Adult-child Differences in Spatial Learning in an Immersive Virtual Environment as a Function of Field-of-view

by

Faith A. McCreary

Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science
in
Industrial and Systems Engineering

Robert Williges, Chair
Katherine Cennamo
Woodrow Barfield

November 6, 1997
Blacksburg, Virginia

Keywords: Virtual Reality, Virtual Environments, Head-mounted Displays, Age-related Differences, Gender-related Differences, Spatial Awareness, Route Learning, Simulator Sickness, Presence

Adult-Child Differences in Spatial Learning in an Immersive Virtual Environment as a Function of Field-of-view

Faith A. McCreary

(ABSTRACT)

Despite the potential of immersive virtual environments (VEs) as educational tools, little is known about how VE system parameters impact a child using the environment. Designers of VE applications targeted at children must rely on studies done with adults to guide their design decisions. The failure to understand how children differ from adults in their responses to VEs poses a serious obstacle to the design of effective learning environments for children.

The main goal of this research was to quantify the impact of varying one VE system parameter, field-of-view, on large-scale, spatial learning in middle elementary schoolchildren and the incidence of side-effects in that population in an immersive VE. The other goals of this research were to identify 1) how, and if, middle elementary schoolchildren's responses to this environment differ from that of adult participants, and 2) how, and if, gender changed participant performance and responses.

Adults and 7-9 year old children were taught a U-shaped route through a six room virtual house, while wearing a helmet mounted display (HMD). Participants viewed the environment under monoscopic conditions with the horizontal field-of-view (HFOV) of the display set at either 30 or 48 degrees. Head tracking was not enabled as the children were unable to maintain a normal head position while wearing the HMD. After the learning period, participants performed tasks designed to assess spatial knowledge of the space: 1) locomotion efficiency was measured by the number of collisions with objects, 2) landmark knowledge was measured by the participant's ability to recognize photos of objects found in the environment 3) route knowledge was measured by the participant's ability to correctly re-trace the route and name the sequence of landmarks along the route, 4) configuration knowledge was measured by the participant's ability to point to occluded landmarks, make spatial inferences, and construct a model of the environment. Participants also completed a simple questionnaire which assessed the incidence of equipment difficulties and side-effects, general enjoyment, and the sense of presence in the VE. Additionally, the participant's vision and balance was checked before and after immersion in the VE.

Locomotion, route knowledge, and configuration knowledge efficiency increased significantly with both age and FOV. At the smaller FOV, both adults and 7-9 year olds developed a significantly lesser degree of spatial knowledge, with the effect being amplified in the 7-9 year olds.   In general, the more sophisticated the level the spatial knowledge required by a task, the greater the impact of FOV and age, with configuration knowledge being achieved significantly less frequently than route knowledge. Gender also significantly impacted the development of configuration knowledge. Only landmark knowledge did not change with age, FOV, or gender.   Also, the incidence of VE balance side-effects decreased significantly with age and was impacted by gender. The incidence of equipment difficulties also decreased with age, with significantly more, and longer, breaks being taken by 7-9 year olds than by adults. Further, general enjoyment of VE immersion and presence decreased significantly with age.

DEDICATION

For Lorene Hodge McCreary (Grandma)
August 6, 1905 - August 9, 1997

ACKNOWLEDGMENTS

I would like to thank everyone who has provided encouragement and support during my graduate studies. I would especially like to thank my committee whose insight and unflagging support added immensely to this effort. Dr. Williges your constant guidance and encouragement throughout this research and during my graduate studies has helped me immeasurably; I especially appreciate your unfailing dedication to your students and your teaching abilities from which I have benefited greatly both in and out of the classroom. Dr. Cennamo, I especially thank you for the time you spent with me in the beginning when I was trying to organize my ideas and for your insightful comments on the many child-related issues in this project. Dr. Barfield your comments and questions have encouraged me to look at this research in new ways and challenged me to broaden my engineering horizons.

I would also like to thank all the children, especially Ella, Caitlin, Josh, and Lance, who participated in this research and made it such fun. I would also like to thank all the parents who took time from their busy schedules to bring their children into the laboratory for this study.

TABLE OF CONTENTS

ABSTRACT I

DEDICATION IV

ACKNOWLEDGMENTS V

TABLE OF CONTENTS VI

LIST OF FIGURES IX

LIST OF TABLES XI

LIST OF ACRONYMS XIII

CHAPTER 1. INTRODUCTION 1

CHILDREN IN IMMERSIVE ENVIRONMENTS 2
FIELD-OF-VIEW 5
    Studies in the Real World *5*
    Studies Using Virtual Worlds *6*
SPATIAL KNOWLEDGE AND ORIENTATION 9
    Spatial Knowledge in Children *11*
    Spatial Orientation in Virtual Environments *13*
PROBLEM STATEMENT 15
RESEARCH HYPOTHESES 17

CHAPTER 2. METHOD 21

EXPERIMENTAL DESIGN 21
DEPENDENT VARIABLES 22
    Spatial Knowledge *23*
    Incidence of Immersion Side-Effects *24*
    Incidence of Equipment Difficulties *24*
    General Enjoyment Rating *24*
    Presence Rating *24*
PARTICIPANTS 24
    Protection of Participant Rights *25*
MATERIALS AND APPARATUS 25
    Vision Tests *25*
    Balance Tests *25*
    Testing Environment *25*
    Virtual Environment *27*
    Post-immersion Questionnaire *30*
    Small-scale Model Construction Task *31*
PROCEDURE 31
    Pre-screening *31*
    Balance Tests *32*
    Virtual Environment Session *32*

Post-Immersion Tasks *35*
Post-Testing Period *36*
PILOT TESTING 37

CHAPTER 3. RESULTS 38

ANALYSIS OF SPATIAL KNOWLEDGE VARIABLES 38
Locomotion Efficiency Analysis *40*
Landmark Knowledge Analysis *40*
Route Knowledge Analysis *41*
Configuration Knowledge Analysis *45*
Analysis of Configuration Knowledge Criterion Measure *55*
Performance Speed Analysis *59*
ANALYSIS OF GENERAL ENJOYMENT MEASURE 61
ANALYSIS OF PRESENCE MEASURE 64
ANALYSIS OF IMMERSION SIDE-EFFECTS VARIABLES 66
Analysis of Balance Tests *67*
Analysis of Vision Measures *69*
Analysis of Subjective Side-Effects Measure *70*
ANALYSIS OF EQUIPMENT DIFFICULTIES VARIABLES 71
Analysis of Break Measures *72*
Analysis of Subjective Equipment Difficulty Measure *74*
CHRONOLOGICAL AGE TRENDS 74

CHAPTER 4. DISCUSSION 76

SPATIAL PERFORMANCE 76
Sensitivity of the Route Knowledge Measures *78*
Sensitivity of the Configuration Measures *79*
IMMERSION SIDE-EFFECTS 80
EQUIPMENT DIFFICULTIES 80
HMD Difficulties *81*
GENERAL ENJOYMENT 82
PRESENCE 83
IMPLICATIONS OF RESEARCH 83
Design and Educational Implications *84*
Future Research Implications *85*
CONCLUSIONS 86

REFERENCES 88

APPENDIX A : IRB PROTOCOL 101

APPENDIX B : INFORMED CONSENT FORMS 106

INFORMED CONSENT FORM FOR ADULT PARTICIPANTS 107
INFORMED CONSENT FORM FOR PARENT OF CHILD PARTICIPANT 111
CHILD ASSENT VERBAL PROTOCOL 115

APPENDIX C : PRE-SCREENING CHECKLIST 116

APPENDIX D: PRE-IMMERSION QUESTIONNAIRE 118

FOR ADULT PARTICIPANTS 118
FOR PARENTS OF CHILD PARTICIPANTS 119

APPENDIX E: POST-IMMERSION QUESTIONNAIRE 121

APPENDIX F : INTRODUCTION TO THE STUDY **123**

APPENDIX G: IMAGES USED AS LANDMARKS IN VIRTUAL HOUSE **125**

APPENDIX H: ADDITIONAL IMAGES USED FOR LANDMARK RECOGNITION TEST **131**

APPENDIX I : RAW DATA **137**

SPATIAL KNOWLEDGE DATA 137
LOCOMOTION EFFICIENCY 137
LANDMARK KNOWLEDGE 139
ROUTE KNOWLEDGE 141
CONFIGURATION KNOWLEDGE 143
PERFORMANCE SPEED 145
SUBJECTIVE DATA 147
IMMERSION SIDE-EFFECTS DATA 149
VE BREAK DATA 151

APPENDIX J : ADULT CHRONOLOGICAL AGE TREND PLOTS **153**

SPATIAL KNOWLEDGE 153
LOCOMOTION EFFICIENCY 153
ROUTE KNOWLEDGE 154
CONFIGURATION KNOWLEDGE 154
PERFORMANCE SPEED 156
GENERAL ENJOYMENT 157
IMMERSION SIDE-EFFECTS 157
BALANCE SIDE-EFFECTS 157
BREAK TAKING 158

APPENDIX K : POTENTIAL ADULT-CHILD DIFFERENCES IN PERFORMANCE AND PRESENCE AS A FUNCTION OF VE SYSTEM PARAMETERS **160**

VITA **166**

LIST OF FIGURES

FIGURE 1. 2^3 BETWEEN-SUBJECT DESIGN. 21
FIGURE 2. TESTING ENVIRONMENT. 25
FIGURE 3. EXPERIMENTER AREA. 26
FIGURE 4. HOUSE LAYOUT, DIMENSIONS ARE GIVEN IN INCHES. DOORS ARE REPRESENTED BY SPACES AND WALLS BY SOLID LINES. THE FENCED AREA AT THE FRONT OF THE HOUSE IS INDICATED BY THE DOTTED LINES. BUSHES IN THE FENCED AREA ARE INDICATED BY OVALS. 28
FIGURE 5. A SAMPLE VIEW UNDER THE HIGH FIELD OF VIEW CONDITION. 29
FIGURE 6. A DIFFERENT SAMPLE VIEW UNDER LOW FOV CONDITION. 30
FIGURE 7. MAP ILLUSTRATING THE ROUTE THROUGH THE HOUSE. THE DOTTED LINE REPRESENTS THE ROUTE AND THE SQUARES REPRESENT LANDMARKS. DOORS ARE REPRESENTED BY SPACES AND WALLS BY SOLID LINES. 34
FIGURE 8. LOCATION OF LANDMARKS USED FOR POINTING TASKS. 35
FIGURE 9. EFFECT OF FOV X AGE INTERACTION ON THE NUMBER OF INDIVIDUALS SATISFYING THE ROUTE KNOWLEDGE CRITERION. 44
FIGURE 10. EFFECT OF FOV X AGE X GENDER INTERACTION ON THE FREQUENCY OF INDIVIDUALS SATISFYING THE ROUTE KNOWLEDGE CRITERION. 45
FIGURE 11. EFFECT OF AGE X GENDER INTERACTION ON THE SPATIAL INFERENCE MEASURE. 47
FIGURE 12. EFFECT OF FOV X AGE X GENDER INTERACTION EFFECT ON MAGNITUDE OF THE MEAN AZIMUTH ERROR FOR POINTING TASK 1. 49
FIGURE 13. SAMPLE SCORING FOR MODEL SHAPE METRIC. 53
FIGURE 14. EFFECT OF FOV X AGE INTERACTION ON MODEL SHAPE METRIC. 55
FIGURE 15. EFFECT OF FOV X AGE INTERACTION ON THE NUMBER OF INDIVIDUALS WHO SATISFIED THE CONFIGURATION KNOWLEDGE CRITERION. 57
FIGURE 16. EFFECT OF FOV X GENDER INTERACTION ON THE NUMBER OF INDIVIDUALS WHO SATISFIED OF CONFIGURATION KNOWLEDGE CRITERION. 57
FIGURE 17. EFFECT OF AGE X GENDER INTERACTION ON THE NUMBER OF INDIVIDUALS WHO SATISFIED THE CONFIGURATION KNOWLEDGE CRITERION. 58
FIGURE 18. EFFECT OF FOV X AGE X GENDER INTERACTION ON THE NUMBER OF INDIVIDUALS WHO SATISFIED THE CONFIGURATION KNOWLEDGE CRITERION. 58
FIGURE 19. EFFECT OF AGE X GENDER INTERACTION ON MEAN MODEL BUILDING TIME. 61
FIGURE 20. FOV X AGE INTERACTION FOR GENERAL ENJOYMENT SCORE. 63
FIGURE 21. AGE X GENDER INTERACTION FOR THE GENERAL ENJOYMENT SCORE. 63
FIGURE 22. FOV X AGE INTERACTION ON NUMBER OF INDIVIDUALS WHO FELT THE VE WAS A REAL PLACE. 65
FIGURE 23. AGE X GENDER INTERACTION ON THE NUMBER OF INDIVIDUALS WHO FELT THE VE WAS A REAL PLACE. 65
FIGURE 24. FOV X AGE X GENDER INTERACTION ON NUMBER OF INDIVIDUALS THAT FELT THE VE WAS A REAL PLACE. 66
FIGURE 25. AGE X GENDER INTERACTION ON THE SONL MEASURE. 69
FIGURE 26. IMPACT OF CHRONOLOGICAL AGE ON MEAN COMPOSITE ROUTE KNOWLEDGE SCORE. 75
FIGURE 27. CLOSE-UP OF 9-YEAR OLD BOY WEARING HMD. 81
FIGURE 28. CHILD RESTING HMD DISPLAY ON HAND TO MINIMIZE PRESSURE ON NOSE. 82
FIGURE 29. CHILD TILTING HEAD BACK SO THAT MAIN HMD WEIGHT RESTS ON FOREHEAD. 82
FIGURE 30. BLOCKS USED AS LANDMARK FOR ROOM 1. 125
FIGURE 31. BUNNY USED AS LANDMARK FOR ROOM 2. 126
FIGURE 32. TRICYCLE USED AS LANDMARK IN ROOM 3. 126
FIGURE 33. TRUCK USED AS LANDMARK IN ROOM 4. 127
FIGURE 34. TEDDY BEAR USED AS LANDMARK IN ROOM 5. 127
FIGURE 35. DOLLS USED AS LANDMARK IN ROOM 6. 128

FIGURE 36. IMPACT OF CHRONOLOGICAL AGE ON THE AVERAGE NUMBER OF COLLISIONS MADE DURING A 5-MINUTE PERIOD. 153
FIGURE 37. IMPACT OF CHRONOLOGICAL AGE ON MEAN COMPOSITE ROUTE KNOWLEDGE SCORE. 154
FIGURE 38. IMPACT OF CHRONOLOGICAL AGE ON THE MEAN SPATIAL INFERENCE SCORE. 154
FIGURE 39. IMPACT OF CHRONOLOGICAL AGE ON MEAN ABSOLUTE AZIMUTH ERROR. 155
FIGURE 40. IMPACT OF CHRONOLOGICAL AGE ON MEAN BUILDING MODEL SCORE. 155
FIGURE 41. IMPACT OF CHRONOLOGICAL AGE ON THE MEAN TIME TO COMPLETE VE SPATIAL TASKS. ... 156
FIGURE 42. IMPACT OF CHRONOLOGICAL AGE ON MEAN MODEL BUILDING TIME. 156
FIGURE 43. IMPACT OF CHRONOLOGICAL AGE ON GENERAL ENJOYMENT SCORE. 157
FIGURE 44. EFFECT OF CHRONOLOGICAL AGE ON THE MAGNITUDE OF SONL MEASURE. 157
FIGURE 45. EFFECT OF CHRONOLOGICAL AGE ON MAGNITUDE OF SHT SCORE. 158
FIGURE 46. EFFECT OF CHRONOLOGICAL AGE ON THE NUMBER OF BREAKS. 158
FIGURE 47. IMPACT OF CHRONOLOGICAL AGE ON BREAK TIME. 159

LIST OF TABLES

TABLE 1. QUESTIONNAIRE ITEM SCORING AND CATEGORIES. 31
TABLE 2. MEAN SCORES FOR THE SPATIAL PERFORMANCE MEASURES. 39
TABLE 3. ANOVA SUMMARY TABLE FOR AVERAGE NUMBER COLLISIONS DURING A 5-MINUTE PERIOD. 40
TABLE 4. ANOVA SUMMARY TABLE FOR THE LANDMARK RECOGNITION MEASURE. 41
TABLE 5. ANOVA SUMMARY TABLE FOR THE COMPOSITE ROUTE KNOWLEDGE MEASURE. 41
TABLE 6. ANOVA SUMMARY TABLE FOR ROUTE MEASURE. 42
TABLE 7. ANOVA SUMMARY TABLE FOR THE LANDMARK PREDICTION MEASURE. 43
TABLE 8. SUMMARY OF THE χ^2 TEST RESULTS FOR ROUTE KNOWLEDGE CRITERION MEASURE. 43
TABLE 9. ANOVA SUMMARY TABLE FOR SPATIAL INFERENCE MEASURE. 46
TABLE 10. MEANS AND STANDARD ERRORS FOR THE AGE X GENDER INTERACTION OF THE SPATIAL INFERENCE MEASURE. 46
TABLE 11. ANOVA SUMMARY TABLE FOR MAGNITUDE OF POINTING TASK 1 AZIMUTH ERROR. 48
TABLE 12. MEANS AND STANDARD ERRORS FOR THE FOV X AGE X GENDER INTERACTION OF THE MAGNITUDE OF THE POINTING TASK 1 AZIMUTH ERROR. 48
TABLE 13. ANOVA SUMMARY TABLE FOR POINTING TASK 2 AZIMUTH ERROR. 49
TABLE 14. ANOVA SUMMARY TABLE FOR AVERAGE OF THE AZIMUTH ERROR MAGNITUDE FOR THE POINTING TASKS. 50
TABLE 15. ANOVA SUMMARY TABLE FOR THE MODEL BUILDING MEASURE. 51
TABLE 16. ANOVA SUMMARY TABLE FOR THE MODEL LANDMARK MEASURE. 52
TABLE 17. ANOVA SUMMARY TABLE FOR MODEL SHAPE METRIC. 54
TABLE 18. MEAN AND STANDARD ERRORS FOR THE FOV X AGE INTERACTION OF THE MODEL SHAPE METRIC. 54
TABLE 19. SUMMARY OF THE χ^2 TEST RESULTS FOR CONFIGURATION KNOWLEDGE CRITERION MEASURE. 55
TABLE 20. ANOVA SUMMARY TABLE FOR THE TIME TO COMPLETE THE VE SPATIAL TASKS. 59
TABLE 21. ANOVA SUMMARY TABLE FOR MODEL BUILDING TIME. 60
TABLE 22. AGE X GENDER INTERACTION FOR MODEL BUILDING TIME. 60
TABLE 23. SUMMARY OF THE KOLOMOGOROV-SMIRNOV TEST RESULTS FOR GENERAL ENJOYMENT MEASURE. 61
TABLE 24. KRUSKAL-WALLIS ONE-WAY ANOVA SUMMARY TABLE FOR GENERAL ENJOYMENT MEASURE. 61
TABLE 25. FOV X AGE INTERACTION FOR GENERAL ENJOYMENT SCORE. 62
TABLE 26. AGE X GENDER INTERACTION FOR GENERAL ENJOYMENT SCORE. 62
TABLE 27. FOV X AGE X GENDER INTERACTION FOR GENERAL ENJOYMENT SCORE. 62
TABLE 28. SUMMARY OF THE χ^2 TEST RESULTS FOR PRESENCE. 64
TABLE 29. MEAN SCORES FOR THE IMMERSION SIDE-EFFECTS MEASURES. 67
TABLE 30. ANOVA SUMMARY TABLE FOR SONL DIFFERENCES. 68
TABLE 31. AGE X GENDER INTERACTION FOR THE SONL MEASURE. 68
TABLE 32. ANOVA SUMMARY TABLE FOR SHT DIFFERENCES. 69
TABLE 33. ANOVA SUMMARY TABLE FOR ACUITY CHANGES. 70
TABLE 34. ANOVA SUMMARY TABLE FOR COLOR VISION CHANGES. 70
TABLE 35. SUMMARY OF THE KOLOMOGOROV-SMIRNOV TEST RESULTS FOR SUBJECTIVE SIDE-EFFECTS MEASURE. 71
TABLE 36. KRUSKAL-WALLIS ONE-WAY ANOVA SUMMARY TABLE FOR SUBJECTIVE SIDE-EFFECTS MEASURE. 71
TABLE 37. MEAN SCORES FOR THE EQUIPMENT DIFFICULTIES MEASURES. 72
TABLE 38. ANOVA SUMMARY TABLE FOR THE NUMBER OF VE BREAKS. 73
TABLE 39. ANOVA SUMMARY FOR THE VE BREAK TIME. 73
TABLE 40. SUMMARY OF THE KOLOMOGOROV-SMIRNOV TEST RESULTS FOR SUBJECTIVE EQUIPMENT DIFFICULTIES MEASURE. 74

TABLE 41. KRUSKAL-WALLIS ONE-WAY ANOVA SUMMARY TABLE FOR SUBJECTIVE EQUIPMENT DIFFICULTIES MEASURE. 74
TABLE 42. NUMBER OF ADULTS IN EACH CHRONOLOGICAL AGE CATEGORY AS A FUNCTION OF FOV. 75
TABLE 43. RAW COLLISION DATA FOR LOWER FOV CONDITION. 137
TABLE 44. RAW COLLISION DATA FOR HIGHER FOV CONDITION. 138
TABLE 45. RAW LANDMARK RECOGNITION DATA FOR LOWER FOV CONDITION. 139
TABLE 46. RAW LANDMARK RECOGNITION DATA FOR HIGHER FOV CONDITION. 140
TABLE 47. RAW ROUTE KNOWLEDGE DATA FOR LOWER FOV CONDITION. 141
TABLE 48. RAW ROUTE KNOWLEDGE DATA FOR HIGHER FOV CONDITION. 142
TABLE 49. RAW CONFIGURATION KNOWLEDGE DATA FOR LOWER FOV CONDITION. 143
TABLE 50. RAW CONFIGURATION KNOWLEDGE DATA FOR HIGHER FOV CONDITION. 144
TABLE 51. RAW PERFORMANCE SPEED DATA FOR LOWER FOV CONDITION. 145
TABLE 52. RAW PERFORMANCE SPEED DATA FOR HIGHER FOV CONDITION. 146
TABLE 53. RAW SUBJECITVE DATA FOR LOWER FOV CONDITION. 147
TABLE 54. RAW SUBJECITVE DATA FOR HIGHER FOV CONDITION. 148
TABLE 55. RAW IMMERSION SIDE-EFFECTS DATA FOR LOWER FOV CONDITION. 149
TABLE 56. RAW IMMERSION SIDE-EFFECTS DATA FOR HIGHER FOV CONDITION. 150
TABLE 57. RAW PERFORMANCE SPEED DATA FOR LOWER FOV CONDITION. 151
TABLE 58. RAW PERFORMANCE SPEED DATA FOR HIGHER FOV CONDITION. 152

LIST OF ACRONYMS

ANOVA	Analysis of Variance
FOV	Field-of-View
GFOV	Geometric Field-of-View
HFOV	Horizontal Field-of-View
HMD	Helmet Mounted Display
HCIL	Human Computer Interaction Laboratory
HITLab	Human Interface Technology Laboratory
IRB	Internal Review Board
LSD	Least Significant Difference Test
SONL	Stand-on-Nonpreferred-Leg
SHT	Stand-Heel-to-Toe
VE	Virtual Environment
VEPAB	Virtual Environment Performance Assessment Battery
VR	Virtual Reality
VRRV	Virtual Reality Roving Vehicle Project

CHAPTER 1. INTRODUCTION

Virtual environments (VEs) can be viewed as passageways to other worlds, both real and imagined. They give users the feeling that they exist within the virtual world. The illusion of being there, or sense of presence, is what distinguishes VEs from other mediums (Ellis, 1993). Another defining characteristic of VEs is the minimal nature of the interface between the user and the computer. Users interact with a virtual world in much the same manner as they would with the real world: objects can be picked up and manipulated, doors can be opened, and views change with head position (Furness and Barfield, 1995). VEs typically include visual and audio elements, and sometimes include haptic or olfactory elements (Barfield, Hendrix, Bjorneseth, Kaczmarek, and Lotens, 1995).

Virtual environments are referred to by a variety of names. Virtual reality (VR), virtual environments, synthetic environments, immersive environments, and cyperspace have all been used to refer to this phenomenon. VEs are used in many fields including education and training, architecture, simulation, entertainment, telerobotics, and scientific visualization (Bailey, 1994; Ellis, 1991; Henry, 1992; McCauley and Sharkey, 1991; Pantelidis, 1993). Within the educational world, the primary uses of VEs are visualization of abstract concepts (Ainge, 1996; Byrne, 1996; Rose, 1995; Merickel, 1991; Winn and Bricken, 1992), simulation of real or imaginary environments (Bricken and Bryne, 1993; Grove, 1996; Osberg, 1995), and development of participatory learning environments (Grove, 1996; Pantelidis, 1994).

Virtual environments take a variety of forms. These forms are typically categorized as either desktop or immersive VEs, with a variant of VEs, augmented reality, sometimes being included in this list. Desktop VEs, or fishtank VEs as they are sometimes called, display the virtual world on a computer monitor, and use stereopsis and head tracking to create the illusion of depth (Arthur and Booth, 1993). Because of this form’s more economical nature, most classroom VE applications fall into this category. Augmented reality overlays the user’s world with virtual elements through the use of see-through displays (Azuma, 1997; Barfield, Rosenberg, and Lotens, 1995).   An example would be SIMNET, a system that allows military personnel wearing HMDs to see the position of occluded objects and individuals while simultaneously viewing the real world (Urban, 1995). Immersive VE replaces the user’s real world with a virtual world through the use of head-mounted displays and other equipment.   It is what people traditionally think of when they hear the term virtual reality. The typical immersive VE system is comprised of a head-mounted display (HMD), an image rendering computer, a device for tracking the user’s position, an input device for interacting with the VE, and computer software which coordinates the interaction (Bailey, 1994; Shaw, 1993; Wann and Mon-Williams, 1996). Immersive VEs are the focus of this research. (Note: for the remainder of this document, VE and immersive VE will be used interchangeably.)

Children in Immersive Environments

Although now out of the price range of many educators, immersive VEs are becoming increasingly affordable as the price of graphic workstations and VE peripherals drops (Wann and Mon-Williams, 1996), and they are increasingly being investigated as a medium for learning (Bricken and Byrne, 1993; Byrne, 1996; Merickel, 1991; Osberg, 1995; Pantelidis, 1994; Rose, 1996; Winn, 1995, Winn and Bricken, 1992). They are also being increasingly utilized by the entertainment industry, with "virtual arcades" appearing in many cities across the country. As a result, ever increasing numbers of children are experiencing immersive environments.

Existing studies of children in immersive environments have focused on developing learning paradigms for VEs and evaluating VEs as an educational tool (Bricken and Bryne, 1993; Byrne, 1996; Rose, 1995; Osberg, 1995; Merickel, 1991; Winn and Bricken, 1992). Much of the research involved groups of children creating virtual worlds and then exploring these worlds in an immersive setting (Bricken and Bryne, 1993; Byrne, 1993; Osberg, 1995; Rose, 1995; Winn, 1995; Winn and Bricken, 1992). Unfortunately, the previous studies offer little besides anecdotal evidence as to the impact of various system parameters on a child's performance in an VE or how children's responses to virtual environments differ from that of adults.

The most detailed accounts of work with children in immersive environments comes from the Human Interface Technology Laboratory (HITLab) at the University of Washington. In the early 1990s, the HITLab in conjunction with the Pacific Science Center explored the feasibility of having students from 10-15 years of age work in VEs and tracked the student's reaction to the experience (Bricken and Byrne, 1993). Students created virtual worlds as part of a summer camp, and then explored the worlds using immersive equipment at the HITLab. From the perspective of the students, the program was a huge success, and the following summer, it was repeated with a more diverse, but still primarily computer-literate, population of students (Byrne, 1993). Related work done by the HITLab include having "at risk" teenagers create an AIDS education world (Byrne, 1996), and teaching Japanese prepositions using an immersive, interactive VE (Rose, 1996). The HITLab's largest, reported educational venture involving children occurred between November 1994 and June 1995 when approximately 3,000 students in grades four through 12 throughout the state of Washington explored immersive environments as part of Virtual Reality Roving Vehicle (VRRV) project (Rose, 1995; Winn, 1995). VRRV participants spent varying amounts of time in VEs, using a joystick to navigate and manipulate objects, with a subset of the students participating in world-building activities. The HITLab work provides some intriguing glimpses of how children respond to VEs and how children's responses to VEs differ from adults.

Bricken and Byrne (1993) observed that children appeared much more active than adults in exploring virtual worlds. The increased activity may be a by-product of children's increased enjoyment of the virtual experience. Overall, students rated their VE experience as extremely enjoyable. In post-immersion surveys, Byrne and Bricken (1993) reported that the student's mean enjoyment rating for VEs was 6.5 out of a possible 7, and Byrne (1996) reported that the mean rating for the student's desire to revisit a VE was 9.35 out of a possible 10. Similarly, Winn (1995) found that students rated their enjoyment of the VEs very highly. Both enjoyment and presence ratings decreased with age (Byrne, 1996; Bricken and Byrne, 1993; Osberg, 1995; Winn, 1995). Further, enjoyment and presence ratings were correlated with high spatial ability (Winn, 1995). Of course, not all children like VEs, but not many children dislike them. Byrne (1996) reported that only one child out of 70 in a virtual world-building study disliked the experience.

Difficulty in interacting with VEs and navigating in VEs decreased with age, as did feelings of disorientation inside the VE (Bricken and Bryne, 1993; Taylor, 1997; Winn, 1995). Part of the difficulty stemmed from problems with the equipment. Taylor (1997) found that equipment difficulties could neutralize the benefits of educational VEs by increasing student frustration and decreasing student motivation. Winn (1995) reported that elementary school students had a hard time holding and manipulating the NRRV wand. Bricken and Byrne (1993) reported that students complained that the equipment had "too many wires to get tangled in" and that the available input devices were unwieldy for maneuvering in the virtual environment. Bricken and Byrne (1993) also reported that students found the resolution of the HMD display inadequate for location recognition and object identification, so students inside the virtual world were often asking students on the outside with access to a high-resolution monitor what they were looking at or where something was.

HMDs cannot replicate the eye's resolution, which is 30-60 arc-seconds (Sanders and McCormick, 1993). However, the resolution of a high-end commercial HMD is 2-4 arc-minutes, while the resolution of entertainment system HMDs is only 4-10 arc-minutes (Barfield, Hendrix, et al., 1995). The impact of HMD resolution deficits is expected to increase as age decreases. Studies have shown that younger children have greater difficulty than adults when dealing with objects that are out of focus (Mackworth and Bruner, 1970; Yendovitskaya, 1971); it is likely that this finding extends to VEs. Children when confronted with an out-of-focus picture made a large number of small eye movements and often fixated on relatively unimportant features, while adults began by making large eye movements, locating significant characteristics of the field, and then fixating mainly on the significant features. As the children aged, their eye movements became more systematic and extraction of pertinent information from the visual field became more rapid, with their performance approximating that of adults in their early teens.

Age also influenced the types of objects that were created for the virtual worlds. Younger students populated their worlds with less complex objects, while the older ones chose more complex, realistic representations of objects (Byrne, 1993). This developmental trend matches work done with pictures which found that children prefer less realistic, less complex scenes than young adults (Bernaldez, Ruiz, and Ruiz, 1984; Bernaldez, Gallardo, and Abello, 1995; and Zube, Pitt, and Evans, 1983).

Available evidence suggests that children experience more immersive VE side-effects than adults and that the incidence of side-effects decreases with age (Bricken and Byrne, 1993; Osberg; 1995; Winn, 1995). Children are more susceptible to motion-sickness (Reason and

Brand, 1972), with susceptibility greatest between 2 and 12 years of age, which translates into an increased susceptibility to VE side-effects (Kolasinski, 1995; Pausch, Crea, and Conway, 1992). This issue is of special concern in VE studies involving children as children are at greater risk for motion-sickness (Reason and Brand, 1972) and are thought to be at greater risk for VE side-effects (Kolasinski, 1995; Pausch et al., 1992).

Anecdotal evidence suggests that children do indeed experience more side-effects than adults (Bricken and Byrne, 1993; Osberg; 1995; Taylor, 1997; Winn, 1995). Surprisingly, a child's potential for side-effects is apparently inversely proportional to his/her potential for enjoyment (Osberg, 1995; Winn, 1995). Besides the usual motion sickness type side-effects, VE side-effects can also include temporary ataxia and vision changes (Kolasinski, 1995; Mon-Willians, Wann, and Rushton, 1993; Pausch et al., 1992). Ataxia, or postural disequilibrium, is of particular concern and can be decreased by limiting immersion to short periods of time (Fowlkes, 1987; Kolasinski, 1996). Limiting immersion time in order to allow gradual adaptation to the system is especially important for novice users (McCauley and Sharkey, 1991). Bricken and Byrne (1993) report that many students complain of feeling dizzy at the end of a VE session, but report no serious side-effects. Winn (1995) found a negligible number of reports of queasiness and disorientation, which he felt allayed the fear that short-term exposure to VEs was harmful to children. However, most students in his study were limited to 5-10 minutes of immersion, which makes extrapolation of these findings to other immersive situations difficult as side-effects apparently increase with the length of immersion (Lamptom, Kolasinski, Knerr, Bliss, Bailey, and Witmer, 1994). Osberg (1995) reported that the overall incidence of malaise for the schoolchildren who participated in HITLab projects was less than 5%. This figure is sharply at odds with studies done with adults. Regan and Price (Regan, 1994; Regan and Price, 1994) found that 61% of their 146 subjects reported symptoms of malaise during a 20-minute immersive session and the 10-minute post-immersion session. However, their experimental method concentrated participants' attention on symptoms of malaise and may have heightened participants' awareness of symptoms which may partially explain the differences between the studies. Kolasinski (1996) found that 85% of research participants who were exposed to a low-end VE experienced some degree of malaise, and 35% experienced delayed or lingering effects. However, she exposed participants to a low-end system, which may explain the increased symptomatology.

As in adults, surveys are the most common method for gathering children's subjective responses to a VE (Bricken and Byrne, 1993; Hix and Hartson, 1993; Martin, 1996; Taylor, 1997; Winn, 1995). They are the typical method for assessing simulator side-effects and have been shown to be effective for VEs (Kennedy, Lane, Lilienthal, Berbaum, and Hettinger, 1992; Kennedy, Berbaum, and Lilienthal, 1993). In adults, ataxia can generally evaluated using balance measures (Hamilton et al., 1989; Kennedy et al., 1995; Kolasinski, 1996; Thomley et al., 1986) with the same method likely to work with children.

Field-of-View

In the real world, field-of-view (FOV) is the visual angle of the scene subtended at an individual's eye; while in the virtual world, FOV is the horizontal and vertical dimensions of the display used to view the virtual scene (Pausch et al., 1992). Today's HMDs are incapable of matching the eye's FOV. While the eye's FOV is approximately 200 degrees horizontally by 120 degrees vertically (Boff and Lincoln, 1988), the best HMDs have a FOV of 110 degrees by 50 degrees (Bailey, 1994), with the FOV of most HMDs ranging from 30 to 80 degrees horizontally and less than half that vertically (Barfield, Hendrix, et al., 1995) . The resulting FOV restriction diminishes both the usability and generated sense of presence of virtual environments. It is thought the degradation in performance and presence results from the scarcity of overlapping peripheral information in restricted FOV conditions. During normal FOV conditions, consecutive head movement result in overlapping visual information with the overlap generally being at least 50% and sometimes as high as 90% (Haber, 1983). Under restricted FOV conditions, this overlap disappears or is severely curtailed. Studies evaluating the impact of FOV restrictions and the accompanying curtailment of peripheral information on humans have been performed in both the real and virtual worlds. Regrettably, no known studies exist which evaluate the impact of FOV restrictions on children.

Studies in the Real World

Hagen, Jones, and Reed (1978) explored the impact of restricted FOV on the ability to make size and distance estimates using pictorial representations. Participants looked at the pictures under four different monocular viewing conditions: 1) an untruncated monocular view, 2) a peephole view, and 3) a rectangular truncation view, and 4) photographed color slides. The participants were examined on their ability to scale the size and distance of five triangles at different distances under each of the viewing conditions. Under the truncated conditions, participants consistently compressed their size and distance estimates, resulting in a telephoto-like effect. Hagen et al. believed that the compression in size and distance was the result of the lack of information detailing the degree of foreground cropping. Thus, mediums, such as VEs, which similarly restrict this information, will likely produce similar size and distance compressions.

Dolezal (1982) took a more personal approach to investigating FOV restrictions. He restricted his FOV to 12 degrees horizontally and 11 degrees vertically by wearing two paper tubes for a total of 6 days. He found that he had difficulty keeping moving objects within his FOV and that he was often surprised by objects unexpectedly entering his FOV. Again, as in Hagen et al.'s (1978) study, the size and distance of objects were compressed. Large eye movements were replaced by head movements, similar to those seen in HMD wearers (Venturino and Wells, 1990), resulting in increased scanning behavior. However, the increased scanning behavior did not compensate for the lack of overlap between the FOV of successive head movements, resulting in a substantial reduction in the quantity of available visual information. Dolezal found the available visual information discontinuous and insufficient for effective locomotion and orientation. He often felt disoriented, frequently bumped into objects, and could not form cognitive maps of new environments. He also found that the restricted FOV slowed his responses to changes in his local environment. He suggested that the peripheral information overlap, available under normal FOV conditions, helps individuals orient themselves in their environment and is needed to competently perform many of the spatial tasks required by daily living.

While investigating the mobility of low vision individuals, Pelli (1986) restricted the FOV of individuals with normal vision and measured mobility performance in a laboratory maze and a shopping mall. FOV restrictions ranged from 1 to 60 degrees. Pelli measured participants' performance in terms of travel speed and objects collisions. The degree of route or configurational knowledge developed by participants was not measured. At 10 degrees the locomotion performance for the maze seriously degraded, with performance in the shopping mall seriously degrading at about 4 degrees. Very little vision was needed to walk through these environments with a degree of competency. Pelli expressed surprise at the results and wondered why people with the requisite amount of vision are reluctant to travel alone. He suggested that individuals with FOV impairments are reluctant travelers due to concerns about travel hazards, e.g. high curbs. An alternative explanation, which Pelli did not consider, is that individuals with such impairments become disoriented in unfamiliar environments due to their impaired ability to develop cognitive maps, and because of the disorientation prefer not to travel by themselves.

Alfano and Michel (1990) investigated the impact of FOV restrictions on locomotion and reaching performance, and the development of cognitive maps. The FOV of participants was restricted to 9, 14, or 22 degrees for the reaching task and to 9, 14, or 60 degrees for the locomotion and small-scale cognitive map tasks. Additionally, a control group with a normal FOV performed the same tasks. Locomotion performance was measured by walking through a winding path; reaching performance was measured using a hand-eye coordination task; cognitive map performance was measured with a room layout reconstruction task. Performance on all tasks was impacted by FOV restrictions, with 9 and 14 degree FOVs showing the greatest performance decrements. Under the 9 and 14 degree FOV conditions, cognitive map participants could not determine where they were relative to the room and its furnishings, while locomotion participants doubled their path traversal time and made at least 18 times the errors, and reaching participants took significantly longer and made significantly more errors. In general, participants under restricted FOV conditions took longer, made more mistakes, and formed more misperceptions about the environment. In post-test interviews, the cognitive task participants with a restricted FOV reported the room dimensions had changed when they returned to the room under their normal FOV. Additionally, participants under restricted FOV conditions experienced discomfort, disorientation, and dizziness.

Studies Using Virtual Worlds

An interesting study by Psotka, Davison, and Lewis (1993) sheds light on the distance compression evidenced in previously discussed studies (Dolezal, 1982; Hagan et al., 1978). Psotka and his fellow researchers as part of a desktop VE experiment had participants view a virtual room from various FOVs and geometric FOVs. The viewpoint of the virtual scene was centered in the middle of the room and the scene was panned 360 degrees. Participants then traced the path taken through the room on the room's floorplan; when they traced the path, they substantially shortened the distance between the virtual viewpoint and the room's furnishings. Participants apparently treated the FOV of the virtual scene as if it corresponded to their entire FOV. A similar finding was reported by Brickner and Foyle (1990) as part of their investigation of FOV effects in Head-down and Head-up displays. They found that with a narrow FOV participants flew substantially closer to virtual pylons than with the wide FOV, and collided with the pylons more frequently. They interpreted these results to mean that participants were treating the display surface as the "entire world" and not as a "window on the world". That is, they were treating the FOV of the virtual scene as if it corresponded to their entire FOV.

Wells, Venturino, and Osgood (1988) explored the impact of HMD FOV restrictions on the development of spatial awareness, which was measured by the number of correctly placed targets in a replacement task, and the search time on a task involving variable numbers of distracter targets. The FOV restrictions were 20^{o} H by 20^{o} V, 45^{o} H by 42.5^{o} V, 60^{o} H by 50^{o} V, 90^{o} H by 60^{o} V, and 120^{o} H by 60^{o} V. Search time was affected by FOV restrictions, but surprisingly replacement error for the targets was not. One explanation for the experiment's lack of sensitivity for replacement error is that the restricted FOV conditions were overlaid on the 120^{o} H by 60^{o} V visual field of the larger VE, which was perceivable during the experiment. Thus participants may not have experienced the degradation in spatial awareness seen in other experiments. Venturino and Wells (1990) performed additional analysis on the experimental data and found that FOV restrictions resulted both in an increase in head movements similar to those reported by Dolezal (1982) and in a decrease in the head movement's velocity. They found head movements were correlated with the time to acquire and memorize target locations. As FOV increased, participants made fewer head movements and needed less time to acquire the spatial information.

In related experiments, Venturino and Kunze (1989) further investigated the impact of HMD restricted FOV on spatial awareness, which was again assessed using a replacement task. The display (120^{o} H by 60^{o} V) consisted of a terrain scene and a smaller region in the center of the display which contained a collection of targets and threats. The size of the smaller region was determined by the FOV treatment level. Five levels of FOV were again used, ranging from 20^{o} H by 20^{o} V to 90^{o} H by 60^{o} V. The impact of memory load on performance was assessed by varying the number of targets (3, 6, or 9). As in the earlier study (Wells, Venturino, and Osgood, 1988), with a smaller FOV, participants moved their heads more frequently and more slowly. FOV restrictions significantly impacted target acquisition time and curtailed participants' spatial memory. For 3 targets, 20^{o} H x 20^{o} V degree FOV was adequate; for 6 targets, a FOV greater than 20^{o} H x 20^{o} V was needed; for 9 targets, a FOV larger than 60^{o} H x 60^{o} V degrees was required.

The impact of FOV restrictions on cognitive processes was further explored in another experiment by Wells and Venturino (1989). Again, they investigated the impact of HMD restricted FOV on spatial awareness, which was assessed using a replacement task.

Simultaneously, participants performed a secondary tracking task. As the FOV decreased, performance on the secondary task decreased thus demonstrating the cognitive costs of restricting the FOV. The results suggested that performance in restricted FOV conditions was dependent on the characteristics of the task, and that complex environments with many objects were likely to necessitate larger FOVs if users were to achieve an acceptable level of spatial awareness. Similarly, Wells, et al. (1989) found that performance on a simulated combat mission was a function of both the HMD FOV and task difficulty, where difficulty was again measured by the number of targets. Participants could adequately perform the easy tasks with a 20 degree horizontal field-of-view (HFOV), but needed a HFOV of 60 degrees to achieve a similar level of performance on the harder tasks. Osgood and Wells (1991) also attempted to assess the minimum, viable FOV of HMDs for a simulated airborne night combat task. Participants in the study were all experienced fighter pilots. Again, time to target acquisition decreased as the FOV increased. Osgood and Wells found that HFOVs larger than 30 degrees resulted in significantly better performance.

Piantanida, Boman, Larimer, Gille, and Reed (1992) looked at the impact of FOV on a visual search task. The FOV of a HMD with 100˚ H by 60˚ V FOV was restricted to 4, 28, 41, and 53 degrees using circular apertures. Participants searched for a square, which was located on a sphere centered at the user, appearing at any azimuth within plus or minus 45 degrees of the horizontal under each of the circular FOV conditions and under the full FOV of the HMD. The data showed a strong correlation between increasing field of view and decreasing search time. Different surround colors did not affect performance significantly. Participants did however experience greater discomfort with the black background due to the resulting diplopia, which was caused by the increased contrast.

Cha, Horch, and Normann (1992) studied the impact of FOV restrictions on locomotion. Participants achieved near-normal walking speeds when navigating an obstacle course with a FOV of 30 degrees. They found that increasing the FOV past 30 degrees had little impact on participants' speed. Participants adapted rapidly to the narrowed FOV, with their mean speed improving from .2 to .6 meters per second and the mean number of collisions decreasing from nine to three over the span of 50 route traversals.

McGreevy (1993, 1994) studied field geologists at work under both normal and restricted FOV conditions using ethnographic methods to collect anecdotal information from the participants. An HMD restricted the participants' FOV to 25˚ H x 20˚ V, with the input to the display coming from two video cameras attached to the participant's head. Participants wearing the HMD reported substantial degradation of their ability to navigate and integrate spatial information from the environment. As in other studies (Dolezel, 1982; Venturino and Kunze, 1989; Wells and Venturino, 1990), participants wearing the HMD increased their frequency of scanning. They also increased their use of pacing to establish distances. As FOV was not manipulated in the virtual environment, the extent of the contribution of FOV to the results could not be determined.

Snow (1996) investigated the impact of HMD FOV restrictions on a variety of Virtual Environment Performance Assessment Battery (VEPAB) tasks (Lampton, Knerr, Goldberg, Bliss, Moshell, and Blau, 1994), as part of a larger study of the impact of VE system parameters on performance and presence in virtual environments. FOV of the HMD was limited to 24° H by 18° V, 36° H by 27° V, and 48° H x 36° V. Study results were consistent with studies discussed previously, with FOV generating some of the largest effects in the study. As in Lampton, Knerr, et al.'s study (1994), the middle distances were consistently overestimated in the VEPAB distance estimation task. Decreasing the FOV increased overestimation. Performance on the locomotion task decreased with the FOV, and the time needed for a visual search task increased as the FOV decreased.

Spatial Knowledge and Orientation

Both in the real world and in virtual worlds, an individual's FOV delimits the portion of the world that is visible to the individual. Individuals gather environment cues from the visible environment, with spatial knowledge being acquired through the processing of these cues. This process is both constructive and dynamic, with complete spatial knowledge of a large-scale space developing as follows: 1) spatial knowledge involving landmarks is acquired, 2) routes are then established between landmarks with spatial knowledge along routes evolving from topological to metric, and 3) landmarks and routes are organized into clusters from which an overall coordinated frame of reference forms such that Euclidean properties are available both within and between clusters (Siegal and White, 1975). When the environment is especially large, chunking of the environment into smaller regions is required, with common features functioning as links between the different levels of representations. Examples of environment chunking would be the nesting of towns under a county, the nesting of counties under a state, and the nesting of states under a country.

Much of the literature categorizes spatial knowledge in terms of 1) the kinds of spatial knowledge and 2) the types of knowledge structures used to represent it. The elemental components of spatial knowledge are landmark knowledge, route knowledge, and configurational knowledge (Wickens, 1992), while the types of structures used to represent the knowledge are commonly classified as procedural and declarative (Anderson, 1985). Spatial orientation is then the ability to use these structures and elements to orient oneself in the environment.

Declarative knowledge is knowledge about facts and things (Anderson, 1985), or in the case of spatial knowledge, it is knowledge about a particular place. Declarative spatial knowledge allows individuals to say whether or not a place exists and to recognize that place when it is seen. Procedural knowledge, on the other hand, is knowledge about how to perform cognitive activities (Anderson, 1985). It involves strategies and rules that can be used to manipulate declarative knowledge. In the case of spatial knowledge, it is using routes or cognitive maps to navigate within the environment.

The most elemental level of spatial knowledge is landmark knowledge, or the ability to recognize important objects and places in the environment. Landmark knowledge is declarative and allows individuals to discriminate between here and there, but it cannot help individuals get from here to there -- that requires route knowledge. A landmark may be any object in the environment, so the number of potential landmarks in the environment is essentially unlimited. In general, landmarks are chosen either due to their distinctiveness (Lynch, 1960, Infield, 1991) or personal meaningfulness (Infield, 1991). Adults and children differ substantially in their choices of landmarks. Allen (1982) found adults generally choose landmarks that are related to actual or potential changes in direction, such as intersections, while children generally selected objects that were prominent but of uncertain spatial usefulness, such as window displays or the color of curtains. Landmark selection by children resembled that of adults who find themselves in an environment without significant landmarks (De Jonge, 1962). Interestingly enough, Allen (1982) also found that on a distance-ranking task for a pictorialized walk, 10 year-olds performed at the same level as adults if tested with landmarks chosen by adults, but performed remarkably worse if tested with landmarks chosen by age-peers, while the performance of seven year-olds was unaffected by the set of landmarks used for testing.

The next level of spatial knowledge to develop is route knowledge, or the ability to navigate from one place to another by using landmarks. Route knowledge is procedural and allows individuals to travel from one place to another, but it does not allow them to identify alternative, untraveled routes. It is usually acquired through personal exploration and provides an essentially egocentric frame of reference. Routes are ordered sequences of places, with landmarks servings as guideposts. Route knowledge includes information about distance. Distance estimates in both children and adults are related to actual distances by power functions (Allen, Siegal, and Rosinki, 1978; Briggs, 1972; Thorndyke, 1981) and are correlated with the transportation mode, travel time, effort, and the amount of information stored about the route. Thus a route with many changes in direction would be thought longer than a simple route of similar length (Cohen, Baldwin, Sherman, 1978; Kosslyn, Pick, and Fariello, 1974; Sadalla, Staplin, and Burroughs, 1979; MacEachren, 1980; Thorndyke, 1981). Further, adults produce significantly more accurate distance estimates for routes with high landmark potential (Allen, Siegel, et al., 1978; Allen, Kirasic, Siegel, and Herman, 1979).

The highest level of spatial knowledge is configurational knowledge, or the ability to form an internalized cognitive map of the environment. Configurational knowledge, or survey knowledge as it is sometimes called, allows individuals to describe the relative position of two places even when routes connecting the places have never been traversed. It is usually acquired over the course of time as the result of many trips through an area along a variety of routes, or it may be acquired through the study of navigational aids, such as maps (Goldin and Thorndyke, 1982; Thorndyke and Hayes-Roth, 1982). It provides an essentially world-centered frame of reference. Configurational knowledge is more flexible than route knowledge in that it provides the knowledge needed to recover from navigational errors, while route knowledge becomes useless as soon as one deviates from the route.

Once accumulated, spatial knowledge can be used to travel to selected locations in the following manner: 1) orienting oneself with respect to one's current location relative to proximal objects and one's destination, 2) selecting a route that goes to the target destination, 3) monitoring one's actions to ensure that one is still on the right route, and 3) recognizing that one has reached the selected location (Downs and Stea, 1973).

Spatial Knowledge in Children

Children demonstrate wayfinding skills in the real world every day, yet psychology has traditionally stressed children's deficiencies with respect to adults. Piaget and Inhelder's (1956) classic model of spatial knowledge development stressed that children first learned the topological concepts of space that related to their local neighborhood, continuity, and order. As topological spatial knowledge is concerned only with elements of an object or a configuration, it does not permit the development of cognitive maps or allow the child to determine Euclidean distances and make spatial inferences. Piaget and Inhelder argued that such abilities are not acquired until middle or late childhood, when a child's original egocentric frame of reference evolves to a more allocentric one.

Typically, inferences about the extent of an individual's spatial knowledge are derived from procedures designed to externalize the individual's cognitive map. Recently, researchers have argued some deficiencies exhibited by children are the result the extraneous demands of the methods used to assess spatial development and not the result of spatial deficiencies on the part of the child. For example, verbal protocols confound verbal abilities and spatial knowledge, while sketch maps confound configurational knowledge with extralization ability, i.e. understanding and engendering symbolizations and conventions (Siegal, 1981). The use of such methods is believed to result in the underestimation of children's spatial abilities.

Using altered methodologies, researchers have demonstrated that young children are not nearly as egocentric as thought by Piaget and Inhelder (Acredolo, 1978; Huttenlocker and Presson, 1973; Hurdek, 1978; Kosslyn et al., 1974; Liben, 1978). For example, researchers have found children can perform the basic tasks needed in both map reading and map planning long before the age predicted by Piaget and Inhelder (1956). Blaut and Stea (1971) had children five years of age and older view aerial photographs. They found that the youngest children could interpret geographical features in each of the photographs and solve problems associated with the aerial maps. They demonstrated that children are capable of the elemental processes needed in both map reading and map planning, e.g. rotation between horizontal and vertical views, long before they are typically exposed to maps. Blaut and Stea argue that "we can explain these abilities only if we assume that a very highly evolved cognitive map has already been formed in many children by the age of five." Similarly, Bluestein and Acredolo (1977) found that children three to five years of age could identify and locate objects in a room using a simple map. They found that most three year olds could perform simple map reading tasks when the map was aligned with their view of the room, while four year olds could generally use the map once it had been shown to them, and five year olds could use incorrectly aligned maps to perform the tasks.

Considerable experimental evidence exists which documents the impact of various methods used to solicit cognitive maps from children. Rivlin et al. (1974) found that second and fourth graders were very successful in translating their images of their classroom to scale models, when given an unfurnished, scaled model of their classroom and asked to set it up to look like their real classroom using scaled furnishings. Further, the children could use the model to answer detailed questions about the classroom, implying they had formed coherent, detailed images of the environment. In a study of children's knowledge of familiar, large-scale spaces, Matthews (1995) found that some of the best space representations produced by 6-11 year old children were achieved with the use of large-scale plans and aerial photographs. He also found that verbal protocols inhibited the young child severely, preventing accurate assessment of their true environmental capability (Matthews, 1995). In a similar study, Cohen, Weatherford, Lomenick, and Koeller (1979) asked children 7 and 11 years of age to estimate from memory the distances between six objects that had been recently viewed. Cohen and his colleagues used three procedures to elicit distance estimates: 1) layout reconstruction, 2) magnitude estimation, and 3) straight-line-reconstruction. They found that 7 and 11 year olds performed equally well when using layout reconstruction, but 7 year olds performed significantly worse using the other two methods.

The match between how spatial knowledge is acquired and how it is represented is an important consideration when assessing children, especially young children. Siegel, Herman, Allen, Kirasic (1979) taught kindergartners and second- and fifth-graders locations within either a small-scale or large-scale environment. Children were most accurate when the acquisition scale and the representation scale was the same, and were least accurate when the acquisition scale was small and the representation scale was large. Cohen et al. (1979) found children's proficiency at switching between frames of references grows significantly between 6 and 11 years of age. Children were asked to estimate the distance between six points in a familiar space and to estimate the distances between six objects in an unfamiliar room. Younger children could reconstruct the layout as easily as the older children, but were much less accurate when the tasks involved rescaling or reorienting their representation of the environment.

Clearly though, the spatial abilities of children do develop as they age, with children passing through developmental stages equivalent to the phases an adult passes through while developing a cognitive map of a new area (Siegal, 1977). Herman (1980) proposed that age-related differences in the speed of acquisition, storage, and access of spatial information may drive children's performance gains on tasks requiring configurational knowledge. The ability of children to make use of distinctive visual features, or landmarks, improves over childhood (Gibson, 1969). Other studies have demonstrated that both visual search efficiency (Bisanz and Resnick, 1978) and recognition ability (Mandler and Robinson, 1978) improves as children age. Consequently, landmark and route learning becomes increasingly effective as children age. Similarly, the ability to develop configurational knowledge improves dramatically in middle childhood (Curtis, Siegal, Furlong, 1981; Piaget, 1970), with the ability to form landmark knowledge and route knowledge being the least affected by developmental differences once the child is school-age (Curtis et al., 1981). Additionally, male superiority at spatial tasks first appears around age seven or eight with the performance gap between males and females widening as the children mature (Newcombe, 1982).

In limited, large-scale spaces, children as young as six or seven can exhibit convincing evidence of their ability to form configurational knowledge. Hazen, Lockman, and Pick (1978) trained 3-6 year old children to follow either a U-shaped route or a zigzag route through a series of rooms, each of which contained a distinguishing landmark. Once the route and landmarks were learned, the children's knowledge of the environment was tested based on their ability to travel the route in reverse, build a small-scale model of the environment, and make spatial inferences about places between which they had not directly traveled. Children who traversed the U-shaped route rather than the zigzag route gained a significantly greater degree of spatial knowledge. To construct a correct model, the children had to coordinate their knowledge of the overall shape of the space with their knowledge of the landmark sequence. All the children grasped the knowledge related to landmarks. Some children appeared to have both knowledge of the layout and the landmarks, but failed to merge the information and successfully build a model. Older children acquired the requisite knowledge more quickly, more accurately, and gained a higher degree of configurational knowledge as evidenced by their ability to make inferences about objects behind doors which not been previously opened. 80% of the 6-year-olds made correct spatial inferences, while only 60% of the 5-year-olds made correct inferences, and only 40% of the 4-year-olds made correct inferences.

In another study, Kosslyn et al. (1974) compared the inference-making ability of 4 to 5 year olds and adults, and found that while adults did make more accurate inferences than the children, the children's inferences were remarkably good. Study participants were trained to go from home base to any of 10 locations, but were not allowed to move directly between the 10 locations. They were then asked to order in closeness to a given location all the other locations. The results from both the adults and children adhered fairly closely to the true layout, with the inferences made by both age groups conforming more closely to Euclidean distances than to the distances the participants had actually traveled.

Pick and Lockman (1982) compared the configurational ability of three to four year olds and their eight to ten year old siblings by having them point at objects occluded by the walls and floors in their own home, with the parents of the children serving as the control group. Both the children and the adults were approximately equally accurate at pointing at objects on the same floor. However, when pointing to objects on different floors, the younger children were noticeably deficient at the pointing task, while older children were nearly as accurate as their parents, with the parents being equally accurate in pointing at objects on the same floors and on different floors.

Spatial Orientation in Virtual Environments

As in real environments, spatial knowledge in virtual environments begins with the processing of environmental cues, and evolves from landmark knowledge to route knowledge to configuration knowledge. However in VEs, environmental cues are gathered from a simulated representation of a world, which poses additional difficulties for the user. Because of technological limitations, virtual scenes fall short of their real world counterparts and as a result introduce biases into the processing cycle.

Arthur, Hancok, and Chrysler (1993) had participants reproduce a spatial layout under both real and binocular virtual viewing conditions. Participants in both conditions actively explored the spatial layout, which was comprised of 9 objects. Participants then reproduced a scaled down version of the layout in a map. No significant differences were found suggesting that spatial knowledge acquisition in virtual environments through navigation is similar to actual navigation.

Henry (1992) compared the spatial abilities of architects in both real and immersive virtual environments. Architects in both groups toured an art gallery while performing spatial dimension and orientation tasks. Participants in the immersive VE condition experienced the virtual gallery while wearing a HMD with a 90 degree FOV. The spatial tasks the participants performed included estimating the dimensions of the gallery and pointing at objects seen previously on the tour. Henry discovered no differences in the pointing task, but found that spatial dimensions were substantially underestimated in the immersive environment when compared to the actual environment. As FOV was not manipulated in the course of the experiment, its exact contribution to the consistent pattern of distance underestimation in the virtual environment could not be assessed. Similarly, McGreevy (1993, 1994) found that field geologists wearing a HMD experienced difficulties estimating distances and used pacing to form distance estimates. Again, as FOV was not manipulated in the virtual environment, the extent of the contribution of FOV to the results could not be determined.

Regian and Shebilske (1992) investigated the use of immersive VEs as a training medium for visual-spatial tasks. One of their experiments involved participants learning to navigate a virtual maze, comprised of 3 levels with each level containing 4 rooms. Rooms in the maze resembled each other, with unique color-coded objects used to distinguish rooms. Each room had at least one passageway connecting it to the other rooms. Participants learned to navigate the maze through a combination of three verbally-guided tours and a one-hour free exploration period. Participants then attempted to find the shortest path between two specified rooms. Three routes were required in all, with the routes designed to take the participants through all the rooms in the maze. The first route could be completed with a minimum of eight rooms, the second with a minimum of four rooms, and the third with a minimum of six rooms. Regian and Shebilske then compared the experimental results to the results of a random walk, based on the Monte-Carlo method. They then made the questionable claim that the differences were the result of learning. Based on the Monte-Carlo simulation, a participant could enter 14 routes for the first route, and still show significant learning, while performance on the third route could not be eliminated by chance; a better test of the results would have been to include a control group with no experience of the maze (Satlich, 1995).

Satlich (1995) investigated the process by which individuals orient and navigate in a large-scale, virtual environment, which consisted of 39 separate rooms with over 500 objects.

The HMD used for the experiment had a HFOV of 100 degrees. Participants either developed spatial knowledge for the environment through direct experience with the virtual environment or indirectly through the study of maps. Pointing to objects previously encountered in the building was used to assess landmark knowledge, while route knowledge was assessed by estimating the distance between points or objects in the building and following the shortest route between two points. Configurational knowledge was assessed using an Euclidean distance task. Surprisingly, people who had direct experience with the VE either performed equivalently or worse on all tasks than the control group, who had only studied maps; in the real world, adults with direct experience perform significantly better on spatial tasks than those who studied maps or other navigational aids (Presson and Hazelrigg, 1984; Scholl, 1993). As had been found in previously mentioned VE studies, the results showed participants were underestimating distances (Brickner and Foyle, 1992; Henry, 1992; Psotka et al., 1993). Again, as FOV was not manipulated in the experiment, the impact of FOV on performance could not be assessed.

As in planned environments in the real world, the ease with which spatial knowledge is acquired in virtual environments depends on the design of the environment. Bricken and Bryne (1993) found that virtual world design significantly impacted the development of spatial knowledge based on an analysis of worlds built by children at a technology and science summer camp. Virtual worlds with significant landmarks around the periphery of the world were easier for students to orient themselves in than worlds with easily confused landmarks or with one central landmark.

Problem Statement

Virtual environments give students an opportunity to interact with a computer-generated simulation of a real or imaginary environment in an intuitive manner. They simplify interaction with the simulated world and synthesis of its information as users interact with the virtual world in much the same way they interact with the natural world. They liberate students from the boundaries of the real world and allow them to explore worlds they might otherwise never experience. Today’s educational VEs allow children to explore villas in Ancient Greece (Grove, 1995) and pyramids in Ancient Egypt (Ainge, 1996), perform virtual physics experiments (Nemire, 1995), visit molecules (Byrne, 1996), and inhabit worlds of their own making (Bricken and Byrne, 1993; Rose, 1995). The vast majority of children who experience these virtual worlds find the experience both fun and highly motivating. The potential for educational VEs appears as limitless as a child’s imagination.

Whether VE technology fulfills its potential depends largely on how students react to the simulated environments and the impact of the technology on the learning process. The characteristics of both the students and the VE system play critical roles in this process. A plethora of experiments with adults have studied the impact of VE system parameters on VE effectiveness. However, the literature has little to offer in predicting the impact of student characteristics, such as age, on VE effectiveness. This gap is particularly evident to designers of VEs aimed at children. Little is known about how the system parameters which define a VE impact a child using the environment, what the impact of the parameters are on the child's ability to learn, or how the child's age changes the impact of the parameters.[1] Designers of VEs targeted at children must rely on studies done with adults to guide their design decisions. The failure to understand how children differ from adults in their responses to VEs poses a serious obstacle to the design of effective learning environments for children.

Studies with adults have shown that FOV is a critical factor in determining the effectiveness of VEs. In the real world, consecutive head movements result in overlapping visual information, with the information from one head movement overlapping much of the information yielded by the previous movement. However, with a restricted FOV, the information from successive head movements yields little overlapping visual information, resulting in a reduction in the quantity of information available for locomotion and navigation. As a result, an individual's ability to move competently about in the environment and to develop spatial knowledge can be substantially degraded. Further, restricted FOVs create telephoto-like distortions of the dimensions of the environments, resulting in underestimation of both object size and distance. Similar effects have been documented in VEs where the limitations of the HMD results in restricted FOVs. VEs amplify these effects resulting in an even greater decrements in performance.

Studies with children in VEs have focused on developing learning paradigms for VEs and evaluating VEs as an educational tool. These studies offer little besides anecdotal evidence as to the impact of VE system parameters on a child's performance in a VE. This evidence suggests that children, with their more immature and slower cognitive processes, are more sensitive than adults to the perceptual limitations of VEs and experience correspondingly greater performance decrements. Additionally, children between the ages of 2 and 12 are the most susceptible to motion sickness and experience a greater degree of immersion side-effects.

As in adults, FOV restrictions and the corresponding reduction in visual information is expected to adversely impact the spatial performance of children. This effect is expected to be amplified in children with their immature spatial abilities and slower processing speeds. Spatial knowledge develops as children age, with children passing through developmental stages corresponding to the phases an adult passes through while developing configuration knowledge of a space. Additionally, male superiority at spatial tasks starts appearing around age seven or eight with little gender differences in ability found in younger children (Newcombe, 1982). Landmark knowledge has been exhibited by pre-schoolers, with the ability to form landmark knowledge being fully developed by the time a child reaches elementary school. In limited large-scale spaces, route knowledge has been exhibited by 3-6 year olds and configuration knowledge has exhibited by 5-6 year olds. However, age-related differences in the speed of acquisition, storage, and access of spatial information exist and drive age-related performance gains on many spatial tasks. The ability to form configuration knowledge improves dramatically in middle childhood, with the ability to form landmark and route knowledge being the least affected by developmental differences once a child is school age.

---

[1] See Appendix K for a summary of potential adult-child differences as a function of VE system parameters.

The main goal of this research was to investigate the impact of varying one system parameter, FOV on the performance of middle elementary schoolchildren and the incident of side-effects in that population in an immersive VE. The other goals of this research were to identify 1) how, and if, middle elementary schoolchildren’s responses to this environment differ from that of adult participants, and 2) how, and if, gender affected participant performance and responses. This study is a first step in systematically assessing the impact of VE parameters on children and assessing how the age and gender of a child changes the impact of these parameters. Hopefully, such knowledge will help VE system designers create more usable and effective VEs for children of all ages.

Research Hypotheses

The general hypothesis of this research was that 7-9 year old children differ from adults in their responses to immersive virtual environments, and that children in this age group would be more adversely impacted by the perceptual deficiencies of virtual worlds than adults. The advantages of better understanding child users of VEs are undeniable. Children are not just short adults. Better understanding them makes possible the development of design and learning strategies which improve child-computer interaction and allow the smallest VE users to more effectively utilize the affordances provided by virtual settings. Navigational efficacy is of particular concern as navigation difficulties can cancel out many of the of the purported advantages of educational VEs by increasing student frustration and decreasing student engagement and motivation (Taylor, 1997). The present work focuses on adult-child differences related to the development of the spatial knowledge which supports navigation, and the impact these differences may have on usability and learning in the virtual world.

Based on the general hypothesis and the nature of the proposed study, the specific hypotheses that follow were formulated.

- **Hypothesis 1.** Locomotion efficiency, as measured by the number of collisions with objects in the VE, will increase with age and FOV. Significant differences in performance will exist between 7-9 year old children and adults under the same FOV restrictions and between participants from the same age range under different levels of FOV.

  Difficulties moving about in an environment has been shown to interfere with learning and enjoyment in the virtual world (Bricken and Bryne, 1993). FOV has been shown to affect an individual’s ability to competently travel through both real and virtual environments (Alfano and Michel, 1990; Cha et al., 1992; Snow, 1996). The effect was expected to be amplified in children who are less capable of dealing with the demands of VEs (Bricken and Bryne, 1993; Winn, 1995).

- **Hypothesis 2**. Landmark knowledge, as measured by the landmark recognition test, will not increase with age or with FOV. No significant differences in performance will exist between children and adults; or between participants in the same age range at different levels of FOV.

  Recognition of environmental landmarks is the first step in orienting oneself in the virtual environment and is a necessary pre-requisite for learning. Pre-schoolers can recognize objects in pictures, especially those representing central information (Amen, 1941; Long, 1961). By middle elementary school, this ability is fully developed. Researchers have found that the ability to form landmark knowledge remains relatively static once a child enters elementary school (Curtis et al., 1981).

- **Hypothesis 3**. Route knowledge will increase with age and with FOV. Significant differences in performance will exist between 7-9 year old children and adults under the same FOV and between participants from the same age range under different levels of FOV. In particular,

  a) Performance on the composite route knowledge measure and model landmark measure will increase with age and with FOV.

  b) A significantly larger percentage of children than adults will not be able to achieve route knowledge of the space, with participants in the same age range at the higher level of FOV achieving route knowledge significantly more frequently than those at the lower FOV. Participants will be considered not to have achieved any degree of route knowledge if they 1) could not correctly sequence the landmarks in the house model, and 2) scored 9 or less on the composite route knowledge measure.

  Route knowledge allows users to find their way through a virtual landscape and is necessary for learning in large-scale environments. Without it, users feel lost in the virtual space. An uncomfortable experience for most adults, and an often scary one for younger children. Route learning efficacy increases with age through middle childhood (Gibson, 1969; Herman, 1980; Piaget and Inhelder, 1956; Siegal, 1977). But in limited, large-scale spaces, such as the experimental VE, the route knowledge of children in this age group has been shown to be comparable to that of adults in the same setting (Hazen et al., 1978; Kosslyn, 1974; Pick and Lockman, 1982). However, an individual's ability to form spatial knowledge in both real and virtual environments is negatively impacted by FOV restrictions (Alfano and Michel, 1990; Cha et al., 1992; Snow, 1996) with this effect expected to be amplified in children who are less capable of dealing with the demands of VEs (Bricken and Bryne, 1993; Winn, 1995).

- **Hypothesis 4**. Configuration knowledge will increase with age and FOV. Significant differences in performance will exist between 7-9 year old children and adults under the same FOV and between participants from the same age range under different levels of FOV for all tasks. In particular,

a) Performance on the model building, the spatial inferences, and the direction pointing tasks will increase with age and FOV;

b) A significantly larger percentage of children than adults will not be able to achieve configuration knowledge of the space, with participants in the same age range at the higher level of FOV achieving configuration knowledge significantly more frequently than those at the lower FOV. Participants will be considered not to have achieved any degree of configurational knowledge if they 1) could not construct a correct house model, 2) could not correctly answer at least six spatial inference questions, and 3) had an average, absolute azimuth error greater than 10 degrees for the pointing tasks.

Like route knowledge, configuration knowledge helps users orient themselves in the virtual world. Without it, users will still be able to find their way through a virtual landscape, albeit less effectively. Configuration learning efficacy increases with age until middle or late childhood (Curtis et al., 1981; Gibson, 1969; Herman, 1980; Piaget and Inhelder, 1956; Siegal, 1977). But in limited, large-scale spaces, such as the experimental VE, the configuration knowledge of children in this age group has been shown to be comparable to that of adults in the same setting (Kosslyn, 1974; Pick and Lockman, 1982). However, an individual's ability to form spatial knowledge in both real and virtual environments is negatively impacted by FOV restrictions (Alfano and Michel, 1990; Cha et al., 1992; Snow, 1996) with this effect expected to be amplified in children who are less capable of dealing with the demands of VEs (Bricken and Bryne, 1993; Winn, 1995). Additionally, turns have been shown to interfere with the development of spatial knowledge in children with children often linearizing spaces containing turns when building models of the spaces (Hazen et al., 1978). Further, configuration knowledge is difficult for adults to form in virtual environments and may not be achievable by children with their more immature spatial abilities and slower processing speeds (Herman, 1980).

- **<u>Hypothesis 5</u>**. The time needed to complete the experimental tasks will decrease as age and FOV increases. Significant differences in the time needed to complete tasks will exist between 7-9 year old children and adults under the same FOV restrictions and between participants from the same age range under different levels of FOV.

Time to complete tasks is a critical element of task design both in and out of a VE. Along with accuracy, the time taken to travel a path through both real and virtual environments has been shown to be affected by the FOV (Alfano and Michel, 1990; Cha et al., 1992; Snow, 1996). Anecdotal evidence suggested that children would be affected to a greater degree by the difficulties associated with interacting with VEs and by the perceptual limitations of today's current hardware (Bricken and Bryne, 1993; Winn, 1995) thereby increasing the time needed to perform experimental tasks. Further, while children in the target age group are fully capable of performing the experimental tasks, developmental effects related to the speed and ease of cognitive processing were expected to lengthen the time needed to complete the tasks (Herman, 1980).

- **Hypothesis 6**. The incidence of VE side-effects will decrease as age and FOV increases. Significant differences in the incidence of VE side-effects as measured by the post-immersion questionnaire will exist between 7-9 year old children and adults under the same FOV and between participants from the same age range under different levels of FOV.

  VE side-effects could pose a serious obstacle to wide-spread use of educational and entertainment VEs by children. Children between the ages of 2 and 12 are the most susceptible to motion-sickness (Reason and Brand, 1972) and appear to be equally susceptible to immersion side-effects (Bricken and Bryne, 1993; Winn, 1995).

- **Hypothesis 7**. The incidence of difficulties interacting with the VE equipment will decrease as age increases. Significant differences in the incident of equipment difficulties as measured by the post-immersion questionnaire and by the number and duration of experimental breaks will exist between 7-9 year old children and adults under the same FOV.

  Equipment has been blamed for many of the difficulties experienced by children in VEs. Anecdotal evidence suggests the children will be affected to a greater degree by the difficulties associated with interacting with VEs and by the perceptual limitations, e.g. resolution deficiencies, of today's current hardware (Bricken and Bryne, 1993; Winn, 1995).

- **Hypothesis 8**. The general enjoyment level for the VE will decrease as age increases. Significant differences in the level of enjoyment as measured by the post-immersion questionnaire will exist between 7-9 year old children and adults under the same FOV.

  Anecdotal evidence suggests that the younger the participant, the greater the enjoyment of the VE experience (Bricken and Bryne, 1993; Winn, 1995).

- **Hypothesis 9**. The sense of presence in the VE will decrease as age increases. Significant differences in the sense of presence as measured by the post-immersion questionnaire will exist between 7-9 year old children and adults under the same FOV.

  Anecdotal evidence suggests that the younger the participant, the greater the sense of presence in the VE (Bricken and Bryne, 1993).

CHAPTER 2. METHOD

The experiment described here is a virtual adaptation of a 1978 experiment in which Hazen, Lockman, and Pick investigated children's development of spatial knowledge in a large-scale environment. The tasks and procedures used in the original study were adapted to the virtual world: the large-scale environment used in the original study was re-created in the VE, and comparable tasks were used to evaluate participant performance. This experiment differs from the original study in terms of the factors manipulated and in the addition of pointing tasks to the protocol. The age range of participants was extended to include adults, and an additional factor, FOV was manipulated. Hazen et al.'s original study served as a basis for formulating performance expectations for child participants and evaluating the impact of virtual environment design on participants.

Experimental Design

The between-subject experiment factorially combined participant age range (AGE), FOV (FOV), and gender (GENDER). There were two levels of AGE (7-9 year old children and adults), two levels of FOV (30˚ H x 22˚ V and 48˚ H x 36˚ V), and two levels of GENDER (males and females). The experimental design has 8 conditions with 9 participants per cell for a total of 72 subjects. The experimental design is illustrated in Figure 1.

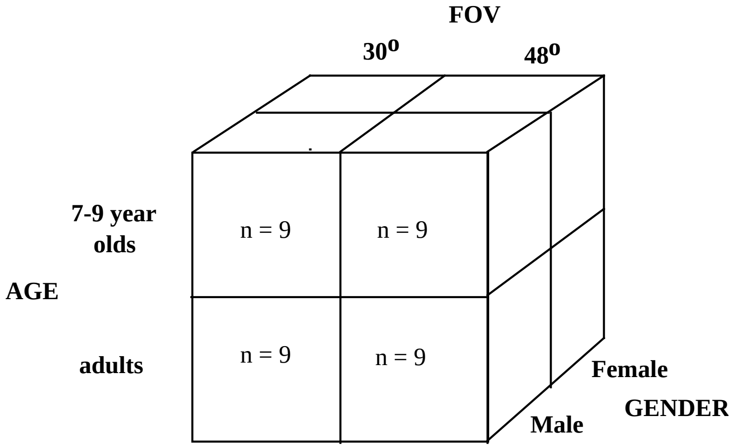


Figure 1. 2^3 between-subject design.

AGE, FOV, and GENDER were between-subject, fixed factors. AGE and GENDER by necessity, and FOV as the nature of the experimental tasks was such that participants exposed repeatedly to the environment would benefit too much from transfer effects. The major drawback of this design were that a larger number of subjects per cell was required and the variation due to subjects could not be removed from the error term. The sources of variation for the design were AGE, FOV, GENDER, AGE x FOV, AGE x GENDER, FOV x GENDER, and Subjects / AGE FOV GENDER. The ANOVA structural model for the design was

$$Y_{ijklm} = \mu + \alpha_i + \beta_j + \chi_k + \alpha\beta_{ij} + \alpha\chi_{ik} + \beta\chi_{jk} + \alpha\beta\chi_{ijk} + \gamma_{l(ijk)} + \varepsilon_{m(ijkl)}$$

The AGE conditions were selected based on the following criteria: 1) individuals from each level should be at relatively the same developmental stage with respect to their spatial capabilities, 2) under normal viewing conditions, individuals from each level would generally be expected to successfully perform the experimental tasks, 3) one level should be comprised of the youngest children that satisfy the previous constraints, and 4) levels should be large as possible while still meeting the previous constraints. The literature suggests that the earliest age at which a child could reasonably be expected to successfully complete tasks similar to the experimental tasks is six or seven years (Acredolo, 1977; Blaut and Stea, 1971; Cornell and Hay, 1984; Hazen et al., 1978; Herman and Siegal, 1978; Huttonlocher and Newcombe, 1984) with developmental discontinuities occurring at 5, 6-7, 10-11, and 14-16 years of age (Kenny, 1983). Taking a conservative approach, the lower endpoint of the age range containing the child participants was set at seven years and the upper endpoint was set to nine. For the purposes of the study, participants 18 years of age or older were considered adults with fully developed spatial capabilities. As this was an initial study to explore adult-child differences in virtual environments, AGE was limited to two levels. Further studies are needed to clarify the age-related differences among children.

The FOV restrictions for the study were based on equipment constraints. The upper FOV limit was set to 48˚ H x 36˚ V as it is largest FOV achievable with the available HMD. The lower FOV limit was set to 30˚ H x 22˚ V as it is the typical FOV restriction for VR goggles, a low cost alternative to HMDs that are popular in educational and entertainment circles. (A more detailed discussion of the method used to manipulate the experimental HMD's FOV can be found in the *Materials and Apparatus* section in this chapter.)

Dependent Variables

The main objective of this study was to investigate the impact of varying one system parameter, FOV, on the spatial awareness and learning ability of children and the incident of side-effects in that population in an immersive VE. The other objectives of this study were to 1) identify how, and if, children's responses to the VE differed from that of adults, and 2) determine what role gender played in participant performance and responses. The dependent variables described here were formulated to fulfill these objectives.

Both subjective and objective measures were gathered. The subjective measures relate to the degree of VE side-effects experienced by the participants, the degree to which the participants had difficulties with the equipment, and the degree to which the participants enjoyed the experience. The objective measures relate to spatial knowledge and physical side-effects of the VE. Additionally, time spent by participants in the VE, the time to complete the experimental tasks, and the number and duration of breaks taken during the VE portion of the experiment were tracked.

A simple spatial learning task was used to gauge participant performance. The task was kept simple in order to minimize the time spent in the VE and to moderate the level of difficulty for child participants. Although a VE poses no inherent danger to its users, some users do experience motion sickness-like side effects as the result of their immersion, and side-effects have been shown to increase with the length of the exposure (Lampton et al., 1994). This issue is of special concern in VE studies involving children as children are at greater risk for motion-sickness (Reason and Brand, 1972) and are thought to be at greater risk for VE side-effects (Kolasinski, 1995; Pausch et al., 1992).

Spatial Knowledge

Spatial knowledge was divided into locomotion ability, landmark knowledge, route knowledge, and configurational knowledge. These stages categorize the increasingly sophisticated levels of spatial knowledge that develop as individuals explore an environment (Wickens, 1992).

- Locomotion, or the ability to move oneself about in the environment, is the most fundamental skill and was measured by the average number of collisions with VE objects during a 5-minute period.

- Landmark knowledge, or the ability to state with certitude an object exists within an environment and to be able to recognize the object when it appears in the visual field, was measured by the number of objects that were correctly identified as appearing (or not appearing) in the environment during a post-immersion test (landmark recognition measure).

- Route knowledge, or the ability to navigate from one place to another by using landmarks, was measured by an composite route knowledge measure comprised of 1) the number of correctly selected doors (route measure) and 2) the number of correctly predicted landmarks (landmark-prediction measure).

- Configurational knowledge, or the ability to form an internalized cognitive map of the environment, was measured by 1) the number of correct spatial inferences made in the VE, 2) the correctness of the house model constructed in the post-VE session, 3) the time needed to complete the tasks within the VE, 4) the time needed to construct the house model, and 5) azimuth errors for the in-VE pointing tasks.

A detailed discussion of each measure, including any associated scoring method, can be found in the *Procedure* section of this chapter.

Incidence of Immersion Side-Effects

The incidence of immersion side-effects was measured by the responses to the post-immersion survey (see Appendix E), changes in vision acuity, and changes in postural stability. The vision and balance measures used in this study are all of the form (M_1 - M_2) where M_1 was the performance result for a given test during the pre-immersion trial and M_2 was the corresponding value for post-immersion performance.

Incidence of Equipment Difficulties

The degree to which participants experienced difficulties interacting with the VE equipment was measured by the responses to the post-immersion survey (see Appendix E). Survey questions related to the usability of the HMD display, the joystick, and the VE workstation.

General Enjoyment Rating

The incidence of immersion side-effects was measured by the responses to the post-immersion survey (see Appendix E). Survey questions related to whether the participant found VR interesting and fun. Additionally, participants were asked under what circumstances they would like to use VR, e.g. for learning or as a game.

Presence Rating

Generated presence was measured by responses to the post-immersion survey (see Appendix E). The presence survey question related to whether the participant felt the VE was a real place.

Participants

Each treatment condition contained 9 participants. In all, 36 seven to nine year old children (18 male and 18 female) and 36 adults (18 male and 18 female) were needed to fill the treatment conditions. Children were recruited from the local school district, and adults were recruited from the local university. All participants were screened for health problems, normal visual acuity, normal color vision, and normal postural stability. (See the *Procedure* section of this chapter for a more detailed discussion of the screening process.) Participants were paid $5.00 for the session.

In all, 46 children and 38 adults participated in the study with 6 children and 2 adults participating in pilot testing. The remaining 40 children and 36 adults participated in the actual experiment with 4 children not completing the experiment. Of the children that did not complete the experiment, one boy (aged 9 years 2 months) did not satisfy the color vision requirement, one girl (aged 9 years 5 months) stopped in the middle of the experiment due to the sudden onset of intestional flu, one girl (aged 7 years 4 months) failed to visit all the rooms in the virtual house and was dropped from the experiment, and one girl (aged 7 years) found the HMD so uncomfortable that she decided to stop after 5 minutes.

Protection of Participant Rights

Participants were connected to their experimental data only by a participant number assigned by the experimenter. No record matching the participant number to the participant's name was made. All written accounts of this study identify data only by participant number.

Materials and Apparatus

Vision Tests

Visual ability was assessed with the Bausch and Lomb® Vision Tester, a standard tool for measuring visual perception. Near visual acuity for both eyes was measured using the F-3 Test. Color vision was assessed using the F-7 Test.

Balance Tests

A stopwatch was used to measure the time the participants were capable of holding a particular posture. A hundredth of a second was the smallest division measurable by the stopwatch. All tests took place on a hard, smooth floor.

Testing Environment

The testing environment was comprised of an experimenter area and an experimental area. The room where testing took place is shown in Figure 2.

Figure 2. Testing Environment.

The experimental area (shown in the forefront of Figure 2) contained a large table for building the house model, a chair, and a workstation area for VE users. The workstation area was comprised of an adjustable table on which the VE input device rested and seating for the participant. Participants remained seated in the chair while using the VE equipment; this posture was found to be the most comfortable for participants during pilot testing.

The experimenter area contained a table with a monitor for viewing the virtual scene, a video camera that was connected to a monitor in the waiting area, and seating for the experimenter. A close-up of the experimenter area is shown in Figure 3.

Figure 3. Experimenter area.

An adjacent room in the HCIL was used as a waiting area. Participants also used this area during break periods. This area contained comfortable seating for the parents and a video-audio hookup that allowed the parents to see and hear child participants during the experimental session. It also contained a computer which was be loaded with computer games and allowed web surfing.

Virtual Environment

The VE system parameters of interest which were not manipulated in this study included audio feedback = yes, head-tracking = no, stereopsis = no, display resolution = 640 H x 480 V pixels, scene update rate[2] = 12 Hz.

Software and Hardware

The software that generated the virtual environment and interfaced the VE system peripherals was run on a Pentium-based personal computer. Dimension International's Superscape VRT 4.0 software set was used to create the virtual environment. Virtual Research Systems' VR4 HMD was used to present the visual and auditory components of the VE to the participant.

Final determination of input device was made during pilot testing. The input device was selected from a candidate pool comprised of General Reality's Cyberstick , a 5th Glove, and a two-dimensional joystick. The Cyberstick is a baseless joystick, or wand, that allows users to simply move their hand up and down and sideways to change direction while wand triggers allow users to manipulate objects in the environment. The 5th Glove is a data glove with fiber-optic flex sensors that allows a user to move easily through a virtual world by combining hand gestures with the pitch and roll of the user's hand. Children slightly older than the target age group had used similar input devices to navigate and interact with immersive VEs (Bricken and Byrne 1993; Merickel, 1991). However, pilot testing for this experiment found that both the data glove and the wand were too large for small hands to easily manipulate. The 2-dimensional joystick was chosen as it could be easily used by both children and adults to perform the experimental tasks. The two-button joystick could be used to move around or activate objects, e.g. open door, in the VE. The movement of the joystick was dampened and restricted to the X-Y plane in order to increase the its usability for the younger participants.

Environment Description

The environment consisted of six rooms connected by doors. The layout of the environment is shown in Figure 4. The environment which was used for this study was a slightly enlarged version of the one used by Hazen et al. (1978). Participants who experienced the original version of VE in which the rooms were sized as in the Hazen et al. (1978) study complained of feeling that "the rooms were too small to move about in" and that they were "going to bump into a wall" when they turned around. Room size and door width were enlarged in later versions of the VE to compensate for this "claustrophobic" shrinking of room size which resulted from the distance compression effect introduced by the FOV restrictions (Dolezal, 1982; Hagan et al., 1978). Rooms in the original study were 5'6" squares, while rooms were 10'10" squares in the experimental VE. The environment flooring consisted of a checkerboard

---

[2] Note, the development hardware and software did not allow strict control of the update rate and the value given represents the maximum possible update rate.

pattern. Doors connected the rooms (opaque curtains were used in the original study). A fence was added to the front of the house to prevent participants from wandering aimlessly in the larger world during the learning period for the house.

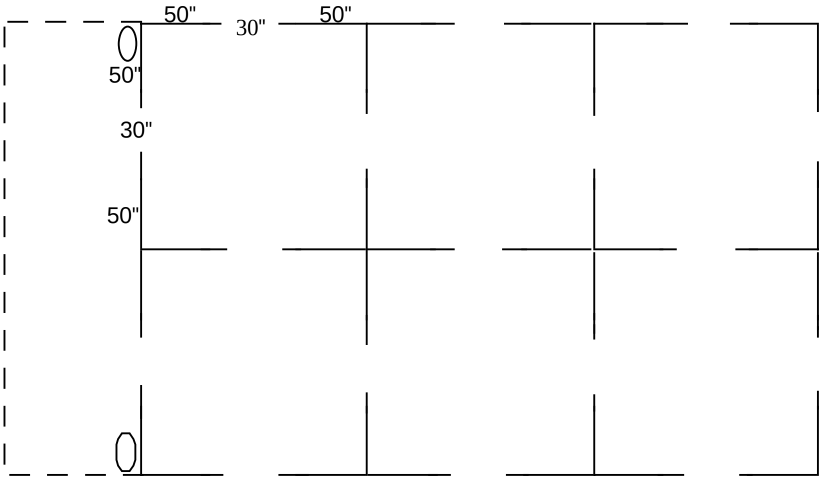


Figure 4. House layout, dimensions are given in inches. Doors are represented by spaces and walls by solid lines. The fenced area at the front of the house is indicated by the dotted lines. Bushes in the fenced area are indicated by ovals.

Rooms had a uniform look with a distinctive landmark located in each room. See Figures 5 and 6 for snapshots of the rooms under the two FOV conditions. The lower FOV level was achieved with Superscape's VRT 4.0 software. Using the software, the display area was resized to correspond to a 30˚ H x 22˚ V FOV with the zoom being manipulated to ensure that the FOV and geometric FOV (GFOV) were identical. The area surrounding the display area was blacked out as shown in Figure 6.

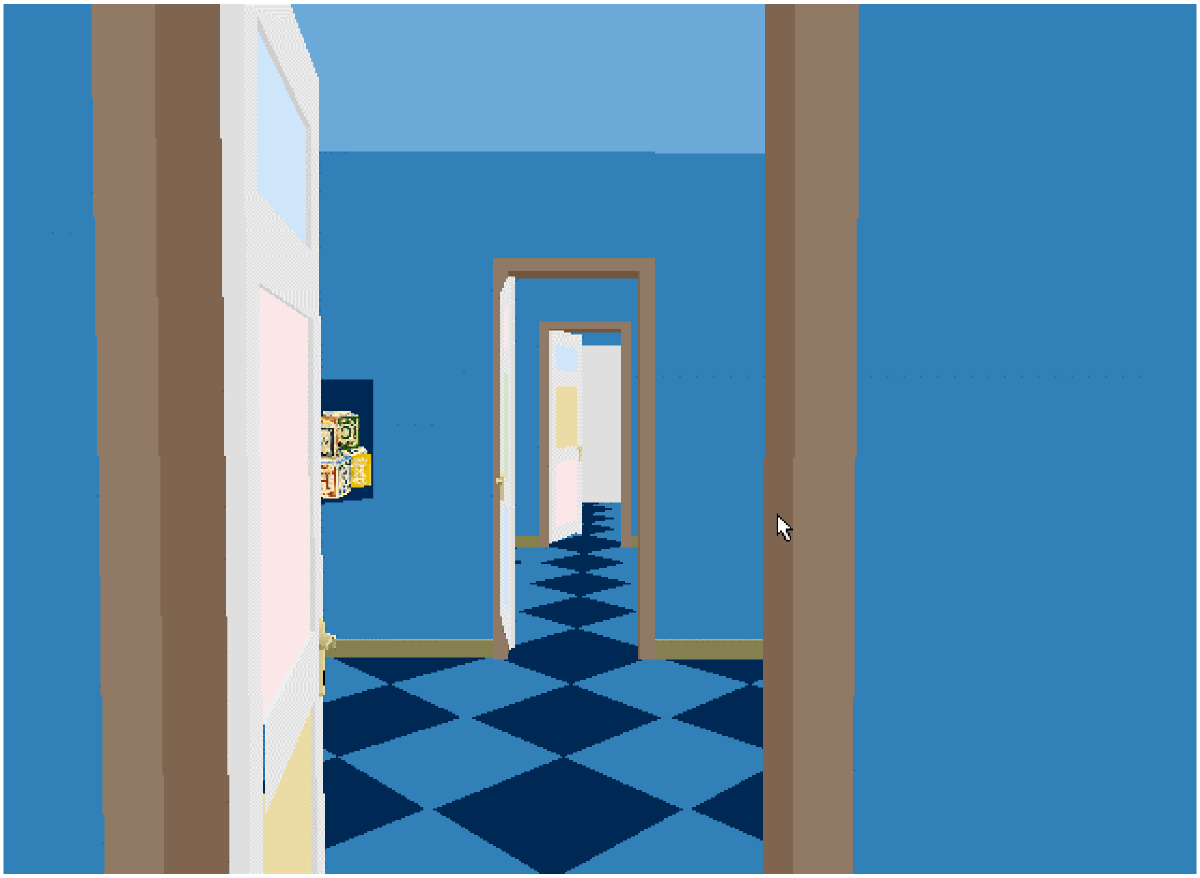


Figure 5. A sample view under the high field of view condition.

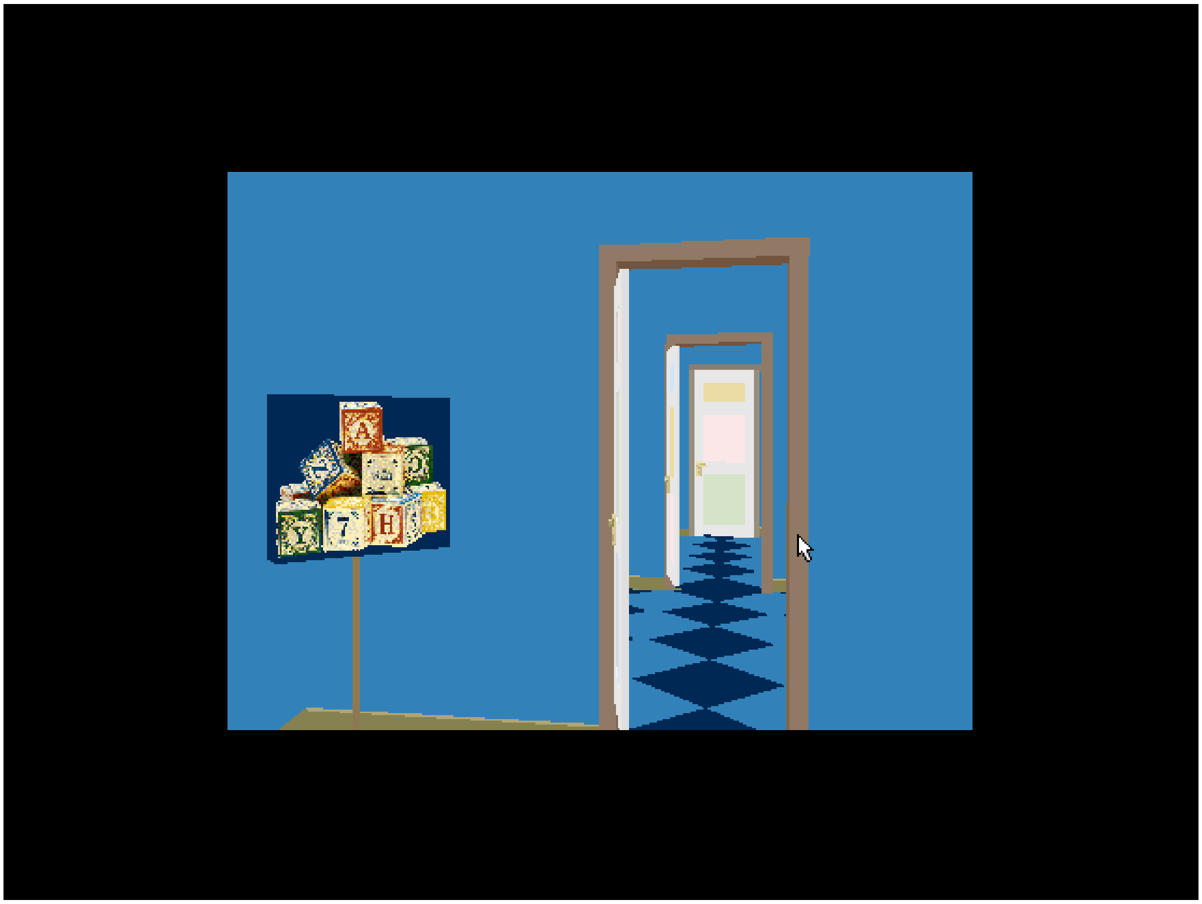


Figure 6. A different sample view under low FOV condition.

Enlarged, digitized pictures of toys were used as landmarks (see Appendix G), with each picture raised at least three feet off the floor. The pictures was placed on an easel (instead of the floor as in the original study) in order to minimize the need for extreme, rapid head movements which often accelerate the development of simulator sickness. Pilot testing was used to verify that the pictures used as landmarks were easily identifiable and distinguishable by participants.

Post-immersion Questionnaire

Questionnaire items comprised of 4 categories: General Enjoyment (G), Equipment Difficulty (E), Side-effects (S), and Presence (P). The score for an individual category was the sum of the scores for the items in the category. See Table 1 for a detailed discussion of category membership and item scoring.

Table 1. Questionnaire Item Scoring and Categories.

Number	Question	Score		Category
		Yes	No	
1	Did you like virtual reality (VR)?	1	0	General Enjoyment
2	Was the picture in the helmet-mounted display hard to see?	1	0	Equipment Difficulty
3	Was the joystick hard to use?	1	0	Equipment Difficulty
4	Did you find VR interesting?	1	0	General Enjoyment
5	Was moving around in the environment easy?	0	1	Equipment Difficulty
6	Does your stomach hurt?	1	0	Side-effects
7	Does your head hurt?	1	0	Side-effects
8	Do you want to visit VR again?	1	0	General Enjoyment
9	Is your vision blurred?	1	0	Side-effects
10	Do you feel tired?	1	0	Side-effects
11	Do your eyes feel funny?	1	0	Side-effects
12	Was the helmet-mounted display heavy?	1	0	Equipment Difficulty
13	Is VR harder than using a computer?	0	1	Equipment Difficulty
14	Would you like to learn things in VR?	1	0	General Enjoyment
15	Do you feel dizzy?	1	0	Side-effects
16	Did the VR environment feel like a real place?	1	0	General Enjoyment
17	Did you get tangled in the wires when using the VR equipment?	1	0	Equipment Difficulty
18	Does any part of your body hurt?	1	0	Side-effects
19	Was VR boring?	0	1	General Enjoyment
20	Are you having difficulty concentrating?	1	0	Side-effects
21	Do your eyes feel tired?	1	0	Side-effects
22	Would you like to play a VR game?	1	0	General Enjoyment
23	Was the helmet-mounted display comfortable?	0	1	Equipment Difficulty

Small-scale Model Construction Task

The materials used to create the small-scale model included six 8” square boxes covered with construction paper to resemble rooms in the virtual environment and smaller versions of the six pictures used as landmarks in the virtual environment.

Procedure

Pre-screening

Sessions began with the introduction of the participant (and his/her parent when applicable) to the waiting area. While in the waiting area, the purpose of the area was explained, and use of the games and web surfing software was demonstrated. Additionally if the participant was a child, the experimenter pointed out the video-audio hookup to the experimental area, and explained how the parent would be able to observe the child during the experimental session.

The participant (and his/her parent if the participant is a child) then moved to the testing area. The participant (and his/her parent) were then provided with a short introduction to the research (see Appendix F). At this time, either the adult participants (or the parents of child participants) were asked to fill out an informed consent form (see Appendix B) and a short questionnaire on their (or their child's) previous VE and computer experience, current physical condition, and history of motion sickness (see Appendix D). Next the Bausch and Lomb® vision acuity test (F-3) was administered to participants to ensure they met the minimum vision requirements. Assuming their visual acuity is 20/40 or better, the Bausch and Lomb® color vision test (F-7) was used to assess their color vision. Assuming they met minimal color vision requirements, balance tests were administered. Only participants in good physical condition, with no currently existing symptoms of motion sickness, and having minimum levels of vision continued in the study.

Balance Tests

Balance stability was assessed using the Stand-on-Nonpreferred-Leg (SONL) and Stand-Heel-to-Toe (SHT) postural tests. The tests were administered pre- and post-immersion to all participants. Participants wore either shoes without heels or went without shoes for all tests. The participant was given a 30 second rest break after each test. The feasibility of children performing these tests was determined during pilot testing.

Stand-on-Nonpreferred-Leg

Participants stood erect on their nonpreferred foot with their arms crossed against their chest for a maximum of 30 seconds or until they could no longer maintain the posture (Thomley et al., 1986). The number of seconds spent in the posture was recorded.

Stand-Heel-to-Toe

Participants stood in an erect heel-to-toe posture with their arms crossed against their chest for a maximum of 60 seconds or until they could no longer maintain the posture (Thomley et al., 1986). The number of seconds spent in the posture was recorded.

Virtual Environment Session

Participants determined when, and for how long, they took breaks from the VE. No upper limit was placed on the number of breaks taken or their duration. However, the number of breaks and total break time was recorded for later analysis.

During the VE session, participants were carefully monitored for adverse side effects of immersion. Any participant experiencing adverse side-effects was verbally reminded of his or her freedom to withdraw from the experiment. Parents of child participants experiencing adverse side-effects were reminded of their freedom to withdraw their child from the study. Participants received auditory feedback whenever they collided with an object in the VE and whenever they opened or closed a door.

Virtual Environment Training

After completing the prescreening, the participant (and parent) was introduced to the hardware required to interface with the VE and was allowed to examine the various elements, e.g. HMD, input device. As part of the introduction, the experimenter explained that computer-generated graphical images would appear inside the helmet. Next use of the input device for navigating and interacting with the VE was demonstrated without the HMD. The experimenter (or parent if the participant is a child) then donned the HMD and the demonstration was repeated. At that point, the participant donned the equipment and the demonstrations were again repeated. Child participants were then told that his/her parent would be moving to the waiting area, and were reminded that the parent would be able to see and hear everything that went on in the experimental area.

The participant was then given 10 minutes to explore the demonstration VE. (VE system parameters for the demonstration VE were identical to those of the experimental VE.) By the end of that period, the participant was expected to have successfully opened a door and gone through it. If desired, participants could take a short break at the end of the training. At the end of the break, participants would re-don the VE gear.

Spatial Learning

Participants were shown a U-shaped route through the six rooms that made up the virtual environment. This route is shown in Figure 7. Before entering the VE, participants were told that they would be taking a trip through a “toy house” and that they would be asked to learn the spatial layout of the “toy house”. Participants were allowed 12 minutes to learn the layout of the house. During this period all participants completed at least one circuit through the house[3], with the majority completing an additional 1-2 circuits.[4] Collisions of the participant’s virtual body with objects in the VE was tracked.

---

[3] The experimental protocol specified that any participant unable to complete at least one circuit would be dropped from the experiment. Only one girl (aged 7 years 4 months) was unable to meet this criteria.

[4] The exact number of circuits through the house was not tracked as after the initial tour, participants were allowed to explore the house in free-form manner.

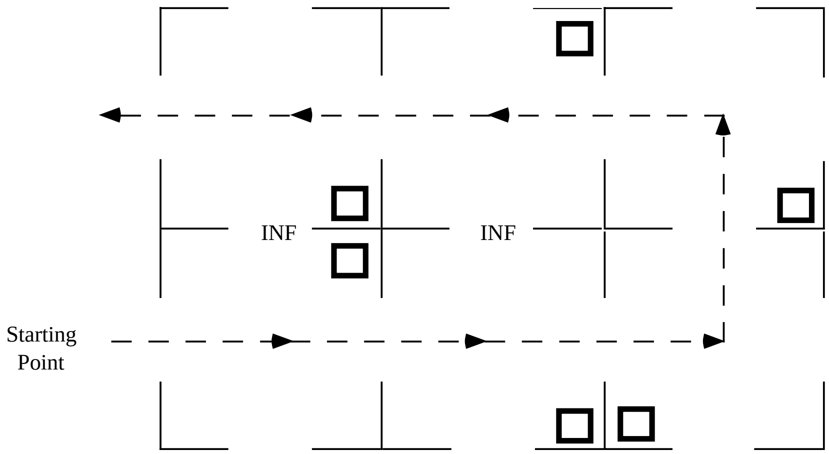


Figure 7. Map illustrating the route through the house. The dotted line represents the route and the squares represent landmarks. Doors are represented by spaces and walls by solid lines.

Participants entered the toy house at the starting point of the route. When they entered the house, all doors along the route were open and unlocked; doors not on the route were locked. The experimenter guided the participant through the rooms along the appropriate route, having the participant find and identify the landmark in each room. Doors were closed by the experimenter after the participant exited a room. After exiting the last room on the route, participants were told to explore the house on their own for the remainder of the learning period. They were instructed to find and name the landmark each time they entered a room, and reminded that they would be asked questions about the layout of the house, including whether doors are locked or unlocked, later in the experiment.

Route Knowledge and Spatial Inferences

At the end of the learning period, participants were returned to their initial position in front of the toy house. All doors in the toy house were closed. Participants were asked to look around to determine their position and were asked, “What toy will you see when you open the door in front of you?”. After the participant answers, the experimenter said “Alright”, and the participant entered the first room on the route. If the correct toy was identified, the experimenter praised the participant; otherwise, the experimenter said, “Please look for the picture and tell me what toy you see. ”

For the remainder of the rooms, route knowledge was measured by having the participant point to the door which provided passage to the next room, landmark knowledge was measured by having the participant name the toy that would be found in the next room, and spatial inference performance was measured by asking what toys were on the other side of doors that had never been entered but that led to another room, i.e. the doors labeled INF in Figure 7. If a room contains an inference door, the participant was asked, “Show me a door that is locked but that has a toy behind it.” If the participant answered correctly, the participant was asked “What toy would you see if you could open that door?” After the participant answered, the experimenter would again say “Alright”. The inference door remained closed. Route knowledge was elicited by asking the participant, “Show me the unlocked door that will take you to the next room in the house. ” If participants answered incorrectly, the correct door was pointed out to them. Landmark knowledge was elicited by asking the participant, “What toy will you see when you go through that door into the next room?” After answering, participants would then travel to the next room. If the correct toy had been identified, the experimenter would praise the participant; otherwise, the experimenter would say, “No, it is a ______”. This process was repeated for each room in the house.

Pointing Tasks

After entering the last room in the house, participants were asked to turn and face the door they had just passed through. At this time, their viewpoint was moved to the center of the room. Participants were then asked to “point to” two landmarks that had been seen previously on the route but were currently obstructed. Participants pointed at an object by orienting themselves so that the cursor arrow in the center of the display area was pointing at the object. The position of the participant relative to the landmarks is shown in Figure 8.

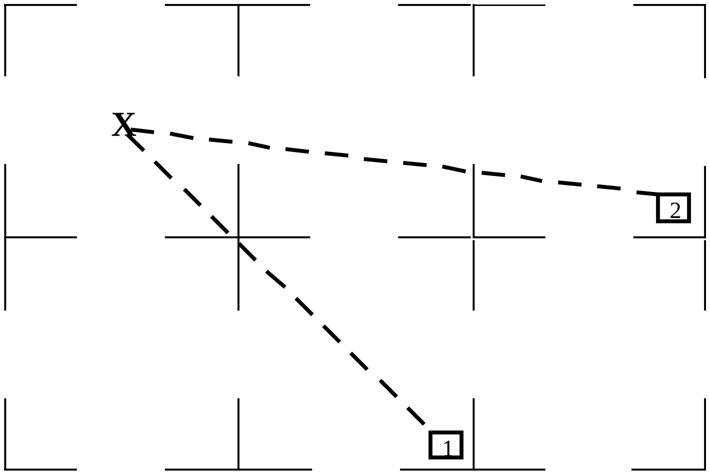


Figure 8. Location of landmarks used for pointing tasks.

Post-Immersion Tasks

After completing the pointing tasks, participants exited the VE. At this time, vision and balance tests were re-administered. Additionally, a questionnaire (see Appendix E) assessed the degree of VE side-effects and hardware difficulties experienced by participants. It also assessed the extent to which the participants enjoyed the VE experience. The questionnaire was administered verbally to child participants to eliminate the impact of reading skill variability on the study. As adult participants were pulled from the local university population, they were assumed literate and capable of successfully filling out the questionnaire.

Participants then viewed a sequence of twenty pictures. These pictures were either the pictures used as landmarks in the immersive environment or were pictures of toys not found in the immersive environment. Participants were asked to specify whether or not each image could be found in the immersive environment; no feedback was provided to the participants as to the correctness of their answer. Images were presented in random order.

Model-building

Participants were next asked to create a small-scale model of the virtual environment. At the beginning of the small-scale model construction task, participants were seated at a table and shown the items that would be used to create the model: 1) boxes painted to represent the rooms within the virtual environment, and 2) smaller versions of the pictures of toys used as landmarks in the environment. The boxes and pictures were spread out on the table. The participant was told to make a house out of the boxes and toys so that the model looks just like the "toy house" in the VE. If the instructions were not understood, the experimenter gave a sequence of non-directive prompts, e.g. "Can you put the boxes in the same shape as the rooms in the virtual toy house? Put the toys in so they are next to the same toys that the virtual toys were next to. Make it just the same, only smaller." Once the model was complete, the participant was asked to pretend he/she is walking through the little house the same way he/she walked through the virtual house and was asked to point out the route taken through the house to verify the participant correctly remembered the direction traveled and the sequence of toys along the route. The participant was then asked if he/she was happy with the model. Any participant that was unhappy with the model was given the chance to re-build the model. Each participant was allowed a maximum of three attempts at building the model.

Post-Testing Period

The VE session took 40-60 minutes for adult participants and 50-90 minutes for child participants with the time in VE being recorded for later use during the analysis. For safety purposes, participants who experienced immersion side-effects were required to remain in the waiting area until at least an hour had elapsed from their last time of immersion. Similarly, participants who exhibited visible unsteadiness in gait or stance were required to remain in the laboratory until all symptoms had disappeared. Fortunately, no participants exhibited such problems.

Additionally, participants were urged not to do any extensive driving (or perform a similar activity such as biking) for at least three hours after their last time of immersion.

Pilot Testing

The suitability of the proposed experimental procedures and dependent measures was assessed under the “best” and “worst” treatment conditions, where the best condition was considered to be adults under the largest FOV level and the worst condition was considered to be 7-9 year olds under the lowest FOV restriction. The least successful participants were to be able to successfully perform at least some portion of the spatial tasks, while the most successful performers were to be able to successfully perform close to 100% of the tasks.

The main goal of pilot testing, or pre-testing, was verifying that the difference between the least successful and most successful participants was large enough to potentially be detectable using the proposed analysis techniques. The other goal was the fine-tuning of experimental procedures. In particular, pilot testing was used to assess

a) the complexity of the virtual environment,
b) the sensitivity of the dependent measures,[5]
c) input device suitability,
d) the posture of participants during the immersive session,
e) environmental landmark identifiability, and
f) postural task suitability.

Of primary concern was the complexity of the layout. It was seen as the primary determiner of the overall difficulty of the experimental tasks. The goal was that the complexity of the layout would be such that the worst performers would successfully perform some portion of the spatial tasks, while the best performers would successfully perform close to 100% of the tasks. Originally, the complexity of the layout was to be controlled by manipulating the number of rooms in the house and the number of turns in the path taken through the house. However, increasing either the number of rooms or the number of turns in the house was found to dramatically increase the amount of time children spent in the VE, thereby increasing their risk of developing side-effects. Given the lack of quantitative data on the incidence of VE side-effects in children and the potential for increased symptomalogy in children, the experimenter decided to control the difficulty of the experimental tasks by manipulating the learning period for the environment. By decreasing or increasing the duration of the learning period for the environment, the difficulty of the tasks was easily, and safely, adjusted to satisfy the previously stated goal.

---

[5] Sensistivity was assessed by comparing the differences in dependent measures across treatment conditions during pilot testing and verifying that these differences were of a magnitude to be potentially detectable at the desired α level.

CHAPTER 3. RESULTS

A two-way Analysis of Variance (ANOVA) was performed for each of the parametric dependent variables. Homogeneity was verified using the Cochran test. Due to the dearth of quantitative studies involving children in immersive environments, pairwise comparisons were made with using the Least Significant Difference (LSD) Test, one of the least conservative post-hoc tests (Winer et al., 1991). Family-wise error for the test was minimized by limiting post-hoc comparisons to conditions where the null hypothesis was false.

While the nature of the relationship between the independent variables and the dependent measures was generally predictable from the existing literature, the magnitude of the effect was not given the lack of quantitative performance data for children relative to FOV restrictions and VEs in the literature. The raw data used to calculate these results can be found in *Appendix I*.

Analysis of Spatial Knowledge Variables

Spatial knowledge was analyzed in terms of locomotion efficiency, landmark knowledge, route knowledge, and configurational knowledge.

- Locomotion analysis was based on the average number of collisions with VE objects during a 5-minute period.
- Landmark knowledge analysis was based on the number of objects that were correctly identified as appearing (or not appearing) in the environment during a post-immersion test.
- Route knowledge analysis was based on a composite route knowledge measure comprised of 1) the number of correctly selected doors (route measure) and 2) the number of correctly predicted landmarks (landmark-prediction measure).
- Configurational knowledge analysis was based on 1) the number of correct spatial inferences, 2) the correctness of the constructed house model, 3) the time needed to complete the tasks within the VE, 4) the time needed to construct the house model, and 5) azimuth errors for the pointing tasks.

Spatial performance data is summarized in Table 2. With the exception of the average azimuth error for the pointing tasks, no significant correlation ($a \leq 0.05$) was found between the spatial measures and either computer use or video game playing.

Table 2. Mean scores for the Spatial Performance Measures.

	30 Degree HFOV				48 Degree HFOV			
	7-9 year olds		Adults		7-9 year olds		Adults	
	Female	Male	Female	Male	Female	Male	Female	Male
Locomotion Efficiency								
• Collisions / 5 minutes	59.5	72.7	45.9	25.2	32.1	23.4	15.0	4.6
Landmark Knowledge								
• Landmark Recognition (maximum = 20)	19.1	19.6	19.6	19.4	19.8	19.6	19.6	19.6
Route Knowledge								
• Composite Route Knowledge (maximum = 12)	5.6	6.0	7.2	7.3	8.1	9.3	9.6	11.0
• Existence of Route Knowledge[6] (maximum = 9)	2	0	4	4	7	6	8	9
Configuration Knowledge								
• Spatial Inferences (maximum = 8)	0.2	1.0	2.4	5.1	2.9	2.2	6.2	7.8
• Average Azimuth Error (degrees)	72.8	73.3	59.0	26.6	71.5	49.3	18.7	10.5
• Building Model (maximum = 31)	13.2	13.9	21.9	22.8	22.3	21.2	26.9	29
• Existence of Configuration Knowledge[7] (maximum=9)	0	0	3	6	3	3	7	9
Performance Speed								
• Time to Complete VE Tasks (seconds)	616	637	612	534	528	484	502	423
• Building Model Time (seconds)	167	166	176	77	119	120	87	53

---

[6] Participants were considered not to have achieved any degree of route knowledge if they 1) could not correctly sequence the landmarks in the house model, and 2) scored 9 or less on the composite route knowledge measure.

[7] Participants were considered not to have achieved any degree of configurational knowledge if they 1) could not construct a correct house model, 2) could not correctly answer at least six spatial inference questions, and 3) had an average, absolute azimuth error greater than 10 degrees for the pointing tasks.

Locomotion Efficiency Analysis

Analysis of Collision Measure

An ANOVA was performed on the average number of collisions made during a 5-minute period in the VE.[8] The average number of collisions made during a 5-minute period was used instead of the total number of collisions in order to minimize the impact of participants spending varying amounts of time in the VE. The ANOVA summary table for the data is shown in Table 3. No significant correlations were found for this measure (a ≤ 0.05). No maximum limit existed for this measure.

Table 3. ANOVA Summary Table for Average Number Collisions During a 5-Minute Period.

Source	*df*	*SS*	*MS*	*F*	*p*
Field of View (F)	1	18496	18496	13.371	0.001*
Age Group (A)	1	10599	10599	7.664	0.007*
Gender (G)	1	796	796	0.580	0.451
F x A	1	707	707	0.513	0.477
F x G	1	151	151	0.112	0.742
A x G	1	1426	1426	1.034	0.314
F x A x G	1	1166	1166	0.841	0.362
S/ FAB	64	88527	1383		
Total	71	121869			

* $p < .05$

As seen in the ANOVA summary table, the main effects of FOV and age, but not their interactions, were again significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean number of collisions during a 5 minute period was 46.991 with a standard error of 8.128, while under the 48 degree HFOV, the mean value was 22.726 with a standard error of 4.717. The mean value for 7-9 year olds was 50.886 with a standard error of 7.954, while the mean value for adults was 18.831 with a standard error of 4.332.

Landmark Knowledge Analysis

Analysis of Landmark Recognition Measure

An ANOVA was performed on the number of photos that were correctly identified as appearing or not appearing in the VE during the post-immersion test. See Table 4 for the ANOVA summary table. No main effects, or interactions, were significant with $\alpha \leq 0.05$. This measure was not impacted by either FOV or AGE. The mean landmark recognition score was

---

[8] The average number was found by determining the total number of collisions made during the VE experimental session dividing by the number of 5 minute segments.

19.375 (out of a possible 20) with a standard error of .144. No significant correlations were found for this measure ($\alpha \leq 0.05$)

Table 4. ANOVA Summary Table for the Landmark Recognition Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	2.000	2.000	1.316	0.257
Age Group (A)	1	0.500	0.500	0.333	0.569
Gender (G)	1	0.222	0.222	0.152	0.704
F x A	1	2.000	2.000	1.314	0.257
F x G	1	1.389	1.389	0.918	0.344
A x G	1	0.000	0.000	0.001	1.000
F x A x G	1	2.722	2.722	1.780	0.187
S/ FAB	64	97.778	1.528		
Total	71	106.611			

* p < .05

Route Knowledge Analysis

Analysis of Composite Route Knowledge Measure

An ANOVA was performed on the composite route knowledge measure, as well as its component measures (the route measure and the landmark prediction measure). The composite route knowledge measure was formed by adding together the scores from the two component measures and had a maximum score of 12. See Table 5 for the ANOVA summary table. The relationship between this measure and the time to complete the VE spatial tasks was significant ($r=-.589$, $\alpha \leq 0.05$) indicating that individuals who score lower on this measure also took longer to complete VE the tasks. No other significant correlations were found for this measure.

Table 5. ANOVA Summary Table for the Composite Route Knowledge Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	159.014	159.014	45.660	0.000*
Age Group (A)	1	42.014	42.014	12.064	0.001*
Gender (G)	1	11.681	11.681	3.353	0.072
F x A	1	0.014	0.014	0.006	0.950
F x G	1	5.014	5.014	1.442	0.235
A x G	1	0.014	0.014	0.001	0.950
F x A x G	1	0.347	0.347	0.100	0.753
S/ FAB	64	222.889	3.483		
Total	71	440.986			

* p < .05

This measure was slightly more sensitive than either its component measures. Both main effects of FOV and age, but not their interactions, were significant with $\alpha \leq 0.05$. Under the 30 degree

HFOV, the mean score for the composite measure was 6.528 (out of a possible 12) with a standard error of .335, while under the 48 degree HFOV, the mean score was 9.500 with a standard error of .335. The mean score for 7-9 year olds was 7.25 with a standard error of .362, while the mean score for adults was 8.778 with a standard error of .432.

Analysis of the Route Measure. An ANOVA was performed on the number of correctly identified doors along the route. See Table 6 for the ANOVA summary table. This measure relates to knowing what direction to turn after seeing a particular landmark. The maximum score for this measure was 6. No significant correlations were found for this measure ($\alpha \leq 0.05$).

Table 6. ANOVA Summary Table for Route Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	40.500	40.500	30.381	0.000*
Age Group (A)	1	8.000	8.000	6.005	0.017*
Gender (G)	1	2.000	2.000	1.503	0.225
F x A	1	0.222	0.222	0.172	0.684
F x G	1	0.222	0.222	0.170	0.684
A x G	1	2.722	2.722	2.041	0.158
F x A x G	1	0.500	0.500	0.382	0.542
S/ FAB	64	85.333	1.333		
Total	71	139.500			

* $p < .05$

Both main effects of FOV and age, but not their interactions, were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean score for the route measure was 3.333 (out of a possible 6) with a standard error of .218, while under the 48 degree HFOV, the mean score was 4.833 with a standard error of .176. The mean score for 7-9 year olds was 3.750 with a standard error of .227, while the mean score for adults was 4.417 with a standard error of .230.

Analysis of Landmark Prediction Measure. An ANOVA was performed on the number of correctly predicted landmarks along the route. See Table 7 for the ANOVA summary table. The maximum score for this measure was 6. No significant correlations were found for this measure ($\alpha \leq 0.05$).

Table 7. ANOVA Summary Table for the Landmark Prediction Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	39.014	39.014	27.748	0.000*
Age Group (A)	1	13.347	13.347	9.492	0.003*
Gender (G)	1	4.014	4.014	2.850	0.096
F x A	1	0.347	0.347	0.252	0.621
F x G	1	3.125	3.125	2.227	0.141
A x G	1	3.125	3.125	2.224	0.141
F x A x G	1	1.681	1.681	1.206	0.278
S/ FAB	64	90.000	1.406		
Total	71	154.653			

* $p < .05$

Both main effects of FOV and age, but not their interactions, were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean score for the landmark prediction measure was 3.194 (out of a possible 6) with a standard error of .221, while under the 48 degree HFOV, the mean score was 4.667 with a standard error of .209. The mean score for 7-9 year olds was 3.500 with a standard error of .227, while the mean score for adults was 4.361 with a standard error of .246.

Analysis of Route Knowledge Criterion Measure

χ^2 tests were performed on the number of individuals that had not achieved any degree of route knowledge of the virtual space.[9] See Table 8 for a summary of the results. Post-hoc tests were done by decomposing RxC contingency tables into 2x2 contingency tables and performing χ^2 tests. Individuals were considered not to have achieved any degree of route knowledge if they

1. could not correctly sequence the landmarks in the house model, and
2. had a composite route knowledge score of less than 10.

Table 8. Summary of the χ^2 test results for route knowledge criterion measure.

Source	***df***	χ^2
Field of View (F)	1	24.981*
Age Group (A)	1	5.625*
Gender (G)	1	0.225
F x A	3	28.353*
F x G	3	2.571
A x G	3	5.851
F x A x G	7	29.072*

---

[9] The Yates correction was used when expected frequency for a cell was less than 5.

* $p<.05$

The number of individuals who satisfied the route knowledge criterion increased significantly with AGE and FOV (α ≤ 0.05). Additionally, the FOV x AGE and FOV x AGE x GENDER interactions were significant (α ≤ 0.05). Under the 30 degree HFOV, 10 individuals satisfied the criterion, while 30 individuals satisfied the criterion under the 48 degree HFOV. Of the 7-9 year olds, 15 satisfied the criterion, while 25 adults satisfied the criterion.

Post-hoc tests (α ≤ 0.05) on the FOV x AGE interaction found that adults and children under the higher FOV restriction satisfied the route knowledge criterion significantly more frequently than 7-9 year olds under the lower FOV restriction. Additionally, adults under the lower FOV restriction satisfied the criterion significantly more frequently than children under the same FOV restriction. Further adults under the lower FOV restriction satisfied the criterion significantly less frequently than adults under the higher FOV restriction. The effect of the FOV x AGE interaction is shown in Figure 9.

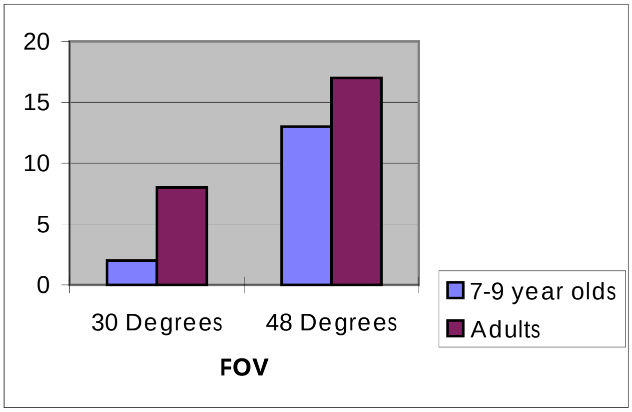


Figure 9. Effect of FOV x AGE interaction on the number of individuals satisfying the route knowledge criterion.

Post-hoc tests (α ≤ 0.05) on the FOV x AGE x GENDER interaction revealed that adults under the higher FOV restriction satisfied the route knowledge criterion significantly more often than participants under the lower FOV restriction. Further 7-9 year old females under the higher FOV restriction satisfied the criterion significantly more frequently than 7-9 year olds under the lower FOV restriction, while 7-9 year old males under the higher FOV restriction satisfied the criterion significantly more frequently than 7-9 year old males under the lower FOV restriction. Finally, adults under the lower FOV restriction satisfied the criterion significantly more often than 7-9 year old males under the same FOV restriction. The effect of the FOV x AGE x GENDER interaction is shown in Figure 10.

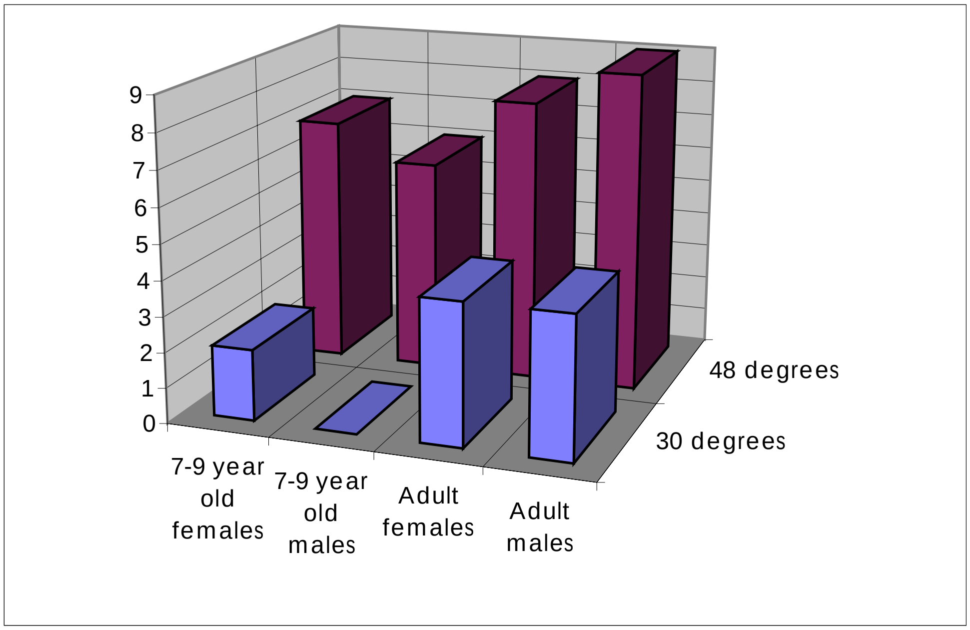


Figure 10. Effect of FOV x AGE x GENDER interaction on the frequency of individuals satisfying the route knowledge criterion.

Configuration Knowledge Analysis

Analysis of Spatial Inferences Measure

An ANOVA was performed on the spatial inference score. Each spatial inference tasks had two components: 1) identifying the locked door (labeled INF in Figure 7) which contained a toy behind it, and 2) identifying the toy behind the locked door. There were 4 spatial inference tasks, with a point was added to the measure score for each task component that was done correctly. See Table 9 for the ANOVA summary table. The maximum score for this measure was 8. The relationship between this measure and the composite route knowledge measure was significant (r=.604, $\alpha \leq 0.05$). No other significant correlations were found.

Table 9. ANOVA Summary Table for Spatial Inference Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	120.125	120.125	35.891	0.000*
Age Group (A)	1	260.681	260.681	77.880	0.000*
Gender (G)	1	21.125	21.125	6.315	0.015*
F x A	1	7.347	7.347	2.203	0.143
F x G	1	7.347	7.347	2.203	0.143
A x G	1	19.014	19.014	5.684	0.020*
F x A x G	1	0.125	0.125	0.048	0.847
S/FGA	64	214.222	3.347		
Total	71	649.986			

* $p < .05$

The main effects of FOV, age, and gender along with the age and gender interaction were significant with $\alpha \leq 0.05$. Increasing both FOV and age had a positive impact on the score with 7-9 year olds under the lower FOV condition having essentially no ability to make spatial inferences. Even under the higher FOV condition, the mean proportion of correctly made spatial inferences for 7-9 year olds was only 31%. Under the 30 degree HFOV, the mean score was 2.194 (out of a possible 8) with a standard error of .418, while under the 48 degree HFOV, the mean score was 4.778 with a standard error of .506. The mean score for 7-9 year olds was 1.583 with a standard error of .337, while the mean score for adults was 5.389 with a standard error of .474. The mean score for females was 2.944 with a standard error of .478, while the mean score for males was 4.028 with a standard error of .514. The means and standard errors for the gender and age interaction can be found in Table 10.

Table 10. Means and Standard Errors for the AGE x GENDER interaction of the spatial inference measure.

Age Grouping	***Gender***	***Mean Score***	***Standard Error***
7-9 year olds	Female	1.556	0.466
7-9 year olds	Male	1.611	0.363
Adults	Female	4.333	0.705
Adults	Male	6.444	0.544

Additionally, males performed significantly better than females, with the AGE x GENDER interaction having the effect shown in Figure 11. LSD post-hoc tests on the significant AGE x GENDER interaction ($\alpha \leq 0.05$) revealed that adult males performed significantly better than both adults females and the 7-9 year olds while adult females performed significantly better than the 7-9 year olds. However, 7-9 year old males did not perform significantly better ($\alpha \leq 0.05$) than 7-9 year old females at the spatial inferences measures.

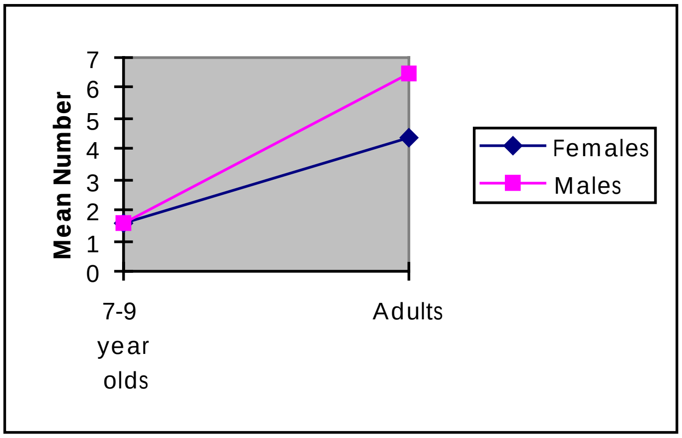


Figure 11. Effect of AGE x GENDER interaction on the spatial inference measure.

Analysis of Azimuth Errors for Pointing Tasks

An ANOVA was performed on the magnitude of azimuth errors (degrees) for the two pointing tasks as well as the magnitude of the mean azimuth errors for the pointing tasks. In pointing tasks, the participants were ask to orient themselves so that the cursor arrow in the center of the VE display area pointed at the occluded landmarks. (The position of the participants relative to the landmarks during the pointing tasks is shown in Figure 8.) The estimated angle was then subtracted from the actual angle of the target landmark with the result becoming the azimuth error for the pointing task.[10] The relationship between the magnitude of the azimuth errors for the two pointing tasks was significant ($r=.553$, $\alpha \leq 0.05$). No other significant correlations were found.

Magnitude of Azimuth Error for Pointing Task 1. An ANOVA was performed on the magnitude of the azimuth error (degrees) for pointing task 1. No maximum limit existed for this measure. See Table 11 for the ANOVA summary table. The relationship between the magnitude of the azimuth error for pointing task 1 and participant computer usage was significant ($r=.461$, $\alpha \leq 0.05$) indicating individuals who used the computer more often also pointed at occluded objects more accurately. Additionally, the relationship between the magnitude of the azimuth error for pointing task 1 and the spatial inference score was significant ($r=.516$, $\alpha \leq 0.05$). No other significant correlations were found for this measure.

---

[10] Both the estimated and actual angles for the landmark were determined by the Superscape VRT 4.0 software set.

Table 11. ANOVA Summary Table for Magnitude of Pointing Task 1 Azimuth Error.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	7797	7797	6.470	0.013*
Age Group (A)	1	37312	37312	30.953	0.000*
Gender (G)	1	9403	9403	7.801	0.007*
F x A	1	3869	3869	3.216	0.078
F x G	1	63	63	0.0537	0.819
A x G	1	14	14	0.014	0.914
F x A x G	1	5434	5434	4.512	0.038*
S/FGA	64	77166	1206		
Total	71	141059			

* $p < .05$

The main effects of FOV, age, and gender along with the FOV x AGE x GENDER interaction were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean magnitude of the azimuth error was 63.266 degrees with a standard error of 6.724, while under the 48 degree HFOV, the mean error was 42.453 degrees with a standard error of 7.781. The mean error for 7-9 year olds was 75.624 degrees with a standard error of 7.245, while the mean error for adults was 30.095 degrees with a standard error of 5.463. The mean error for females was 64.287 degrees with a standard error of 7.631, while the mean error for males was 41.431 degrees with a standard error of 6.801. The means and standard errors for the FOV, age, and gender interaction can be found in Table 12.

Table 12. Means and standard errors for the FOV x AGE x GENDER interaction of the magnitude of the pointing task 1 azimuth error.

FOV	***Age Grouping***	***Gender***	***Mean Score***	***Standard Error***
30 Degrees	7-9 year olds	Female	82.825	13.909
30 Degrees	7-9 year olds	Male	74.576	11.604
30 Degrees	Adults	Female	68.440	10.529
30 Degrees	Adults	Male	27.223	11.082
48 Degrees	7-9 year olds	Female	92.170	15.536
48 Degrees	7-9 year olds	Male	52.925	15.613
48 Degrees	Adults	Female	13.715	3.362
48 Degrees	Adults	Male	11.002	3.666

LSD post-hoc tests on the significant FOV x AGE x GENDER interaction ($\alpha \leq 0.05$) revealed that adult males at the higher FOV level performed significantly better than adult females under the lower FOV restriction, but did not perform significantly better than adult males at the lower FOV restriction. Further adult males at both FOV restrictions perform significantly better than 7-9 year olds under either FOV restriction. Additionally, adult males at the lower FOV restriction perform significantly better than adult females at the same FOV restriction and 7-9 year old females at the higher FOV restriction, while adult females at the higher FOV restriction perform significantly better than 7-9 year olds under both FOV restrictions and also perform significantly better than adult females under the lower FOV restriction. Finally, 7-9 year old males at the higher FOV condition perform significantly better than 7-9 year old females under the same FOV restriction. The effect of the FOV x AGE x GENDER interaction is shown in Figure 12.

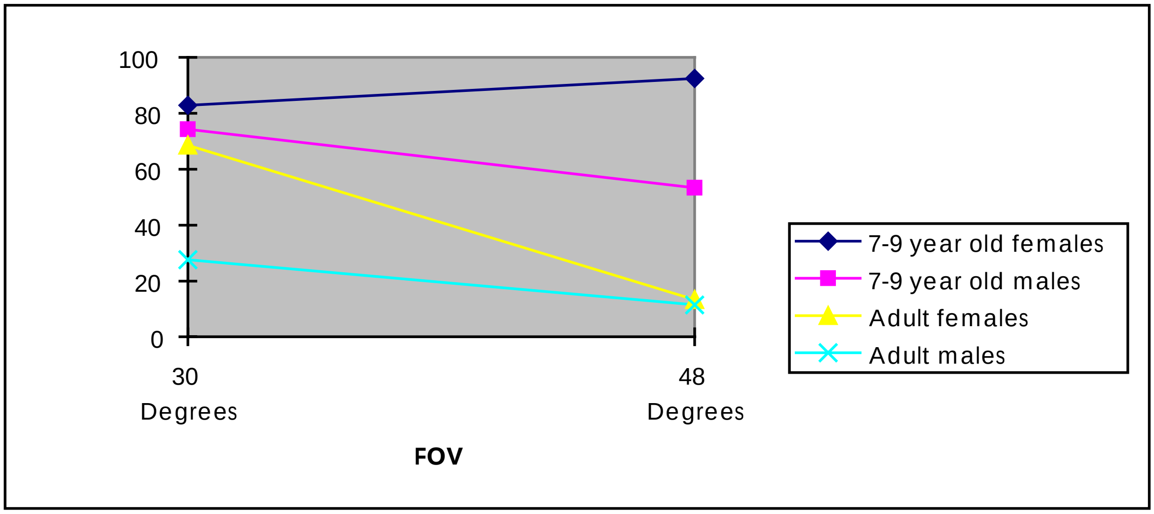


Figure 12. Effect of FOV x AGE x GENDER interaction effect on magnitude of the mean azimuth error for pointing task 1.

<u>Magnitude of Azimuth Error for Pointing Task 2</u>. An ANOVA was performed on the magnitude of the azimuth error (degrees) for pointing task 2. No maximum limit existed for this score. See Table 13 for the ANOVA summary table. The relationship between the magnitude of the azimuth error for pointing task 2 and the spatial inference score was significant (r=.473, $\alpha \leq 0.05$). No other significant correlations were found for this measure.

Table 13. ANOVA Summary Table for Pointing Task 2 Azimuth Error.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	7246	7246	5.22	0.026*
Age Group (A)	1	16834	16834	12.13	0.001*
Gender (G)	1	1226	1226	0.88	0.351
F x A	1	13	13	0.01	0.922
F x G	1	21	21	0.02	0.903
A x G	1	1911	1911	1.38	0.245
F x A x G	1	660	660	0.48	0.493
S/FGA	64	88837	1388		
Total	71	116748			

* p < .05

The main effects of FOV and age, but not their interactions, were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean magnitude of the azimuth error was 52.621 degrees with a standard error of 6.759, while under the 48 degree HFOV, the mean error was 32.557 degrees with a standard error of 5.998. The mean error for 7-9 year olds was 57.880 degrees with a standard error of 7.177, while the mean error for adults was 27.298 degrees with a standard error of 5.272.

Magnitude of Mean Azimuth Error. An ANOVA was performed on the magnitude of the mean azimuth error (degrees) for the pointing tasks. No maximum limit existed for this measure. See Table 14 for the ANOVA summary table. A significant correlation was found between performance on this measure and computer usage (r=.477, $\alpha \leq 0.05$) indicating individuals who used the computer more often also pointed at occluded objects more accurately. Additionally, the relationship between the mean magnitude of the azimuth error for the pointing tasks and the spatial inference score was significant (r=.563, $\alpha \leq 0.05$). No other significant correlations existed for this measure.

Table 14. ANOVA Summary Table for Average of the Azimuth Error Magnitude for the Pointing Tasks.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	7517.6	7517.6	8.290	0.005*
Age Group (A)	1	26067.1	26067.1	28.753	0.000*
Gender (G)	1	4355.5	4355.5	4.807	0.032*
F x A	1	1084.0	1084.0	1.204	0.278
F x G	1	2.9	2.9	0.004	0.955
A x G	1	398.8	398.8	0.442	0.510
F x A x G	1	2470.1	2470.1	2.728	0.104
S/FGA	64	58036.0	906.8		
Total	71	99931.9			

* $p < .05$

The main effects of FOV, age, and gender, but not their interactions, were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean magnitude of the azimuth error was 57.942 degrees with a standard error of 8.631, while under the 48 degree HFOV, the mean error was 37.506 degrees with a standard error of 6.008. The mean azimuth error for 7-9 year olds was 66.752 degrees with a standard error of 6.070, while the mean error for adults was 28.697 degrees with a standard error of 6.600. The mean azimuth error for females was 55.502 degrees with a standard error of 8.259, while the mean error for males was 39.947 degrees with a standard error of 6.461.

Analysis of Building Model

The correctness of each building model was assessed by two metrics, the sequence of landmarks in the model and the shape of the model. The building model measure equals

$$\{\text{Landmark score}\} + \{\text{Shape score}\} - 2\{\text{number of attempts} - 1\}$$

Additionally, a point was subtracted from the total score for each of the following occurrences.

1. The symmetry of the model was reversed.
2. The path traced through the model was incorrect.

The maximum score for the building model measure was 31. ANOVAs were used to analyze the mean score of 1) the landmark metric, 2) the shape metric, and 3) the building model measure. The ANOVA summary table for the building model measure can be found in Table 15.

Table 15. ANOVA Summary Table for the Model Building Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	850.78	850.78	26.238	0.000*
Age Group (A)	1	1023.78	1023.78	31.572	0.000*
Gender (G)	1	7.03	7.03	0.225	0.643
F x A	1	28.75	28.75	0.898	0.350
F x G	1	0.28	0.28	0.013	0.926
A x G	1	13.78	13.78	0.425	0.517
F x A x G	1	9.75	9.75	0.306	0.585
S/FGA	64	2075.67	32.43		
Total	71	4009.83			

* $p < .05$

Both main effects of FOV and age, but not their interactions, were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean score for the model was 17.986 with a standard error of 1.224, while under the 48 degree HFOV, the mean score was 24.861 with a standard error of 1.004. The mean score for 7-9 year olds was 17.653 with a standard error of 1.104, while the mean score for adults was 25.194 with a standard error of 1.073.

Relationship Between Model Building and Other Configuration Knowledge Measures. Outstanding performance on either the model building, spatial inference, or pointing tasks was expected to be indicative of configuration knowledge for the space, and indeed a significant correlation was found between the spatial inference and model performance tasks (r=.589, $\alpha \leq 0.05$), the spatial inference and pointing tasks (r=.563, $\alpha \leq 0.05$), and the model and pointing tasks (r=.446, $\alpha \leq 0.05$). It was expected that individuals failing to perform well at either the spatial inference (>5) or pointing tasks (<10) would be unlikely to build a perfect model. However, of the 27 participants who built a perfect model, seven (two adults and five 7-9 year olds) exhibited configuration knowledge only at the model building task. In fact, the model building task was the only task where children exhibited configuration knowledge and then only under the higher FOV condition.

Landmark Metric. An ANOVA was performed on the model landmark metric score. See Table 16 for the ANOVA summary table. For each landmark, one point was given if it was adjacent to the landmark that precedes it on the route (assuming there was one) and another point was given if it was adjacent to the landmark that follows it on the route (assuming there was one); for those landmarks found in rooms with spatial inference doors (labeled INF in Figure 7), an additional point was given if the landmark was placed adjacent to the toy found behind the spatial inference door. Additionally, .5 was added to the total score for every landmark which was placed in the correct corner relative to the path traced by the participant through the house. A maximum score of 2.5 points was possible for each landmarks 1, 3, 4, and 6; a maximum score of 3.5 was possible for landmarks 2 and 5. The maximum score for the metric was 17.

Perfect performance on the sequencing of landmarks in VE (landmark prediction measure) or the model was expected to be indicative of superior route knowledge, and a significant correlation ($r=.567$, $\alpha \le 0.05$) between the landmark prediction measure and the model landmark metric was found. It was expected that individuals failing to sequence the landmarks correctly in the VE would be unlikely to sequence the landmarks correctly in the model. Each of the 13 participants (11 adults and 2 7-9 year olds) who got the landmark sequence correct in the VE got it correct in the model. However, of the 59 participants who incorrectly sequenced the landmarks in the VE, 27 of them (12 children and 15 adults) correctly sequenced them in the model.

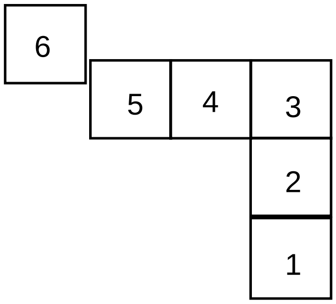
Table 16. ANOVA Summary Table for the Model Landmark Measure.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	333.68	333.68	23.203	0.000*
Age Group (A)	1	264.50	264.50	18.397	0.000*
Gender (G)	1	5.01	5.01	0.354	0.557
F x A	1	0.13	0.13	0.017	0.926
F x G	1	0.50	0.50	0.034	0.853
A x G	1	1.68	1.68	0.125	0.734
F x A x G	1	5.56	5.56	0.391	0.536
S/FGA	64	920.39	14.38		
Total	71	1531.44			

* $p < .05$

Both main effects of FOV and age, but not their interactions, were significant with $\alpha \le 0.05$. Under the 30 degree HFOV, the mean score for the landmark metric was 8.625 (out of a possible 17) with a standard error of 0.721, while under the 48 degree HFOV, the mean score was 12.931 with a standard error of 0.656. The mean score for 7-9 year olds was 8.861 with a standard error of 0.729, while the mean score for adults was 12.694 with a standard error of 0.688.

Shape Metric. An ANOVA was performed on the landmark metric score. See Table 17 for the ANOVA summary table. For each wall in a room that was correctly connected to another room, 1 was added to the total score. No credit was given for walls where less than 50% of the wall is aligned with the adjacent wall. For each pair of walls that were aligned but were not touching, 1 point was deducted from the total score. See Figure 14 for a demonstration of the scoring process. A maximum score of two points was possible for rooms 1, 3, 4, and 6; a maximum score of three points is possible for rooms 2 and 5. The maximum score for this metric was 14.



Final Score = 7

Room 1: 1 for adjoining room 2.

Room 2: 1 for adjoining room 1.
1 for adjoining room 3.

Room 3: 1 for adjoining room 2.
1 for adjoining room 4.

Room 4: 1 for adjoining room 3.
0 for adjoining room 5
as wrong wall.

Room 5: 1 for adjoining room 4.

Room 6: No points as 20% of
walls 5 and 6.

Figure 13. Sample scoring for model shape metric.

More than 80% of the participants who constructed incorrect models were children, with the mean age of the adults in this category 40.375 and the mean age of the children 8.851. (Mean age for the adult participants in the study was 30.661 with the mean age of children in the study 8.530.) Participants who were unable to successfully reconstruct the shape of the house did attempt to represent their internal representation of the house. The shapes of incorrectly constructed houses were not random. Most incorrect models separated the model into symmetric halves and had a route bend in the middle, with many elongating the bend. Less than 40% of the participants who constructed an incorrect model depicted the shape of the house as a straight line. However, of the 12 participants who depicted the shape of the house as a straight line, 11 were children and one was an adult, with 8.885 the mean age of the children and 52.580 the age of the adult.

Table 17. ANOVA Summary Table for Model Shape Metric.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	86.681	86.681	10.06	0.002*
Age Group (A)	1	183.681	183.681	21.32	0.000*
Gender (G)	1	0.347	0.347	0.04	0.842
F x A	1	36.125	36.125	4.19	0.045*
F x G	1	0.347	0.347	0.04	0.842
A x G	1	0.125	0.125	0.01	0.904
F x A x G	1	1.681	1.681	0.20	0.660
S/FGA	64	551.333	8.615		
Total	71	860.319			

* $p < .05$

Both main effects of FOV and age along with their interaction were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean score for the landmark metric was 10.250 (out of a possible 14) with a standard error of 0.488, while under the 48 degree HFOV, the mean score was 12.444 with a standard error of 0.492. The mean score for 7-9 year olds was 9.750 with a standard error of 0.602, while the mean score for adults was 12.944 with a standard error of 0.418. The means and standard errors for the FOV and age interaction can be found in Table 18.

Table 18. Mean and standard errors for the FOV x AGE interaction of the model shape metric.

Age Grouping	***FOV***	***Mean Score***	***Standard Error***
7-9 year olds	30	7.944	0.7858
7-9 year olds	48	11.556	0.7012
Adults	30	12.556	0.6965
Adults	48	13.333	0.4644

LSD post-hoc tests on the significant FOV x AGE interaction ($\alpha \leq 0.05$) revealed children under the lower FOV condition performed significantly worse than either children under the higher FOV condition or adults under either FOV condition. As seen in Figure 14, children under the higher FOV condition were not significantly different from the adults under either the low or high FOV restriction. Additionally, adults under the two FOV conditions were not significantly different from each other. However, adult performance on this measure was near ceiling level for both levels of FOV making detection of differences difficult.

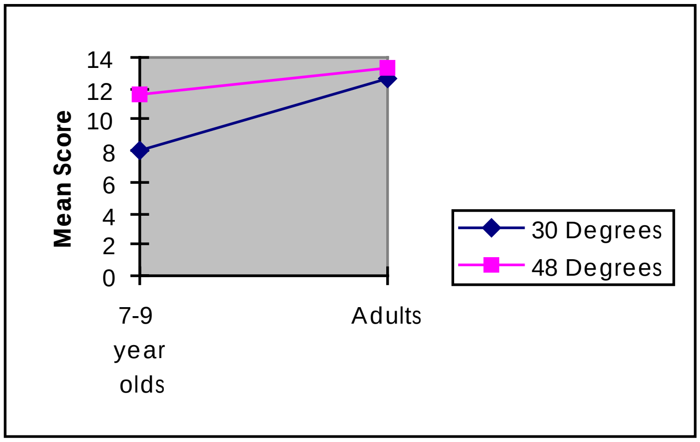


Figure 14. Effect of FOV x AGE interaction on model shape metric.

Analysis of Configuration Knowledge Criterion Measure

χ^2 tests were performed on the number of individuals that had not achieved any degree of configuration knowledge of the virtual space.[11] See Table 19 for a summary of the results. Post-hoc tests were done by decomposing RxC contingency tables into 2x2 contingency tables and performing χ^2 tests. Individuals were considered not to have achieved any degree of configurational knowledge if they

1. Could not construct a correct house model,
2. Could not correctly answer at least six spatial inference questions, and
3. Had an average, absolute azimuth error greater than 10 degrees for the pointing tasks.

Table 19. Summary of the χ^2 test results for configuration knowledge criterion measure.

Source	***df***	χ^2
Field of View (F)	1	9.574*
Age Group (A)	1	20.451*
Gender (G)	1	1.416
F x A	3	30.080*
F x G	3	11.046*
A x G	3	23.282*
F x A x G	7	29.032*

* $p<.05$

The number individuals who satisfied the configuration knowledge criterion increased significantly with AGE and FOV ($\alpha \leq 0.05$). Additionally, the FOV x AGE, FOV x GENDER,

---

[11] The Yates correction was used when expected frequency for a cell was less than 5.

AGE x GENDER, and FOV x AGE x GENDER interactions were significant ($\alpha \leq 0.05$). Under the 30 degree HFOV, 9 individuals satisfied the criterion, while 22 individuals satisfied the criterion under the 48 degree HFOV. Of the 7-9 year olds, 6 satisfied the criterion, while 25 adults satisfied the criterion. Of the 30 people who satisfied the criterion, all but 2 adults also satisfied the route knowledge criterion. Further, the configuration knowledge criterion was satisfied significantly less frequently than the route knowledge criterion ($\chi^2=4.7$, $\alpha \leq 0.05$). Interestingly, of the 12 individuals who satisfied only the route knowledge criterion, only 2 were adults with all but 2 of the children coming from the higher FOV condition. Further, of the 30 individuals who satisfied neither criterion, only 8 were adults with all the children coming from the lower FOV condition. Overall,

- 42% of the participants satisfied the configuration knowledge criterion, with 69% of the adults and 16% of the children falling into this category. All the children and 75% of the adults in this category were in the 48 degree FOV condition.

- 3% of the adults and 28% of the 7-9 year olds satisfied only the route knowledge criterion, with all the adults in the lower FOV condition and 80% of the 7-9 year olds in the higher FOV condition.

- Fully, 42% of the participants satisfied neither criterion, with 22% of the adults and 56% of the 7-9 year olds in this category. All were from the 30 degree FOV condition.

Post-hoc tests ($\alpha \leq 0.05$) on the FOV x AGE interaction found that adults under the higher FOV restriction satisfied the configuration knowledge criterion more frequently than 7-9 year olds under either FOV restriction and adults under the lower FOV restriction. Further 7-9 year olds under the lower FOV restriction satisfied the criterion significantly less frequently than 7-9 year olds under the higher FOV restriction and adults under the lower FOV restriction. The effect of the FOV x AGE interaction is shown in Figure 15.

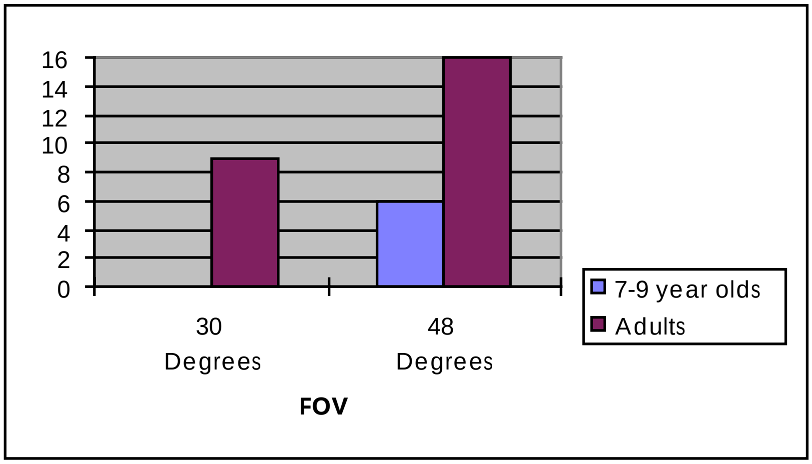


Figure 15. Effect of FOV x AGE interaction on the number of individuals who satisfied the configuration knowledge criterion.

Post-hoc tests ($\alpha \leq 0.05$) on the FOV x GENDER interaction found that participants of either sex under the higher FOV restriction satisfied the criterion more frequently than females under the lower FOV restriction. Further males under the higher FOV restriction satisfied the criterion more frequently than males under the lower FOV restriction. The effect of the FOV X GENDER interaction is shown in Figure 16.

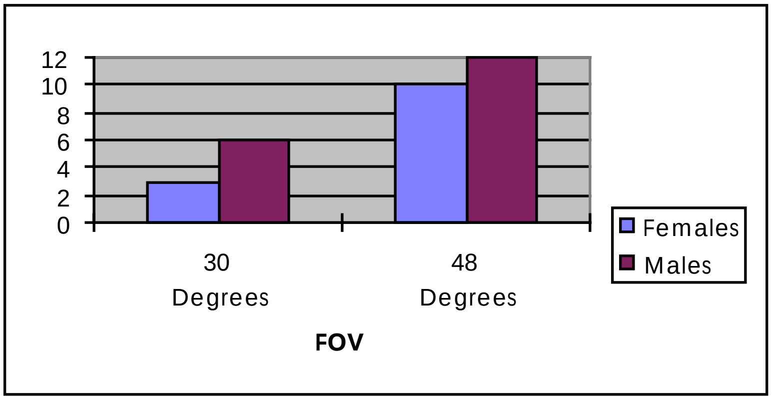


Figure 16. Effect of FOV x GENDER interaction on the number of individuals who satisfied of configuration knowledge criterion.

Post-hoc tests ($\alpha \leq 0.05$) on the AGE x GENDER interaction revealed that adults satisfied the criterion significantly more frequently than 7-9 year olds with adult males satisfied the criterion significantly more frequently than adult females. The effect of the AGE x GENDER interaction is shown in Figure 17.

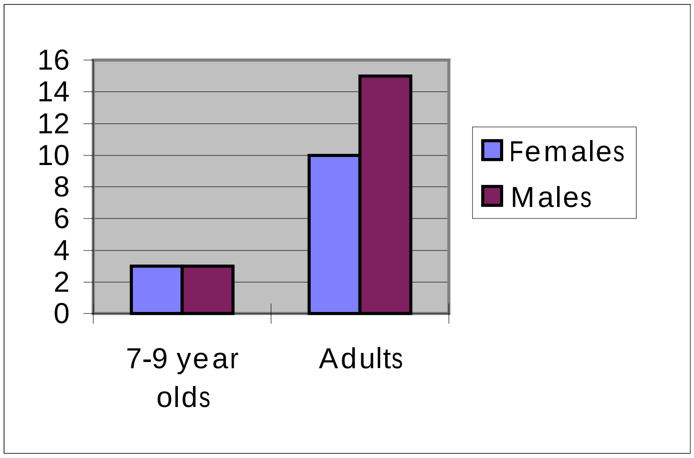


Figure 17. Effect of AGE x GENDER interaction on the number of individuals who satisfied the configuration knowledge criterion.

Post-hoc tests ($\alpha \leq 0.05$) on the FOV x AGE x GENDER interaction revealed that adult males under both FOV restrictions satisfied the criterion significantly more frequently than 7-9 year olds under both FOV restrictions. Further adult females under the higher FOV restriction satisfied the criterion significantly more frequently than 7-9 year olds under the lower FOV restriction. The effect of the FOV x AGE x GENDER interaction is shown in Figure 18.

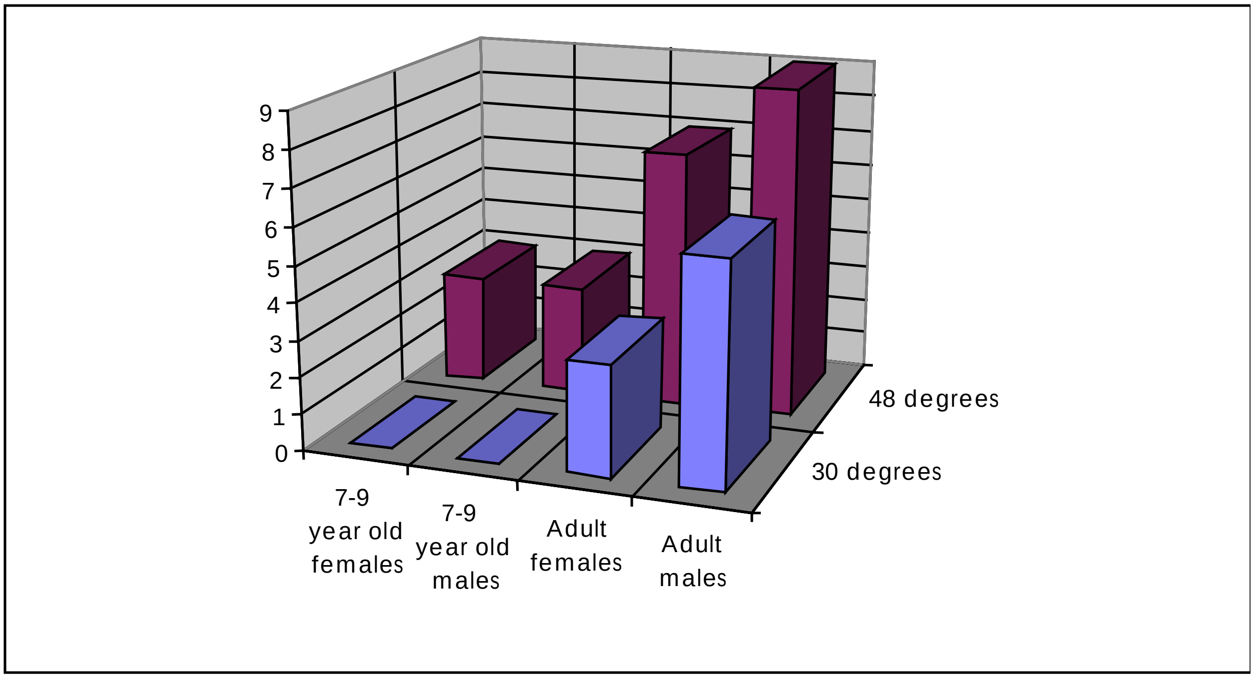


Figure 18. Effect of FOV x AGE x GENDER interaction on the number of individuals who satisfied the configuration knowledge criterion.

Performance Speed Analysis

Analysis of Time to Complete VE Spatial Tasks

An ANOVA was performed on the time needed to complete the spatial tasks in the VE. See Table 20 for the ANOVA summary table. Time was measured in seconds and did not include participant break periods. No maximum limit existed for this measure. No significant correlations were found for this measure ($\alpha \leq 0.05$).

Table 20. ANOVA Summary Table for the Time To Complete the VE Spatial Tasks.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	238971	238971	10.200	0.002*
Age Group (A)	1	110764	110764	4.734	0.033*
Gender (G)	1	36450	36450	1.563	0.217
F x A	1	392	392	0.024	0.897
F x G	1	4868	4868	0.211	0.650
A x G	1	20672	20672	0.880	0.351
F x A x G	1	4481	4481	0.192	0.663
S/ FAB	64	1499446	23429		
Total	71	1916043			

* p < .05

As seen in the ANOVA summary table, the main effects of FOV and age, but not their interactions, were both significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean time to complete the VE tasks was 615.390 seconds with a standard error of 30.071, while under the 48 degree HFOV, the mean time was 499.915 seconds with a standard error of 16.513. The mean time for 7-9 year olds was 596.915 seconds with a standard error of 28.390, while the mean time for adults was 518.393 seconds with a standard error of 25.071.

Analysis of Model Building Time

An ANOVA was performed on the number of seconds needed to construct the house model. See Table 21 for the ANOVA summary table. No significant relationship between the model building time and time to complete VE spatial tasks was found. However, a significant relationship was found between this measure and the spatial inference measure (r=-0.496, $\alpha \leq 0.05$). No other significant correlations were found.

Table 21. ANOVA Summary Table for Model Building Time.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	48168	48168	12.760	0.001*
Age Group (A)	1	36490	36490	9.674	0.003*
Gender (G)	1	19691	19691	5.223	0.026*
F x A	1	412	412	0.118	0.742
F x G	1	5119	5119	1.362	0.248
A x G	1	19730	19730	5.235	0.026*
F x A x G	1	4480	4480	1.192	0.280
S/FGA	64	241522	3774		
Total	71	375612			

* p < .05

The main effects of FOV, age, and gender, along with the age and gender interaction were significant with $\alpha \leq 0.05$. Under the 30 degree HFOV, the mean score was 147.200 with a standard error of 13.811, while under the 48 degree HFOV, the mean score was 95.470 with a standard error of 8.323. The mean score for 7-9 year olds was 143.843 with a standard error of 11.141, while the mean score for adults was 98.822 with a standard error of 12.164. The mean score for females was 137.871 with a standard error of 12.253, while the mean score for males was 104.790 with a standard error of 11.513. The means and standard errors for gender and age interaction can be found in Table 22.

Table 22. AGE x GENDER interaction for model building time.

Age Grouping	***Gender***	***Mean Score***	***Standard Error***
7-9 year olds	Female	143.830	13.971
7-9 year olds	Male	143.864	17.434
Adults	Female	131.915	20.460
Adults	Male	65.732	7.8642

Males performed significantly faster than females, with the AGE x GENDER interaction having the effect shown in Figure 20. LSD post-hoc tests on the significant AGE x GENDER interaction ($\alpha \leq 0.05$) revealed that adult males performed significantly faster than both adults females and the 7-9 year olds. No other significant differences in speed of performance existed. Adult females did not perform faster than the 7-9 year olds, and 7-9 year old males did not perform significantly faster than 7-9 year old females at the model building.

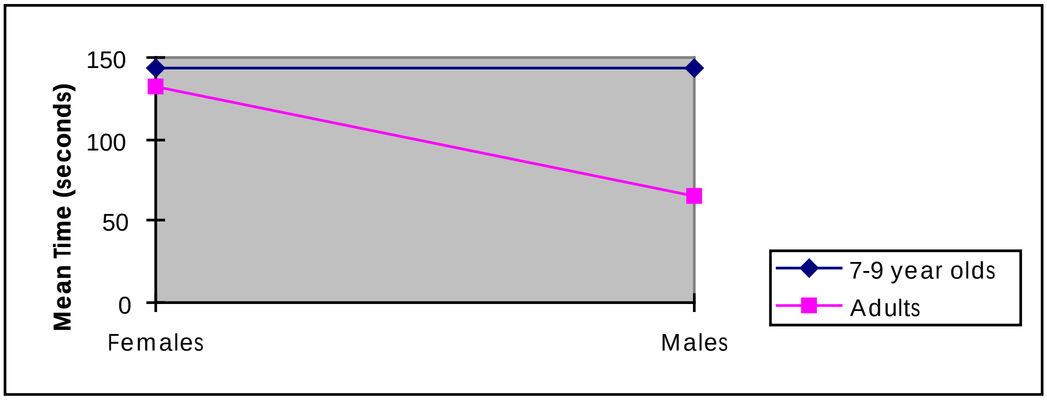


Figure 19. Effect of AGE x GENDER interaction on mean model building time.

Analysis of General Enjoyment Measure

Kolomogorov-Smirnov tests were performed on the main effects for the general enjoyment measure and were used as post-hoc tests for the significant interactions. A summary of these results can be found in Table 24. Kruskal-Wallis One-Way ANOVAs were performed on the interactions. A summary of the results can be found in Table 24. The maximum score for this measure was 7. No significant correlations were found for this measure ($\alpha \leq 0.05$).

Table 23. Summary of the Kolomogorov-Smirnov test results for general enjoyment measure.

Source	***df***	χ^2
Field of View (F)	2	1.200
Age Group (A)	2	10.888*
Gender (G)	2	.889

* p<.05

Table 24. Kruskal-Wallis One-Way ANOVA summary table for general enjoyment measure.

Source	***df***	KW	p
F x A	3	15.690	.001*
F x G	3	2.952	0.400
A x G	3	13.521	0.004*
F x A x G	7	16.940	0.018*

* p<.05

The main effect of AGE was significant with 7-9 year olds enjoying VEs significantly more than adults ($\alpha \leq 0.05$). Additionally, the FOV x AGE, AGE x GENDER, and FOV x AGE x GENDER interactions were significant ($\alpha \leq 0.05$). The mean score for 7-9 year olds was 5.778 (out of a possible 7) with a standard error of 0.098, while the mean score for adults was 5.028

with a standard error of 0.197. The means and standard errors for the FOV x AGE interaction can be found in Table 25. The means and standard errors for the GENDER x AGE interaction can be found in Table 26. The means and standard errors for the FOV x AGE x GENDER interaction can be found in Table 27.

Table 25. FOV x AGE interaction for general enjoyment score.

FOV	*Age Grouping*	*Mean Score*	*Standard Error*
30 Degrees	7-9 year olds	5.722	0.177
30 Degrees	Adults	4.889	0.241
48 Degrees	7-9 year olds	5.833	0.090
48 Degrees	Adults	5.167	0.316

Table 26. AGE x GENDER interaction for general enjoyment score.

Age Grouping	*Gender*	*Mean Score*	*Standard Error*
7-9 year olds	Female	5.667	0.181
7-9 year olds	Male	5.889	0.076
Adults	Female	4.889	0.301
Adults	Male	5.17	0.259

Table 27. FOV x AGE x GENDER interaction for general enjoyment score.

FOV	*Age Grouping*	*Gender*	*Mean Score*	*Standard Error*
30 Degrees	7-9 year olds	Female	5.556	0.338
30 Degrees	7-9 year olds	Male	5.889	0.111
30 Degrees	Adults	Female	5.000	0.236
30 Degrees	Adults	Male	4.778	0.434
48 Degrees	7-9 year olds	Female	5.778	0.147
48 Degrees	7-9 year olds	Male	5.889	0.111
48 Degrees	Adults	Female	4.778	0.572
48 Degrees	Adults	Male	5.556	0.242

Post-hoc tests ($\alpha \leq 0.05$) on the FOV x AGE interaction revealed that 7-9 year olds under either FOV restriction enjoyed VEs significantly more than adults under the lower FOV restriction. No other significant differences were found. The effect of the FOV x AGE interaction is shown in Figure 20.

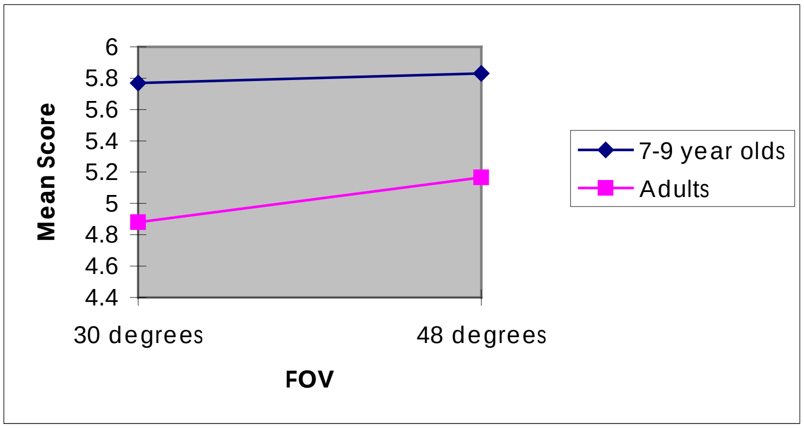


Figure 20. FOV x AGE interaction for general enjoyment score.

Post-hoc tests (α ≤ 0.05) on the AGE x GENDER interaction revealed that 7-9 year old males enjoyed the experience significantly more than adult females. No other significant differences were found. The effect of the AGE x GENDER interaction is shown in Figure 21.

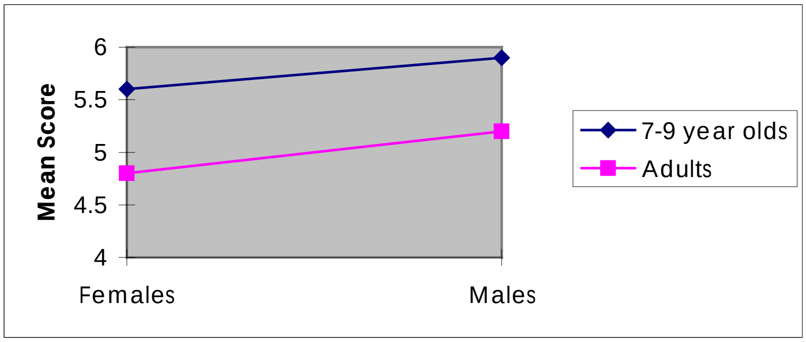


Figure 21. AGE x GENDER interaction for the general enjoyment score.

Post-hoc tests (α ≤ 0.05) on the FOV x AGE x GENDER interaction revealed that 7-9 year old males under either FOV restriction enjoyed the experience significantly more than adults under the lower FOV restriction. No other significant differences were found.

Analysis of Presence Measure

χ^2 tests were performed on the number of individuals that believed the virtual environment felt like a real place.[12] See Table 28 for a summary of the results. Post-hoc tests were done by decomposing RxC contingency tables into 2x2 contingency tables and performing χ^2 tests.

Table 28. Summary of the χ^2 test results for presence.

Source	***df***	χ^2
Field of View (F)	1	0.900
Age Group (A)	1	8.100*
Gender (G)	1	0.225
F x A	3	9.000*
F x G	3	3.150
A x G	3	10.350*
F x A x G	7	13.501*

* $p<.05$

The number individuals who achieved some degree of configuration knowledge increased significantly with AGE ($\alpha \leq 0.05$). Additionally, the FOV x AGE, AGE x GENDER, and FOV x AGE x GENDER interactions were significant ($\alpha \leq 0.05$). The number of 7-9 year olds who believed the VE felt like a real place was 26, while only 14 adults believed the VE felt like a real place.

Post-hoc tests ($\alpha \leq 0.05$) on the AGE x FOV interaction revealed adults under the lower FOV restriction believed significantly less frequently than children under both FOV restrictions that the VE felt like a real place, and adults under the higher FOV restriction believed significantly less frequently than 7-9 year olds under the same FOV restriction. The effect of the AGE x FOV interaction is shown in Figure 22.

---

[12] The Yates correction was used when expected frequency for a cell was less than 5.

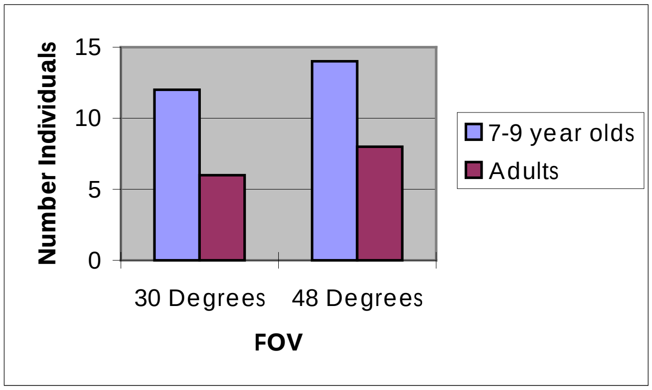


Figure 22. FOV x AGE interaction on number of individuals who felt the VE was a real place.

Post-hoc tests (α ≤ 0.05) on the AGE x GENDER interaction revealed that 7-9 year olds believed significantly more frequently than adult females that the VE felt like a real place. No other significant differences were found. The effect of the AGE x GENDER interaction is shown in Figure 23.

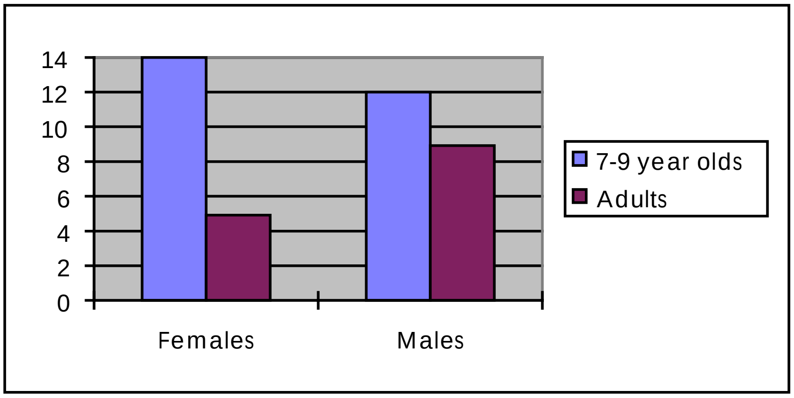


Figure 23. AGE x GENDER interaction on the number of individuals who felt the VE was a real place.

Post-hoc tests (α ≤ 0.05) on the FOV x AGE x GENDER interaction revealed that adult females under the lower FOV restriction believed that the VE felt like a real place significantly less often than 7-9 year olds under both FOV restrictions and adult males under the lower FOV restriction. Further, 7-9 year old females under the higher FOV restriction believed that the VE felt like a real place significantly more often than adults under the higher FOV restriction. No other significant differences were found. The effect of the FOV x AGE x GENDER interaction is shown in Figure 24.

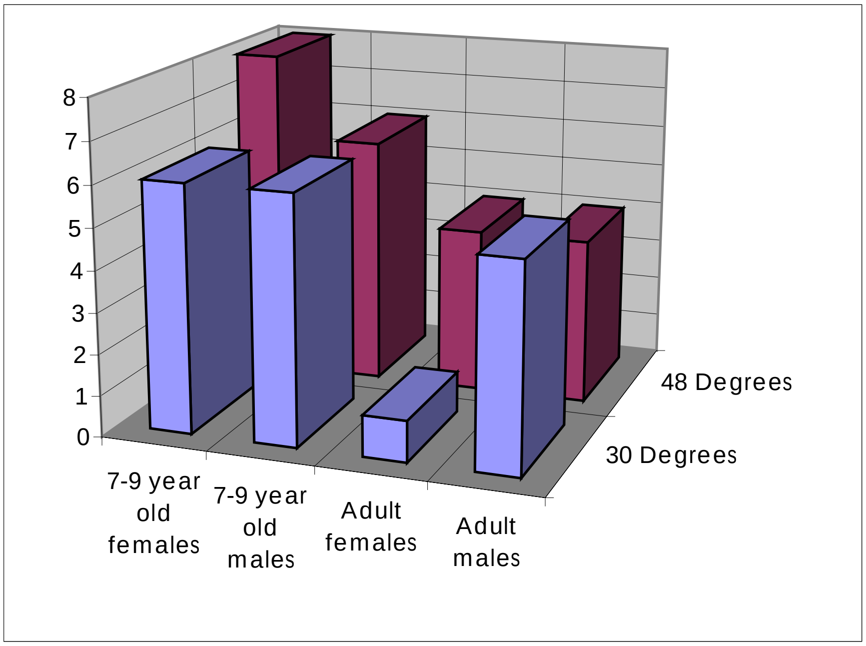


Figure 24. FOV x AGE x GENDER interaction on number of individuals that felt the VE was a real place.

Analysis of Immersion Side-effects Variables

The incidence of immersion side-effects was measured by the responses to the post-immersion survey (see Appendix E), changes in vision acuity, and changes in postural stability. No significant relationship was found between the total amount of time spent in VE and the degree of side-effects experienced. Although the time spent in the VE did differ, it did not do so substantially. See Table 29 for a summary of the side-effects data.

Table 29. Mean scores for the Immersion Side-effects Measures.

	30 Degree FOV				48 Degree FOV			
	7-9 year olds		Adults		7-9 year olds		Adults	
	Female	Male	Female	Male	Female	Male	Female	Male
Balance Measures								
• SONL Balance Measure (maximum = 30)	-5.11	-0.66	0.77	-0.22	-9.00	-1.66	-0.33	0.00
• SHT Balance Measure (maximum = 60)	-4.22	0.66	-2.00	0.11	-8.77	-5.55	-0.66	1.44
Vision Measures								
• Acuity Metric (maximum = 11)	-0.55	-0.33	0.22	0.11	0.55	0.22	0.44	-0.11
• Color Metric (maximum = 6)	-0.44	0.00	0.00	0.00	0.22	0.00	-0.11	-0.11
Survey								
• Subjective Side-effects Measure (maximum = 9)	2.66	1.33	1.22	1.88	1.88	1.55	1.44	0.66

Analysis of Balance Tests

Balance stability was assessed using the Stand-on-Nonpreferred-Leg (SONL) and Stand-Heel-to-Toe (SHT) postural tests. The balance measures used in this study are all of the form (M_1 - M_2) where M_1 was the performance result for a given balance test during the pre-immersion trial and M_2 was the corresponding value for post-immersion performance. A significant correlation was found between the SONL and SHT measures (r= 0.504, $\alpha \leq 0.05$). No other significant correlations were found.

Stand-on-Nonpreferred-Leg. An ANOVA was performed on the difference between pre- and post-immersion scores on the SONL test. The maximum score for this measure was 30. See Table 29 for the ANOVA summary table. The difference was in seconds.

Table 30. ANOVA Summary Table for SONL differences.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	37.56	37.56	1.260	0.266
Age Group (A)	1	312.50	312.50	10.486	0.002*
Gender (G)	1	138.89	138.89	4.662	0.035*
F x A	1	18.00	18.00	0.6045	0.440
F x G	1	20.06	20.06	0.674	0.415
A x G	1	174.22	174.22	5.842	0.018*
F x A x G	1	2.72	2.72	0.091	0.763
S/FGA	64	1908.00	29.81		
Total	71	2611.94			

* $p < .05$

As seen in the ANOVA summary table, the main effects of age and gender, along with their interaction, were again significant with $\alpha \leq 0.05$. The mean value for 7-9 year olds was -4.111 (out of a possible 30) seconds with a standard error of 1.035, while the mean value for adults was 0.056 seconds with a standard error of 0.985. The mean value for females was -3.417 seconds with a standard error of 1.195, while the mean value for males was -.639 seconds with a standard error of 0.731. The means and standard errors for the AGE x GENDER interaction can be found in Table 31. Although significant main effects and interactions were detected, the magnitudes of the differences were small and no visible differences in gait were observed by the experimenter.

Table 31. AGE x GENDER interaction for the SONL measure.

Age Grouping	***Gender***	***Mean Difference***	***Standard Error***
7-9 year olds	Female	-2.1667	2.03478
7-9 year olds	Male	-0.4444	1.16946
Adults	Female	-4.6667	0.43202
Adults	Male	-.833333	0.89256

The degree of side-effects as measured by the SONL test decreased significantly as AGE increased. Further, males experienced significantly fewer side-effects than females. Post-hoc tests ($\alpha \leq 0.05$) on the AGE x GENDER interaction revealed that 7-9 year old females experienced significantly more balance side-effects than 7-9 year old males or adults. The effect of the AGE x GENDER interaction is shown in Figure 25.

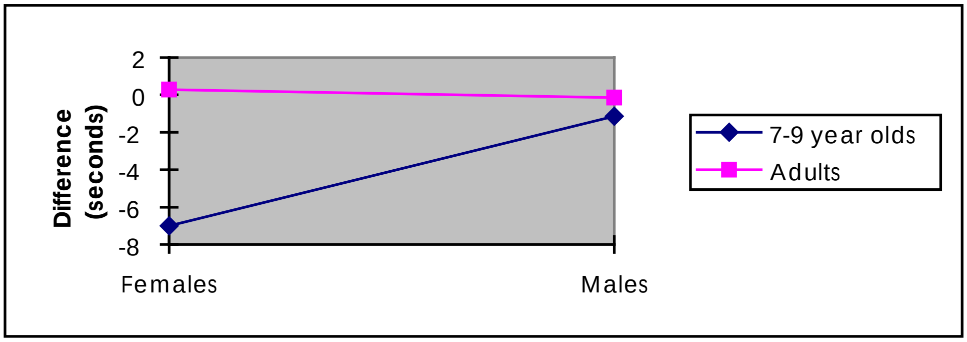


Figure 25. AGE x GENDER interaction on the SONL measure.

Stand-Heel-to-Toe. An ANOVA was performed on the difference between pre- and post-immersion scores on the SHT test. The maximum score for this measure was 60. See Table 32 for the ANOVA summary table. The difference was in seconds for the test.

Table 32. ANOVA Summary Table for SHT differences.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	74.01	74.01	0.926	0.341
Age Group (A)	1	316.68	316.68	3.941	0.050*
Gender (G)	1	7.35	7.35	0.094	0.763
F x A	1	203.35	203.35	2.538	0.116
F x G	1	74.01	74.01	0.922	0.341
A x G	1	39.01	39.01	0.493	0.488
F x A x G	1	74.01	74.01	0.924	0.341
S/FGA	64	5138.44	80.29		
Total	71	5926.87			

* $p < .05$

As seen in the ANOVA summary table, the main effects of age was again significant with $\alpha \leq 0.05$. The mean value for 7-9 year olds was -4.722 (out of a possible 60) seconds with a standard error of 2.009, while the mean value for adults was -0.278 seconds with a standard error of 0.647. 7-9 year olds again experienced significantly more balance side-effects than adults. Although a significant main was detected, the magnitude of the change was small and no visible differences in gait were observed by the experimenter.

Analysis of Vision Measures

The vision measures relate to visual acuity and color perception. The measures used in this study are all of the form ($M_1 - M_2$) where M_1 was the score for a given vision test during the pre-immersion trial and M_2 was the corresponding score for post-immersion performance. The maximum value for this measure was 11. The Bausch and Lomb® Vision Tester was used to score performance. Near visual acuity for both eyes was measured using the F-3 Test. Color vision was assessed using the F-7 Test.

Acuity Metric. An ANOVA was performed on changes in the F-3 test score. See Table 33 for the ANOVA summary table. No main effects, or interactions, were significant with $\alpha \leq 0.05$. This measure was not impacted by either FOV or AGE. The maximum score for this measure was 11. No significant correlations were found for this measure ($\alpha \leq 0.05$).

Table 33. ANOVA Summary Table for Acuity Changes.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	3.125	3.125	2.280	0.136
Age Group (A)	1	0.681	0.681	0.504	0.483
Gender (G)	1	0.347	0.347	0.252	0.616
F x A	1	3.125	3.125	2.287	0.136
F x G	1	1.681	1.681	1.234	0.272
A x G	1	0.125	0.125	0.093	0.763
F x A x G	1	0.014	0.014	0.010	0.920
S/FGA	64	87.556	1.368		
Total	71	96.653			

* p < .05

Color Metric. An ANOVA was performed on changes in the F-7 test score. See Table 34 for the ANOVA summary table. No main effects, or interactions, were significant with $\alpha \leq 0.05$. This measure was not impacted by either FOV or AGE. The maximum score for this measure was 6. No significant correlations were found for this measure ($\alpha \leq 0.05$).

Table 34. ANOVA Summary Table for Color Vision Changes.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	0.2222	0.2222	1.051	0.310
Age Group (A)	1	0.0000	0.0000	0.005	1.000
Gender (G)	1	0.0556	0.0556	0.267	0.610
F x A	1	0.8889	0.8889	4.202	0.055
F x G	1	0.5000	0.5000	2.367	0.129
A x G	1	0.0556	0.0556	0.264	0.610
F x A x G	1	0.5000	0.5000	2.362	0.129
S/FGA	64	13.5556	0.2118		
Total	71	15.7778			

* p < .05

Analysis of Subjective Side-Effects Measure

Kolomogorov-Smirnov tests were performed on the main effects for the subjective side-effects measure and were used as post-hoc tests for the significant interactions. The maximum score for this measure was 9. A summary of the results can be seen in Table 35. Kruskal-Wallis One-Way ANOVAs were performed on the interactions. See Table 36 for a summary of the results. No main effects, or interactions, were significant with $\alpha \leq 0.05$. This measure was not impacted by either FOV or AGE. A significant correlation was found between this measure and the subjective equipment difficulties measure ($r= 0.462$, $\alpha \leq 0.05$). No other significant correlations were found.

Table 35. Summary of the Kolomogorov-Smirnov test results for subjective side-effects measure.

Source	***df***	χ^2
Field of View (F)	2	0.222
Age Group (A)	2	2.722
Gender (G)	2	0.889

* $p<.05$

Table 36. Kruskal-Wallis One-Way ANOVA summary table for subjective side-effects measure.

Source	***df***	KW	p
F x A	3	4.461	0.217
F x G	3	0.515	0.917
A x G	3	4.321	0.229
F x A x G	7	5.030	0.657

* $p<.05$

Analysis of Equipment Difficulties Variables

The degree of equipment difficulties was measured by the responses to the post-immersion survey (see Appendix E), and by the number and duration of breaks taken by the participants during the VE portion of the study. See Table 37 for a summary of the equipment difficulties measure.

Table 37. Mean scores for the Equipment Difficulties Measures.

	30 Degree FOV				48 Degree FOV			
	7-9 year olds		Adults		7-9 year olds		Adults	
	Female	Male	Female	Male	Female	Male	Female	Male
Break Measures								
• Number of breaks[**]	1.44	1.00	0.11	0.00	1.11	1.44	0.22	0.11
• Duration of breaks (seconds)[*]	316	274	67	0	305	478	16	18
Survey								
• Subjective Equipment Difficulties Measure (maximum = 7)	3.33	2.55	3.66	1.77	3.33	2.22	2.66	1.77

Analysis of Break Measures

Break taking, both frequency and duration, was self-regulated by the participant. Both the number and duration of the breaks taken by participants during the VE portion of the study was tracked. No maximum limit existed for this measure. A significant relationship was found between the number and duration of breaks (r=.826, $\alpha \leq 0.05$). No other significant correlations were found for this measure.

Number of Breaks. An ANOVA was performed on the number of breaks taken during the VE portion of the study. No maximum limit existed for this measure. See Table 38 for the ANOVA summary table. A significant relationship was found between a participant's chronological age and the number of breaks (r=-.593, $\alpha \leq 0.05$). No other significant correlations were found for this measure.

---

[*] Statistic includes only information about breaks taken during the spatial learning and testing portions of the immersion session. It does not break information from the VE training period.

Table 38. ANOVA Summary Table for the Number of VE Breaks.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	0.1250	0.1250	0.287	0.599
Age Group (A)	1	23.3472	23.3472	52.124	0.000*
Gender (G)	1	0.1250	0.1250	0.282	0.599
F x A	1	0.0139	0.0139	0.030	0.861
F x G	1	0.6806	0.6806	1.524	0.222
A x G	1	0.0139	0.0139	0.035	0.861
F x A x G	1	0.6806	0.6806	1.521	0.222
S/FGA	64	28.6667	0.4479		
Total	71	53.6528			

* p < .05

As seen in the ANOVA summary table, the main effect of age was significant with α ≤ 0.05. No other main effects or interactions were significant. 7-9 year olds took significantly more breaks than adults. The mean value for 7-9 year olds was 1.253 with a standard error of 0.140, while the mean value for adults was 0.111 with a standard error of 0.134.

<u>Break Time</u>. An ANOVA was performed on the amount of time spent taking breaks during the VE portion of the study. No maximum limit existed for this measure. See Table 39 for the ANOVA summary table. A significant relationship was found between a participant's chronological age and the duration of breaks (r=-.512, α ≤ 0.05). Interestingly, a significant relationship was found between this measure and the SHT balance measure (r=-.561, α ≤ 0.05) indicating that individuals who spent more time taking breaks also experienced less balance disruptions. No other significant correlations were found for this measure.

Table 39. ANOVA Summary for the VE Break Time.

Source	***df***	***SS***	***MS***	***F***	***p***
Field of View (F)	1	29768	29768	0.690	0.410
Age Group (A)	1	1819596	1819596	42.114	0.000*
Gender (G)	1	4868	4868	0.112	0.738
F x A	1	57687	57687	1.336	0.252
F x G	1	91022	91022	2.117	0.152
A x G	1	43316	43316	1.008	0.321
F x A x G	1	23689	23689	0.551	0.462
S/FGA	64	2765777	43215		
Total	71	4835722			

* p < .05

As seen in the ANOVA summary table, the main effect of age was significant with α ≤ 0.05. 7-9 year olds spent significantly more time taking breaks than adults. No other main effects or interactions were significant. The mean value for 7-9 year olds was 343.693 with a standard error of 45.601, while the mean value for adults was 25.751 with a standard error of 29.469.

Analysis of Subjective Equipment Difficulty Measure

Kolomogorov-Smirnov tests were performed on the main effects for the subjective equipment difficulty measure and were used as post-hoc tests for the significant interactions. The maximum score for this measure was 7. A summary of the Kolomogorov-Smirnov test results can be found in Table 40. Kruskal-Wallis One-Way ANOVAs were performed on the interactions. See Table 41 for a summary of the results. No main effects, or interactions, were significant with $\alpha \le 0.05$. This measure was not impacted by either FOV or AGE. A significant correlation between this measure and the subjective side-effects measure was found (r=.462, $\alpha \le 0.05$). No other significant correlations were found for this measure.

Table 40. Summary of the Kolomogorov-Smirnov test results for subjective equipment difficulties measure.

Source	***df***	χ^2
Field of View (F)	2	2.0000
Age Group (A)	2	0.8889
Gender (G)	2	3.5556

* p<.05

Table 41. Kruskal-Wallis One-Way ANOVA summary table for subjective equipment difficulties measure.

Source	***df***	KW	p
F x A	3	7.044	0.319
F x G	3	9.922	0.179
A x G	3	2.235	0.897
F x A x G	7	7.921	0.245

* p<.05

Chronological Age Trends

As part of the analysis of significant AGE effects, participants were grouped by chronological age and the category performance evaluated. (Individual participant chronological age information can be in *Appendix I*, which contains the raw scores for each measure.) Children were grouped by age, i.e. 7 year olds, 8 year olds, and 9 year olds. The age of adult participants roughly spanned 3 decades, with each adult grouping corresponding to a decade. The resulting adult grouping is shown in Table 42.

Table 42. Number of adults in each chronological age category as a function of FOV.

	Lower FOV Condition	Higher FOV Condition	Total Number
18-29 year olds	8	12	20
30-39 year olds	3	5	8
40 year olds and up	7	1	8

No age-related effects were observed in the 7-9 year olds, however, the general adult trend on most measures was for the behavior of oldest adults to resemble that of the children. An example of this can be seen in Figure 26 where the previous chronological age breakdown was used to group participants into smaller age groups for the composite route measure. No statements as to the significance of these trends can be made due to the nature of the experimental design.

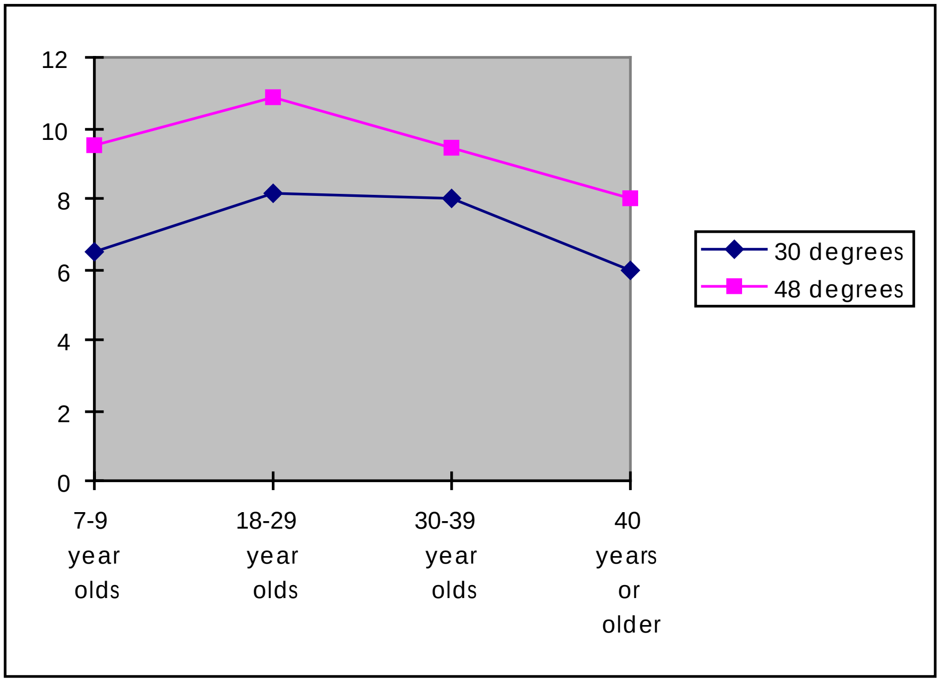


Figure 26. Impact of chronological age on mean composite route knowledge score.

Further examples of age-related trends in adult participants can be found in *Appendix J* which contains chronological age plots for all primary measures[13] where AGE was significant ($\alpha \leq 0.05$).

---

[13] A measure was considered primary if it was not a component measure for another measure.

CHAPTER 4. DISCUSSION

The study described here marks the beginning of a systematic exploration of adult-child differences in immersive VEs, and is a first step in quantitatively assessing the impact of VE system design choices on children in immersive VEs. The benefits of empirically studying children in immersive settings are clear. Children are not merely short adults. They bring a very different set of skills and perspectives to immersive settings, and these differences are likely to have a profound effect on both the design and content of VEs. Better understanding these differences makes possible the development of design and learning strategies which improve child-computer interaction and allow the smallest VE users to more effectively utilize the affordances of virtual worlds.

The present study focused on adult-child differences related to navigational efficacy in virtual worlds, and the impact these differences have on usability and learning. Navigation efficacy, and the spatial knowledge that enables it, was chosen as the focus of this research as navigational difficulties can neutralize the reported positive benefits of educational VEs by increasing student frustration and decreasing student motivation and engagement (Taylor, 1997). A critical factor in determining navigational efficacy in VEs is FOV. This study examined the impact of two FOVs on navigational efficacy in an immersive environment. The lower FOV level was 30 degrees and is the typical FOV restriction for VR goggles, a low cost alternative to HMDs that are popular in educational and entertainment circles. The upper FOV level was 48 degrees, which was the upper limit for the experimental HMD. It is also fairly representative of the upper-end HMDs that are used by educators.

This section discusses the results of this work with respect to spatial performance, immersion side-effects, equipment difficulties, general enjoyment, and presence. Lastly, implications for design and future research are discussed, and a summary is given of the conclusions that may be drawn from this study. Readers are cautioned that the results discussed here apply only to the variable ranges used in the study. Extrapolation of these results to other ages of children or FOVs outside the range tested can potentially be misleading. Extrapolation is further limited by the lack of stereopsis and head tracking in the experimental VE.

Spatial Performance

As expected, spatial performance increased with age. Further, the impact of FOV on spatial performance was as expected and consistent with previous studies with adults (Alfano and Michel, 1990; McGreevy, 1993, 1994; Venturino and Wells, 1990; Wells et al., 1988). As FOV decreased, both 7-9 year olds and adults developed a significantly lesser degree of spatial knowledge, with the effect being amplified in the 7-9 year olds. Only the most elemental level of spatial knowledge, the ability to recognize important objects in the space, was unaffected by either FOV or age, with performance on the associated task near perfect for all participants.

Further, with respect to the research hypotheses stated in the introduction, the following specific conclusions can be drawn.

- Collisions with objects in the VE decreased as FOV and age increased.
- Landmark knowledge remained invariant as FOV and age increased.
- Route knowledge increased as FOV and age increased.
- Configuration knowledge increased as FOV and age increased.

Additionally, the time to complete the VE spatial tasks, both in and out of the environment, increased as FOV and age decreased.

In general, the more sophisticated the level of spatial knowledge required by a task, the greater the impact of both FOV and age, with configuration knowledge being achieved significantly less frequently than route knowledge. Approximately,

- One fifth the adults and over half the children demonstrated convincing evidence of neither route or configuration knowledge,[14] with all of the individuals coming from the 30 degree HFOV condition.

- Two adults and almost a third of the children demonstrated convincing evidence only of route knowledge, with all the adults in the 30 degree HFOV condition and four fifths of the children in the 48 degree HFOV condition.

- 69% of the adults and 16% of the children demonstrated convincing evidence of both route and configuration knowledge, with all the children and three fourths of the adults coming from the 48 degree HFOV condition.

These results contrast sharply with the Hazen et al. (1978) study which found that in an equivalent real world space using identical spatial inference and model building tasks fully 80% of the 6 year olds demonstrated convincing evidence of configuration knowledge. Here, only adults under the higher FOV condition performed these tasks at approximately the same level as the 6 year olds in the Hazen et al.'s (1978) real world study. Additionally, the children in this study demonstrated configuration knowledge only at the model building task, which was the only configuration knowledge task that did not take place in the VE. These results suggest that 7-9 year olds are significantly less capable than adults at dealing with FOV deficiencies and the associated cognitive costs.

---

[14] Participants were considered not to have achieved any degree of route knowledge if they 1) could not correctly sequence the landmarks in the house model, and 2) scored 9 or less on the composite route knowledge measure.

Participants were considered not to have achieved any degree of configurational knowledge if they 1) could not construct a correct house model, 2) could not correctly answer at least six spatial inference questions, and 3) had an average, absolute azimuth error greater than 10 degrees for the pointing tasks.

Gender was significant only in the development of configuration knowledge. It was not found to be significant for route knowledge measures. However, the trend for all route knowledge scores was for males to score higher than the females. Given the fairly small cell size, it may be worth considering these trends for future research, as all raw route knowledge data uniformly exhibits this trend. The impact of gender on configuration measures was greatest in adults. Except for those configuration measures where performance was near ceiling level, adult males consistently out performed adult females. This effect was seen to a lesser extent in the 7-9 year olds. In part, it was less evident in the children as the generally low level of performance by children on configuration measures made detection of significant differences less likely. Additionally, male superiority at spatial tasks only starts appearing around age seven with little gender differences in ability found in the younger children (Newcombe, 1982). Although the mean age of the children in this study was 8.7 years with the mean age of the girls 8.5 and the boys 8.9, the impact of gender differences may not have been great enough to significantly improve the performance of boys in the 7-9 year old age range.

Gender was also a significant factor in the time taken to build a model of the space. Surprisingly, although adult males performed significantly faster than either the adult females or the children, adult females failed to perform significantly faster than the children. Adult females in the study generally spent a substantial period of time verbalizing what they remembered about the house and seemed less sure of themselves than other participants, and while children knew less about the structure, they also did not worry about it and proceeded quickly to the task which may account for the lack of a significant difference in task speed.

Interestingly, potential age-related trends could be seen in the adults when they were separated into subgroups based on chronological age. As the ages of adults roughly spanned 3 decades, the adults were broken into 3 subgroups, each spanning approximately one decade and containing a variable number of people. (See Table 42 for further details of this decomposition.) On the higher level spatial knowledge tasks, the performance of the oldest subgroup whose members were 40 years and older resembled that of the 7-9 year olds. The decreased performance of the oldest participants may be an artifact of the age differences in information processing or psychomotor performance reported in earlier studies (Birdi and Pennington, 1997; Gist, Rosen, and Schwoerer, 1988; Westerman, Davies, Glendon, Stammers, and Matthews, 1995), or it may be attributable to the reported increase in computer anxiety, and corresponding decrease in performance, among older adults (Mahar, Henderson, and Deane, 1997; Sharit and Czaja, 1994). In any case, these results should be considered exploratory. The present study was not designed to verify the statistical significance of these differences, and further empirical studies are needed to explore these apparent trends.

Sensitivity of the Route Knowledge Measures

Perfect performance on the sequencing of landmarks in VE or the model was expected to be indicative of superior route knowledge, and a significant correlation was found between the two measures. It was expected that individuals failing to sequence the landmarks correctly in the VE would be unlikely to sequence the landmarks correctly in the model. As expected, all of the participants who correctly sequenced landmarks in the VE correctly sequenced them in the model. In all, four fifths of the participants incorrectly sequenced the landmarks in the VE. Surprisingly, two fifths of those participants managed to correctly sequence the landmarks in the model. Externally representing and manipulating route knowledge appeared to be more effective, especially for the children, than verbalizing the information in the VE where the cognitive demands of the VE appear to have interfered with the verbalization process.

Sensitivity of the Configuration Measures

Outstanding performance on either the model building, spatial inference, or pointing tasks was expected to be indicative of configuration knowledge for the space, and indeed a significant correlation was found between the measures. It was expected that individuals failing to perform well at either the spatial inference or pointing tasks would be unlikely to build a perfect model. Although almost two fifths of the participants built a perfect model, seven (two adults and five 7-9 year olds) exhibited configuration knowledge only at the model building task. Again, externally representing and manipulating spatial knowledge outside the VE appeared to be more effective than verbalizing the information in the VE.

Children were most successful at the model building task. This task was the only one where children exhibited configuration knowledge albeit only under the higher FOV condition. Many children’s model performance was markedly better than their in-VE performance. When asked, the children credited their improvement to

1. Not wearing a heavy thing on their head while making the model,
2. Seeing and manipulating all the components of the house at one time, and
3. Viewing and manipulating the model from above.

Children were markedly deficient at the in-VE pointing tasks when compared to adults under similar conditions. Although the children were pointing to occluded objects that were on the same floor, the degree of degradation in their performance was similar to that of younger children in the real work who are pointing at objects on different floors (Pick and Lockman, 1982). The children also experienced great difficulty making spatial inferences in the VE with children in the lower FOV condition having essentially no ability to make spatial inferences. Even under the higher FOV condition, only a third of the spatial inferences made by the children were correct. These findings contrast sharply with the real world where the majority of 7-9 year olds would be expected to competently perform all three configuration tasks in a similarly sized real world space. 7-9 year olds were significantly less capable than adults at accessing configuration knowledge in the VE, where the cognitive costs of the VE appear to have interfered with the access process.

Immersion Side-effects

Most participants experienced no side-effects and those that did experienced only minor, transient problems. No significant changes in vision were experienced and the subjective immersion side-effects mean score was 1.6 out of a possible 9. The only significant results were for the balance measures, which are linked to the development of ataxia, or postural disequilibrium.

As expected, age played a significant role in ataxia's development with 7-9 year olds experiencing significantly more balance disturbances than adults. Gender was also significant for the first balance measure with females experiencing significantly greater balance disturbances than males. Despite the significance of the changes, the magnitude of the changes were small and the mean change for participants was approximately -3 seconds. The only effect of the changes was a slight wobbly feeling; no visible differences in gait or posture were observed by the experimenter.

Extrapolation of these results to other VEs may be tenuous as the movement of the VE input device had been dampened and restricted to the X-Y plane in order to increase its controllability for the younger participants. The restricted movement eliminated the extreme, rapid movements in the VE which often accelerate the development of immersion side-effects. Further, although the participants spent on average a total of 31 minutes in the VE, the typical participant took at least one break during that period with many of the children taking several, which is likely to have greatly decreased the incidence of side-effects.

Equipment Difficulties

As reported in earlier studies, child participants experienced more difficulties than the adult participants with age the only significant factor for these measures (Bricken and Bryne, 1993; Taylor, 1997; Winn, 1995). In particular, with respect to the research hypotheses stated earlier in this thesis, the following specific conclusions can be drawn.

- 7-9 years olds took significantly more breaks than adults.
- 7-9 year olds took significantly longer breaks than adults.

Although no significant differences appeared in the post-immersion survey, child participants verbalized their frustration with the equipment more frequently than adults during the session. The HMD, particularly its heaviness, was a primary target of these complaints.

The average child spent only 8.9 minutes in the VE before taking a break, with break taking and verbal complaints about the headgear increasing as the experimental session wore on. Whether or not break taking related solely to equipment difficulties can not be said. However, equipment difficulties were the main reason given by participants for taking breaks. It may be that children simply take more breaks in general when learning new concepts. Still, the time children spent in the VE was short, with most spending about a half hour in the environment, and as the children were all school-age, they normally spend even longer periods in school without taking breaks. Further, with few exceptions, the children thoroughly enjoyed their time in the VE and pressured their parents to stay long after the experiment to explore other environments. Another factor may have been the nature of the experimental environment with more engrossing, game-like environments potentially seeing a reduction in break taking.

HMD Difficulties

Many participants found the HMD excessively heavy and disliked the main weight of the HMD resting on their nose. The HMD completely covered most children's noses, even when the HMD was adjusted to the smallest setting, making breathing through the nose difficult. The impact of adult-child head size differences on HMD fit can be seen in Figure 27, where a 9 year old's nose has been completely covered by the HMD.

Figure 27. Close-up of 9-year old boy wearing HMD.

Children adopted a variety of postures to alleviate the discomfort associated with the HMD. The most common postures for children were 1) resting the HMD display on a hand (see Figure 28), 2) dropping the head completely to the chest so the main weight rested on the straps at the back of the head, and 3) tilting the head back so the weight of the HMD was more evenly distributed over the face (see Figure 29). These postures were seen to a much less extent in adults whose body anthropometry was better suited to the HMD.

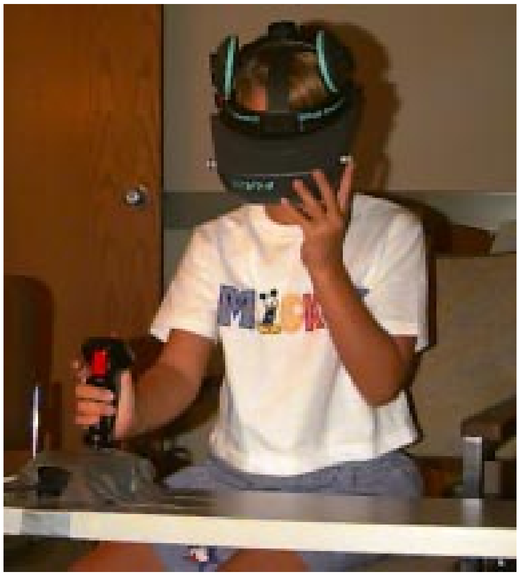


Figure 28. Child resting HMD display on hand to minimize pressure on nose.

Figure 29. Child tilting head back so that main HMD weight rests on forehead.

General Enjoyment

The general enjoyment score is in striking contrast to the side-effects and equipment difficulties results, with 7-9 year olds enjoying the VE experience significantly more than adults. Additionally, 7-9 year olds verbalized their enjoyment more often during the VE session. With the exception of 2 girls, the tested children were uniformly enthusiastic about their virtual experience and stayed after the experimental session to play games. As in earlier studies, enjoyment of immersive VEs appears to be inversely proportional to the potential for immersion side-effects and equipment difficulties (Bricken and Bryne, 1993; Winn, 1995). Interactions involving gender and age were also significant with 7-9 year old males emerging as the clear winners in VE enjoyment.

The significantly greater degree of enjoyment experienced by child participants may partially explain the lack of significant results in the immersion side-effects and equipment difficulty subjective measures. Child participants appeared to frequently “forget” previous difficulties when answering the survey. When asked afterwards why difficulties verbalized during the session were not indicated on the survey, child participants generally replied that the problem did not seem really important in comparison to the fun had in the environment. Adults appeared much less forgiving, with their survey results tallying closely to their immersion comments. Another contributing factor for this behavior may be the manner in which the children were administered the survey. In order to control the impact of reading skill variability in the children, the survey was read aloud to the children by the adult experimenter who recorded their answers. Children may have felt less free to admit difficulties or disfavor to an adult who was not well known and who additionally may have been perceived as “owning” the VE.

Presence

As in earlier studies involving children, children experienced presence to a significantly greater extent than adults (Bricken and Bryne, 1993; Taylor, 1997; Winn, 1995). 67% of the 7-9 year olds felt the VE toy house was a real place as opposed to 38% of the adults. Additionally, unlike adults, the children, especially the younger ones, frequently talked to VE objects, e.g. bunnies or robots, and sometimes simulated conversations between objects and themselves. Like enjoyment, presence appears to be inversely proportional to the potential for immersion side-effects and equipment difficulties. Age and its interactions were all significant with 7-9 year olds consistently experiencing presence to a greater degree than other participants, especially adult females.

Unlike earlier research, FOV was not found to be a significant predictor of presence. However, the FOVs levels were separated by only 18 degrees which may not have been sufficient to generate significant differences. Further, the experimental protocol involved significant dialogue between participant and experimenter which is likely to have decreased the sense of presence. Additionally, the simplicity of the post-immersion questionnaire may have missed many of the gradations in participant perceptions. Likert-type scales are generally used to gather the gradations of user perception, however such scales are ineffective for younger children, such as the youngest ones in the study, who do not yet have a firm grasp of ordinal concepts. Participant verbalizations during the immersion session might be one way of capturing these perceptions more fully. Once captured, this information could be quantified using verbal protocol techniques such as content analysis.

Implications of Research

In terms of theoretical implications, the present study supports the original hypothesis that middle elementary school children, 7-9 years old, differ significantly from adults in their responses to immersive VEs, and that children in this age group are significantly more impacted by the perceptual deficiencies of virtual worlds than adults. Overall, the study makes several contributions to VE research and design. First, it quantifies the impact of FOV restrictions on the development of spatial knowledge by middle elementary schoolchildren in a large-scale, immersive space and the impact of immersion on that population. Second, it quantifies how the spatial performance of middle elementary schoolchildren differs from that of adults in the same setting. Third, it discusses techniques commonly used to study spatial knowledge with adults in VEs and describes how the age of the participant impacts the effectiveness of these techniques. Such information provides guidance both to designers of VEs aimed at children and to researchers interested in systematically assessing the impact of VE system parameters on children.

Design and Educational Implications

Many of the lessons learned about VE design with adults appear applicable to environments used by children. As with adults, FOV restrictions negatively impact children's ability to move and orient themselves in a virtual space. However, children are impacted to a greater extent by the cognitive costs associated with these restrictions and suffer a correspondingly greater decrement in spatial learning. Even in the experimental VE, which was very simple and contained large, distinctive landmarks, the ability of middle elementary schoolchildren to form route knowledge was substantially degraded and their ability to form configuration knowledge near non-existent under the tested FOV conditions.

Although the present study is only a first step in quantitatively assessing the impact of FOV restrictions on children in VEs, it has implications for both VE designers and education specialists as well as VE equipment purchasers. The present findings indicate that VE tasks requiring the development of a higher degree of spatial knowledge will not be suitable for middle elementary schoolchildren under the tested FOV restrictions. Additionally, VE equipment purchasers should be aware that while VR glasses and devices with similarly restricted FOVs are often cheaper than most immersive display devices, their smaller FOVs severely hamper spatial learning in middle elementary schoolchildren. Clearly too, large-scale VEs targeted at children in this age group must be carefully designed to maximize spatial orientation cues and provide spatial performance aids, e.g. maps, in order to minimize the likelihood of a child getting lost in the virtual space. Getting lost, whether in the real world or the virtual world, can be a scary experience for a child.

Designers may also want to consider manipulating the geometric FOV (GFOV) of the VE display to alleviate spatial performance problems caused by FOV shortcomings. Manipulating the GFOV is a common method for increasing the "perceived" FOV of a display thereby increasing the user's ability to form spatial knowledge. It involves mapping the "perceived" FOV onto a display, much as an artist maps a portion of the real world onto a canvas. Like drawings, it relies heavily on perspective changes and other pictorial cues to convey information.

However, designers are cautioned that the impact of GFOV manipulation on children has not been quantified in an immersive setting and its impact on children may be very different from that of adults. Studies with pictures suggest that perspective manipulation is substantially less effective with children than adults, with children gaining different information than adults from analysis of pictures with dimensional information (Dornbush and Winnick, 1966; Hagen, 1972).

This research also raised some serious questions about the suitability of immersive VEs for elementary age school children given the lack of light, usable immersive display devices. Although children appear to find VEs intrinsically motivating, HMD difficulties seriously impeded both usability and learning in the environment. Complaints about the headgear were common, with children taking breaks anywhere from 5 to 12 minutes, reportedly because of HMD difficulties. The children's frequent break taking disrupted the learning process and required them to re-orient themselves to the task each time they returned to the VE. Clearly, light-weight HMDs whose dimensions better fit child users are needed if children are ever to fully utilize VEs as learning spaces. Until the time that HMDs become more light-weight and comfortable, designers of VE systems aimed at children will want to consider using forms of VEs that do not require heavy or ill-fitting headgear, e.g. autostereoscopic displays.

Designers should carefully consider whether target tasks can be accomplished given the frequency with which middle elementary school children take breaks in an immersive setting. Tasks and learning scenarios for this age group should be amenable to being broken into a sequence of short segments and should not require the child to spend an extended period of time in the VE. Instructional review segments may be needed to help the children re-orient themselves to a task after an extended break.

Additionally, designers should consider not using head-tracking in immersive systems targeted at middle elementary schoolchildren. Children in this age group have difficulty keeping the head in a normal viewing position when wearing an HMD and often assume unusual, static positions that allow them to more comfortably distribute the HMD's weight (see Figures 28 and 29). Such head positions, while more comfortable, would often leave the child staring at the floor or the ceiling in a system with head tracking.

Future Research Implications

Ample opportunities remain to further the knowledge of adult-child differences in immersive VEs and further explore the impact of VE design choices on children. This study is merely a first attempt at locating significant differences in adult and child responses to VEs. Future research into age-related differences in immersive VEs is needed. In particular, future research should consider

- Investigating the suitability of different VE devices, especially displays, for use by children and their impact of a child's ability to learn in VEs,

- Exploring more fully the impact of VE system parameters on children to more fully understand the scope of adult-child differences in VEs,[15]

- Expanding the age level coverage to allow exploration of developmental differences in children and potential age-related differences in adults.

- Considering other tasks to more fully understand the impact of VE design choices on children's ability to learn in VEs,

- Probing more fully the impact of gender, and other individual differences, on spatial navigation in VEs, and

- Developing more effective methods of gathering and quantifying presence and other subjective impressions in children, especially those whose ordinal understanding is not yet firm enough to allow the use of Likert-type scales.

Additionally, duplication of this study in the real world should be considered, as it would allow separation of the human costs relating to the virtual environment from those associated with restricting the FOV.

Conclusions

The preceding discussion raised a number of issues regarding middle elementary school children and VEs, and attempted to provide guidance to designers of VEs aimed at children in this age group. Most children in this age group were wildly enthusiastic about virtual worlds and experienced negligible, negative side-effects from immersion. The children did find the HMD overly heavy and too large to fit comfortably on small heads, with HMD difficulties impacting both usability and learning in the VE. If learning is to be pleasurable and VEs are to fulfill their potential as learning environments for children in this age group, more lightweight and better fitting HMDs must be developed. With respect to the hypotheses stated earlier in this thesis, the following conclusions can be drawn.

- Locomotion, route knowledge, and configuration knowledge efficiency increased significantly with both age and FOV. In general, the higher the level of spatial knowledge required by a task, the greater the impact of both FOV and age, with configuration knowledge being achieved significantly less frequently than route knowledge. Additionally, the development of configuration knowledge was also significantly affected by gender, with males outperforming females.

---

[15] See Appendix K for a summary of potential adult-child differences in VEs as a function of VE system parameters.

- The ability to recognize objects seen in the VE did not increase with age or FOV as expected.

- The incidence of VE balance side-effects decreased significantly as age increased and was impacted by gender. No significant differences were discovered for the vision or the side-effects post-immersion survey results.

- The incidence of equipment difficulties increased significantly as age decreased. Significantly more, and longer, breaks were taken by 7-9 year olds than by adults.

- General enjoyment and presence in the VE decreased significantly as age increased.

REFERENCES

Acredolo, L. (1977). Developmental changes in the ability to coordinate perspectives of a large-scale space. Developmental Psychology, 13, 1-8.

Acredolo, L. (1978). Development of spatial orientation in infancy. Developmental Psychology, 11, 495-501.

Ainge, D. (1996). Introducing Primary Students to VR With Vitrus WalkThrough: Two Pilot Studies. VR in the Schools, 2(1), 10-15.

Alfano, P., and Michel, G. (1990). Restricting the field of view: perceptual and performance effects. Perceptual and Motor Skills, 70, 35-45.

Allen, G. (1982). The organization of route knowledge. In R. Cohen (Ed.), New Directions for Child Development: Children's Conceptions of Spatial Representations. San Francisco: Jossey-Bass.

Allen, G., Kirasic, K., and Siegel, A., and Herman, J. (1979). Development issues in cognitive mapping: the selection and utilization of environmental landmarks. Child Development, 50, 1062-1070.

Allen, G., Siegal, A., and Rosinski, R. (1978) The role of perceptual context in structuring spatial knowledge. Journal of Experimental Psychology: Human Learning and Memory, 4, 617-630.

Amen, E. (1941). Individual differences in apperceptive reaction: a study of the responses of preschool children to pictures. Genetic Psychology Monographs, 10, 319-385.

Anderson, J. (1985). Cognitive Psychology and Its Implications, 2nd Ed. New York: W. H. Freeman and Company.

Appleyard, D. (1969). Why buildings are known. Environment and Behavior, 1, 131.

Arthur, K.., and Booth, K. (1993). Evaluating 3D task performance for fish tank virtual worlds. ACM Transactions on Information Systems, 11(3), 239-265.

Arthur, E., Hancock, P., and Chrysler, S. (1993). Spatial orientation in real and virtual worlds. In Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting, (pp. 328-332).

Azuma, R. (1997). A Survey of Augmented Reality. Presence, 6(4), 355-385.

Bailey, S. (1994). Creating a Virtual Reality as a Perceptual Equivalence for Training. Educational Media International, 31(4), 221-223.

Barfield, W., Hendrix, C., Bjorneseth, O., Kaczmarek, K., and Lotens, W. (1995). Comparision of Human Sensory Capabilities with Technical Specifications of Virtual Environment Equipment. Presence, 4(4), 329-356.

Barfield, W., Rosenberg, C., and Furness, T. (1995). Situation awareness as a function of frame of reference, computer-graphics eyepoint elevation, and geometric field of view. International Journal of Aviation Psychology, 5(3), 233-256.

Barfield, W., Rosenberg, C., and Lotens, W. (1995). In W. Barfield and T. Furness (Eds.), Virtual Environments and Advanced Interface Design (pp. 542-576). Oxford University Press.

Barfield, W., and Weghorst, S. (1993). The sense of presence within virtual environments: A conceptual framework. In G. Salvendy and M. Smith (Eds.), Human-computer interaction: Software and hardware interfaces, (pp. 699-704). Amsterdam: Elsevier.

Bernaldez, F., Gallardo, D., and Abello, R. (1995). Children's landscape preferences: from rejection to attraction. In C. Spencer (Ed.), The Child's Environment (pp. 221-228). Academic Press.

Bernaldez, F., Ruiz, J., and Ruiz, M. (1984). Landscape perception and appraisal, ethics, aesthetics, and utility. In Proceedings of the Eighth International Conference on Environment and Human Action. Berlin: IAPS 8.

Birdi, K., and Pennington, J. (1997). Aging and Errors in computer-based work: an observational field study. Journal of Occupational and Organizational Psychology, 70, 35-47.

Bisanz, J., and Resnick, L. (1978). Changes with Age in Two Components of Visual Search Speed. Journal of Experimental Child Psychology, 25, 129-142.

Blaut, J., and Stea, D. (1971). Studies in geographical learning. Annals of the Association of American Geographers, 61, 387-393.

Bluestein, N., and Acredolo, L. (1977). Developmental changes in map reading skills. E.R.I.C. Document No. ED 154902.

Boff, K., and Lincoln, J. (Eds.) (1988). Engineering Data Compendium: Human Perception and Performance. Wright-Patterson Air Force Base: AAMRL.

Bricken, M. and Byrne, C. (1993). Summer students in virtual reality: A pilot study on educational applications in virtual reality technology. In A. Wexelblat (Ed.), Virtual reality applications and explorations (pp. 199-217). Toronto: Academic Press Professional.

Brickner, M., and Foyle, D. (1990). Field of view effects on a simulated flight task with head-down and head-up sensor imagery displays. In Proceedings of the Human Factors Society 34th Annual Meeting (pp. 1567-1571). Santa Monica, CA: Human Factors Society.

Briggs, R. (1972). Cognitive distance in urban space. Unpublished doctoral dissertation, Ohio State University.

Byrne, C. (1993). Virtual Reality and Education. Human Interface Technology Laboratory, Technical Report TR-93-6.

Byrne, C. (1996). Water on Tap: The Use of Virtual Reality as an Educational Tool. Unpublished doctoral dissertation, University of Washington.

Caird, J. (1994) The effect of virtual hand size on the perception of grasp extent. Ergonomicas and Design, 4, 403-405.

Carr, K., and England, R. (1993). The role of realism in virtual reality. In Virtual Reality International 93: Proceedings of the Third Annual Conference on Virtual Reality, (pp. 24-33). London, UK: Meckler.

Cha, K., Horch, K., and Normann, R. (1992). Mobility performance with a pixelized vision system. Vision Research, 32(7), 1367-1372.

Chung, J. (1992). A comparison of head-tracked and non-head-tracked steering modes in the targeting of radiotherapy treatment beams. In Proceedings of the 1992 ACM Symposium on Interactive 3D Graphics, (pp. 193-196).

Cohen, R., Baldwin, L., and Sherman, R. (1978). Cognitive maps of a naturalistic setting. Child Development, 49, 1216-1218.

Cohen, R., Weatherford, D., Lomenick, T., and Koeller, K. (1979). Development of spatial representations: role of task demands and familiarity with the environment. Child Development, 50, 1257-1260.

Cornell, E., and Hay, D. (1984). Children’s Acquisition of a Route Via Different Media. Environment and Behavior, 16(5), 627-641.

Curtis, L. Siegel, A., and Furlong, N. (1981) Developmental differences in cognitive mapping: configurational knowledge of familiar large-scale environments. Journal of Experimental Psychology, 31, 456-469.

De Jonge, D. (1962). Images of urban areas: their structures and psychological foundations. Journal of the American Institute of Plannners, 28, 266-276.

Dolezal, H. (1982). Living in a world transformed: perceptual and performatory adaptation to visual distortion. Academic Press.

Dorethy, R. (1977). Motion parallax as a factor in the differential spatial abilities of young children. Unpublished Master's Thesis, Illinois State University.

Dornbush, R. and Winnick, W. (1966). The relative effectiveness of stereometric and pattern stimuli in discrimination learning in children. Psychonomic Science, 5, 301-301.

Downs, R, and Stea, D. (1973). Image and Environment: Cognitive Mapping and Spatial Behavior. Chicago: Aldine Publishing Company.

Draper, M. (1995). Exploring the Influence of a Virtual Body on Spatial Awareness. Unpublished thesis, University of Washington.

Dvorine, I. (1953). The Pseudo-Isochromatic Plates, Second Edition. The Psychological Corporation.

Ehrlich, J., and Singer, M. (1994). Are stereoscopic displays necessary for virtual environments? In Proceedings of the 38th Annual Meeting of the Human Factors and Ergonomics Society, (pp. 952). Santa Monica, CA: HFES.

Ellis, S. (1991). Nature and Origin of Virtual Environments: a bibliographical essay. Computing Systems in Engineering, 2(4), 321-47.

Ellis, S. R. (1993). What are virtual environments? In *ICAT '93,* (pp. 81-89). Tokyo, Japan: ICAT.

Fowlkes, J., Kennedy, R., and Lilienthal, M. (1987). Postural disequilibrium following training flights. In Proceedings of the 31st Annual Meeting of the Human Factors Society (pp. 488-491). Santa Monica, CA: Human Factors Society.

Furness, T., and Barfield, W. (1995). Introduction to Virtual Environments and Advanced Interface Design. Virtual Environments and Advanced Interface Design, T. Furness and W. Barfield (eds.), (pp. 1-13). Oxford University Press.

Garling, T., Lindberg, E., and Mantyla, T. (1983). Orientation in buildings: effects of familiarity, visual access, and orientation aids. Journal of Applied Psychology, 68(1), 177-186.

Gibson, E. (1969). Principles of Perceptual Learning and Development. New York: Appleton-Century-Crofts.

Gist, M., Rosen, B., and Schwoerer, C. (1988). The influence of training method and trainee age on the acquisition of computer skills. Personnel Psychology, 41, 255-265.

Goldin, S., and Thorndyke, P. (1982). Simulating Navigation for Spatial Knowledge Acquisition. Human Factors, 24(4), 457-471.

Golledge, R. Methods and methodological issues in environmental cognition research. In G. Moore and R. Golledge (Ed.), Environmental Knowing. Stroudsburg, PA: Dowden, Hutchinson, and Ross.

Grove, J. (1995). VR in the United Kingdom: A Greek History Project. VR in the Schools, 1(2), 5.

Haber, R. (1983). The impeding demise of the icon: a critique of the concept of iconic storage in visual information processing. Behavior and Brain Science, 6, 1-54.

Hagen, M. (1972). How children see pictures: the development of the perception of surface layout as pictured in art. Unpublished master's thesis, University of Minnesota.

Hagen, M., Jones, R. and Reed, E. (1978) On a neglected variable in theories of pictorial perception: truncation of the visual field. Perception and Psychophysics, 23(4), 326--330.

Hamilton, K., Kantor, L., and Magee, L. (1989). Limitations of postural equilibrium tests for examining simulator sickness. Aviation, Space, and Environmental Medicine, 60(3), 246-251.

Hazen, N., Lockman, J., and Pick, H. (1978). The development of children's representations of large-scale environments. Child Development, 49, 623-636.

Heeter, C. (1992). Being there: The subjective experience of presence. Presence, 1(2), 262-271.

Held, R. and Durlach, N. (1992). Telepresence. Presence, 1(1), 109-112.

Hendrix, C. (1994). Exploratory studies on the sense of presence in virtual environments as a function of visual and auditory display parameters. Unpublished Master's Thesis, University of Washington.

Henry, D. (1992). Spatial Perception in Virtual Environments: Evaluating an Architectural Application. Unpublished masters thesis, University of Washington.

Henry, D. and Furness, T. (1993) Spatial perception in virtual environments: evaluating an architectural application. Proc. of the IEEE Conference -- Virtual Reality Annual Internation Symposium (VRAIS) , 33-40. Seattle, WA.

Herman, J. (1980). Children's cognitive maps of large-scale spaces: effects of exploration direction and repeated experience. Journal of Experimental Child Psychology, 29, 126-143.

Herman, J., and Siegal, A. (1978). The development of cognitive mapping of the large-scale environment. Journal of Experimental Child Psychology, 26, 389-406.

Hix, D., and Hartson, R. (1993). Developing User Interfaces: Ensuring Usability Through Product and Process. John Wiley and Sons.

Huttenlocher, J., and Newcombe, N. (1984). The Child's Representation of Information About Location. In C. Sophian (Ed.), Origins of Cognitive Skills: the Eighteenth Annual Carnegie Symposium on Cognition (pp. 81-111). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Huttenlocher, J., and Presson, C. (1973). Mental rotation and the perspective problem. Cognitive Psychology, 4, 277-299.

Infield, S. (1991). An Investigation into the Relationship Between Navigation Skill and Spatial Abilities. Unpublished doctoral dissertation, University of Washington.

Jackson, N., Robinson, H., and Dale, P. (1977) Cognitive Development in Young Children. Brooks/Cole Publishing Company.

Kenny, S. (1983). Developmental Discontinuities in Childhood and Adolescence. In K. Fisher (Ed.), Levels and Transitions in Children's Development. San Francisco: Jossey-Bass.

Kennedy, R., Lane, N., Lilienthal, M., Berbaum, K., and Hettinger, L. (1992) Profile analysis of simulator sickness symptoms: application to virtual environment systems. Presence, 1(3), 285-301.

Kennedy, R., Lane, N., Berbaum, K., and Lilienthal, M. (1993). Simulator Sickness Questionnaire: An Enhanced Method For Quantifying Simulator Sickness. International Journal of Aviation Psychology, 3(3), 203-220.

Kennedy, R., Lanham, D., Drexler, J., and Lilienthal, M. (1995). A method for certification that aftereffects of virtual reality exposures have dissipated: preliminary findings. In A. Bittner and P. Champney (Eds.), Advances in Industrial Ergonomics and Safety VII, (pp. 263-270). London: Taylor and Francis.

Kosslyn, S., Pick, H., and Fariello, G. (1974). Cognitive Maps in Children and Men. Child Development, 42, 707-716.

Kolasinski, E. (1995). Simulator sickness in virtual environments. U.S. Army Research Institute Technical Report 1027.

Kurdeck, L. (1978). Perspective-taking as the cognitive basis of children’s moral development: a review of the literature. Merrill-Palmer Quarterly, 24, 3-28.

Lampton, D., Knerr, B., Goldberg, S., Bliss, J., Moshell, J., and Blau, B. (1994). The virtual environment performance assessment battery (VEPAB): Development and evaluation. Presence, 3(2), 145-157.

Lampton, D., Kolasinski, E., Knerr, B., Bliss, J., Bailey, J., Witmer, B. (1994). Side effects and after effects of immersion in virtual environment. In Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting (pp. 1154-1157). Santa Monica, CA: Human Factors Society.

Liben, L. (1978). Perspective-taking skills in young children: seeing the world through rose-colored glasses. Developmental Psychology, 14, 87-92.

Long, M. (1961). Research in picture study: the reaction of grammar school pupils to geographical pictures. Geography, 46, 322-337.

Lynch, K. (1960). The Image of the City. Cambridge, MA: MIT Press.

MacEachren, A. (1980). Travel time as the basis of cognitive distance. The Professional Geographer, 32, 30-36.

Mackworth, N., and Bruner, J. (1970). How adults and children search and recognize pictures. Human Development, 13, 149-77.

Mahar, F., Henderson, R., and Deane, F. (1997). The effects of computer anxiety, state anxiety, and computer experience on users’ performance of computer based tasks. Person. Individ. Diff. 22(5), 683-692.

Mandler, J., and Robinson, C. (1978). Developmental Changes in Picture Recognition. Journal of Experimental Child Psychology, 16, 122-136.

Martin, D. (1996). Doing Psychology Experiments, 4th ed. Brooks/Cole Publishing Company.

Matthews, M. (1995). Young Children's Representations of the Environment: a comparison of techniques. In C. Spencer (Ed.), The Child's Environment, (pp. 103-120). Academic Press 1995.

McCauley, M., and Sharkey, T. (1991). Spatial orientation and dynamics in virtual reality systems: lessons from flight simulation. In Proceedings of the 35th Annual Meeting of the Human Factors Society (pp. 1348-1352). Santa Monica, CA: Human Factors Society.

McGreevy, M. (1993). The presence of field geologists in a Mars-like terrain. Presence, 1(4), 375-403.

McGreevy, M. (1994). Ethnographic Object-Oriented Analysis of Explorer Presence in a Volcanic Terrain Environment: Claims and Evidence (NAS 1.15:108823). Moffett Field, CA: National Aeronautics and Space Administration.

Merickel, M. (1991). A Study of the Relationship Between Perceived Realism and the Ability of Children to Create, Manipulate, and Utilize Mental Images in Solving Problems. Unpublished dissertation, Oregon State University.

Mon-Williams, M., Wann, J., and Rushton, S. (1993). Binocular vision in a virtual world: visual deficits following the wearing of a head-mounted display. Ophthalmic Physiol. Opt., 13(4), 387-391.

Nemire, K. (1995). Virtual Environment Science Laboratory (VESL™). VR in the Schools, 1(2), 9.

Newcombe, N. (1982). Sex-related differences in spatial ability: problems and gaps in current approaches. In Potegal, M. (ed.), Spatial Abilities: development and physiological foundations, (pp. 223-250).

Osberg, K. (1995). Virtual Reality and Education: where imagination and experience meet. VR in the Schools, 1(2), 1-3.

Osgood, R.K. and M.J. Wells. (1991). The effect of FOV size on performance of a simulated air-to-ground night attack. In Proceedings of Helmet Mounted Displays and Night Vision Goggles, (pp. 10-1-10-7). Pensacola, Florida.

Pantelidis, V. (1993). Virtual Reality in the Classroom. Educational Technology, 33(4), 23-27.

Pantelidis, V. (1994). Virtual Reality and the School Library / Information Skills Curriculum. North Carolina Libraries, 52(3/4), 114-116.

Pausch, R., Crea, T., and Conway, M. (1992). A literature survey for virtual environments: military flight simulator visual systems and simulator sickness. Presence, 1(3), 344-363.

Pelli, D. (1986). The visual requirements of mobility. In G. Woo (Ed.), Low vision: principles and applications. (pp. 134-145). New York: Springer-Verlag.

Piaget, J. (1970). Genetic Epistemology. New York: Columbia University Press.

Piaget, J. And Inhelder, B. (1956). The Child's Conception of Space. New York: Norton.

Piaget, J. And Inhelder, B. (1956). The Psychology of the Child. Basic Books.

Piantanida, T., Boman, Larimer, J., Gille, J. and Reed, C. (1992). Studies of the FOV/resolution tradeoff in virtual reality systems. In Proceedings of the SPIE - the International Society for Optical Engineering (pp. 448-56).

Pick, H., and Lockman, J. (1982). Development of spatial cognition in children. In J. Baird and A. Lutkas (Eds.), Mind, Child, Architecture (pp. 48-63). Hanover, NH: University Press of New England.

Postka, J., Davison, S., and Lewis, S. (1993). Exploring immersion in virtual space. Virtual Reality Systems, 1(2), 70-84.

Presson, C., and Hazelrigg, M. (1984). Building Spatial Representations Through Primary and Secondary Learning. Journal of Experimental Psychology: Learning, Memory and Cognition, 10, 716-222.

Reason, J., and Brand, J. (1975). Motion sickness. London: Academic Press.

Regan, E. (1995). Some evidence of adaptation to immersion in virtual reality. Displays, 16(3), 135-139.

Regan, E., and Price, K. (1994). The frequency of occurrence and severity of side-effects of immersion virtual reality. Aviation, Space, and Environmental Medicine, 65(6), 527-530.

Regian, J., and Shebliske, W. (1992). Virtual Reality: An Instructional Medium for Visual-Spatial Tasks. Journal of Communication, 42(4), 136-49.

Reinhart, W., Beaton, R., and Snyder, H. (1990). Comparison of depth cues for relative depth judgments. In Proceedings of the SPIE - The International Society for Optical Engineering vol. 1256, (pp. 12-21). Bellingham, WA: SPIE.

Rivlin, L., Rothenberg, M., Justa, F., Wallis, A., and Wheeler, F. (1974). Children's conceptions of open classrooms through use of scaled models. In D. Carson (Ed.), Man-Environment Interactions: Evaluations and Applications. Washington, D.C.: Environmental Design Research Association.

Rose, H. (1995). Assessing Learning in VR: Towards Developing a Paradigm Virtual Reality Roving Vehicles (VRRV) Project. Human Interface Technology Laboratory, Technical Report R-95-1.

Rose, H. (1996). Design and Construction of a Virtual Environment for Japanese Language Instruction. Unpublished masters thesis, University of Washington.

Sadella, E., Staplin, L., and Burroughs, W. (1979). Retrieval processes in distance cognition. Memory and Cognition, 7, 291-296.

Sanders, M., and McCormick, E. (1993). Human Factors in Engineering and Design, 7th ed. McGraw-Hill, Inc.

Satalich, G. (1995). Navigation and Wayfinding in Virtual Reality: Finding the Proper Tools and Cues to Enhance Navigational Awareness. Unpublished masters thesis, University of Washington.

Scholl, M. (1993). Cognitive Maps as Orienting Schemata. Cognition, 4, 615-628.

Sharit, J., and Czaja, S. (1994). Ageing, computer-based task performance, and stress: issues and challenges. Ergonomics, 37(4), 559-577.

Shaw, J. (1993, August). Virtual reality resource guide. AI Expert, p. 34-43.

Sheridan, T. (1996). Further musings on the psychophysics of presence. Presence, 5(2), 241- 246.

Siegal, A. (1977). Finding one’s way around the large-scale environment: the development of spatial representations. In H. McGurk (Ed.), Ecological Factors in Human Development. Amsterdam: North Holland.

Siegal, A. (1981). The externalization of cognitive maps by children and adults: in search of ways to ask better questions. In L. Liben, A. Patterson, N. Newcombe (Eds.), Spatial Representation and Behavior Across the Life Span: theory and application (pp. 167-194). Academic Press.

Siegel, A., Herman, J., Allen, G., and Kirasic, K. (1979). The development of cognitive maps of large- and small-scale spaces. Child Development, 50, 582-585.

Siegel, A., and White, S. (1975). The Development of Spatial Representation of Large-Scale Environments. In H.W. Reese (Ed.), Advances in Child Development and Behavior. New York: Academic Press.

Slater, M. and Usoh, M. (1993). Presence in immersive virtual environments. In 1993 IEEE Annual Virtual Reality International Symposium, (pp. 90-96). Piscataway, NJ: IEEE.

Snow, M. (1996). Charting Presence in Virtual Environments and Its Effects on Performance. Unpublished doctoral dissertation, Virginia Polytechnic and State University.

Snyder, H. (1988). Toward the determination of electronic display image quality. In Advances in Man-Machine Systems Research, 4 , (pp. 1-68). Greenwich, CN: JAI Press.

Spencer, C., and Darvizeh, C. (1995). The case for developing a cognitive environmental psychology that does not underestimate the abilities of young children. In C. Spencer (Ed.), The Child's Environment (pp. 15-25). Academic Press.

Steuer, J. (1992). Defining virtual reality: Dimensions determining telepresence. Journal of Communication, 42(4), 73-93.

Stevens, K. (1995). The perception of 3-dimensionality accross continuous surfaces. In Ellis, S., M. K. Kaiser, and A. J. Grunwald (Eds.), Pictorial communication in virtual and real environments (pp. 449-459). New York: Taylor & Francis

Strommen, E. (1993). Is it easier to hop or walk? Development issues in interface design. Human-Computer Interaction, 8(4), 337-352.

Taylor, W. (1997). Student Responses to their Immersion in a Virtual Environment. Presented at the Annual Meeting of the American Educational Research Association, Chicago.

Thomley, K., Kennedy, R., and Bittner, A. (1986). Development of postural equilibrium tests for examining environmental effects. Perceptual and Motor Skills, 63, 555-564.

Thorndyke, P. (1981). Distance estimation from cognitive maps. Cognitive Psychology, 13, 526-550.

Thorndyke, P., and Hayes-Roth, B. (1982). Differences in Spatial Knowledge from Maps and Navigation. Cognitive Psychology, 14, 560-589.

Urban, E. (1995). The Information Warrior. IEEE Spectrum, 32(11), 66-70.

Venturino, M., and Kunze, R. (1989) Spatial awareness with a helmet-mounted display. In Proceedings of the Human Factors Society 33rd Annual Meeting, (pp. 1388-1391). Santa Monica, CA: Human Factors Society.

Venturino, M., and Wells, M. (1990). Head movements as a function of field of view size on a helmet-mounted display. In Proceedings of the Human Factors Society 34th Annual Meeting, (pp. 1572-1576). Santa Monica, CA: Human Factors Society.

Vernon, M. (1976). Development of Perception of Form. In Hamilton, V., and Vernon, M. (eds.) The Development of Cognitive Processes, (pp. 133-189). Academic Press.

Wann, J., and Mon-Williams, M. What does virtual reality NEED?: human factors issues in the design of three-dimensional computer environments. International Journal of Human-Computer Studies, 44, 829-847.

Waldern, J. (1993). Virtual reality — the next generation. In Virtual Reality International 93. Proceedings of the Third Annual Conference on Virtual Reality, (pp. 87-100). London, UK: Meckler.

Webley, P. (1995). Sex differences in home range and cognitive maps in eight-year-old children. In C. Spencer (Ed.), The Child's Environment (pp. 163-172). Academic Press.

Wells, M., and Venturino, M. (1989). The effect of increasing task complexity on the field of view requirements for a visually coupled system. In Proceedings of the Human Factors Society 33rd Annual Meeting, (pp. 91-95). Santa Monica, CA: Human Factors Society.

Wells, M., Venturino, M., and Osgood, R. (1988). Using target replacement performance to measure spatial awareness in a helmet-mounted simulator. In Proceedings of the Human Factors Society 32nd Annual Meeting, (pp. 1429-1433). Santa Monica, CA: Human Factors Society.

Wells, M., Venturino, M., and Osgood, R. (1989). Effect of FOV size on performance at a simple simulated air-to-air mission. Helmet Mounted Displays, 1116,126-137.

Westerman, S., Davies, D., Glendon, A., Stammers, R., and Matthews, G. (1995). Age and cognitive ability as predictors of computerized information retrieval. Behavior & Information Technology, 14(5), 313-326.

Wickens, C. (1992). Engineering Psychology and Human Performance. Harper Collins.

Wilcox, B., and Teghtsoonian, M. (1971). The control of relative size by pictorial depth cues in children and adults. Journal of Experimental Child Psychology, 11, 413-429.

Winer, B., Brown, D., and Michels, K. (1991). Statistical Principles in Experimental Design. McGraw-Hill, Inc.

Winn, W. (1995). Virtual Reality Roving Van Project. T.H.E. Journal, 5 (12).

Winn, W., and Bricken, W. (1992). Designing Virtual Worlds for use in Mathematics Education, the example of experiential algebra. Educational Technology, 32(12), 12-19.

Yendovitskaya, T. (1971). Development of sensation and perception. In A. Zaporozheta and D. Elkonin (Eds.), The psychology of pre-school children. Cambridge, MA: MIT Press.

Zeltzer, D. (1992). Autonomy, interaction, and presence. Presence, 1(1), 127-132.

Zenyuh, J., Reising, J., Walchli, S., and Biers, D. (1988). A comparison of a stereoscopic 3- D display versus a 2-D display using advanced air-to-air format. In Proceedings of the Human Factors Society 32nd Annual Meeting, (pp. 53-57). Santa Monica, CA: Human Factors Society.

Zube, E., Pitt, D., and Evans, G. (1983). A lifespan developmental study of landscape assessment. Journal of Environmental Psychology, 3, 115-128.