Washington, D.C. 1997.

5. FM-90-10 Military Operations on Urbanized Terrain, US Headquarters Department of the Army, Washington, D.C., 1979.

6. FM 90-10-1 An Infantryman's Guide to Combat in Built-up Areas, US Headquarters Department of the Army, Washington, D.C., 1993.

7. MCWP 3-35.3 Military Operations on Urbanized Terrain, US Department of the Navy, Headquarters US Marine Corps, Washington, D.C., 1998.

8. MOUT ACTD Handbook # 3 Experimental Individual Tasks for the Infantryman in Urban Combat, I-96, Version 7, Omega Training Group Inc., 1999.

9. Peterson, B., Wells, M., Furness, T.A. III, & Hunt, E., *The Effects of the Interface on Navigation in Virtual Environments*, Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting: 1496-1500, Santa Monica, CA, 1998.

10. Chance, S.S., Gaunet, F., Beall, A.C., Loomis, J.M., *Locomotion Mode Affects the Updating of Objects Encountered During Travel: The Contribution of Vestibular and Proprioceptive Inputs to Path Integration*, Presence 7(2): 168-178, 1998.

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   Monterey, California
   darken@nps.navy.mil

4. Mr. Barry Peterson
   The MOVES Institute
   Naval Postgraduate School
   Monterey, California
   peterson@cs.nps.navy.mil

5. Kara Harp Okulu Komutanligi
   Kara Harp Okulu Kutuphanesi
   Bakanliklar, Ankara
   06200 TURKEY
   avaroglu@kho.edu.tr

6. 1st LT Eray Unguder
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   57400 TURKEY
   unguder@hotmail.com

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   Levent, Istanbul
   TURKEY
   bkarahan@harpak.tsk.mil.tr

8. Middle East Technical University
   Balgat, Ankara
   TURKEY
   lib-hot-line@metu.edu.tr

9. Bilkent University
Balgat, Ankara
TURKEY
library@bilkent.edu.tr