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RICE UNIVERSITY

SPATIAL ABILITY AND VIRTUAL REALITY: TRAINING FOR INTERFACE EFFICIENCY

by

JUSTIN MILLER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF ARTS

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ABSTRACT

Spatial Ability And Virtual Reality: Training For Interface Efficiency

by

Justin Miller

Virtual Reality (VR) has been deemed the interface of the future. However, many people get lost navigating through a simple DOS hierarchy due to low spatial ability. Research has shown that spatial ability can be increased through training, and that there is a link between spatial ability and VR. This experiment attempts to replicate and combine those studies by trying to improve the subjects' spatial ability and increase the efficiency of a VR interface. Thirty subjects were pre- and posttested on their spatial ability, as well as their ability to navigate through a virtual environment. Half the subjects underwent 15 hours of training using seven spatial ability tests. The trained subjects improved their spatial ability, not just on those seven tests, but in general. There was no significant correlation between spatial ability and ability to navigate in VR, and no difference in improvement in that ability between the two groups.
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INTRODUCTION

Virtual Reality is the promising technology of the future. In its infancy, it provides us with the ability to be whoever, or whatever, we want. It allows us to be wherever, or whenever, we want. It gives us great flexibility: to do almost anything we want! Designers can build virtual worlds which let us live in space, on the moon, or underground. They will build virtual worlds where we can interact with beautiful supermodels, or our favorite movie stars, or even our own dream date. Virtual Reality (VR) is already a major tool in the entertainment industry, as people of all ages line up to pay a dollar per minute to play games in a virtual world. However, VR is also being used for more serious applications. NASA is currently using VR to help train astronauts, and products are currently being developed for the medical industry. Jaron Lanier, founder of VPL, a prominent VR company, and industry leader, has speculated that by the end of the century, powerful VR machines will be available for use at home (Lanier & Biocca, 1992).

With the spread of VR technology from entertainment to business and eventually the home, the use of such technology, like the radio, TV, or telephone, may bring about major changes in our society. These changes will affect the way people gather information, socialize, and even go to work. Like it or not, if this technology takes root, almost everyone will become navigators in the world of Virtual Reality.

However, VR is not the end all and be all of future computer technology; rather, it is just the front-end, the interface. Behind the scenes will still be the processors and the network links. The only thing missing will be the DOS,
Windows, or Macintosh interface. No longer will people use a mouse to point to a folder on the screen, or even a typewriter to enter commands. The interface will be in a virtual environment. Perhaps it will be an environment specifically tailored for the task at hand, surrounding the user with all the commands necessary, available with a nod of the head, or a point of the finger, or even a simple utterance. Users will be placed inside a computer-generated world, with important information surrounding them.

A problem arises at this point. DOS, and other computer operating systems, use a hierarchical file structure. This means that the main directory has several sub-directories, each of which have sub-sub directories, and so forth in an unlimited fashion. However, users of these machines often get lost in this hierarchical file structure and are unable to figure out where they are relative to the directory they want to be in, much less how to get there (Vincente, Hayes, & Williges, 1987). How then, can we keep the user from getting lost when surrounded by the vast amounts of information which can be presented in a VR interface? This is an important question which must be addressed if Virtual Reality is to assume the role in society that has previously been discussed. VR will not have the major impact that many people are predicting if it turns out to be an inefficient interface which confuses, and loses, the user. What Vincente et al. (1987) found was that those people who are low in spatial ability, as measured by five tests from the Kit of Factor Referenced Cognitive Tests (Ekstrom et al., 1976), were more likely to get lost using a hierarchical structure like DOS, compared to those people who are high in spatial ability.

Virtual Reality has also been linked with spatial ability, which is made
up of two factors: spatial visualization and spatial orientation. Spatial visualization is generally defined as the ability to mentally rotate and manipulate two- and three-dimensional stimuli. Spatial orientation, on the other hand, is generally thought of as the ability to comprehend the arrangement and orientation of visual stimuli, and an ability to determine spatial orientation with respect to one's own body. In other words, spatial visualization deals with the ability to manipulate visual stimuli, whereas spatial orientation deals with the ability to have a sense of orientation for the visual stimuli.

Arthur, Hancock, and Chrysler (1993) were interested in how an individual would mentally represent virtual space. They did not know if the spatial abilities, especially spatial orientation, which everyone has used all their lives would also be used in a virtual environment. They had subjects examine a room full of objects and then draw a map diagramming the relative locations of all the objects in the room. One group of subjects was in the actual room with the objects and was allowed to move around inside the room and look at the objects. Another group of subjects was presented with a virtual room filled with virtual objects. The layout of the rooms was identical; the only difference was that one of the rooms and the objects inside it were all in a virtual environment. On the mapping task, the subjects in the virtual condition scored almost the same as the subjects in the real condition. There was no significant difference between the two groups. The authors concluded that, "the spatial representation formed by using virtual reality appears equivalent to that of the representation with the actual objects" (p. 328). In other words, the authors showed that spatial orientation in the real
world is the same ability that helps people navigate through a virtual world. Spatial ability does not discriminate between these two worlds. Therefore, if it was possible to train people to improve their spatial ability, particularly their spatial orientation, then not only would they benefit in many of the other ways mentioned above, but they would also be more efficient at navigating through a virtual environment. This research focuses on training subjects to improve their spatial ability, in an attempt to increase their ability to navigate through a virtual environment.

Spatial ability

It is not surprising that spatial ability would have this kind of impact on our ability to navigate through virtual reality and even a DOS hierarchy considering the large impact spatial ability has on our lives. Spatial ability has been linked with many different skills, as well as with intelligence in general. In addition, there has been an effort to determine the origins of an individual's spatial abilities, particularly whether they are genetic or environmentally determined. And further, if they are environmentally determined, if and how they can be improved.

One skill to which the study of spatial ability has been applied is mathematics. Spatial ability has been linked to mathematical ability quite frequently and in different areas, such as geometry (Battista, Wheatley, & Talsma, 1982), SAT scores (Burnett, Lane, & Dratt, 1979), and statistics (Elmore & Vasu, 1980), as well as with different age subjects, such as children in high school (Sherman, 1983; Sherman, 1979; Sherman, 1980a), and junior high (Pedersen, Elmore, & Bleyer, 1986). These studies have also instigated the
study of the validity of spatial ability tests (Kovac, 1989). In addition to math, other areas have been shown to be positively correlated with spatial ability. The relationship between spatial ability and some of these are intuitive, such as physics (Wormack, 1979), engineering (Blade & Watson, 1955), and mechanical abilities (Lunneborg & Lunneborg, 1984), while its relationship with others is less intuitive, such as writing (Wormack, 1979a), athletic skills (Hult & Brous, 1986), and musical ability (Hassler, Birbaumer, & Feil, 1985). Further, spatial ability has been linked to the number and kind of courses taken in school (Burnett & Lane, 1980; Blade & Watson, 1955), and to general intelligence (Lansman, Donaldson, Hunt, & Yantis, 1982; Ozer, 1987; Drew & Waters, 1986). It has helped develop new ways of assessing intelligence (Hunt, 1982) and has been correlated with career orientations (Eisenberg & McGinty, 1977) and certain personality components (Bryant, 1982). As a result of all this work, new tests have been developed to help test spatial abilities (Elliot, Medoff, & Kimmel, 1987; Vandenberge & Kuse, 1978).

Reviewing all the work on spatial abilities, one of the first things noticed is the difference between men's and women's spatial abilities. Although some researchers found no gender differences, (Hult & Brous, 1986; Dorval & Pepin, 1986; Schultz & Austin, 1983; Sherman, 1980; Hassler, Birbaumer, & Feil, 1985), others did. Differences were found in a variety of ways, including both those which were experimentally determined (Burnett, Lane, & Dratt, 1982; Burnett, Lane, & Dratt, 1979; Sanders, Soares, & D'Aquila, 1982; McGee, 1979; Elmore & Vasu, 1980) and those which were determined on the basis of self-reports (Lunneborg & Lunneborg, 1984). Regarding self-reports, it has been shown that men tend to overestimate their spatial ability, while women tend to underestimate theirs (Sherman, 1983).
Experimentally determined gender differences cover many different areas. Differences, in which males have better spatial ability than females, have been found in young children (Kerns & Berenbaum, 1991; Burns & Reynolds, 1988) as well as adults. Salkind (1976) determined that spatial abilities were developmental, and related strongly to the haptic (tactile) senses. When looking at elderly men and women however, there is an added twist to the findings. Elderly men have been found to be better at spatial orientation than elderly women, but there was no gender difference for spatial visualization (Cohen, 1976). It should be noted, however, that studies (Salthouse & Mitchell, 1990; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990) have shown that spatial abilities decrease with age, that these changes happen regardless of prior spatial ability. Gender differences have also been studied in conjunction with career orientation (Eisenberg & McGinty, 1977), and personality (Ozer, 1987; Waggett & Lane, 1990). In addition, Ethington and Wolfle, (1984) and Fennema and Tartre (1985), found that low spatial ability hinders females’ math ability more than it does for men. However Sherman (1979) found that spatial ability is a better predictor of math ability for girls than it is for boys. Further, research has also shown that coursework (Burnett & Lane, 1980) can help improve a female's spatial ability more than a man's, and that the type of coursework can also make a difference. McKeever (1986) looked at gender not as bipolar but rather as existing along a continuum. He found that subjects who were more androgynous had better spatial abilities than those who were less androgynous. These findings have prompted researchers to question why there are such gender differences. A theory was developed which stated that
these gender differences are genetically based, and are passed down from one
generation to the next through an x-linked recessive gene, thus accounting
for the gender differences. This theory has received some support (Loehlin,
Sharan, & Jacoby, 1978; Jensen, 1978; Jensen, 1975; Yen, 1975), in addition to
scepticism (Bouchard & McGee, 1977; McGee, 1979). Recently however,
researchers tend to agree that spatial ability is due to environmental
conditions, and can be trained and improved (Dorval & Pepin, 1986; Lord,
1985; Salthouse & Mitchell, 1990; Smothergill, Hughes, & Timmons, 1975;
Brinkmann, 1966). In fact, more recent research has found that gender
differences are disappearing (Feingold, 1988), and others have indicated that
there might be alternative reasons for the gender differences (Burstein, Bank,
& Jarvik, 1980).

Research has shown that right handed people generally have greater
spatial ability than left handed people (McGee, 1976; Burnett, Lane, & Dratt,
1982; McKeever, 1986). However, Burnett, Lane, & Dratt (1982) have argued
that what should be looked at is not left handedness vs. right handedness, but
rather the continuum extending from extreme left handedness through
ambidexterity to extreme right handedness. When this continuum was
examined, Burnett, Lane, & Dratt (1982) found that both extreme left-handers
and extreme right-handers are at a disadvantage in terms of spatial ability.
Again the question of "why?" comes up, and researchers have looked toward
the brain for answers. Research has shown that, at least for females, the left
hemisphere of the brain is more related to spatial abilities than the right side
(Bowers & LaBarba, 1988; Sherman, 1974; Marino & McKeever, 1989), and
therefore right handed women have significantly better spatial abilities than
left handed women (McGee, 1976). However, the work by Burnett, Lane and Dratt (1982), indicated that extreme right handedness was just as bad as extreme left handedness in terms of spatial ability and suggests that "decreased hemispheric specialization is associated with increased spatial ability." (p. 57)

**Virtual Reality**

According to Biocca (1992), a goal of Virtual Reality is for the user to have a strong sense of presence. By presence, Biocca means that the user will have sensations of actually being in a given environment and will perceive the virtual objects as being equally present. Shapiro and McDonald (1992) add that not only does VR have "the potential to involve users in sensory worlds that are indistinguishable or nearly indistinguishable from the real world. In addition, Virtual Reality environments may even merge with the real world." (p. 94) This meshing of Virtual Reality with the actual reality may be even more confusing to users than a simple hierarchical menuing structure, such as in DOS (Vincente, Hayes, & Williges, 1987), and a high spatial ability may be even more crucial for a successful interface. As Regian, Shebilske, & Monk (1992) point out, "The [VR] interface preserves (a) visual-spatial characteristics of the simulated world, and (b) the linkage between motor actions of the [user] and resulting effects in the simulated world." (p. 136) Therefore, those people with low spatial abilities will most likely be at a disadvantage in using a VR interface, and even those with moderate or high spatial abilities could benefit from an increase of those abilities.
Training spatial ability

Computers and video games have been used by researchers to improve the spatial ability of children (Slesnick, 1983) as well as adults. Rhoades (1981) indicated that training of spatial ability appeared possible, both directly and indirectly through coursework, but his work was not conclusive. Miller (1993) received results which indicated a partial, or near, transfer of training from a video game to spatial ability tests for college age students. In addition, computers and video games are now being used to train people to fly military fighter jets and helicopters and to perform other complex tasks, as well as improve their spatial ability (Gopher, 1992).

Dorval and Pepin (1986) conducted a study which used a computer game that was not Virtual Reality, but a 3D simulation. In order to study the effects of playing a video game on spatial visualization, they took students who had no prior experience of video game playing and tested them on the Space Relations Test of the Differential Aptitude Test (DAT). The subjects were then randomly divided into either an experimental or a control group. For six weeks the subjects in the experimental group played a video game (Zaxxon, on Colecovision) five times per session, over eight sessions. The frequency of the sessions was determined by the subjects, but consisted of at least one a week and no more than two in any one week. The game, Zaxxon, was chosen because it was one of the few three-dimensional games available at the time, and had relatively high face validity for spatial visualization. The object of Zaxxon is to control a spaceship in three-dimensional space, the goal being to shoot the enemies while avoiding the the enemies' shots and any stationary objects. Both groups were again tested on an alternate form of the
Space Relations test of the DAT six weeks later.

In the Dorval and Pepin (1986) study, the experimental group improved their spatial ability significantly compared with the control group. In addition, there were no gender differences in spatial ability in either the pretest or the posttest, and the men and women in the study improved equally from the training.

Miller (1993) attempted to replicate this study using a different video game called Block Out. It, too, was chosen for its high face validity for spatial visualization. Miller also used two different spatial tests rather than the one used by Dorval and Pepin, the Guilford-Zimmerman test and the Identical Blocks test.

In that study, subjects took pretests of both spatial ability tests and were divided into control and experimental conditions. The subjects in the experimental condition then returned five times a week for four weeks to train using the video game. The subjects in the control group underwent no training, but were asked to not play the game. Each training session lasted one hour, for a total of twenty hours of training. At the end of the month, the subjects returned and took the posttest of the two spatial tests.

The experimental group showed a significant improvement on the Identical Blocks test, but not the Guilford-Zimmerman test. It was suggested that this "near" transfer took place due to the similarity between the blocks used in the video game and the blocks used in the spatial test. However, the "far" transfer to the Guilford-Zimmerman test did not occur due to the different nature of the target to be rotated. Whereas the video game used blocks, the Guilford-Zimmerman test used old style alarm clocks. These results, in conjunction with others mentioned above (Dorval and Pepin, 1986;
Slesnick, 1983; Vincente, Hayes, & Williges, 1987) indicate that spatial ability can in fact be trained, and improved upon. However, it should be noted that in none of the literature on training spatial ability has there been any mention of successful transfer of that training, other than the near transfer Miller (1993) received. This present study will attempt to train and improve the spatial ability, specifically the spatial orientation, of the subjects in the experimental condition, with the purpose of increasing their efficiency in a virtual environment. Further, this study will attempt to get transfer of training from the spatial tests the subjects trained on to a new spatial test that they have not seen before.

**Hypotheses**

1. The first hypothesis is that it is possible to train a person’s spatial ability, and therefore the experimental subjects will show a greater improvement on the composite spatial test than the control subjects.

2. The second hypothesis states that this training is actually an improvement in those subjects’ spatial ability, rather than an improvement in their ability to take those seven tests, as shown by the experimental subjects higher score on a new spatial test.

3. The third hypothesis is that the subjects’ scores on the spatial ability tests are positively correlated with their ability to navigate in a virtual environment.

4. The fourth and final hypothesis is that subjects in the experimental condition will show a greater improvement in their ability to navigate through the virtual environment than the subjects in the control condition.
METHOD

Subjects:

The subjects used in this experiment were 30 undergraduate students at Rice University. The students either fulfilled a course requirement by participating, and/or received a cash payment for their time. A lottery system was used so that five of the fifteen subjects in the experimental condition each received $50 in addition to fulfilling their course requirements. The other ten subjects in that condition, as well as the fifteen subjects in the control condition did not receive any money, but did fulfill their course requirements.

Measures:

The equipment used consisted of the Eliot-Price Board Block (Perspectives) Test (1978), the Eliot-Donnelly Test (1978), the Card Rotations Test (Ekstrom, French & Harmon, 1976a), the Cube Comparisons Test (Ekstrom, French & Harmon, 1976c), the Guilford-Zimmerman Aptitude Survey - Part 5 Spatial Orientation (1947), the Map Planning Test (Ekstrom, French & Harmon, 1976d), the Maze Tracing Speed Test (Ekstrom, French & Harmon, 1976e), and the Choosing a Path Test (Ekstrom, French & Harmon, 1976b).

Virtual Reality Measures:

Dave and Buster's Inc., an amusement hall with many video games, donated the use of their VR equipment, a game called Virtuality. The object of this game is to navigate through a virtual environment and hunt down
your opponent before you yourself are hunted down. Each game lasts four minutes, and can either be played alone against the computer, or by up to four people against each other. Subjects played alone, against the computer, during the pre- and posttests so that their scores were not confounded. Subjects played 3 games during the pretest, and 3 games during the posttest. Instructions on how to play were given prior to the subjects first game, and there was a video presenting all of the instructions repeatedly throughout the entire pretest.

To play the game, subjects wore a head-mounted display (HMD), as well as a belt pack. These tracked the players’ movements. The players stood in a ring and were free to turn their bodies around as well as duck, dodge or make any other movements of that sort. Walking was accomplished by holding down a button on the joystick. The HMD contained a stereo sound system which allows voice and other sounds to be heard by the player. This was an immersive system, meaning that the person could not see the outside world. The only evidence of the outside world was the occasional noise from the group watching.

The player’s task was to move around the arena, which had a center plane with steps leading up on all four sides to four other planes. Each plane had obstacles which must be avoided or utilized as something to hide behind. All players were free to move around the arena at will. In addition to the opponent, a pterodactyl sometimes appeared above, swooping down to attack the player. The player had to locate the pterodactyl and kill it before it killed the player. A record is kept of how many times the player killed his opponent, and how many times the player was killed. The subjects’ ability to
navigate in the virtual environment was quantified by using their score in the Virtuality game, which is the number of times they killed their opponent minus the number of times they were killed.

**Procedure:**

Subjects were required to attend a general instructions meeting where they were told that half of the group would be involved in the experiment for a full month and would need to return five times a week for the duration of the month; the other half of the group would just be required to return once, a month later. They were informed that the amount of their compensation would depend on to which group they were assigned. They were also told that the assignment to groups would be random, and that if they could not be in either of the groups, whichever they are assigned to, they should leave before the experiment started. Next, the subjects were each given a consent form to fill out and sign, as well as a questionnaire about their game playing experience (See Appendix A).

After the subjects turned in their consent form and questionnaire, they were given a pretest of spatial ability. This pretest was a composite test made up of questions from each of the seven tests to be used by the experimental group for training: the Eliot-Price Board Block (Perspectives) Test, the Eliot-Donnelly Test, the Cube Comparisons Test, the Guilford-Zimmerman Aptitude Survey - Part 5 Spatial Orientation, the Map Planning Test, the Maze Tracing Speed Test, and the Choosing a Path Test (See Appendix B). Pilot tests had determined how much time was required by the average person to complete each of these sections, and each section was individually timed to
allow less than the needed amount of time in order to ensure that there would be no ceiling effects (i.e. subjects scoring very well on the pretest and leaving little or no room for improvement on the posttest).

The composite test was checked for reliability using an odd/even split half model as per Nunnally and Bernstein’s (1994) suggestions on testing the reliability of speeded tests. The correlation between the odd and even halves of the pretest was .71, corrected using the Spearman-Brown formula for split half models to .83. For the post test the uncorrected correlation was .75, and the corrected correlation was .86.

After the composite spatial ability pretest was completed, times were determined for the subjects to take their pretest of Virtuality. The subjects were then randomly divided into control and experimental conditions. The list of which subjects were in the control condition was then read off, and they were excused and reminded of the session for their Virtuality pretest. The subjects in the control group were told that they would be called back in approximately one month in order to complete the experiment. The subjects in the remaining, experimental group were told that they would be required to show up for the experiment five days a week, for a total of four weeks, and that each session would last approximately 45 minutes for a total of 15 hours of training per subject. Times were then established throughout the week so that all 15 subjects could make five sessions per week. There were a total of 12 sessions, two a day from Monday through Saturday. The subjects were required to attend five of those 12 sessions each week, but were encouraged to not go to more than one session per day. In a few rare instances, subjects did come to more than one session per day in order to attend the appropriate number of sessions for the month.
At each session, the subjects were given one of the spatial orientation tests. After the test was completed, the answers were read aloud and the subjects scored their answers. Whenever a subject got a wrong answer, time was taken to go over that problem and discuss what was done wrong, and what should be done to get it right. The experimenter as well as the other subjects participated in explaining why that answer was incorrect. After the subject understood, the rest of the answers were read until there was another incorrect answer.

After the test was scored, the subjects recorded their scores on a scoresheet which was used throughout the month to chart improvement. Then the subjects went around the room discussing the methods and strategies they used for solving the various problems. It was also pointed out which subjects did best and which strategies they used, and that was compared with the subjects who did not do as well and the strategies they used. Descriptions and a brief discussion of the various strategies used by the subjects on these tests can be found in Appendix C. All the subjects, particularly those who did not do the best, were encouraged to try all the other strategies, especially those used by the high scorers, over the month-long training period. If there was enough time in the session, which there usually was, another spatial test was administered and the same procedures were repeated. The tests were rotated each day, so that by the end of the month each test had been taken an average of six times. There were two tests, however on which the subjects all got perfect scores after the third or fourth time. Those tests were skipped during the third week (or the remainder thereof) and were taken again during the fourth week with no decrement in
scores. This procedure was followed to provide additional training on those tests that were more difficult and had not been finished.

The composite spatial ability pretest was to be used again as a spatial ability composite posttest. Therefore the questions on the composite test were not in the training materials, as that would give the subjects in the experimental condition practice on those specific problems rather than on the skill in general.

At the end of the four weeks, the subjects in both the experimental and control groups took the spatial ability composite posttest as well as the Card Rotations Test, which none of them had ever seen before. Within the next few days they were taken back to Dave and Buster's to take the posttest of Virtuality. As before, the subjects each played three four-minute games and their score was the average of the three games. After the posttest the subjects were paid in cash and/or experimental credits. The subjects then received a debriefing, and were given the opportunity to ask any questions.

The Virtual Reality pre- and posttests were checked for reliability by calculating Cronbach's alpha for each of the tests. For the pretest, alpha was .41, for the posttest it was .60. A correlation matrix of the VR scores by trial can be seen in Table 1.

RESULTS

In order to accurately measure the subjects' performance on the composite spatial ability tests, z scores were calculated for each of the seven sections, and then averaged together to give each subject one score for spatial
TABLE 1.

Correlation Matrix for individual VR trials.

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.  VR pretest 1</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.  VR pretest 2</td>
<td>.21</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.  VR pretest 3</td>
<td>.07</td>
<td>.30</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.  VR posttest 1</td>
<td>.15</td>
<td>.57**</td>
<td>.14</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.  VR posttest 2</td>
<td>-.01</td>
<td>.34</td>
<td>.31</td>
<td>.45*</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>6.  VR posttest 3</td>
<td>.02</td>
<td>.46*</td>
<td>.51**</td>
<td>.25</td>
<td>.30</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*p<.05   **p<.01
n=30
ability. A simple summation of the scores from the seven different sections of the test was not appropriate since the sections did not have equal numbers of questions. A sum would have more heavily weighted those sections of the test that had more, easier, questions compared to a section which had fewer, more difficult, questions. Computing the percentage correct in each section and then averaging those values together was also not a valid technique for the opposite reason: because it would weight the sections with fewer questions more than it would weight the sections with many questions. Therefore, z scores were computed for each section of the pretest. For the posttest, z scores were again computed, but the original means and standard deviations from the pretest were used so that difference scores could be accurately calculated. All further mention of spatial ability scores in this paper will be the z scores as calculated above unless otherwise noted. The VR scores, however, were not z scores: they were simply the average of the scores on that test. For example, the VR pretest score is the average of the subject's three scores for the three times the subject took the VR pretest.

Descriptive statistics for the VR pre- and posttests, the spatial pre- and posttests, the new spatial posttest (Card Rotations Test), as well as the spatial and VR difference scores can be found in Table 2, broken down by group. A correlation matrix for those variables can be found in Table 3 (the correlations were computed across groups).

The first hypothesis states that spatial ability is trainable. The mean score of the control group on the spatial posttest was .43, for the experimental group
TABLE 2.
Descriptive statistics of VR and Spatial tests.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Min.</th>
<th>Max.</th>
<th>Range</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR pretest</td>
<td>2.87</td>
<td>1.77</td>
<td>-33</td>
<td>7.33</td>
<td>7.66</td>
<td>.41</td>
</tr>
<tr>
<td>(control)</td>
<td>3.49</td>
<td>1.89</td>
<td>-33</td>
<td>7.33</td>
<td>7.66</td>
<td></td>
</tr>
<tr>
<td>(experimental)</td>
<td>2.25</td>
<td>1.43</td>
<td>-33</td>
<td>5.0</td>
<td>5.33</td>
<td></td>
</tr>
<tr>
<td>VR posttest</td>
<td>5.54</td>
<td>2.41</td>
<td>1.00</td>
<td>10.33</td>
<td>9.33</td>
<td>.60</td>
</tr>
<tr>
<td>(control)</td>
<td>6.09</td>
<td>2.40</td>
<td>2.00</td>
<td>10.33</td>
<td>8.33</td>
<td></td>
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<tr>
<td>(experimental)</td>
<td>5.00</td>
<td>2.37</td>
<td>1.00</td>
<td>9.33</td>
<td>8.33</td>
<td></td>
</tr>
<tr>
<td>VR difference</td>
<td>2.68</td>
<td>2.10</td>
<td>-1.67</td>
<td>7.00</td>
<td>8.67</td>
<td>---</td>
</tr>
<tr>
<td>(control)</td>
<td>2.60</td>
<td>1.76</td>
<td>-34</td>
<td>5.33</td>
<td>5.67</td>
<td></td>
</tr>
<tr>
<td>(experimental)</td>
<td>2.76</td>
<td>2.46</td>
<td>-1.67</td>
<td>7.00</td>
<td>8.67</td>
<td></td>
</tr>
<tr>
<td>Spatial pretest (z)</td>
<td>.00</td>
<td>.52</td>
<td>-93</td>
<td>1.01</td>
<td>1.94</td>
<td>.83</td>
</tr>
<tr>
<td>(control)</td>
<td>-.02</td>
<td>.54</td>
<td>-93</td>
<td>1.01</td>
<td>1.94</td>
<td></td>
</tr>
<tr>
<td>(experimental)</td>
<td>.02</td>
<td>.52</td>
<td>-88</td>
<td>.70</td>
<td>1.58</td>
<td></td>
</tr>
<tr>
<td>Spatial posttest (z)</td>
<td>.90</td>
<td>.65</td>
<td>-45</td>
<td>2.07</td>
<td>2.52</td>
<td>.86</td>
</tr>
<tr>
<td>(control)</td>
<td>.43</td>
<td>.47</td>
<td>-45</td>
<td>1.18</td>
<td>1.63</td>
<td></td>
</tr>
<tr>
<td>(experimental)</td>
<td>1.37</td>
<td>.41</td>
<td>.64</td>
<td>2.07</td>
<td>1.43</td>
<td></td>
</tr>
<tr>
<td>Spatial difference (z)</td>
<td>.90</td>
<td>.60</td>
<td>-24</td>
<td>2.34</td>
<td>2.58</td>
<td>---</td>
</tr>
<tr>
<td>(control)</td>
<td>.45</td>
<td>.35</td>
<td>-24</td>
<td>1.1</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td>(experimental)</td>
<td>1.35</td>
<td>.45</td>
<td>.87</td>
<td>2.34</td>
<td>1.47</td>
<td></td>
</tr>
<tr>
<td>New Spatial test*</td>
<td>135.07</td>
<td>18.75</td>
<td>83</td>
<td>158</td>
<td>75</td>
<td>.96</td>
</tr>
<tr>
<td>(control)</td>
<td>128.47</td>
<td>19.57</td>
<td>83</td>
<td>156</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>(experimental)**</td>
<td>142.14</td>
<td>15.52</td>
<td>111</td>
<td>158</td>
<td>47</td>
<td></td>
</tr>
</tbody>
</table>

* With outlier excluded, n = 29.

** With outlier excluded, n = 14.
n=30 for each test; n=15 for each group
TABLE 3.

Correlation Matrix for VR and Spatial tests.

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. VR pretest</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. VR posttest</td>
<td>.53**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. VR difference</td>
<td>-.23</td>
<td>.70**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Spatial pretest (z)</td>
<td>.20</td>
<td>.12</td>
<td>-.02</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Spatial posttest (z)</td>
<td>-.20</td>
<td>-.19</td>
<td>-.05</td>
<td>.48**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Spatial difference (z)</td>
<td>-.38*</td>
<td>-.31</td>
<td>-.03</td>
<td>-.34</td>
<td>.66**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>7. New Spatial test ***</td>
<td>-.14</td>
<td>-.10</td>
<td>.00</td>
<td>.46*</td>
<td>.67**</td>
<td>.35</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*p<.05   **p<.01   ***outlier excluded, n=29.
n=30
it was 1.37. An Analysis of Covariance (ANCOVA) was performed, factoring out the subjects' spatial pretest scores from their spatial posttest scores. The adjusted least square mean of the control group was .44; for the experimental group it was 1.36. The analysis showed that the experimental group improved significantly more than the control group. (F=56.17, p<.001). See Table 4. This improvement is shown in Figure 1.

The second hypothesis states that this improvement was not merely an artifact of the experimental subjects' training on these tests (different questions), but was actually an improvement in their spatial ability. However, one subject was an outlier, scoring over five standard deviations below the mean. It is not clear whether the subject misunderstood the directions for the test or exactly what the problem was; but that subject's data on that test was thrown out. In order to test this hypothesis an Analysis of Variance (ANOVA) was performed on the two groups' performances on the new posttest. With the outlier removed, the mean of the experimental group was 142.14, compared to 128.47 for the control group, yielding an F-ratio of 4.31, which is significant at p=.048. See Table 5. A box plot of these scores by condition can be seen in Figure 2.

The third hypothesis was that the subjects' scores on the spatial ability tests will be positively correlated with their ability to navigate in a virtual environment. To test this hypothesis, the correlation between the spatial pretest and the VR pretest (r=.20, 95% conf: -.18 ≤ ρ ≤ .58), the spatial posttest and the VR posttest (r=-.19, p=.32), and the two difference scores (r=-.03, p=.86) were calculated.
TABLE 4.

ANCOVA of spatial posttest scores (z), factoring out the spatial pretest scores (z).

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>6.28</td>
<td>1</td>
<td>6.28</td>
<td>56.17</td>
<td>.001</td>
</tr>
<tr>
<td>Pretest</td>
<td>2.49</td>
<td>1</td>
<td>2.49</td>
<td>22.31</td>
<td>.001</td>
</tr>
<tr>
<td>Error</td>
<td>3.02</td>
<td>27</td>
<td>.11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=30
FIGURE 1.

Plot of spatial pre- and posttest scores by condition.

TABLE 5.

ANOVA of the new posttest by condition.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>1354.41</td>
<td>1</td>
<td>1354.41</td>
<td>4.31</td>
<td>.048</td>
</tr>
<tr>
<td>Error</td>
<td>8491.45</td>
<td>27</td>
<td>314.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=29 - the outlier is not included
FIGURE 2.

Box plot of the new posttest by condition.
The fourth hypothesis was that subjects in the experimental condition would show a greater improvement in their ability to navigate through the virtual environment than the subjects in the control condition, due to their increased spatial ability. To test this an ANCOVA was performed, covarying out VR pretest scores from the VR posttest scores. The analysis showed that the adjusted mean for the control group was 5.65 and for the experimental group 5.44 (F<1). See Table 6.

In addition, the demographic data collected on the questionnaire was analyzed. Although there was no effect of age or year in school, there was a significant effect of gender on VR pretest (F=5.64, p=.02) and VR posttest (F=7.70, p=.01) performance, with the men scoring higher on both. There was however, no difference on the VR improvement scores for the males as compared to the females. When the spatial pretest scores and the subjects' self reported game experience were factored out of the VR pretest scores, the gender difference was no longer significant (F=2.86, p=.10). See Table 7. On the composite spatial pretest, males scored an average of .123 and females scored an average of -.124 (F=1.75, p=.20). See Figure 3. On the composite spatial posttest, males scored an average of .97 and females scored an average of .83 (F<1). Regarding the improvement of spatial ability, males scored an average of .85 and females scored an average of .95 (F<1) on the difference between the composite pre- and posttests. On the new spatial posttest, males scored an average of 137.80 and females scored an average of 132.14 (F<1).
TABLE 6.

ANCOVA of VR posttest score, factoring out the VR pretest score.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>.31</td>
<td>1</td>
<td>.31</td>
<td>.07</td>
<td>.79 (n.s.)</td>
</tr>
<tr>
<td>VR Pretest</td>
<td>38.62</td>
<td>1</td>
<td>38.62</td>
<td>8.63</td>
<td>.01</td>
</tr>
<tr>
<td>Error</td>
<td>120.89</td>
<td>27</td>
<td>4.48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=30
FIGURE 3.

Box plot of the spatial ability composite pretest scores by gender.
TABLE 7.

ANCOVA of VR pretest score by gender, factoring out the spatial pretest score and the subjects' ratings of their game experience.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F ratio</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>8.17</td>
<td>1</td>
<td>8.17</td>
<td>2.86</td>
<td>.10 (n.s.)</td>
</tr>
<tr>
<td>Spatial pretest</td>
<td>4.27</td>
<td>1</td>
<td>4.27</td>
<td>1.50</td>
<td>.23 (n.s.)</td>
</tr>
<tr>
<td>Game exp.</td>
<td>4.48</td>
<td>1</td>
<td>4.48</td>
<td>1.57</td>
<td>.22 (n.s.)</td>
</tr>
<tr>
<td>Error</td>
<td>74.20</td>
<td>26</td>
<td>2.85</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n=30
DISCUSSION

Previous research in this field has been somewhat mixed as to whether spatial ability can be trained. The first hypothesis of this thesis states that spatial ability is in fact trainable. This hypothesis was supported, with the experimental group improving significantly more than the control group on the composite spatial abilities test. This is not a surprising fact given the results of recent literature, which has found that spatial ability can be improved. Hypothesis two, however, attempts to extend the training of spatial ability by transferring it to a new spatial ability test. One could argue that although the specific questions given in the pre- and posttest were not used in the training of the subjects in the experimental condition, through continued exposure to the tests, those subjects could have learned some of the quirks or special strategies which can be applied to those tests. Therefore, the argument would continue, those subjects may score better on the posttest without actually improving their spatial ability.

However, hypothesis two states that the experimental group will out perform the control group on a new spatial test, with item types the subjects had never seen before. Further, the strategies the subjects learned during the training were specific to the tests they were taking and could not be easily transferred to this new test. This hypothesis was supported, indicating that the experimental treatment did raise spatial ability.

The third hypothesis makes the link from the spatial ability of the subjects to the virtual reality navigational ability of the subjects. It states that there should be a correlation between the scores on the spatial pretest and the
VR pretest, as well as between the spatial posttest and the VR posttest, and further, between the spatial difference score and the VR difference score. However, none of these correlations was significant, indicating, surprisingly, that there is no connection between spatial ability and the ability to navigate through a virtual environment. Possible reasons for this finding will be discussed below.

The fourth hypothesis assumes that there is a connection between spatial ability and VR ability, and states that since the experimental group will improve more on their spatial ability, they will also increase more on their ability to navigate through the VR environment. However, with the lack of a connection between spatial ability and VR ability as discussed with hypothesis three, it is not unexpected that there was no significant difference between the two groups' improvement in their ability to navigate in the virtual environment.

The remaining question, however, is why there was no link between spatial ability and the subjects' ability to navigate in the virtual environment. The reasons to expect that such a link exists in the first place are based primarily on previous research. Vincente, Hayes and Williges (1987) found that people with low spatial ability got lost navigating through a DOS based interface, compared to people with high spatial ability. Dorval and Pepin (1986) found that training on a 3D game, similar to a non-immersive, very low VR situation, increased the subjects' spatial ability. In addition, spatial ability has been correlated with a very wide variety of areas, from mathematical ability to athletic and musical ability, all of which are part of people's everyday lives. According to Biocca (1992) a goal of VR is to give the
users a sense of presence, to make them feel as though they are actually in
that environment with the virtual objects. Shapiro and McDonald (1992)
continue by saying that VR has the potential to present worlds which are
virtually indistinguishable from the real world. Regian, Shebilske and Monk
(1992) agree, stating that the VR interface can preserve both the visual-spatial
characteristics as well as the linkage between motor actions of the user and
the resulting effects in the simulated world. From all this, it is clear that just
as in the real world, high spatial ability should lead to a better ability to
navigate through a virtual world, just as it helps users navigate through the
DOS hierarchy.

However, this study does not support that assumption, and several
possible explanations can be given. First of all, due to the limited amount of
time available on the VR equipment, each subject was only given three trials
for the pretest and three trials for the posttest. The inter-trial correlations
shown in Table 1 show a general increase in correlations from trial to trial,
indicating that perhaps the subjects were still learning how to use the VR
equipment. Since they would still be at the steep part of their learning curve
the inter-trial variability would be very high, leading to a high error term,
and non-significant results. Perhaps if the subjects were given more time to
learn and become familiar with the VR equipment their scores would
asymptote. Then it would be more appropriate to look for a significant
correlation with spatial ability, and perhaps it would be found. Ackerman’s
(1991) phases of skill acquisition provides a theoretical framework for this
explanation: phase one starts with the subjects’ “initial confrontation with
the task.” In this phase the subjects begin to “understand the basic task
requirements." If there is not enough training, the subjects might not reach phase two where associations are formed and the subjects learn how to accomplish the task more efficiently. Using Ackerman's (1991) model as a backdrop, one could see how the subjects would be getting used to the VR equipment in phase one, and not bringing in their spatial ability until phase two. Without enough time spent training on the VR equipment, some subjects might have never reached phase two, and therefore there would be no correlation between spatial ability and VR ability.

Secondly, the above researchers discuss the goals and potentials of Virtual Reality, not the current state of the technology. If the virtual environments used in this experiment were not of a high enough quality to convince the users that "they were actually there," then Biocca's goal and Shapiro and McDonald's potential were never reached. If the users were not presented with a high fidelity simulation of the real world, then it is no surprise that there was no correlation with performance in that environment, even if there is a strong connection with spatial ability and the real world.

It should also be noted that in previous research there has been some disagreement over whether spatial ability differs across genders, with some researchers (e.g., Jensen, 1978) arguing that the difference is actually biologically based. More recent research (e.g., Lord, 1985), however, has shown that the differences, if existent at all, are merely sociologically based, with the most recent research (e.g., Feingold, 1988) showing that gender differences are disappearing altogether. This research supports the most recent findings in this field. There were no gender differences with respect to
spatial ability.

Collapsed across groups, there were correlations between gender and VR performance on both the VR pretest and the VR posttest. However, when the spatial pretest scores and the ratings of game experience were factored out of the VR pretest scores, the gender difference was not significant.

This paper has supported the recent literature in finding that spatial ability can in fact be trained and improved. Further, this research has found that this improvement is not simply an improvement on a specific test or set of tests, but on spatial ability in general. In that respect, this study contributes an important finding to the literature. All other studies use some other means, such as a computer or video game, to train spatial ability and the results are based on a pre- and posttest of the same type of spatial test. This study used a battery of seven different spatial ability tests in order to train it's subjects. The successful transfer to a new spatial test is no doubt the result of the varied training given by those tests. Whereas other methods of training have used one approach, this method benefitted from the seven pronged training regimen. This is not surprising considering the findings of Schmidt and Bjork (1992) who found that variety in the training regimen led to greater performance at test time.

Contrary to previous literature, no correlation was found between spatial ability and performance in a virtual environment. Possible causes for this are: 1) not enough VR trials to flatten the learning curve; 2) a virtual environment which was not “real” enough to facilitate transfer; or 3) spatial ability is simply not correlated with performance in a virtual environment. In light of the other work which has been done in this area, as well as the increasing correlations among the VR trials, causes one and two are the most
likely. Future research should be conducted to look at spatial ability and performance in a much more realistic virtual environment, while allowing the subjects more time to adapt to the VR interface.
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249-255.


APPENDIX A - QUESTIONNAIRE

Name: ___________________  Phone Number: ___________________

Major: ___________________  Class Year:   1  2  3  4

Course: ___________________

Gender:  male  female  Age:  __________

Do you consider yourself primarily:
  Left handed  Right handed  Ambidextrous

How much experience do you have playing these video games:

<table>
<thead>
<tr>
<th></th>
<th>none</th>
<th>hardly any</th>
<th>some</th>
<th>a lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Tetris</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2. Space Invaders</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3. Street Fighter</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Nintendo /</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Genesis sports</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Jewel Box</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>6. Steel Talons</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>7. Widelris</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>8. Fatal Fury</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>9. The Simpsons</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>10. Pinball</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>machines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Terminator 2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>12. Block Out</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>13. X-Men</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>14. Mercs</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>15. Teenage</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Mutant Ninja Turtles</td>
<td></td>
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<tr>
<td>16. Driving</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>simulators</td>
<td></td>
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<td>17. Wheel of</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fortune</td>
<td></td>
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<td>18. Any text based</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>adventure game</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Virtuality</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>20. Missile</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Command</td>
<td></td>
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</tr>
</tbody>
</table>
APPENDIX B - COMPOSITE SPATIAL PRE- AND POSTTEST

This test examines your ability to imagine objects from different perspectives.

For each problem in the test, you must imagine that a wooden chair has been positioned in the middle of a room measuring twelve units (feet) square by ten units (feet) high. Each problem in the test will present you with a drawing of the chair and a diagram of the room.

Note the dots (marked A, B, C, D, or E) in the example problem below. These dots represent holes bored through the walls, ceiling, and floor of the room to allow you to see the chair from outside the room. To facilitate orientation in the right hand drawing, the location of the holes is described next to the drawing. Your task is to select the hole through which you must look in order to see the chair as it appears in the drawing to the left.

![Diagram of a chair with holes marked A, B, C, D, and E]

A. Front  
B. Front  
C. Rear  
D. Ceiling  
E. Floor

To solve the sample problem, look at the drawing and decide where your eye would have to be in relation to the chair. You would be in front of the chair, slightly to the left of it, and quite low - a bit below the level of the seat of the chair. If you were to look from point A, you would not see any part of the chair's right side; if you were to look from point C or point D, you would not see any part of the underside of the seat; if you were to look from point E in the floor, you would see more of the side and more of the underside of the seat. The correct choice is point B.

Now try to solve the 24 problems of this test.  Mark your answers on the answer sheet by circling the appropriate letter.
CUBE COMPARISONS TEST -- S-2 (Rev.)

Wooden blocks such as children play with are often cubical with a different letter, number, or symbol on each of the six faces (top, bottom, four sides). Each problem in this test consists of drawings of pairs of cubes or blocks of this kind. Remember, there is a different design, number, or letter on each face of a given cube or block. Compare the two cubes in each pair below.

The first pair is marked D because they must be drawings of different cubes. If the left cube is turned so that the A is upright and facing you, the N would be to the left of the A and hidden, not to the right of the A as is shown on the hidden hand member of the pair. Thus, the drawings must be of different cubes.

The second pair is marked S because they could be drawings of the same cube. That is, if the A is turned on its side the X becomes hidden, the B is now on top, and the C (which was hidden) now appears. Thus the two drawings could be of the same cube.

Note: No letters, numbers, or symbols appear on more than one face of a given cube. Except for that, any letter, number or symbol can be on the hidden faces of a cube.

Work the three examples below.

The first pair immediately above should be marked D because the X cannot be at the peak of the A on the left hand drawing and at the base of the A on the right hand drawing. The second pair is "different" because F has its side next to C on the left hand cube but its top next to C on the right hand cube. The blocks in the third pair are the same, the J and K are just turned on their side, moving the O to the top.

Your score on this test will be the number marked correctly minus the number marked incorrectly. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct. Work as quickly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP.

DO NOT TURN THE PAGE UNTIL YOU ARE ASKED TO DO SO.
MAP PLANNING TEST — SS-3

This is a test of your ability to find the shortest route between two places as quickly as possible. The drawing below is a map of a city. The dark lines are streets. The circles are road-blocks, and you cannot pass at the places where there are circles. The numbered squares are buildings. You are to find the shortest route between two lettered points. The number on the building passed is your answer.

Rules: 1. The shortest route will always pass along the side of one and only one of the numbered buildings.
2. A building is not considered as having been passed if a route passes only a corner and not a side.
3. The same numbered building may be used on more than one route.

Look at the sample map below. Practice by finding the shortest route between the various points listed at the right of the map. The first problem has been marked correctly.

```
A \[\ldots\] B \[\ldots\] C \[\ldots\] D \[\ldots\] E \[\ldots\] F \[\ldots\] G \[\ldots\] H

I

J

K

L

M

V \[\ldots\] W \[\ldots\] X \[\ldots\] Y \[\ldots\] Z

The shortest route from:  

1. A to Z  
2. E to S  
3. P to J  
4. V to K  
5. O to F  
6. G to M  
7. D to Q  
8. F to T  

Passes building:  
1.  
2.  
3.  
4.  
5.  
6.  
7.  
8.  

The answers to the other practice problems are as follows: 2 passes 5; 3 passes 3; 4 passes 2; 5 passes 4; 6 passes 4; 7 passes 6; 8 passes 5.

Your score on this test will be the number of right answers. It will not be to your advantage to guess unless you have some idea which route is correct. Work as rapidly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has one page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.
CHOO SING A PATH -- SS-2

This is a test of your ability to choose a correct path from among several choices. In the picture below is a box with dots marked S and F. S is the starting point and F is the finish. You are to follow the line from S, through the circle at the top of the picture and back to F.

In the problems in this test there will be five such boxes. Only one box will have a line from the S, through the circle, and back to the F in the same box. Dots on the lines show the only places where connections can be made between lines. If lines meet or cross where there is no dot, there is no connection between the lines. Now try this example. Show which box has the line through the circle by blackening the space at the lower right of that box.

The first box is the one which has the line from S, through the circle, and back to F. The space lettered A has therefore been blackened.

Each diagram in the test has only one box which has a line through the circle and back to the F. Some lines are wrong because they lead to a dead end. Some lines are wrong because they come back to the box without going through the circle. Some lines are wrong because they lead to other boxes that do not have lines going through the circle.

GO ON TO THE NEXT PAGE
MAZE TRACING SPEED TEST — SS-1

This is a test of your ability to find a path through a maze quickly. You are to draw a pencil line through each maze without having to cross any printed lines.

Look at the two drawings below. In the left square a pencil line has been drawn to show the correct path from top to bottom. The square on the right shows an incorrect path. It is incorrect because the pencil line crosses a printed line.

Correct

Incorrect

Practice for speed on the squares below. Remember, you must make a pencil line through each square without having to cross a printed line.

Your score on this test will be the number of squares through which a line has been correctly drawn. If you should become stuck in any square, you may skip to the following one. You should try to avoid making mistakes, but you will not be penalized for lifting your pencil, for retracing a path that leads to a dead end, or for accidentally crossing lines at the sides of the path being taken. Work as quickly as you can without sacrificing accuracy. On the test, follow the squares around the page the way that they are connected, starting at the top of the left-hand column.

You will have 3 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.
WAIT BEFORE YOU TURN THE PAGE
The Guilford-Zimmerman Aptitude Survey

Part 5/Spatial Orientation

INSTRUCTIONS.
This is a test of your ability to see changes in direction and position. In each item you are to note how the position of the boat has changed in the second picture from the original position in the first picture.

Here is Sample Item 1.

These bars represent the boat’s prow.

This is the correct answer. It shows that the prow of the boat has dropped below the aiming point.

(If the prow had risen, instead of dropped, the correct answer would have been C, instead of D.)

These are the five possible answers to the item

A  
B  
C  
D  
E  

This is the prow (front end) of a motor boat in which you are riding.

This is the aiming point. It is the exact spot you would see on land if you sighted right over the point of the prow.

This is the same aiming point shown above. Note that the prow has dropped below it.

Sample Item 1

To work each item: First, look at the top picture and see where the motor boat is headed. Second, look at the bottom picture and note the CHANGE in the boat’s heading. Third, mark the answer that shows the same change on the separate answer sheet.

Try Sample Item 2.

This also shows that the prow of the boat is to the right of the aiming point. So, it is the correct answer.

(If the boat had turned to the left, instead of to the right, the correct answer would have been A.)

A  
B  
C  
D  
E  

This is the aiming point.

This is the same aiming point. The motor boat is now headed to the right of it.

Sample Item 2
APPENDIX C - NEW SPATIAL POSTTEST

CARD ROTATIONS TEST — S-1 (Rev.)

This is a test of your ability to see differences in figures. Look at the 5 triangle-shaped cards drawn below.

All of these drawings are of the same card, which has been slid around into different positions on the page.

Now look at the 2 cards below:

These two cards are not alike. The first cannot be made to look like the second by sliding it around on the page. It would have to be clipped over or cased differently.

Each problem in this test consists of one card on the left of a vertical line and eight cards on the right. You are to decide whether each of the eight cards on the right is the same as or different from the card at the left. Mark the box beside the S if it is the same as the one at the beginning of the row. Mark the box beside the D if it is different from the one at the beginning of the row.

Practice on the following rows. The first row has been correctly marked for you.

Your score on this test will be the number of items answered correctly minus the number answered incorrectly. Therefore, it will not be to your advantage to guess, unless you have some idea whether the card is the same or different. Work as quickly as you can without sacrificing accuracy.

You will have 3 minutes for each of the two parts of this test. Each part has 1 page. When you have finished Part 1, STOP. Please do not go on to Part 2 until you are asked to do so.

DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.
APPENDIX D - STRATEGIES USED ON SPATIAL ABILITY TESTS.

Throughout the training phase of this experiment, the subjects discussed the various strategies they had used for the seven different spatial ability tests. This appendix will discuss those strategies, test by test, and point out, where possible, which ones led to better performance. It should be noted however, that it is not clear whether the strategy led to better performance, or whether better spatial ability led to the use of a specific strategy. Probably both occurred on various tests. For example, in the cube comparison test, the subjects who did the best were able to find a diagonal line cutting through the cube in three dimensions, and then rotate the cube along that diagonal once in order to determine the correct answer. However, most subjects were not able to conceptualize this diagonal line, presumably because they did not have the spatial ability to do so. Some strategies seem to work better for people with higher spatial ability, while others are more effective for people with lower spatial ability. The subjects in this study were encouraged to try all the different strategies discussed to see which one worked best for them.

The Eliot-Donnelly “Chair” Test:

• The instructions directed the subjects to imagine that the dots were holes in the walls, ceilings and floors of the room allowing you to see the chair from outside the room. “Your task is to select the hole through which you must look in order to see the chair as it appears in the drawing...”

• An alternative strategy which some of the subjects adopted was to imagine themselves sitting in the chair, and then looking around to see
where the dots were.

• There was no difference in the performance of the subjects based on which strategy they used. Both were effective, as the subjects quickly mastered this test.

The Cube Comparisons Test:

• The most basic strategy for this test was to simply rotate the cube 90 degrees at a time. So for example, first the subject would flip the cube up, and then rotate it to the left to see if it matched the first cube. This tended to be the first strategy tried by most subjects, although it was also the least efficient for most. Subjects with low spatial ability tended to do better using this strategy.

• By the end of the training, the most popular strategy consisted of looking at the orientation of specific letters and seeing if they matched the orientation of those letters on the other cube. For example the subject might notice that the tip of the “A” is pointing towards the top of the “M” in one cube, and look to see if it is in the other cube as well. This strategy allowed for some very quick judgements and was the best strategy for the majority of subjects.

• The most difficult strategy to employ consisted of “seeing” a three dimensional diagonal cutting through the cube. Rotating the cube along this diagonal allowed a very quick and accurate judgement of similarity between the two cubes. Very few of the subjects in the study, approximately two out of 15, were able to find this diagonal. The other subjects could either comprehend what these subjects were describing but not do it, or not even comprehend it at all. The subjects using this strategy did the best, but it’s not
clear whether they did so do to the strategy or to the spatial ability which allowed them to use the strategy.

Eliot-Price Board Block (Perspectives) Test:

- One strategy subjects used for this test was to look at one piece to determine approximately where they are viewing it from, and then to look at the surrounding pieces to narrow down the options to the correct choice.

- Another strategy used was to look for several pieces which are lined up, and then see where they are pointing to in order to determine the orientation. A variation on this method was to look for a big open area, and match that to the open area in the original drawing.

- The third strategy, which most of the subjects adopted by the end of the training, was to look at the board itself. If it’s not a circle, then see whether you are looking at a point or an edge. For example, if the board is a triangle, then if you are looking head on at a point, then there are only three possibilities. Similarly, if you are looking at a flat side head on, there are still only three possibilities. After that it was relatively easy for the subjects to determine the correct answer. This was the most efficient strategy.

Map Planning Test:

- When the subjects first started this test they tended to put a finger on the starting point and a finger on the ending point, and then move them together until they found the correct path. This was relatively slow, and therefore not very efficient.

- Some subjects would find the starting point, and then move in the
general direction of the ending point before actually finding it. This was possible since the letters around the outside of the map (the starting and ending points) were always in the same positions. As the subject’s gaze moved towards where the ending should be, the actual target would come into focus, if the subject got that far. Most subjects using this strategy just wrote down as their answer the first building they passed. This was very fast, but often led to incorrect answers.

• A similar strategy had subjects find the starting and ending points, and then travel from the start towards the finish, turning only when forced to. Some subjects using this strategy also just wrote down their answer as soon as they passed any building, leading to very fast, but often incorrect answers.

The Guilford-Zimmerman Aptitude Survey - Part 5/Spatial Orientation

• The first strategy used by most subjects was to break the problem down into three steps. First they would see if the picture has move up or down, then they would look to see if it move right or left, and finally they would try to determine if it was slanted, and if so which direction. They would then look at the answers and see if any of them matched the three descriptions they had (i.e. up, left, slanted down to the right).

• A similar strategy also broke the picture up into steps, but first the subjects would detect slant (the most difficult of the three steps) and then look at the answers, eliminating any that didn’t match the slant. This strategy was only marginally better than the first one.

• Some subjects pictured themselves actually being on the boat, and then determined how the surroundings look. Not all the subjects were able to use
this strategy, and some who did reported getting "seasick"! The subjects who
used this strategy performed the best, but again it's not clear if that's due to the
strategy itself, or simply to the high spatial ability which allowed them to use
that strategy.

The Maze Tracing Speed Test:

• The main difference in strategies dealt with the distance between where
  the eyes were focused and where the point of the pencil was. In addition,
  some subjects started from the end of each block, tracing backwards. These
  subjects tended to do better. For most of the training, and for the pre- and
  posttests, the subjects were asked to start from the beginning of each block.

• Some subjects kept the focus of the eyes and the tip of the pencil on the
  same spot, occasionally tracing into dead ends and then backtracking. Other
  subjects kept their eyes a little ahead of the pencil, scouting out possible dead
  ends if they were close. The pencil was almost always moving however.

• The most effective strategy for this test involved looking at the entire
  block, finding the correct path, and then tracing it with the pencil. These
  subjects did not start tracing until they had found the complete path through
  the block.

Choosing a Path Test:

• The first strategy tried by most of the subjects was simply to start with
  the first box, tracing through looking to see if any of the lines went through
  the circle and back to the box.

• The next strategy the tended to adopt was more efficient. They would
start from the circle, and then trace backwards to the boxes, looking for boxes that they could get to from both sides of the circle.

• The last strategy they tried was simply to look through the test for and problems that had lines leaving the circle on one side and go directly to a box, without any junctions. If there was such a line, then that box had to be the correct answer. Then the subjects would go back and use one of the previous strategies for the rest of the problems.