2009

The role of image resolution to locomotion tasks in virtual desktop wayfinding

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The Role of Image Resolution to Locomotion Tasks in Virtual Desktop Wayfinding

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
Department of Secondary Education
College of Education
University of South Florida

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Date of Approval:
December 12, 2008

Keywords: Virtual Environment, Eye Tracking, Navigating

Dedication

This dissertation is dedicated to my great grandmother, Fanny Francis Martin. She never learned to read and quit the first grade when she was 16 to help plow the family farm with a set of mules. Her desire for her family to have more opportunities and her lifelong learning through keen observations and storytelling were profound influences on me to always better myself. I would also like to dedicate this dissertation to my mother and father Fanny Ruth Wilson and Robert Boston Wilson whose encouragement to not give up during some very difficult times has been significant.

Acknowledgements

I would like to thank Dr. Ann Barron my major professor for her continued support, encouragement and guidance through my degree program and research as a student at the University of South Florida. I would also like to thank Dr. Constance Hines for her guidance and support in the research design of this dissertation. Also, I would like to express my appreciation to Dr. Steve Downey for his guidance in virtual learning environments and Dr. James White for his support over the years in my program of study in Instructional Technology at the university.

Lastly, I would like to acknowledge two fellow Ph.D. students at the University of South Florida for their support. Chitra Subramaniam doctoral candidate, past coworker and one of my faculty when I was a department chair at a college. Her encouragement and support in my coursework and during the dissertation process was invaluable. Also, Dr. Denise Haunstetter one of my past faculty when I was a department chair at a college. Her encouragement and assistance during the data collection process and coursework was also invaluable.

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ABSTRACT

An experimental study at a large research university evaluated the role of image resolution on 60 participant's locomotion tasks in an interior virtual desktop wayfinding environment. Four virtual environments were developed using different resolutions for wayfinding images including high level 150 ppi, medium high level 100 ppi, medium level 75 and low level 30 ppi images. The environment was designed to accommodate forward, backward, sideways and figure 8 locomotion tasks as defined by the VEPAB. The effects of the different image resolutions on time-on-task performance scores to navigate through the environment, object-based visual attention as recorded by two eye movements - saccade and gaze fixation detections in viewing the images and the perceived usability of the computer system and virtual environment as measured by two post tests - the *System Usability Scale* and the *Virtual Environment Presence Questionnair*e were evaluated. Eye movement scores were collected with an eye tracking system that used the dark pupil method of eye analysis with a video lipstick camera. Results indicate that image resolution has a statistically ($p < .05$) significant effect on time-on-task performance wayfinding tasks and on object-based visual attention as indicated by gaze fixation scores. Participants fixated longer on lower resolution images, which affected their time-on-task performance. Resolution did not have a statistically significant effect on the perceived usability of the computer system or virtual environment.

Chapter One

Introduction

In their research, Chun and Wolfe (2001) posit that learners see what they attend to in the learning experience. A specific object is usually not seen unless the eyes focus on it. Frequently, the environment around us provides more visual information than we can take in and process at a specific time. We are only able to process the visual information that continually flows through the environment by focusing our vision on specific information that is important for a particular task. Understanding visual attention and how attention is triggered and sustained is significant to understanding subsequent actions and behaviors. Understanding content such as graphic images that are effective at triggering and sustaining visual attention is equally important because changes in this content may impact attention in general and the supporting actions and behaviors that follow.

The role of graphic images in attention is important to understand because images influence what the eye focuses on and may affect learning and learning choices for students. It is essential to consider the increasing role images play in learning since more image-intensive environments such as virtual worlds are increasingly developed for training, learning, and simulations. How images attract attention and what variables can occur in images may affect the overall performance and choice for learners in image intensive environments such as virtual worlds. Understanding variables in images such as compression and resolution is important so that as these environments evolve, learning outcomes and performance are not negatively influenced. Judicious selection of images also becomes increasingly important as visual material taxes a computer's and network's resources, necessitating compression of image resolution for efficient transmission, while attempting to maintain sufficient image resolution. The balance between what is appropriate and what is efficient image resolution and how this may affect attention and learning is important to understand.

Statement of the Problem

Most research studies in image resolution tend to focus on comparisons of still, print images (Taylor & Allenbach, 1998, Taylor, Pizlo & Allenbach, 1999), video images and video frame rates (Reddy, 1997). While these findings are important, there is limited research on the role of image resolution in more authentic desktop virtual learning environments or the role of image resolution in user preference and selection in wayfinding in these environments. In virtual environments, the learner is able to move past images and to make decisions in moving in the environment based on images. A better understanding of image resolution in virtual environments needs to be gained to evaluate how variables in images may impact the learner and to provide more information as to what is important in compressing virtual environments to make them more functional. Understanding what is important to compress, such as image resolution and how much compression can occur is important to developing better virtual learning environments.

Implications in Education and Learning Environments

The theoretical basis for this research lies in research on the Visual Attention Theory (Kyllingsbaek & Habekost, 1990) which identifies tasks that are inherent in selecting and focusing attention and user concentration. The theory allows for the study of visual stimuli that are relevant in any situation where actions are based on visual information from an environment. Eye tracking studies have often sought to determine learners' perceptions and responses (Dijkstra & Timmermans, 1997). Complex tasks such as wayfinding in virtual spaces involve users attending to a variety of visual clues that produce patterns of eye movements such as eye fixations, saccade movements, and the generation of the eye gaze pattern (known as optic flow). In turn, human behaviors such as locomotion are related to the positive generation of optic flow. Achieving optic flow is essential to engaging users in virtual desktop wayfinding as they move within the environment. Understanding how to enhance optic flow and better engage learners in wayfinding will enhance learner performance in virtual environments.

Visual attention is a key basis for understanding and designing more relevant and authentic virtual learning environments. Because the performance of many users in these environments may be influenced by limitations in the resolution of images, we need to understand the role of images on learners' attention and selection to be able to design optimal virtual learning environments that convey accurate representations of emulated spaces in the real world. Typically, image resolution research explores comparison studies of still images, medical imaging and video frame rates.

Purpose of the Study

The purposed of this study was to determine the effects of image resolution on locomotion tasks through an interior virtual desktop learning environment, to examine the role of image resolution on attention and optic flow in the user's physical eye movements and the perceived usefulness of the virtual environment as these relate to locomotion tasks. Providing information to understand these issues will help in the development of more efficient and useful interior virtual environments, a better understanding of how image resolution may affect performance, and considerations for appropriate resolution metrics in virtual environments. The research questions that were addressed in this study are stated below.

Research Questions:

R_1: Is there a significant difference in time-on-task performance in a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

R_2: Is there a significant difference on object-based visual attention in a desktop interior virtual wayfinding environment based upon individual eye tracker data as a function of the change in image resolution of 150, 100, 75 and 30 ppi?

$R_{3:}$ Is there a significant difference in the perception of the usability of a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

Hypotheses:

The following hypotheses were tested:

H_1: Changes in image resolutions of 150, 100, 75 and 30 ppi significantly affect user performance as measured by time-on-task in a desktop interior virtual wayfinding environment.

H_2: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect user visual attention as measured by the eye tracker data.

$H_{2.1}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by the saccade movements obtained by eye tracker data.

$H_{2.2}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by gaze fixation obtained by eye tracker data.

$H_{3:}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment.

$H_{3.1}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the system usability of the virtual environment as measured by scores obtained by the System Usability Scale (SUS©).

$H_{3.2}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment as measured by scores obtained by the Virtual Environment Presence Questionnaire (VEPQ).

Definition of Variables

Proper operationalization of variables was essential to the focus of the research study and appropriate control of variables was required to prevent biased results and findings. The dependent variables for this inquiry were aspects of participant's performance as measured by time-on-task scores, eye movements in terms of saccade and gaze fixation detections scores as measured by the eye tracker and participants' perception of the usefulness of the environment as measured by the SUS© and VEPQ.

The independent variable for this research was the image resolution used in the 3-D environment for the wayfinding tasks. This variable consisted of four levels (150 ppi, 100 ppi, 75 ppi and 30 ppi). Each treatment used for this study constituted to one level of this variable. These treatments are discussed more in-depth in the methodology portion of this research. Additionally, the literature review discusses concerns and limitations with past research approaches to image resolution. The image treatment groups for this research are defined as treatment Group 1 (IR^1) - environment with wayfinding images set to a resolution of 150 ppi, treatment Group 2 (IR^2) – environment with wayfinding images set to a resolution of 100 ppi, treatment Group 3 (IR^3) environment with wayfinding images set to a resolution of 75 ppi, and treatment Group 4 (IR^4) environment with wayfinding images set to a resolution of 30 ppi. Specifics of the images in each group and the selection and development process are discussed in-depth in the methodology portion of this text. Appendix E and Figure 1 also provide samples of images used in each treatment.

To prevent potential contamination of the findings and to minimize bias in the collection of participant data, several extraneous variables were minimized. These variables are discussed in the methodology section of this research and in the literature review to accommodate for individual differences in participants in the study and the potential impact that this might have upon the findings. These variables include participants' prior knowledge and individual differences in spatial ability, computer comfort level and ability, age and gender. Consideration for these extraneous variables was a critical step in the design of the study.

Definition of Terms

Definitions of the terms employed in the study are essential for providing clarity and focus to the concepts as well as a common ground for discussion. Some of these terms provide valuable background to the reader who may be unfamiliar with specific language that is used.

Desktop Interior Virtual Learning Environment is defined as a learning environment delivered via a computer system that emulates a real world interior floor plan space where learners are engaged in performing various tasks in an immersive manner for education.

Eye Tracking is defined as the collection and analysis of a learner's eye gaze data in a specific learning environment. These data are indicative of a user's specific gaze patterns and physical eye movement.

Fixation Detections (Gaze Fixations) are defined as the numeric data that are collected from eye tracking systems when the eye fixes attention to a specific object. These data include numeric scores for how many times the eye holds still as it looks at an area. This is recorded electronically through an eye tracking system. Fixation occurs as the result of saccade scanning.

Image is defined as a two-dimensional representation of a physical object with the same visual stimulus properties as the physical objects it represents (Jarmasz, 2001).

Image fidelity is defined as the degree of coherence between human visual mechanisms and the display of system images. It is the difference that is discernable between versions of an image.

Image Resolution is defined as the actual pixels or picture elements that an image is composed of. The more pixels in an image relates to a larger file size with more detail. An image's resolution can be altered by compressing it from the original state and size to a smaller file size, which has less detail.

Locomotion is defined as synchronized behaviors in response to surroundings and location, including the ability to move around in a virtual environment and avoid barriers and obstacles.

Navigation is the combined task of wayfinding and motion. It inherently must have both the cognitive element (wayfinding), and the motoric element (motion) (Darken & Peterson, 2001).

Optic flow (eye gaze pattern) is defined as the visual phenomena that are experienced as we move through the world. It is the visual information that a user takes in that moves upon the retina and is comprised of fixation and saccade patterns. Human behaviors and reactions to visual stimulation are related to the positive generation of optic flow.

PPI – pixels per inch is defined as pixel density or the number of pixels horizontally and vertically of a computer display.

Resolution is defined as the number of pixels or picture elements in an image. Image resolution plays a role in both the quality and the fidelity of images and is relationally proportional to file sizes of images.

Saccade Detection Scores are defined as the numeric data that are collected from eye tracking systems when the eye scans and rapidly takes in information prior to fixating upon a specific area. These data include numeric scores for how many times the eye moves back and forth as it scans an area.

3-D Desktop Wayfinding is defined as a virtual learning environment that requires the learner to attend to and engage in virtual navigation through a 3-D visual plane using visual tasks, stimuli and a computer input device.

Wayfinding is defined as the cognitive element of navigation. It does not involve movement of any kind but only the tactical and strategic parts that guide movement. Wayfinding and motion are intimately tied together in a complex negotiation that is navigation (Darken & Peterson, 2001).

Significance of the Study

It is important to develop a greater understanding of the role images have in learner choice and performance in desktop interior virtual wayfinding because more virtual worlds are being developed and used for learning. Complex environments are being developed that replicate authentic learning environments and further tax computer system resources even with technology advancements. The nature of complex environments dictates that decisions be made for compression of images to reduce the overall file size, improve system performance, and ensure efficient delivery of the content to the learner. Yet, there is not a standard metric or protocol for how much to compress and alter image resolutions in virtual environments nor what types of images should and should not be compressed. The goal of this research was to determine if image resolution plays a role in user choice and subsequently affects performance tasks such as wayfinding as measured by the time-on-task scores. A clearer understanding of the role of images and effective metrics for compressing images in virtual environments could be established with this additional knowledge. Gaining this information would be vital to designing better virtual learning environments as well as directing the decision making process of how to use and compress images within these types of environments.

Delimitations

There are limitations of the study that may affect the generalizability of the findings. The findings of this study are only generalizable to studies with similar sample populations, similar virtual environments, images and locomotion tasks related to virtual environment interior desktop wayfinding. Specific information on the limitations of the sample of participants, development of the virtual environment, images and the use of the eye tracking equipment are discussed further in the research.

Limitations include the population of participants who are culled from a population of undergraduate college of education students at a major research university in the southeastern United State. Participants also had the opportunity to earn five extra credit points from their instructors from the classes they volunteered from for their participation in the study. This and the sample from which volunteers came from may not be generalizable to other studies.

Limitations also include the physical constraints and expense of the eye tracking system used for part of the data analysis of the study. Because of this, the eye tracking equipment and supporting software was installed on a specific computer tower system that the researcher owned. Participants also used the same laptop computer for the virtual environment treatments. This computer interfaced with the eye tracking software on the supporting computer. Multiple computers were not used in this study.

Limitations at the time of the study with software and computer system hardware used to develop the virtual environments are also generalizability considerations. The virtual environment was developed in Autodesk 3D Studio Max™ and Unreal Tournament 2005™. Images for the environment were created in Adobe Illustrator CS2™ and Adobe PhotoShop CS2™. These were the current versions of the software available at the time the environment was created. The environment was installed and run on a Dell Vostro 1400™ laptop computer systems with an Intel Core2™ processor running Microsoft Windows Vista™. This was also the current computer and operating system at the time of the study. The virtual environment was delivered on the same laptop computer as discussed to each individual participant and not in a VRML web-based environment nor in a multi-player environment.

The design of the virtual environment used in this study replicates an authentic floor of an interior office building. This includes the corridors, offices, common areas, lobby and all supporting spaces of an entire interior floor plan of a building. Because of this, the focus and findings of this study may not transfer to a larger open virtual space such as Second Life™, a virtual world using complex terrain maps, a virtual war craft world, cave environment or to a smaller virtual environment such as a single room.

The focus of this research was on image resolution. Because of this sound was not a consideration of the design. Additionally, the environment concentrated on actual wayfinding and the elements needed for wayfinding and locomotion tasks as replicated from a real interior environment. This interior environment follows specific standards for development including the type of images used and the placement and location of the images. The resolution of the wayfinding images in each of the four treatment groups did not change as participants approached them. They were held consistent in each group as discussed later in this write-up.

Addressing additional virtual environments or exterior virtual environment elements was beyond the scope of this research. Based upon the research findings of this work, future studies could include a more comprehensive evaluation of images in desktop wayfinding with a broader population of participants, a larger virtual environment, and possibly an exterior and interior treatment.

Chapter Two

Review of the Literature

A review of related research and findings that reflect the focus and supporting elements of this research provided valuable data for design considerations. A literature analysis of known research findings also frame the study with a solid foundation of past research from which to build possible clues for additional investigations. This review of supporting literature is limited to the constraints of this study and includes concentrations on the topic of the visual attention theory, image resolution as it relates to vision, eye tracking research, and wayfinding in virtual environments. Some past research crosses several topics since the focus of visual attention and images is often related. The literature review helps to provide a framework of past research that supports and refines the study.

Visual Attention Theories

A discussion on the entirety of the theories of visual attention and the various physiological and psychological aspects of vision and attention are beyond the scope of this research. The majority of research on the subject of visual attention has not focused on virtual environments. However, investigations have probed the topic of visual attention for some time. It is important to include a general review of the research and history of the visual attention theory and the relationship to still images in this literature review to provide the necessary background for the research study. Although these studies primarily focus on still images, valuable insights can be gained from analyzing the past research that apply to this study. The evolution of the visual attention theory and emerging research underlies the need for better understandings of images and their use and impact in virtual learning environments.

Studies focusing on attention and visual patterns of eye movements have been examined for over a century. Theories of attention have developed as the need for understanding the role attention plays in performance and human learning has increased. Early studies were limited to simple observations of behaviors and influenced by researcher's viewpoints (James, 1890) of what participants were observing. As science and technology progressed, disciplines involved in examining visual attention expanded to include neuroscience, cognitive psychology, and computer science.

Overview of Visual Attention Theories

A variety of visual attention theories in applied science and human learning now exist. A closer examination tends to cluster these into categories that include research supporting perspectives of *where, what* and *how* visual attention is being focused, and feature and object-based perspectives of visual attention. The *where* viewpoint of visual attention focuses on the location subjects are orienting their visual focus. The *what* viewpoint of visual attention specifically focuses on the item or item group subjects are attending to. The *how* viewpoint focuses on specifics processes subjects use to attend to information in the visual plane. An overview of each of these categories is essential to understanding the role of visual attention in research. Feature-based and object-based theories of visual attention emerged from efforts to provide more comprehensive explanations of variances in earlier theories. These approaches to visual attention more closely match the research and support understanding visual attention in richer, more complex environments such as virtual environments.

The Where Viewpoint of Visual Attention

Several studies review dynamics of where human attention focuses in learning environments. Von Helmholtz's (1925) early work conducted in the 1860's examined attentional focus by recording observations of participants' visual tendencies to roam and wander to new objects in spatial locations. From his results, von Helmholtz concluded that attention was both purposeful and voluntary. While this research predates the ability to record eye movement in a discrete manner, these findings illustrate that visual attention can be consciously directed to objects, and that eye movement can reflect the will to inspect details of objects.

The What Viewpoint of Visual Attention

The most well known theory of visual attention that relates to what is attended to was proposed as the Spotlight Theory of Visual Attention (Posner, Snyder, & Davidson, 1980, Posner & Cohen, 1984). This theory suggests that attention mechanisms key the focus of attention to objects. Attention therefore, is similar to the effects of a spotlight illuminating a designated area. Posner believed visual attention was influenced by the context and orientation of what was being viewed, and not just the physical movement of the eyes. The Spotlight Theory supports Von Helmholtz' ideas that visual attention is a conscious inspection process of particular areas.

Other research approaches to visual attention have taken a serial perspective to define what a subject is attending to. James (1890) proposed some of the earliest ideas of visual attention related to learning. He defined attention as the identity of what was focused. James believed attention centered on objects in an active and voluntary manner. Oftentimes the perspectives of *what* and *where* attention are focused are matched together to provide a more comprehensive explanation of vision and attention. This blended approach to visual attention research has become the basis of computation models of visual attention.

The How Viewpoint of Visual Attention

How visual attention occurs was a key consideration of Gibson's (1941) research, which proposed that how a subject views information and the subsequent reactions and response to this information comprised visual attention. In this manner, subjects had advanced preparation after focusing on an object, and they could then decide whether to react or not. The *how* perspective of visual attention more thoroughly explains variances in human reactions to objects as results of individual attitudes towards what they are seeing and how they want to react. These variances were never fully explained by either the *what* or *where* perspective of visual attention. The added dimension of *how* visual attention occurs helped to explain many of the shortcomings of other theories of visual attention.

Feature Integration Theory of Visual Attention

The Feature Integration Theory (Triesman & Gelade, 1980) defines attention as a binder or "glue" that groups individual parts of images into an object viewed as a whole. Individual features group into something more meaningful to an observer. Specific properties such as color, size, distance, and so forth become aspects of a whole object that is visually processed. Visual searching for unique features is parallel as opposed to visual searching for features in conjunction, which is serial. Parallel processing allows for objects to be found more quickly regardless of distracters, while serial processing takes longer when more distracters are present (Chun & Wolfe, 2001).

Object-Based Visual Attention Theory

Object-Based Visual Attention emerged as more research evolved and limitations became apparent with explanations of previous theories; further, it supports and defines the Feature Integration Theory of visual attention. Perceptual grouping and organization in attention is serial. First, visual information is organized into groups, which are then selected by attentional mechanisms for further inspection. The relationship of attention and organizational grouping of objects is a dynamic and shared process. More information can be fed between the organized groups and the attentional mechanisms (Jarmasz, 2001).

The Object-Based Visual Attention Theory helped to clarify how attention occurs. Typically, visual processing is categorized into two phases, pre-attentive and attentive processing. Pre-attentive processing is a cursory examination of the visual field for information. It is a basic and quick analysis of the visual information that is present where attention can directly select objects that are then refined over time with more information. Object-based approaches to visual attention support these ideas that attentive processing occurs over regions of space, which more closely follows Posner's Spotlight Theory of Attention.

Object-Based Visual Attention, Feature Integration and the Spotlight Model of Visual Attention

Further research on visual attention underscores a debate between object-based factors, including Feature Integration, that influence attention and the Spotlight Theory of

Visual Attention originally proposed by Posner (Posner & Peterson, 1990). Object-based visual attention discusses elements of objects themselves and the visual grouping of elements that formulates pre-attentive processing. Chun and Wolf's (2001) review of visual attention research discusses the importance of the Spotlight Theory across large spatial contexts of similar size; however, it also indicates that there are limitations when applying Posner's theory to objects or areas with variances in size. Ericksen and fellow researchers, Ericksen and St. Eriksen and St. James (1986) and Ericksen and Yeh (1985), explored limitations of Posner's theory when it was applied to objects with different sizes. In one experiment, participants were presented images of letters around a circle that had either been cued or not cued prior to viewing. Participants were asked to identify if the letter "S" or the letter "C" appeared. Four different variables were manipulated during the experiment; presenting visual distracters, how far visual distracters were from the circle, how long it took for the letters to appear, and the number of positions that were available for letters in the image (size). Findings indicate that participant's reaction times were faster in identifying letters and less identification errors occurred in the small attention focus treatments. Participants made more errors when the attention focus treatment increased. What is interesting in regards to the proposed study, is that real world environments typically have objects that vary in size just as Ericksen et al., (1986 & 1985) demonstrated. Moreover, when the goal is to develop authentic learning environments, object having different sizes would naturally carry over into virtual environments. Such considerations, particularly in designing virtual environments, may in fact make the Spotlight Theory of Visual Attention irrelevant because the size of objects will vary in authentic virtual environments. Object size will also vary as learners move through a virtual space and their perspective and visual plane changes with their movement.

Support of Object-Based Visual Attention

Both the Feature Integration Theory and the Object-Based Theory of Visual Attention have tried to clarify the binding problem of object perception, which earlier theories did not fully explain. A key consideration for some time has been how individual elements such as features or parts of an object tie together so that they register as a whole in the visual system. This has been particularly challenging, given evidence that feature processing actually happens in a different location of the brain than visual processing (Fournier, Ediger & Nelson, 2004). Both of these theories of visual attention are based on the idea that attention integrates features in the same visual location into objects.

The concept of visual attention based upon grouped objects provides a more thorough explanation of how visual attention occurs. Several research studies support that visual attention is related to grouped objects. Kim and Cave (1999) identified the impact of visual selection and the relationship of this by perceptually grouping viewed objects. This research examined two experiments of spatial grouping involving 28 college participants. Participants received 32 trials in each of the two conditions. Participants were asked to search for one of four simple colored geometric shapes. Results demonstrated that location selection, directed by perceptual organization, happened in visual searching. In addition, groups of spatial locations could be selected at one time, even when distracters present. Egeth, Virzi, and Garbart (1984) also examined the role of features and the arrangement of features in objects. Participants looked for a defined target that was a red colored letter “a” placed alongside a red colored letter “n” and black letters. Even when the number of distracters varied in one group and did not in another group, participant searching remained constant. These findings indicate that searching could be limited to subsets of groups.

In another study that investigated object grouping, subjects viewed two overlapping figures, a box and a line drawn through it diagonally. Objects varied by size, white space on either side of them, texture, or line quality. Participants were to recognize two features at once and either report attributes from a solitary object in one condition or attributes from each object in a group, which was the other condition. Results demonstrated that participant identification was more accurate in the condition where attributes were located on single objects vs. participants trying to identify objects distributed on more than one object (Duncan, 1996).

In evaluating participant responses to elements of objects, Treisman and Garry (1980) presented subjects with words and frames. In some conditions, the words were separate from the frame and presented apart as distinctly different objects, and in other conditions, the word was placed inside the frame. The distinction between the edges of the frame was always consistent whether the word was placed inside or outside of the frame. Participants were required to read the word and asked to judge the location of the gap in the edge of the frame and the word. Findings showed performance increased when words were presented inside of the frames to form perceptual objects as opposed to a frame and words outside of it. Seemingly, from the studies reviewed, attention is triggered more by objects that are viewed as wholes and not as individual elements. While each of these studies clarified the role that formation of objects play in attention, additional research needs to be done in more complex environments that can further substantiate these findings.

Is it possible to track multiple objects? Pylyshyn and Storm (1988) examined whether the ability to track several objects and the ability to focus attention from one object to another in rapid sequence was possible. Twenty-four participants in the study tracked four separately moving objects and comparable elements in a display of moving objects. The form of the objects and the number of distracters presented were manipulated in the experiment. Findings show that participants found target changes faster than form changes, and both took longer to find when more distracters were present. However, participants were consistently able to successfully track four to five elements for ten seconds or longer. These findings indicate that it is possible to track multiple objects for periods of time and that further research needs to evaluate the role of distracters.

Recent inquiries as to why object-based attention may not fit into traditional theories of visual attention underscore important concepts that Gestalt principles may not apply to grouped or complex objects. Gestalt principles have been the basis of guidelines for perceptual organization for some time. However, the nature of Gestalt principles may not be applicable to grouped or complex images. Jarmasz (2001) argues that object-based attention is not pre-attended imagery as defined by Gestalt principles. Because of this, Gestalt approaches are inadequate when objects and grouped images are factors in visual attention. The assumption that perceptual organizational principles of objects always follow Gestalt principles may be one of the reasons that traditional theories of visual attention do not necessary fit or explain aspects of attention.

Early eye tracking studies with complex still images also indicate that Gestalt principles may not always apply. Findings indicated that limitations of using Gestalt principles in complex object searching occurred. Yarbus (1967) was one of the first researchers to examine eye tracking with complex images. His results demonstrated that eye movement occurred in sequential patterns and in specific areas of the image depending on the complexity or interest areas of the image to participants. Norton and Stark's (1971) work further supported Yarbus' earlier findings that Gestalt principles may have limitations when applied to complex images. These findings show that subjects tended to focus on fine points of visual information and areas of greatest interest to them. Perhaps the overriding concepts used in Gestalt theories are not appropriate for all environments and all types of visual information. Additional research needs to evaluate the applicability of Gestalt principles to complex objects. Perhaps these principles may not hold true in virtual environments and new principles will need to be considered.

Chun and Wolfe (2001) reviewed research and concluded that only one Gestalt principle concerning objects in motion (the concept of common fate) may apply to complex images. Another consideration is that Gestalt principles are applicable to still images that are not complex. However, these principles cannot necessarily be transferred to objects that are in motion. The majority of research on visual attention uses static images. This is a key limitation of experimental research because virtual environments are dynamic and rich in content. Again, additional research is needed to understand the role of objects and object-based visual attention in rich environments that are not static and to refine our understanding of object-based visual attention with more complex objects and dynamic environments.

Overview of Biomedical Support of Visual Attention

An overview of key research in the field of biomedical science related to visual attention and images is important to discuss in the context of this study as it relates to understanding the role of attention in visual objects and image fidelity. In addition, the research implemented data collected from human eye movements and responses within the applied treatment environments. A cursory review of research on the nature of vision and basic mechanics of the biological structure of the eye is important to understanding the role of vision and the eye's ability to view and process images.

Several researchers have discussed the biological makeup of the eye and the ability of the eye to collect and discern information. Salah, Alpaydm, and Akarum (2005) review the composition of the eye and in particular, the fovea in their research. The fovea is responsible for gathering high-resolution visual content. Conversely, the periphery eye gathers low-resolution visual content. The nature of the fovea is not fixed but changeable and focused. The low-level information taken in from the periphery eye signals the fovea to inspect the visual information for more data. Fovea movements provide data for *what* and *where* information is and what the eye is focusing on.

Foveal movements act as cues for visual information as they review content and center the fovea's focus. These fovea characteristics support aspects of *what* and *where* concepts of visual attention theories and the Spotlight Theory proposed by Posner. However, one of the limitations with this particular research is that the visual content used in the study was comprised of simple hand written numbers and the participants' ability at number recognition. Ten classes of numbers from one to nine were presented to participants in this research. The actual number images used for this study was neither large nor varied enough to demonstrate how fovea movements might occur in a larger area or in a more immersive environment like a virtual treatment. Salah et al. (2005) mention long-term research goals that include examining complex tasks like face recognition. While this research discusses the important mechanisms of the eye and how low level and high level information is processed in visual attention, the findings may be too limited to apply to larger or more complex environments. Additional research needs to examine the effects of fovea movement with more authentic images than the hand written numbers used in this research. More research using a larger environment is needed to better understand the impact of low and high level information on the fovea and fovea movements in regards to visual attention and how this is triggered.

Neuron firing rates also validate biomedical support of visual attention and support aspects of the Visual Attention Theory and content specific to this research initiative. Data collected from neural responses show that neural reactions are higher with visual content that is attended to than with visual content that is ignored (Roelfsema, Lamme & Spekreijse, 1998). One difficulty with research that focuses on visual attention and specifics of neuron firing rates is that graphic images typically used in these experiments tend to be simplistic and comprised of either a number, such as the content used by Salah et al., (2005), or presented on black backgrounds, such as the work of Pashler, Dobkins and Huang (2003). In the research of Pasher, Dobkins and Haung, participants searched for targets with varying levels of contrast in three experiments that used a black background. The target images contrasted from high to low, yet each of the targets remained a gray color. While this research supports that visual content that is attended to have higher neural reactions than content that is not, a deeper understanding of neural rates and attention with more complex images needs to be gained. The nature of the gray target images on black backgrounds limits the generalizability and potential of this research. It also underscores a need for additional research that examines more complex images in more varied and authentic environments and a keener understanding of any potential differences in neuron rates and their relationships to visual attention with more complex images types of images. While this dissertation research may not focus on neuron rates, a deeper understanding of complex and authentic images and their impact on visual attention is indicated.

Receptive fields of neurons also vary with the complexity of the stimulus viewed. Deco, Rolls and Seimens (2002) research demonstrated a difference in the receptive fields of neurons depending upon the complexity of a background scene viewed. Findings show that receptive fields were larger (65 degrees) with single stimulus upon blank backgrounds and decreased to 36.6 degrees when stimulus were in complex, more natural scenes. Receptors that send stimulus to the brain have a larger visual field when the image is simple. This field decreases when images become more complex or are in more complex backgrounds. This is important to understanding visual attention and again focuses on the fact that more research needs to examine the impact of complex images and complex backgrounds on the human brain and the impact on visual attention.

Research on physiological symptoms also supports visual attention theories and that physical reactions occur during image processing and attention in the human brain. Roland (1985) conducted research experiments with subjects that examined blood flow in the brain. In one study, participants were asked to imagine themselves walking on a familiar route from the outside of their front door. During this particular experiment, activation of the superior parietal lobe occurred on both sides, indicating increased blood flow. While many areas of the brain were active during this phase of the experiment, the superior parietal lobe is unique to imaging and image processing in the brain. By focusing their attention and creating a mental image of walking in a familiar environment, participant blood flow to the brain increased. The neural systems involved, which triggered attention and visualizing an outside location, matched those systems of actually viewing a visual object. More research needs to be conducted to understand physiological responses of the brain to attention and to creating mental images.

A comprehensive review of biomedical research that supports visual attention theories is beyond the scope of this research. However, the potential for validating and refining research of visual attention studies using physiological reactions of the brain can be expanded by additional studies and by using supporting equipment that can validate physical movements of the eyes and supporting brain activities. Additional information may provide data to reinforce our understanding of neural responses to focusing on objects and the relationship of attention. These research studies also support the need for more quantifiable measures to record reactions to visual stimuli, which are the focus of this research and the supporting use of an eye tracking system to measure participants' eye responses.

Image Resolution Research in Non-Virtual Environments

A thorough examination of all literature related to image resolutions and image fidelity is not possible within the confines of this research and may not pertain to the unique aspects of images in virtual environments. An overview of images in relation to human learning would be an entire study in itself. However, a review of image studies relative to the research that examine resolution in different types of media should be reviewed prior to examining the limited research that exists with image resolution in virtual environments. A note should clarify key terminology including image fidelity, quality and image resolution and to reinforce the scope of this study. In the definition of terms, visual fidelity is the degree of coherence between human visual mechanisms and the display of images within an environment that the eye is viewing. Image fidelity is the ability to discriminate between an original version of an image or object and a degraded version of the image or object. Image quality relates to the different image resolutions of an image that can occur through compression algorithms used in an effort to reduce an image's file size.

Current studies with image resolution often focus on applications of images in the medical field. Image resolution is of particular interest to doctors and technicians as diagnoses are often directly related to the different types of medical images obtained from equipment and various procedures. As technology has progressed, the ability to electronically transmit these images to a broader range of experts as well as long term ability to archive images by compression have been considerations for research in image resolution and compression. Two studies are important to note as they provide context for image resolution studies that are applicable to this research. Peterson & Wolffsohn (2005) used different types of eye images with various resolutions in research with 20 ophthalmologists. The range of image resolution for the study was images with 2048x1360 pixels, 1280 x 811 pixels and 760 x 569 pixels. All of the images for the study were taken with a digital camera and displayed on a 15" computer monitor at 1280 x 1024 pixels. Participants were asked to rank the images. Findings indicate that the image quality was identified as reduced when the resolution went lower than 767 x 569 ($p<0.005$) or if the image was compressed from a .tiff image to a BMP. Vidmar, Cruess, Hsieh, Dolecek, Pak, Hon, Maggio, Montemorano, Powers, Richards, Sperling, Wong, Yeager (1999) evaluated 180 images of clinical cases divided into sets by eight dermatologists. Three different resolution types were used for three different groups of images of skin categories. Images were randomized into sets of 60 with participants given 60 seconds to diagnose the image and rate their level of confidence. Findings indicated a significant affect among one image group among high resolutions vs. low to medium resolutions. What is important to note from this first research is that the resolution range among the images was broad (three levels – high, mid, low) and that all images were viewed with the same computer system constraints. In addition, participants were able to detect a difference when an image was compressed from the original file type to a compressed file type (Tiff to BMP). An important consideration for the proposed research is controlling the computer system used to view images for consistency, remaining consistent in the delivery of the final image file type and the need to have a range of resolutions to effectively evaluate the effect of resolution and to help establish metrics. The research study illuminates that there may be significance among responses to different image groups also the fact that three ranges of image resolutions; high, mid, low are effective at evaluating different responses to images.

Weigel (1996) noted in his research that the ability to zoom was affected by resolution and the resampling of data, and that this had a direct bearing on learning and limitations of learning. At the particular time of Weigel's research (in the mid to late 1990's), resolution and resampling were under closer inspection because of the affect on users' ability to determine patterns and representations in what they were viewing with GIS systems. Weigel's study built upon the earlier work of Turner, O'Neill, Gardner, and Milne (1989) who investigated the effects of changing spatial scale on the analysis of patterns. This work utilized satellite images of landscape data at various scale increments as a test measure for pattern analysis. Image clarity proved to be a limitation with zooming and scale in large map types that were used for this study. The research indicates that differences in resolution can impact users. This dissertation focuses on an interior virtual space and not large-scale satellite images nor GIS maps. However, the ability to change scale or zoom closer to an object is available to participants because of the nature of locomotion in a virtual environment and the fact that users can move as close to an object or as far away as the design of the specific environment will allow. Only through further research can the effects of resolution on participant's ability to analyze be understood. Particularly, since virtual environment allows user more movement control and subsequently greater ability to inspecting images at any resolution.

Similarly, Kolaczyk and Dixon (2000) built upon earlier studies and replicated the work of Turner et al. Conclusions in their findings indicate that two versions of an image may reflect different results if they the images use different resolutions. Seemingly, the resolution of the image has a direct bearing on users' perceptions. This was particularly so in relationship to studying scalability and pattern analysis. This study further supports the need for additional research and an increased understanding of the role differences in image resolution may play not only in user perception but also in performance. This work only used two variations of resolution and again focused as previous work done on pattern analysis. It is important to understand more subtle variations in image resolutions and to evaluate a broader range of differences to make effective choices in what is an acceptable resolution range for compressing images used in learning environments.

Macklem (2003) conducted research on image fidelity in his *ImageStat* experiment. Participants were exposed to 21 different images on a computer and allowed to alter each image with the *ImageStat* interface until they were able to tell a difference between the original image and a compressed version of the image. The ability to compare a compressed version of an image to an original version allowed participants to determine the point where they no longer looked similar. Findings indicate that 15 of the 21 images used in the study had less than 20 points difference between the subjects. The overall adjusted point range reported among the participants for the majority of images was small. Seemingly, what is considered a visually acceptable resolution of an image does not vary considerably among participants. This is important to note as it applies to the research and supports that although differences may occur in individual participant's spatial abilities, preferences among participants' acceptable image resolution does not vary considerably.

Silverstein and Farrell (1996) conducted research on the relationship of image fidelity to image resolution to examine the ability to discriminate one image from another (fidelity) and the preference of one image over another (resolution). This research involved 17 participants given 25 cards from three decks of cards randomly picked from a computer. Participants were to rank the order of the cards in one experiment. Participants where then exposed to textured and non-textured swatches in the other experiment. Findings indicate only a moderate correlation between participant's evaluation of image fidelity and image quality. However, the applicability of these findings because of the image content used may not relate to a virtual environment nor to different types of images.

Research conducted by Carter, Chalmers and Ward (2003) implemented a single still image of teapots in a computer-generated office graphic. Three different resolutions of the image were developed; a high version at 3072 x 3072, a low version at 1024 x 1024, and a monitor level version, which used the default computer monitor screen resolution. Findings indicate that participants did not report any difference between the high and low-resolution images. There are some considerations and shortcomings to this particular study. The results are difficult to generalize to any other type of environment, as the presence of numerous teapots in an office environment does not necessarily replicate an authentic environment. The range of resolution from high to low image in this study is also large. The question arises as to what might be the results if there was more variety in the resolution range among several levels of images and how this might affect participants. Additional research needs to evaluate the role of authentic uses of images and what is a suitable range of image resolution.

Knoche, McCarthy and Sasse (2005) investigated the effects of variances in mobile TV images. A portion of the research centered on image resolution differences with four different groups of 32 participants. Sixteen video clips from four categories of the most commonly watched media were used in the study; including videos, sports, and music and animation videos. Participants were presented four clips from each category with image resolutions of 240 x 180 pixels, 208 x 156 pixels, 168 x 126 pixels and 120 x 90 pixels. All of the clips were held to a constant length of 2.20 minutes and presented on iPacs. Findings indicate that acceptable images were lower for smaller images and that the highest variability between what was acceptable included clips with degraded text and facial images (such as news clips). Animation clips reported the least amount of variances in what was acceptable. This research relates to this dissertation in that the range of resolution images used (four levels) and the content of the images affected the acceptability of users' resolution differences. Obviously, images of news videos that show text and head shots of news anchors are not going to be as acceptable as images of animations that are composed of containers of consistent color.

Image Resolution and Fidelity in Virtual Environments

Literature related to different image resolution treatments using the same virtual environment background is limited and illuminates the fact that additional research on images in these types of learning environments is needed to understand if there is any applicability of past resolution studies with other types of media to virtual environments. Several current and ongoing research projects conducted at the Max Plank Institute for Biological Cybernetics focus on the growing need to understand the role of images and image fidelity to virtual environment development. Mania, Bulthoff, Cunningham, Adelstein, Thalmann, Mourkoussis, Troscianko and Swan (2005) displayed a tutorial for the use in the development of fidelity metrics between rendered and virtual environments at the *2005 IEEE Virtual Reality Conference*. The tutorial and subsequent research are early step towards psychophysical investigations into the role of image resolution and fidelity in Virtual Environment (VE) simulations with system limitations. A correct matching of system display to human sensory and motor skills is vital to improving VE environments and human performance in these environments. Only through additional research that focuses on factors that may affect VE performance such as image resolution can adjustments be made to improve the virtual environment experience and subsequent learning.

O'Sullivan, Howlett, McDonnell, Ann, and O'Connor (2001) reviewed the importance of perceptually adaptive graphics and the need for understanding visual images within virtual environments in their analysis of research in the *State of the Art Report* at the *2004 Eurographics Conference*. Various approaches to using images in perceptual functions have been studied. This report concluded that the majority of experiments were not conducted in authentic learning environments. The problem with many visually rich images is that there is no clear understanding as to whether more photorealistic images or richer images represent reality in a faithful manner. Larger concerns include determining the best techniques to compress images to increase speed in virtual environments, without having profound effects on the capacity of the user to fully understand and discern what the image represents. These findings are important to not only this dissertation research but because of the fact that a greater understanding needs to be applied to developing virtual environments that balance visually rich images with useful images and that replicate authentic uses of images and not just fanciful nor gratuitous applications that do not have purpose to learning. Also, VE's need to be developed that replicate the use of authentic images in learning. Again, there is a need to have a better understanding and to be able to identify what are the best techniques to compress useful images so that the images are purposeful to the learners in a virtual environment.

Research to identify suitable methods of image simplification were examined by Watson, Friedman and McGaffey (2001). Their study identified which type of image simplification was more effective. Thirty-six man-made or natural 3-D models were used for this study. The models were compressed from their original state to reduce the level of detail 50% or 80%. Three criteria for evaluating participants' interaction with the models were used; types of models, the time it took to name the model and the choice preferences of the objects. Findings indicated that participants took longer to name natural objects and that objects that were 80% to 100% of the original detail were preferred over objects with 30% of the original detail. This study is important as it discusses the struggle in identifying and establishing suitable levels of image simplification. While this was applied to 3-D forms, there may be relevance of these findings with flat images as well as 3-D forms in virtual worlds. A key consideration of this research is the different response of manmade vs. natural objects as well as the preference of 3-D objects with higher levels of details over 3-D objects with lower levels of details. Obviously, levels of detail are important in 3-D images, but considerations for how this applies to images with different resolutions in virtual environments and 3-D need to be understood.

Thompson, Willemsen, Gooch, Creem-Regehr, Loomis, and Beall (2004) investigated whether image resolution had an effect on distance perception and estimation in virtual environments. Forty-eight participants in this study performed a triangulation-walking task for distance judging, using three rendered virtual environments and three real-world environments. Three variations in rendering were used in the virtual environments including high resolution (360 hi resolution images), low resolution texture mapped images, and wire frame images. The performance measure for this study was for participants to compare the distance while standing in a building lobby of a disc placed on the ground for either the different virtual or real world treatments. Findings reported that image resolution did not play a role in distance estimation. However, this research compared a real world to a virtual world with a level of detail that is neither attainable nor authentic to a real world. The inclusion of a wire frame treatment in the virtual world is neither natural nor typical of a natural environment. Also, a mid range level of resolution included in the study might have helped with the generalizability. What is useful to note is that distance estimation does not appear to be hindered in a VE.

Waller, Knapp and Hunt (2001) conducted similar research with 24 participants in three different versions of a room maze, including a wire frame treatment, a rendered treatment and real-world treatment. The focus of this research was on size estimation and pointing tasks. Results found a small amount of difference in the wire frame treatment results over the rendered treatment results. Overall results focused more on individual differences of gender in the performance tasks. Again, the rationale for inclusion of a wire frame treatment alongside a rendered treatment and a real world treatment was not clearly defined. This approach represents extreme variances in rendered treatments and an authentic real world with limited generalizability. Inclusion of a wire frame treatment does not support the need to replicate virtual environments authentically as wire frame treatments do not occur in the real world or in wayfinding. Further considerations of Thompson et al., (2004) research with image resolution and distance perception in a virtual environment and Waller et al., (2001) research with image types on size estimation and pointing tasks should be noted. In both studies, only two levels of image resolution or rendering were analyzed (that of a high level and low level, or a wire frame) and these were compared to a real world. A deeper understanding needs to be gained with more subtle variances in image resolutions that are used similarly and not compared from a virtual world to the real world to effectively evaluate any differences that may occur and why.

Overview of Quality Measures of Image Resolution

The questions arise as to how to identify quality measures to assess image resolution and identify the optimal metrics for measuring and compressing the resolution of images. Effectively establishing methods for rating image quality and resolution has been a consideration for some time with images in virtual environments. Different approaches have attempted to predict the difference in images comparatively and with compressed images and non-compressed images. Niralljan and Ralph (1999) researched fidelity metrics of image compression. Better designs for measures of quality with the human visual system have been a key reflection. One of the methods for quantifying image quality that has been applied is the mean squared error method. This method calculates the deviation from the original image to the distorted image pixel regions. However, there is little correlation with this metric and human evaluation of the images that were compressed using it.

Niralljan and Ralph conducted two experiments of images in a database using the Picture Distortion Method to alter images. Participants viewed 50 high-resolution images in one of the experiments and 75 images with varying resolutions in the second experiment. Findings indicated that the Picture Distortion Method works well on high-resolution images, but not necessarily on low-resolution images nor in natural environments that are complex. The nature of virtual environments is oftentimes complex and many times includes natural elements or an entirely natural replication of an environment. Image resolution may vary considerably among elements in VE's in efforts to compress images to reduce file sizes. The application of this method may not work with virtual environments nor be useful to establishing an accepted metric across all image resolutions that can be used.

Longhurst and Chalmers (2004) conducted research to evaluate the validity of assessment algorithms. The Visual Difference Predictor metric, or Daly Model of altering images, was used to evaluate four different types of matched pairs of images. Images included an exterior image, a natural image of a flower, a 3-D modeled image of cubes, and an image of faces. Participants reviewed two treatments of each image. Participants were asked to draw on top of the images to show the areas that they felt had been altered. An interesting note is that only parts of each of the images were altered by using compression and layering with Adobe Photoshop™. The question arises as to the validity of only altering parts of an image, or again, the applicability of this in a virtual environment that allows a user to be immersed in many images. The population of eight participants used for the study also represents a small sample size and may not be generalizable to other research.

Lossy compression allows for compression of images from the original state to minimize file size and lag time caused by regenerating images in virtual worlds as the worlds are moved through. This type of compression is identified as rate/distortion tradeoff. The JPEG file compression algorithm is perhaps one of the most popular lossy file formats and is used extensively to create map materials and to create more authentic texture replications used in rendering and modeling of 3-D models in virtual environments. As discussed, several different compression metrics have been implemented to try to reduce file sizes while maintaining image clarity and establishing a metric base line. Still, there is no one specific approach that has been accepted as a standard metric that can be applied to the different types of model forms and images in virtual environments. The methodology portion of this dissertation research further discusses the metric for this research, which is based upon the JPEG compression standard.

Understanding Eye Movements and Eye Tracking Research

In many ways, eye tracking and the ability to quantify and scientifically gather information on eye movements and to evaluate what is visually attended to is relatively new. Major advances in the development of hardware and specific software have occurred in eye tracking systems during the past 15 years. Eye tracking used in applied research has been a relatively new development because of the tremendous cost factors of systems and the availability of equipment. By recording movements and actually synthesizing what the human eye attends to and moves towards in images, particularly those used in learning environments, we better can understand the role that images may play.

Eye tracking information is composed of measurements that calculate and record the manner in which the eye reacts to visual stimuli. These measures have become more sophisticated and accurate, as technology has progressed. Two major types of eye movements are typically collected and analyzed during eye tracking research. Other more subtle types of eye movements do exist as reviewed in Rayner's (1998) metanalysis; however, these are often difficult to track. Visual stimuli such as images produce stages in eye movement. When the eye gaze is held constant at a stationary point, eye fixation occurs; this is when the eye fixates on something that specifically captures attention to further examine it. This is referred to as “eye fixation”. Movement between fixation points is termed “saccade movements”. Saccade movements tend to be rapid scanning processes where the eye evaluates surrounding information prior to fixating upon content that focuses the attention. The velocity of these saccade movements can be as high as 500 degrees per second. Saccade movements can rise and drop considerably until the target destination is fixated on. Evaluating what the human eye is attending to and how it reacts to images may provide important details to promoting human learning and enhancing the environments and choices we make in creating learning environments. The ability to cost effectively measure eye movements may provide invaluable data that can support research efforts in designing better and more effective learning environments. More research is needed to understand if thinking and cognitive processes are suspended during the saccade phase of eye movement or not (Van Duren & Sanders, 1995). Additional research on saccade movements and fixations of the eye can provide quantifiable data so that what the eye is attending to and how visual attention is stimulated and achieved can accurately be evaluated.

Complex tasks involve learners’ attending to a variety of visual clues that produce patterns of eye fixations and saccade movements. These patterns of movement, as visual information is scanned and then fixed upon, make up the eye gaze pattern that is commonly referred to as the optic flow of information. Human behaviors such as movement, walking and other physical reactions to visual stimulation, are related to the positive generation of optic flow. Optic flow is essential to actively engage learners in virtual environments because the visual stimulus that is taken in by the eyes is then transferred to behaviors in the VE environment including locomotion and movement. An example of optic flow would include how an image of a sign may initially appear in front of a viewer when they first see it and then appear to move off to one side of their vision as they walk past the sign.

The relationship of attention to eye movement and eye tracking is an area that still needs additional research. Hoffman & Subramaniam's (1995) work supports the theory that attention may precede saccade movements directed to a specific place. Findings in two different experiments showed that participants cannot move their eyes to a specific place while attending to a different one. Further, research conducted by Kowler, Anderson, Dosher and Blaszer (1995) suggested that attentional movements and saccade movements are coupled. In complex tasks, which involve information processing of visual information, attentional movements and saccade movements are linked together. This coupling of attention and eye movements are more related in complex tasks (Duebel & Schneider, 1996) that involve greater focusing and processing. The relationship of saccade movement to attentional mechanisms and the relationship of eye movements coupled to attention provide additional support for the study of eye movement in research.

The ability to evaluate eye movements and the relationship of these movements to attention and what is triggering attention may provide critical information and help establish metrics for acceptable use. In order to develop more efficient learning environments, a better understanding needs to occur of how attention is gained and what types of stimuli are most effective at focusing attention. Supporting data such as eye movements can help in establishing appropriate metrics for image compression and ensure acceptable levels of performance are maintained with design considerations in using images.

A review of key research on human eye movements is essential to understanding the need for using eye tracking in applied research. Human eye movement in relationship to still images such as pictures, photographs, and paintings has been evaluated with varying degrees of sophistication and success for some time. Some of the earliest research conducted with eye tracking, although primitive at the time, provided input to support aspects of visual attention theories and human learning. Javal (1878) used mirrors to view eye movements of participants from behind while they read. He identified that the eye moved in small rapid jerking movements.

Buswell (1935) analyzed the eye movements of 200 participants while they examined complex scenes. Participant's eye movements were evaluated while they viewed images of interior design, art patterns, and architecture. The focus of this research was the evaluation of what participants did when they viewed images of complex content. His results found that participants typically exhibited one of two types of eye movement behavior. One type of eye movement behavior that was indentified involved general surveys of the images with long pauses over details, and the other type of eye movement behavior involved long pauses of fixations over small areas. While this research predates the ability to actively record eye movements, the findings support later research that was able to term and analyze saccade movements and fixation of the eyes.

Yarbus (1967) is well known for his early research with eye tracking methods. He conducted studies of eye scan paths using still images. To evaluate eye movement, he used a small valve under a contact lens device that acted as a cap and affixed to participants' eyes. Fluid was removed to create suction and to evaluate eye movement. Mirrors attached to the caps and projected beams of light allowed him to track participant's eye movements over pictures. These early eye tracking results found that the order of progression of what participants attended to was task dependent. Viewers looked at an image differently depending on what they were told to search. In this research, participants changed eye movement patterns based upon changes in the verbal directions given to them. Besides the primitive nature of the equipment used at the time to evaluate eye movements, the fact that verbal directions given to participants affected the patterns of eye movements should be noted. Questions arise as to what impact not having verbal cues and using more sophisticated modern equipment might have on evaluating eye movements as in the proposed research.

The technical progression of eye tracking systems has been phenomenal the past 15 years. Eye tracking systems were traditionally costly and cumbersome, which negated the ability to use eye tracking data for many research studies. Early attempts to measure eye movements such as Yarbus's (1967) work seem primitive and possibly harmful to participant's eyes by today's standards. Currently wide variety of systems is available for tracking and collecting eye movement information. Systems now include remote cameras and frame grabber cards mounted into computer systems that can accurately record eye movements without being invasive to participants. These systems can be placed in areas with minimal intrusion to the natural habitats of users. Other types of eye tracking systems available use scleral coil methods, which use bundles of wire pressed near the eye with goggles or a head mounted framework to make contact with users. Dual purkinje eye tracking systems also utilize and implement an infrared LED to monitor eye movements. Some types of systems are effective with handicapped individuals who use eye movements to control equipment when they have limited mobility. Total eye tracking packages often include specialized video cameras, head stabilizing systems, and specialized software and hardware components for installation into computers. Data can be tracked in read real time from a participant, recorded and analyzed simultaneously.

Rayner's (1998) metanalysis recaps the evolution of eye tracking through three historic phases of eye movement research. Initial observations recorded in the early 1900s involved simple observations of human eye movement. Later studies focused on observed eye movement for specific studies, including tasks of reading. However, the ability to study eye tracking in imagery was not a reality until the advent of the computer, sophisticated software, and hardware systems, which allow eye data to be gathered and calculated.

Several research studies that have used eye tracking as part of their methodology are important to note as they relate to considerations for this dissertation study. Duchowski, Shivashankaraiiah, Rawls, Gramopadhye, Melloy, and Kanki (2000) utilized immersive eye tracking in a VR environment that replicated authentic aircraft inspection and maintenance simulation. Their research was developed to support efforts to improve inspection and maintenance performance in aircraft training by using virtual environment training. Duchowski, Medlin, Gramopadhye, Melloyt, Cournia and Nairt (2002) also conducted research to evaluate eye movements and to assist with inspection of training for aircraft maintenance. The virtual environment developed in their study replicated textures and mirrored the authentic environment to enhance specifications necessary for successful inspection and maintenance training. Both studies sought to replicate authentic training environments and to use eye tracking systems to evaluate participant performance in the virtual environments, with implications to the real world. Neither of these studies tried to exclusively use eye tracking nor to exclusively evaluate eye movement. However, the effective use of eye tracking to validate research design considerations and supplement data was critical to both of these studies and to the proposed research.

Dijksta and Timmermans (1996) evaluated user behavior in virtual environments with eye tracking to develop a conjoint analysis virtual reality system, VR-DIS. This research discussed the fact that eye-tracking techniques used in the field of architecture have not been explored enough, and that many studies with eye tracking systems are simplistic task studies specific to reading or evaluating discrete parts of images (Dijksta & Timmermans, 1997). This reinforces the fact that more applied research is needed in more authentic environments that replicate real learning spaces and that studying the reaction of users to simple and oftentimes unauthentic images has little value to improving the understanding for better design considerations for creating learning environments. The value of using eye tracking data as a supplementary research tool needs to be explored in environments that are more complex.

Weber (1996) implemented computer controlled video equipment to study the human eye with dimensional architectural models. This research captured how eye movements happened relative to buildings and architectural spaces, and evaluated what architectural elements triggered attention of the eye and eye movements. Findings indicate that individual stimuli were not a determining factor of the forms observed by participants. This study has not been replicated in a virtual treatment where the learner has the ability to navigate around forms and through space. This findings need to be further explored in a VE treatment to evaluate if they are consistent.

Howlette, Lee and O'Sullivan (2004) conducted research with eye tracking systems to examine the salient features that participants focused on. This research is important because it evaluated the visual fidelity of dimensional models to investigate if additional simplification of the models would affect user choice or tasks. Interestingly, these findings report that low-level natural objects had an increased measure of visual fidelity as opposed to manmade objects. The reasoning given was that manmade models are more related to tasks. However, many specific tasks, including interior wayfinding, do not typically include a blend of natural and manmade items within the same environment. Perhaps these findings would not be valid in environments that are either purely manmade or purely natural.

Oertel, Hein and Elsner (2005) conducted research using eye tracking to analyze where eye movement and eye fixation patterns were occurring for users while shopping in online stores. Eye tracking systems are used increasingly for usability testing and in market analysis to understand what potential buyers are focusing upon and the relationship of this to buying trends and effective marketing and design layouts. User interfaces can now be evaluated quantifiably with eye movement data and tracked with the actual purchase of products to analyze the most effective ways that images are used. Data from eye tracking in usability studies is helping to shape metrics for design use. Eye tracking can effectively help in the evaluation of images and designs for online products and in establishing and validating protocols for their use.

Another study conducted by Babcock, Lipps and Pelz (2002) implemented a wearable eye tracking system. The eye tracking system evaluated eye movements of photographers while they shot and electronically edited images from three diverse subject classifications including interior spaces, people, and sculpture. The results showed that there was no significant difference between the treatment groups and the editing time of images between the three different classes. However, the amount of time spent looking at the primary object in the interior classification was 40% longer than in any of the other classifications. This increase in time was associated with the rich surrounding imagery typically in an interior space, as opposed to viewing a person or sculptural object. Again, a better understanding is needed for how and why images that are more visually rich may impact performance and learning, since the task time (electronic editing of the images) showed no significant difference in this study. With many virtual environments using rich complex images, oftentimes without purpose or known value, understanding human responses to environments with rich surrounding images and why responses occur may help in guiding effective protocols for using images in visually rich learning environments.

Hayhoe, Ballard, Triesch, Shinoda, Aivar, and Sullivan, (2002) conducted research using eye tracking to examine natural behavior in virtual environments. The focus of their work sought to examine visual operations embedded in natural tasks. This research used a virtual driving simulator in a virtual environment, *Performer Town*. Road signs were placed in the environment at intersections. Results show that eye fixations on sign images in the virtual driving environment was affected by the task and the location of the sign. Signage used in interior or exterior space must follow known acceptable rules or laws of placement. Tasks may vary; however, oftentimes tasks relative to signage are predetermined because of the fact that signage acts as directional landmarks for wayfinding. The question arises not in the placement or use of signage images for tasks, but in what may happen when the image of the sign is altered. Since any image in a virtual environment can be scrutinized for possible compression in attempts to reduce file size, understanding image resolution of signage and how this may affect task performance is important.

More research is now being conducted utilizing eye tracking systems to supplement studies. Without the major technological advances that have allowed for more cost effective, portable, and non-invasive systems, this research would not be possible. The ability to supplement the proposed research with quantifiable results gathered from participants' eye movements will provide additional clarification on the role of visual attention and images within a virtual wayfinding treatment and help in establishing guidelines for the effective compression and use of these images.

Wayfinding in Virtual Environments

A thorough review of all literature related to wayfinding is not possible within the confines of this research. Most research studies focus on wayfinding in the actual world and not specifically to virtual environments. A majority of research conducted on human wayfinding centers on actual physical environments or exterior wayfinding. Many studies conducted by the United States military discuss efforts to develop better ways to train field soldiers. The following studies are important to note for this research because of pertinent aspects relative to human wayfinding in general regardless of being conducted in virtual or traditional environments or that have direct implications to virtual environment wayfinding and navigation.

A review of wayfinding research would not be complete without noting two significant studies cited throughout traditional and virtual research in architecture, urban planning, and interior wayfinding. These studies form the base for research on human wayfinding. Lynch, an urban planner (1960), wrote about wayfinding in his *The Image of the City* while Passini (1984) wrote *Wayfinding in Architecture*. Both developed guidelines based upon theory and research that discuss the relationship and impact of navigation through a space as a result of design. It is important to review the concepts of both authors, as their influence to human wayfinding has been substantial.

Lynch (1960) focused on wayfinding in urban planning and the design of city spaces. His work became the foundation of design principles in the fields of architecture and urban planning. *Imageability* relates to visual clarity and satisfaction, which promotes effective navigation and wayfinding through an environment. *Imageability* is defined as features of any physical object that enhance the likelihood of promoting a powerful image in observers. Shape, color, and arrangement all facilitate powerful and useful mental images of an environment. Lynch discusses the enhancement of urban environments and emphasizes that environmental image is a consideration in promoting positive interactions, including navigation, within environments. Lynch reviewed data gathered from three different cities, including interviews with residents, sketches done by residents, descriptions, photo classification, and field analysis of the structure of the three environments to support his findings.

Lynch presented five image elements critical to constructing patterns and enhancing navigation and wayfinding. These include paths that act as channels of movement, edges that act as boundaries between areas, districts that formulate distinctive city sections and points of entry, nodes that are smaller points of entry and act as focus lines, and landmarks that are distinctive objects upon which users rely (Lynch, 1960). His five recommendations for the structure of the physical world have become the backbone of design principles in urban planning. Lynch's work is important to understanding human navigation in an environment and what image information is pertinent and promotes navigation and wayfinding. Research has noted that additional studies need to be done to analyze how best to transfer these considerations to virtual worlds. Yet, many of these elements are already inherent design parameters in this research study. This study already accommodates paths (hallways in the virtual environment) that act as channels of movement, edges (walls and floors in the virtual environment) that act as boundaries between areas, and landmarks (signs, directories, furniture) distinctive objects that users rely on. By creating the virtual environment based on accepted elements that promote wayfinding, a more viable analysis can be conducted to examine how images can affect the experience.

Passini (1984) built upon Lynch's earlier work, but focused more on environmental meaning in surroundings as opposed to the physical structures that comprise them. Passini identified organizational principles in design. Deciphering organizational structure and making it clear to end users affects the strategies and performance of navigation and wayfinding tasks. Passini's research involved experiments in urban downtown areas of Montreal, Canada. He identified that human wayfinding is either approached in a linear fashion supported by directional signage and survey, or by route navigation. The careful selection and design of signage can also promote route navigation. This information is critical to the design of environments and navigation as it relates to the placement of signage for decision-making. The dissertation study utilizes these concepts by promoting navigation whether approached in a linear or route fashion by the design and selection of signage. The fact that the signage proposed in the study follows interior wayfinding standards only further supports this.

Funkhouser and Sequin (1993) conducted one of the earliest virtual environment architectural walkthroughs, *Soda Hall* (a building in the computer science division of the University of California, Berkeley). This study was important as it helped to analyze placement of objects and the overall design of the environment prior to the final build out of the actual structure. A key consideration with creating *Soda Hall* was the struggle with the tradeoff of rich rendered images of higher resolution and computer system limitations in the environment as the walkthrough progressed. The generation of algorithms that could call and upload different models and images as movement evolved and not crash the computer system was one of the complex tasks mastered during this process. Interior furniture was created at multiple levels of detail and called up as needed so that the computer system would not collapse while walking though the environment. This study relates to this dissertation research as it underscores the need, even years ago, to better understand and balance image complexity, resolution and compression with computer system limitations as interior walkthroughs are navigated virtually. Even with advances in computer systems, the need to make intelligent decisions with image resolution is important to research and understand because the amount of complexity in larger virtual settings only increases as computer systems allow for bigger environments to be created.

Environment size has been a consideration in other virtual wayfinding studies. Darken and Sibert (1996) examined wayfinding in large-scale virtual environments to locate complex searching clues. Environment size was an important aspect of this research since many studies involve small environments. Participants were exposed to one of four experimental treatments involving large virtual land masses and asked to search for five specific targets. Findings validated that visual clues are essential to navigation in large-scale virtual environments. Without visual clues, participants become disoriented and easily lost. Although this research examined wayfinding in large-scale exterior environments, the findings may hold true in large-scale interior virtual spaces as well. Interesting is the fact that visual clues are essential to promoting success in wayfinding in large environments. More research needs to be conducted to validate how large-scale interior spaces may need similar visual clues to promote wayfinding.

Research has also demonstrated that a virtual wayfinding environment can support spatial knowledge acquisition. Witmer and Singer (1994) were among the first to compare a virtual environment to a real world environment in an walkthrough application. This study used an immersive display with motion controlled by gaze-directed movements directed at onscreen buttons. Each participant identified six landmarks in both a virtual building treatment and the supporting real world building treatment. Data included assessments, questionnaires on navigational knowledge, and assessments of configurable knowledge. Findings support that virtual environment knowledge can be applied to spatial knowledge acquisition and that landmark knowledge can become route knowledge. This study indicates that the relationship between landmark and route knowledge needs further exploration and that additional research can only enhance the understanding of landmark content such as images in virtual environments and the role that they may play in supporting and encouraging route knowledge.

Satalich (1995) also studied wayfinding in immersive environments with landmarks. Sixty-five participants evaluated three different types of navigation approaches including self-exploration, active guidance using predetermined routes, and passive guidance with movement along a predetermined route. All participants were allowed to view a map of the different types of treatments. The virtual building used in the study was comprised of 39 rooms with 500 object landmarks. Reports both support and contradict the overall findings. Overall VR participants performed more poorly than participants exposed to map training did. Modjeska (2000) provides reasoning as to why Satalich's research may have produced contradictory results, including that the use of maps may have been a confounding variable for the self-exploration group and that low-level tasks in the research, including distance estimation, may have been impacted by hardware performance considerations at the time the study was conducted. The research indicated that additional studies are needed to evaluate the role of visual landmarks in immersive virtual building environments and to better understand the role of landmarks in wayfinding.

Foo, Duchon, Warren and Tarr (2006) conducted research with 24 participants to clarify the role landmarks play in virtual wayfinding tasks. Findings indicate that more efficient wayfinding routes were created by having additional landmarks in the virtual environment. Beliefs about the virtual world were also acquired by critical decision points that participants encountered. Norman (1988) noted that knowledge in the world is vital to wayfinding in strange environments, and that knowledge in virtual environments is gained through visual clues such as landmarks, signs, guidance systems, and architectural elements. This is important because knowledge and wayfinding performance in the virtual world should be enhanced by the sign images and using them as landmarks in the environment. The question arises as to how effective these signs are at promoting wayfinding as landmarks when they are of different resolutions.

Additional reviews of research on virtual wayfinding includes the work of Smyth (2004) who sought to evaluate the design of virtual environments that specifically attempt to promote a sense of place to users. Place is a key consideration to promoting performance, usability and acceptance in a virtual environment. These findings support the theory that in order to establish a sense of place within a virtual environment successfully, it is important to promote movement of the body or the illusion of movement of the body within the virtual treatment. Movement is essential to establish a feeling of place in virtual environments. Movement can be actual or simulated, but creating a sense of place is dependent upon the sense of being able to move in a treatment and not just in viewing the surrounding environment. This underscores that a sense of movement is critical to enhancing overall comfort and acceptance of users in virtual environments. This illusion of movement in the virtual environment is one of the factors that differentiate virtual worlds and their supporting images and content from still worlds or video worlds.

Considerations in Wayfinding Research Literature

There are several considerations related to findings from past research with human wayfinding that must be presented. Moffatt, Hampson and Hatxipantelis (1998) noted overall performance differences among male and female participants and Schmitz

(1999) noted that men and women approach wayfinding from different strategies. The following examples of previous research also support the design and methodology of the proposed study by providing insight into gender differences in wayfinding, individual differences in spatial ability and the need for wayfinding decisions to be based on true branching points in an environment. The three following studies discuss research that examines gender differences in wayfinding.

Schmitz (1999) studied 32 adults to examine the effects of gender differences in environmental knowledge of wayfinding. This research focused on wayfinding preferences and anxiety levels among participants. Findings include differences in strategies for how men and women approach wayfinding, including males' preference for mixed methods of spatial wayfinding with routes and landmarks. Female participants in Schmitz's study preferred landmark strategies over route strategies for wayfinding. These findings illustrate that a deeper understanding of the differences in how men and women approach wayfinding needs to be examined through additional research. Also, participant populations in future research need to account for careful considerations of male and female populations so that end results do not become biased.

Cornell, Sorenson and Mio (2003) noted in research on traditional wayfinding that, although female participants reported a weak sense of direction, this was not apparent in the actual orientation or wayfinding abilities of female participants from this particular population. This research further illustrates the importance to needing a deeper understanding of the design of wayfinding environments. Although a weak sense of direction was reported by female participants, this did not reflect the actual performance or abilities of the participants in this study. Additional research needs to validate that perceived senses of gender differences are not necessarily actual differences in gender performance in wayfinding.

The influence of gender and age with virtual exterior wayfinding can provide some clues to the affect those variables may have on virtual interior wayfinding. Cubukcu and Nasar (2005) exposed 160 participants from Ohio State University to simulated outdoor environments using landmarks. Testing included size estimation and basic navigational skills. Participants were first allowed to explore and then asked to estimate positions from start to end points, navigate to end points, select the layout of the environment and sketch the route that they took. For estimating direction and navigating to a destination, male participants performed slightly better than females. For navigating, younger participants performed slightly better than older participants did. The results also discuss that environmental landmarks and clues are essential to preventing anxiety, exhaustion and disorientation in large wayfinding spaces. In addition, the ease of wayfinding within the virtual treatment promoted user comfort. Since this study further discusses the differences, although minor, in estimating direction and navigation in wayfinding between male and female participants, the consideration again arises that more research needs to be done to evaluate the role that landmarks and clues such as images may play in promoting effective wayfinding. Seemingly, having additional wayfinding clues not only reduced participant's anxiety and disorientation, but may have been a factor in only marginal differences between male and female performance in estimating direction and actual navigation. Another key finding from this research is that younger participants performed better for navigation tasks than older participants. Controlling for age needs to be a key consideration for validating further research with landmarks and cues. More research needs to be done to design effective virtual learning environments where all participants can utilize landmarks equally well regardless of their age or gender.

Another key consideration in participant differences pertinent to virtual environment wayfinding and the proposed research is the aspect of individual differences in spatial ability. McGovern (1991) discusses past research that shows participants with lower spatial ability have more errors and longer completion times relative to navigation tasks. Spatial ability can vary greatly and is important to consider for research involving wayfinding and movement in virtual environments as performance may be impacted by participant's predetermined spatial ability. While understanding individual differences is ongoing in research, it is important to review the following three studies to understand the nature and impact of individual differences of spatial ability on wayfinding and performance and to consider appropriate controls for this research to prevent bias.

Chen, Czerwinski and Macredie (2000) note that other researchers have conducted studies, which identify that individual differences do occur in overall performance of wayfinding in both virtual and traditional environments. Individual differences have become important research considerations for participant performance as virtual environments have become more viable for use in studies in human learning and as learning environments. Currently the specific effects of individual differences with regard to participant's spatial abilities in VR research have yet to be understood (Chen & Macredie, 2000). Yet, individual differences in any computer task can encompass aspects of a participant's gender, age, knowledge, cognitive ability, and personality and may affect overall performance. While the specific impact of spatial ability to individual differences and performance is still to be understood, it is important to consider appropriate controls so that these differences can be mediated in a potential research population.

Organizing individual differences has also been attempted to try to gain a further understanding. Egan and Gomez (1985) implemented a three-tiered approach to mediating individual differences including isolation, assaying, and accommodation. Isolation allowed for identifying specific individual difference of a particular group matched with appropriate data to track a particular participant's task performance. This is a key consideration in trying to evaluate the impact of differences in spatial ability and illustrates the need to understand group differences and how these may relate to individual task performance. It is important to establish parameters for including participant groups first, before additional research can be conducted on individual task performance.

Traditional wayfinding in real world environments has also examined the role of individual differences in directional behavior and wayfinding to overall performance. Lawton (1996) utilized 278 participants to investigate wayfinding tasks in traditional wayfinding. Findings indicate that participants with good directional behavior perform better in wayfinding tasks than those without good directional behaviors. One of the limitations of this study to note is the broad gender differential among participants: 174 women and 104 men.

Each of these three studies notes that the individual differences phenomenon exists with spatial ability and wayfinding; however, it is challenging to fully understand the impact in research. Additional research must examine spatial ability and how this may affect performance in wayfinding. More importantly, until there is additional research on how these differences can be accommodated, appropriate control must be developed in research methodologies to eliminate bias and potential contamination of future studies.

A final review of wayfinding literature must also discuss the need for intersections and branching points to ensure that wayfinding can actually be examined. The two following studies discuss the need for authentic decision opportunities to evaluate wayfinding. Wayfinding opportunities occur by appropriate design considerations that allow participants path choices at intersections and branching points in virtual environments. Consideration for what are appropriate decision points is important to mention as it ties into the methodology and design of the particular environment developed for this dissertation research.

Intersections influence spatial problem solving in wayfinding tasks. Intersections act as decision points for participants to perform locomotion tasks that comprise wayfinding. Locomotion is the actual movement associated with wayfinding. Branching points are intersections where decisions are made by selecting a destination. Raubal and Egonhofer (1998) conducted research with participants in unfamiliar environments in a virtual recreation of the Vienna airport. They found that for successful wayfinding to occur, visual clues must be present and readable to participants to promote interaction with intersections. Without the aid of visual clues in complex wayfinding environments to utilize intersections, wayfinding does not occur. This is important to consider because visual clues such as wayfinding images are important, and they must be readable to the participant for wayfinding to occur and appropriately placed at intersections. The question arises that is central to this dissertation research regarding image resolution as to what is considered acceptable levels of readability in images at intersections and branching points.

Research also indicates spatial problem solving is affected by intersections and the complexity of decision making that occurs at intersections. Casakin, Barkowsky, Klippel and Freksa (2000) researched spatial aspects of branching points in physical environments with schematic maps. Their work categorized branching points into a empirical taxonomy with classes and discussions on implications for navigating. Branching points were divided into groups of two to eight intersections with qualitative angles such as perpendicular, acute, obtuse, and straight. Similarly, Jansen-Osmann and Wiedenbauer (2004) also noted in their research that the number of turns in a virtual environment affected participants. Their research had participants estimate distance in a virtual environment in two experiments. Findings indicate that participant's distance estimation in the virtual treatments was impacted by the number of turns in a route. Wayfinding performance was also influenced by visual perceptions of sign information and the decisions at branching points. Both studies are important to note in regards to the dissertation research. Casakin et al., (2000) research implies that complex intersections may affect decisions in wayfinding. However, most complex virtual environments do not have access to schematic maps to assist with branching points, and having a schematic map would invalidate the authenticity of the environment. As with other studies previously discussed, landmarks and signage images are used at intersections. Replications of authentic virtual environments such as the dissertation study do not support schematic maps but do support complex branching points that occur in the real world daily and that participants are expected to be able to navigate in them. Obviously the complexity of turns in a virtual environment may affect distance estimation as found by Osmann and Bettin (2002). Perhaps by conducting additional research a better understanding can be gained of the role of branching points, intersections and complexities in virtual learning environments, particularly if virtual learning environments are to replicate actual learning environments of the real world.

A brief note should clarify the relationship of locomotion to wayfinding in some of the previous research. Locomotion is the activity of wayfinding at the physical level, while wayfinding is the mental processes and decisions that become the locomotionary reactions and movements. Wayfinding is the mental process of reasoning while locomotion is the physical action upon these processes (Modesjeska, 1997). In this manner, wayfinding and locomotion can occur in both the real physical world and virtual environments.

Game Environment Navigation

Literature regarding navigating and wayfinding in gaming environments is also important to review for the dissertation research. Since literature is limited on navigation in virtual environments, reviewing game environment research pertinent to the navigation and imagery focus of the proposed study may provide additional information for guidelines for the focus of this study. Response and performance in these types of environments may provide information on how participants respond to virtual navigation in general. The following studies are important to consider as they provide insights that help to refine the dissertation research.

Stakiewicz et al. (2006) discuss three experiments on human spatial navigation and the effects of perception, memory, and strategy. An ideal-navigator model for indoor navigation was created to evaluate the effect of these variables on human navigation performance. In one experiment, the effect of increasing the overall layout size on spatial wayfinding was evaluated. Findings indicate that efficiency in navigating decreased as the layout size increased. Possible considerations for additional research include the layout size of the virtual environment as this might affect navigation performance.

In another study, Osmann and Wiedenbauer (2004) evaluated three experiments of navigation in a controlled virtual environment. One experiment used children to explore two routes of equal length but with a different number of turns. Adults also replicated the same experiment. Findings indicate that if participants (children or adults) did not compare the routes to the number of turns, both routes appeared to be the same length. Gramann, Muller, Eick, Eva-Maria and Schonebeck (2005) also reported three experiments that investigated spatial orientation in virtual navigation tasks. These findings report that even scarce visual flow was adequate for participant's accurate path integration.

Landmark navigation was evaluated by participants who drove a virtual taxicab through a VE town (Newman, Caplan, Kirschen, Korolev, Sekuler & Kahana, 2007). Participants were to look for passengers and to take the fastest route to a destination. Findings from one experiment indicate that participants quickly become skilled at finding direct paths from random locations by using landmarks. Another experiment varied the degree of landmark and layout cues in two areas. Findings indicate that when the spatial layout was consistent, transfer was low. Seemingly, spatial navigation layout or landmark visual information is adequate for wayfinding. However, when cues conflict such as when both landmarks and surroundings are altered, landmarks are preferred for navigation. The previous research illustrates the need for a deeper understanding of the effect of landmarks in VE navigation. Research indicates that navigation performance is impacted by increased layouts.

An interesting research study involving analysis of virtual environments and navigation was conducted by Maguire, Burgess and O'Keefe (1999). In this research, PET was used to evaluate participants during retrieval tasks in a VR town. Changes to the cerebral perfusion and performance were analyzed. Findings indicate that the right and left hippocampus were activated more when participants reached a destination successfully than when they followed a trail dictated by arrows. A significant correlation between blood flow in the right hippocampus and inferior parietal cortex where reported with the accuracy of navigation. The more accurate the navigation was, the more active were these regions of the brain. Additional research reports that humans can navigate in complex virtual environments with only visual stimulation. Maguire et al., (1999) also discuss studies that confirm the importance of landmarks of spatial representations in navigation and that landmarks need to be realistic to of use when navigation in intricate environments. Additional factors cited that were critical to navigation in large scale places include presence, number of choice points and the placement of landmarks. This research has interesting implications for the dissertation study because findings support that navigation in virtual environments can be accomplished with visual stimulation and that the more accurate the navigation is, the more active are responses in the brain. While this study does not seek to evaluate brain response, responses to eye movements are considerations as well as the analysis of images and their impact on wayfinding and navigation.

Research on Virtual Environments Relating to Vision and Space

Several virtual environment studies that focus on wayfinding and vision are also important to discuss as they provide direction and clarity to the dissertation research. Studies conducted by Phillips (1986) with comparisons of virtual environments to real environments indicate that perceived size discrimination is the same in virtual environment as it is in real world environments. Participants determined object size and height by comparing a real word environment to a virtual environment. Results were consistent in that users discerned objects' proportion size to other objects in a virtual scenario to be the same as they would be in a real world scenario. Phillips' work indicates that there is no difference in virtual world object size perception as opposed to real world object size perception. This is important to note since virtual environments often come into question in regards to the generalizability of research findings to the physical world they represent. Validating that there is not a perceived difference in object size in a virtual vs. real world helps to validate the use and development of the virtual wayfinding environment and the end users' perceived visual experience.

Three-dimensional (3-D) virtual treatments have also been used to investigate the role of design and communication with abstract building volumes relative to architectural education. Schnabel and Kvan's (2002) research evaluated 24 randomly selected architecture students who explored and manipulated a colored dimensional cube in a virtual treatment. Participants replicated in the virtual treatment the creation of massing models with wooden virtual cubes of similar colors. The creation of massing models is often part of traditional learning for architecture students. Findings indicate that participants had a greater understanding of visual space and volume after completing the

3-D virtual environment massing treatment as opposed to the traditional massing model learning exercise in the real classroom. The value of using the virtual learning experience to enhance education and to be able to compare the virtual experience to the traditional learning experience is just beginning to be explored in many fields of learning. A better understanding needs to be acquired of how this enhanced learning may occur and if there are any limitations to or enhancements that may affect the visual learning experience by using 3-D virtual environments.

Follow-on work conducted by Schnabel and Kvan (2002) found that it is possible to understand, communicate, and design architectural spaces in 3-D virtual environments. This research focused on the design process of 3-D virtual environments and their applicability to architectural education. Results of 36 randomly assigned architectural students showed that they were able to design more fluidly through VE 3-D space, and had a keener understanding of the direct relationship of creating and designing because of the virtual environment. Students who were able to design and adjust their designs as they worked in the VE space were able to see the results and affects immediately in a more profound and authentic manner. While both populations of participants from these two studies were pooled from architecture students and focused on enhancements to architectural student education, the findings may also hold value to the general visual experience and for using virtual environments to enhance the learning experience.

Kalisperis, Otto, Muramoto, Gundrum, Masters and Orlando (2002) have conducted ongoing research with architectural students using the Immersive Environments Lab (IEL). IEL was created to assess the implementation of using a virtual environment to teach architecture students. The focus of IEL centers on enriching architectural student education and understanding of volumes and spaces in design. IEL is set up in a studio and students can manipulate and test virtual solids objects and voids. Initial findings support Schnabel and Kvan's research and indicate student enthusiasm was high because of the ability to design dynamically and to see the implications of designing different volumes in an ongoing basis. Research findings on current research need to be reported with 35 participants in a usability study with IEL. Interestingly, the three previously discussed research initiatives show that students were better able to visualize and understand complex design considerations in massing space and the effects of design changes used in creating massing volumes by using virtual environments for learning. Again, the consideration arises in regards to the proposed study that a keener understanding needs to be gained on the effectiveness of using virtual environments for learning and better understanding design considerations for creating these environments and their implications to learning.

Werner and Finkelmeyer (2002) conducted research on three treatments of interactive desktop virtual environments. *Wayfinding and Signage* was the final design study, and utilized VRML to deliver 3-D images. This research allowed students to design and place directional wayfinding signage and room numbering within a virtual environment. Findings indicated that distinctive differences were from the participant pool and their spatial abilities and that actually human spatial navigation increased through the study. This supports the dissertation research and the need to control for individual differences yet the deeper understanding that needs to occur from additional research and the implications of spatial navigation with signage in a VR environment.

Research conducted by Matto Laboratories in Japan focused on the effects of additional visual information on participants in a virtual interior maze treatment. Participant wayfinding tasks performance substantially improved by having additional landmarks in the virtual maze treatment and by adding additional visual information such as supplementary colors and informational heading images in the treatment. The added visual landmark enhancements improved wayfinding performance. This is important to understand more fully, as more visually rich virtual environments are now more attainable and more cost effective to create. As this research indicates, additional landmark information and detail can impact performance. The question still arises as to how much visual detail enhances performance. There is also a need to have a deeper understanding of the thresholds of what are either too much or too little visual enhancements to landmarks in virtual treatments and how this impacts learning.

Chim, Lau, Leong and Si (2003) conducted research with *Cyberwalk*, a web-based distributed virtual walkthrough environment. In *Cyberwalk*, when viewers walk through the environment, the information that is needed is generated and rendered out. Virtual objects are distributed from the server to individual clients on an as-needed basis to accommodate bandwidth considerations. This is a tremendous advancement from the different algorithms and variable versions of rendered models created for the *Soda Hall* walkthrough completed almost a decade prior. *Cyberwalk* employs multi-resolution modeling so that distant images are modeled at a much lower resolution to conserve bandwidth. This also replicates the human visual experience of seeing distant objects as less sharp and closer objects with more detail. *Cyberwalk* however, is still in its infancy. Currently the models and overall resolution are not of the caliber of real world immersive environments. However, the technology and confines of developing *Cyberwalk* may provide critical information for the improvement and cost effectiveness of future virtual environments. Understanding the impact of model resolution in virtual walkthrough environments will provide better parameters for developing effective approaches to creating and delivering environments that balance successful navigation with the needs of the human visual system.

Overview of Goals

The primary goal of this literature review was to synthesize past research, discern areas for new studies, and examine the methodologies used by previous researchers. By better understanding past research efforts, a more concise approach to the design of the dissertation study was achieved, with a clearer focus of the overall goals and end purpose. Careful analysis of factors (visual attention theory, image resolution, and wayfinding tasks) related to a virtual environment were closely examined prior to the development of the final research treatment. In addition, a clear understanding of past initiatives, the limitations of past work, and the ideas for future work provided the framework for the dissertation.

Certainly, research regarding theories of how attention occurs, the role of images, wayfinding and virtual environments has been conducted. Nevertheless, additional research that specifically addresses the understanding of appropriate parameters and refinement for developing virtual environments is now more critical. Particularly, as more visually rich virtual environments are being created for learning without any standard design and development metrics for image resolution. It is critical to have a better understanding of what are effective choices for image resolution as more visually rich environments are created and attainable and as decisions are made to compress visually rich virtual environments by degrading images within them. Only through further research can determinations and a better understanding occur of how image resolution impacts visual attention, wayfinding and overall performance and learning in virtual environments. Only through additional research can effective guidelines be established for what are effective image resolutions, which do not impact learner performance and the overall learning experience in virtual environments.

Chapter Three

Method

The purposed of this study was to determine the effects of image resolution on locomotion tasks through an interior virtual desktop learning environment, to examine the role of image resolution on attention and optic flow in the user's physical eye movements and the perceived usefulness of the virtual environment as these relate to locomotion tasks. This study addressed three research questions and the supporting hypotheses that examined time-on-task performance, eye movements, and in turn object-based visual attention and the perceived usefulness of the environment and system as a function of changes in image resolution. The goal of the research is to have a better understanding of the implication for using different image resolution and hence design metrics in virtual desktop environments. This chapter provides a description of the overall research design and procedures that were utilized in the study.

This study was conducted in two phases. Phase I served as a screening phase in which the volunteer sample was screened on their individual spatial ability performance. Those participants who demonstrated average or higher spatial ability as measured by the Mental Rotation Test were selected for participation in the actual experimental study, which was Phase II. Phase II of the study directly addressed the study's research questions.

This chapter is organized in the following manner: Discussion on the design and development of the virtual wayfinding treatment provide an overview of the development of the virtual environment and key design considerations. Discussions on the development of the wayfinding images in the virtual environment provide an overview of the creation and resolution considerations for the images used in the virtual environment. After discussing the design of the environment and images, individual instruments and tools used for the data collection of the research are covered. These include the Mental Rotation Test (MRT), time-on-task performance, and eye movement data as calculated with the eye tracking system, System Usability Scale (SUS©), and the Virtual Environment Presence Questionnaire (VEPQ). Next, specific procedures of the research are discussed including logistics, computer system set up and the administration of the different instruments and data collection tools. An overview of the data collection is provided with specific results reported in Chapter Five on findings from the pilot study are provided in Appendix A.

Population and Sample

The target population was undergraduate college students. The sample consisted of volunteers from a 2000 level undergraduate basic education course from a major research university in the southeastern United States. Prerequisites for the course include basic computer proficiency; which allow for minimizing the extraneous variable of prior user's prior computer experience and comfort. Extraneous variables such as the participant' prior knowledge, spatial ability and virtual environments exposure were minimized within the content of the study and are discussed later in this write-up.

To select the sample, the researcher contacted instructors from five different sections of a basic teacher education technology course and then visited the classes to discuss the research opportunity early in the spring semester of 2008. Volunteers who were interested in potential participation were given a time frames in which they could participate in the study over a period of six days immediately following their class meetings. Volunteers had the opportunity to obtain five extra credit points for their participation in the study by their instructor as discussed

Selection of Sample

Using an apriori power analysis (Cohen, 1988) with an alpha level set at .05, an estimated medium effect size, and a desired power of .80, the study called for approximately 60 participants with each treatment group consisting of 15 participants. A sample of 78 participants from the class of students participated in the research. Out of the 78 participants, two from the pilot study asked to stop the treatment and four from the final study asked to stop the treatment. This is described in detail in the supporting sections. Twelve students participated in the pilot study and 60 students participated in the final study.

Participants in the study ranged from 18 to 38 years of age. Male and female students had an equal opportunity to participate in the study. However, the subject pool from the course sections was unevenly distributed with more females than males. This is due to the composition of the sections of this course and in general in the college of education at the university. The fact that there was a difference in the numbers of male and female participants were verified with the instructors of the courses prior to the initial experimenter's visit. To ensure that each treatment group would have an equal number of male and females, participants were distributed to each of the four treatment groups and to ensure an equal distribution of gender among the treatment groups, three males and 12 females were randomly assigned to each treatment group in the final study.

Research Design

The study was designed to allow for both the screening for spatial ability of volunteers (Phase I) and the selection of the sample for participation in the experimental study (Phase II) to occur on the same day. The research was comprised of these two phases, which are discussed in more detail later in this write-up. Phase I involved the administration and scoring of the Mental Rotation Test to volunteers. The MRT was used to evaluate spatial abilities of potential participants as discussed later in the text. Those with scores that were higher than average (in the 50^{th} percentile or higher of a normed group by age and gender) were selected for participation in the research study. Phase II of the study involved participants who were actually exposed to one of four virtual environment treatments. The administration of the experimental treatments, data collection and analysis for the research was only conducted with actual participants in the study who were in Phase II.

The research design for Phase II of this study is experimental. Student volunteers who met the spatial ability criteria for participation in the study constituted the sample for Phase II. These participants for Phase II were (N = 60). As previously discussed, four additional participants asked to stop the study. These participants are not part of the final sample of 60 participants.

Participants were randomly assigned to one of four different treatment conditions. The treatment conditions include four different virtual environments. Each virtual environment was comprised of wayfinding images in the treatment that had different image resolutions (Group 1 = wayfinding images comprised of 150 ppi, Group 2 = wayfinding images comprised of 100 ppi, Group 3 = wayfinding images comprised of 75 ppi and Group 4 = wayfinding images comprised of 30 ppi). The outcome variables included in the study are participants' time-on-task performance scores, eye movement scores including saccade movements and gaze fixation detections in the different resolution groups and the perception of the usefulness of the environment as indicated by scores on the System Usability Scale and Virtual Environment Performance Questionnaire in the different resolution groups.

Minimizing Extraneous Variables

Minimizing extraneous variables was a key consideration in the research design prior to soliciting participants. These specific considerations for the study were supported by the literature review.

Previous Environmental Exposure

Extraneous variables were physically minimized prior to the study to diminish potential bias, contamination or confounding data. During the initial experimenter visit to the classrooms, students in each course section were verbally asked by the researcher if they had any prior knowledge or experience in architectural drawing, perspective drawings or drafting. Student volunteers were also asked if they had ever taken any coursework involving perspective drawing, architectural drawings or drafting. This type of exposure could have presented confounding information. Furthermore, additional check boxes were added on the Participant Sign-In Sheet (see Appendix B) that requested respondents to indicate if they had any prior knowledge by taking courses in these areas.

Any student who checked either check box and indicated any amount of prior knowledge in any of these areas was not included in the study. Students who would have indicated prior experience or courses in any of these areas would have been told that they would not be eligible for the study and would not have been selected volunteering or possible inclusion in the study. However, none of the students from any of the five sections of the course indicated any prior knowledge or experience in architectural drawing, perspective drawings or drafting.

Computer Skills

The volunteers from which the sample was comprised of students enrolled in one of the five sections of the undergraduate technology teacher education course (EME 2040). Students had several technology-based activities prior to their participation in this research since the study was conducted after the midterm of the spring 2008 semester in which they were enrolled in the course. Thus, technology skills needed to participate in the treatments were gained prior to the study. This was verified by consultations with the instructors of the course. As discussed in literature, minimizing the lack of prior experience in technology was important to ensuring an unbiased sample.

Individual Differences

Minimizing individual differences is a key component of task-related research. Differences among participants in a group can in fact play a direct role in overall scores and the data collected as discussed in the literature. Individual differences have been identified for some time as confounding variables. However, there is not one definitive approach to controlling for differences among participants (Chen, 2000). Differences in spatial ability were important considerations for the dissertation research as spatial ability might have affected performance in using a virtual environment. Lampton, Knerr, Goldber, Bliss, Moshell and Black (1995) discuss differences in participants' visual task performance and individual differences that can occur because of display types in virtual environments.

To minimize for this, the study was conducted in two phases as previously discussed. Phase I served as the screening phase in which the Mental Rotation Test was administered to all volunteer candidates. Volunteers were first administered the MRT. This MRT was immediately scored by the researcher and volunteers with low spatial abilities (i.e., those who received a score of less that 50^{th} percentile as compared to their norm group) were not selected to participate in the study. These volunteers were given a business card to present to their instructor and told that they were free to go back to their classes or other activities. Those volunteers who scored above the 50^{th} percentile as compared to their norm group were selected to participate in Phase II of the study. Specific details of the MRT instrument are discussed later in this write-up.

Stanney, Kingdon and Graeberm (2002) discussed the impact of age on participant performance with complex virtual systems in their technical report. Minimizing differences in participants' age in the research was accomplished by the design in using a population selected from the undergraduate university courses. This provided a more narrow age range of 18 to 38 years of age as opposed to older participants with ages of 50 or more. Gender differences were also monitored to ensure that an equal distribution of male and female participants were in each treatment group as discussed.

Design and Development of the Desktop Interior Virtual Wayfinding Treatment Environment

The proper development of the interior virtual wayfinding environment for the research study was important to consider and involved design contemplation related to the literature, virtual environment and wayfinding standards and technology considerations. Duchowski et al., (2002) state that the goals of virtual environments are to match the appearance of the physical environment that they seek to replicate. Based upon these considerations and the literature review, a virtual learning environment that replicates an actual interior environment floor plan was created to examine the effects of image resolution on locomotion tasks.

In turn, the effect of image resolution on user choice and locomotion tasks was examined because of the wayfinding process. Since the focus of the study was on the relationship of image resolution to eye movements, and in turn, performance scores related to optic flow and locomotion tasks, the environment was developed to contain authentic replications of wayfinding images. Parent's (1997) review of life-like virtual environments identifies design guidelines including viewing, inspection, exploration, and navigation. Eye geometry guidelines include image presentations in virtual environments. The experimental environment developed for this research followed these principles.

To assist in identifying acceptable locomotion tasks in the virtual learning treatment design, the Virtual Environment Performance Assessment Battery Survey (VEPABS) was used. The VEPABS was created to establish benchmarks for virtual environment training tasks and has been used in military simulations to evaluate human performance in virtual environments (Lampton et al., 1994). VEPABS identifies performance tasks such as vision, locomotion, tracking and reaction time in 3-D immersive virtual environments. VEPABS defines a series of basic human performances that relate to complex tasks in virtual environments.

For the purpose of this research, only tasks relating to locomotion (walking) were considerations for the design. The environment replicates an actual interior floor plan space where locomotion specific tasks are used for wayfinding. Locomotion is identified as tasks involved in perceived physical movement such as forward movement (straightway), backward movement (backing up), turn movement (alternating left and right 90 degree turns), and figure eight movement (moving around a figure eight shaped series of walls) (Lampton et al., 1994).

The interior virtual environment includes all of the specific locomotion tasks as part of the design, while mirroring the actual interior environment that was replicated. A floor plan of the virtual environment is presented in Appendix D. The floor plan selected for the study forces participants to perform all of the subtasks of locomotion as part of wayfinding and navigating through the environment. Participants must perform all locomotion tasks identified in the VEPABS including forward movement, backward movement, turn movement and figure eight movement as they navigate through the environment in search of the conference room. Branching points were also an important consideration and need to be noted from the previous literature review as they define authentic choices. The locomotion tasks indicated in the VEPABS and the replication of the virtual environment dictate the number of branching points. Each branching point in the environment provided participants with opportunities to make authentic choices for moving.

The virtual environment was created using Autodesk 3d Studio Max™ and an authentic interior floor plan of an office building. As mentioned, the floor plan accommodated all locomotion subtasks identified by VEPABS and authentic opportunities for choices with branching points. All interior elements for the model were based on measurements from actual standards for interior spaces including the appropriate dimensions of corridors, doors, lighting and hardware necessary for an actual real world environment as defined in the *Time Saver Standards of Interior Design* (De Chiara, Panero, & Zelnik, 1991). By developing the environment this way, all of the interior components were held constant and in correct relationships to human proportions. To accommodate for the figure 8 shape identified as a locomotion task in VEPABS, the conference room was developed mirroring acoustic wall panels of accurate dimensions placed in a figure 8 configuration. The 3-D model was output and embedded in Unreal Tournament™, an immersive 3-D gaming environment. Examples of the floor plan and screenshots of the environment are contained in Appendix D and Appendix G respectively.

Unreal Tournament™ was used as the final development and delivery environment to avoid any issues with participants colliding into walls and not being allowed to move. Other types of virtual development tools have concerns with user collisions into elements such as walls, which can affect user performance. Unreal Tournament™ allows navigation that is more precise in virtual environments with keyboard input and faster regeneration times of graphics. Life-like attributes were added to the model including office furniture to replicate the real world lobby area outside of the elevators including sofas, easy chairs and plants. Textures supporting interior code standards such as carpet fibers, corridor paint, wood doors materials and steel door handles were added. Interior images of poster photographs with frames (see Appendix F) were also placed on the walls at points in the corridors to replicate the actual placement of poster images in the real interior environment.

The visual plane through the floor plan was articulated so that the participants in the environment experienced an eye level of an average height person of 5'- 6". Average viewing height is a design criteria identified in the VEPABS. The environment was developed with a fixed entry point where each participant would begin at the lobby entrance of the floor. The same base virtual environment was used in all treatment groups for the study. The environment was programmed so that user movement was allowed by selecting any of the four arrow keys from the laptop computer keyboard. User position was programmed so that participant's field of view could be rotated by the computer mouse.

Development of Wayfinding Images in the Virtual Environment

As reviewed in literature, object-based visual attention discusses objects being treated as a whole, which then leads to further inspection of the individual parts as attention focuses. To study the effect of different image resolutions on participants' attention, task performance and decision making in wayfinding, directional wayfinding images were used in the virtual environment. Wayfinding images encompass graphic elements of imagery, shapes, wording, color, size and composition and are more complex and authentic as opposed to previous images used in research. Based upon the literature, these images are treated as whole objects and not as individual elements that they are comprised of in object-based visual attention.

Literature also supports the use of landmarks and landmarks used as signage to enhance performance in virtual environments and the need for additional research with image resolution in more authentic environments to identify better resolution metrics and choices. Also, literature indicates that prior research with images used images that were either too simplistic or not authentic in studies of object-based visual attention. It is also important to note as discussed, that optic flow is the apparent visual motion of objects such as signage through space that occurs as objects are moved past. Optic flow is an important consideration when using signage images and landmarks as these images will appear differently as movement occurs through the space. For these reasons the wayfinding images for this research were both purposeful and necessary in order to replicate a large interior virtual space. Appendix E illustrates the sample wayfinding images used in the virtual environment. By using the concepts and limitations from previous literature, a better understanding of image resolution's impact on performance, choice and attention can be gained.

In experimental treatments with participants, O'Neil (1999) noted that wayfinding in settings with signage was easier than in settings without signage. The placement of the wayfinding images on the walls of the environment for this research was dictated by code standards for interior spaces (De Chiara et al., 1991) to adhere to authenticity in creating the environment. Height and placement standards were followed. All digital images of signs were per signage system specifications including sign type, materials, directional icons, or text as indicated by interior signage system standards. Signage system criteria included regulatory considerations for viewing angles, placement, and readability factors in relation to letter style, spacing, color and copy position. These standards were followed for the wayfinding signs in order to replicate the real world environment, to support the validity of this research and to reinforce and refine the literature reviewed.

Resolution of the Wayfinding Images

The virtual environment was created with four different treatment versions, based upon the actual resolution of the directional wayfinding images in the environment. Each environment evolved from the same base model previously discussed. The resolutions of the wayfinding images were set consistently in each of the four treatment groups. Treatment Group 1 had all wayfinding images set to a resolution of 150 ppi; Group 2 had all wayfinding images set to a resolution of 100 ppi; Group 3 had all wayfinding images set to a resolution of 75 ppi; and all wayfinding images for Group 4 were set to a resolution of 30 ppi. Past literature discussed resolution differences among treatment groups, and typically involved inclusion of a wire frame treatment or only two variations of image resolution, high or low. To replicate a more authentic environment as discussed in the literature review, a wire frame treatment was not included in this study.

The development of the different resolutions used for the images in this research relate to standards for compressed picture quality as discussed by Wallace (1991) and supported by similar studies on quantifying levels of detail. DCT coding as discussed by Wallace supports four levels of image quality using bits per pixel JPEG compressions; .25 - .5 bits per pixel produces a moderate to good quality image; .5 - .75 bits per pixel produces good to very good quality; .75 - 1.5 bits per pixel produces excellent quality; and 1.5 - 2.0 bits per pixel produces the highest quality, which is typically indistinguishable from the original. Research shows examples of this in applied use (.25 - .5 bits per pixel approximately translates to 25 - 50 pixels per inch; .5 - .75 bits per pixel approximately translates to 50 to 75 pixels per inch; .75 - 1.5 approximately translates to 75 to 150 pixels per inch and 1.5 - 2.0 approximately translates to 150 to 200 pixels per inch). Based upon these studies and the lack of known or acceptable image compression metrics for VE's as discussed in the literature, the resolution of images used for this research fall under each of these four guideline levels for quality and compression. The literature also reinforces a need for a better understanding of more variances in image resolution beyond a high resolution vs. a low resolution image as past research has done.

The resolution of the images used in the wayfinding experiment was adjusted for each treatment group to the four resolution groups (150 ppi, 100 ppi, 75 ppi, and 30 ppi). Since the focus of this research is image resolution, the effects of only the embedded wayfinding images were varied in the final resolution output. The overall virtual space resolution for the base environment remained a constant resolution of 1200 dpi. The computer screen resolution for the treatments was set to 1024 ppi x 768 ppi, 32 bit. The screen resolution of the computer monitor used the standard Microsoft Windows™ at 96 dpi and was held constant for the delivery of all treatment groups. Figure 1 shows a representative sample of the wayfinding images at the different resolution levels.

Sample Group 1
Images 150 ppi

Sample Group 2
Images 100 ppi

Sample Group 3
Images 75 ppi

Sample Group 4
Images 30 ppi

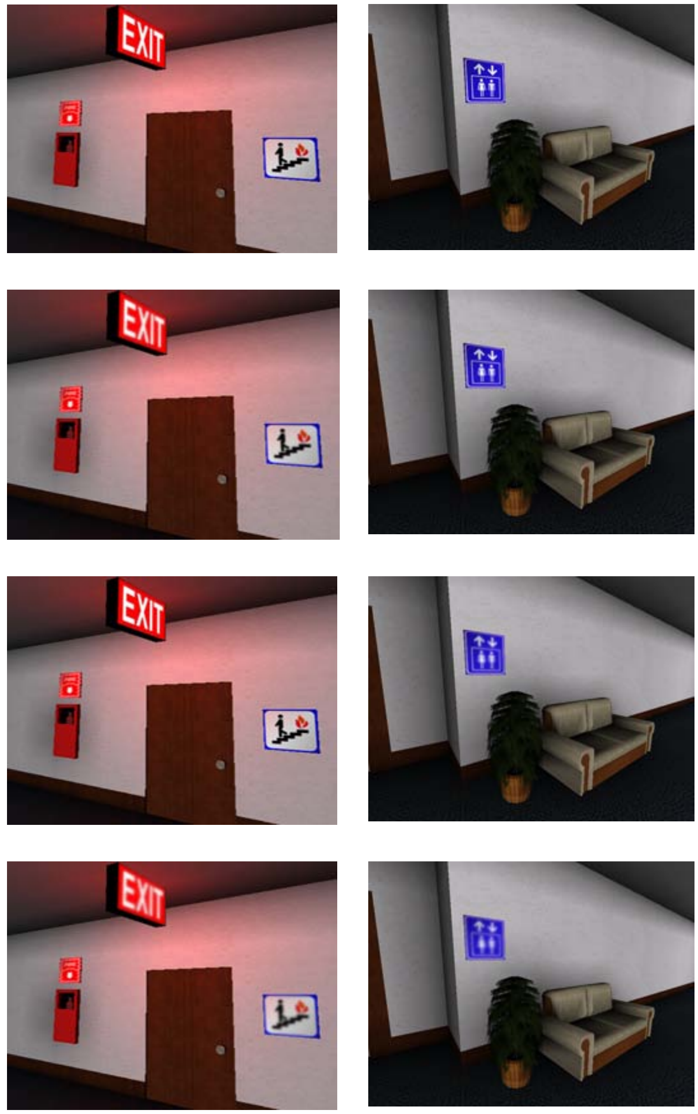


Figure 1. *Sample Wayfinding Images with Different Resolution Levels*

Computer System Considerations

As discussed in the literature, variances have also occurred and been reported with different input devices in virtual environment tests of task performance. To minimize potential variances, all participants viewed the display environment for the study on the same laptop computer system and with the same input devices. Navigating through the environment was accomplished by selecting one of the four arrow keys from the keyboard and the computer system mouse. Using the same system provided consistency with computer system considerations and minimizing confounding variables.

Eye Tracking Background

As reported in literature, the ability to track and analyze eye movements can supplement research by providing important data on human responses to images and the analysis of these responses to attention. A common goal of eye movement analysis is the collection and evaluation of fixation detections and saccade movements of the eye over particular objects that are viewed. The value in assessing eye movements is the ability to quantify what the eye is in fact fixating upon and how long the eye is fixing upon a specific object or area (Salvucci & Goldberg, 2000). Eye movement analysis is important to effectively understand differences in image resolution and how the eye reacts to these differences and in turn responds to them. Since this study implements an eye tracking system for data collection, the specifics of the system and methods of data collection are reported later in this chapter.

As indicated by the research, eye tracking data can provide critical information to validate human eye movements and allow for a better understanding of object-based attention and what participants are viewing. Literature also discusses the need for additional research with eye tracking studies in more rich and authentic environments and in more virtual environment treatments conditions.

Logistics of the Research Area and Equipment

Research Area

A research area was set up in a vacant faculty office on the college campus for the study and coordinated through the researcher's major professor. The office contained of a table, computer desk, a chair, computer equipment for the study and shelves. The chair was positioned in front of the computer desk so that participants could sit in the chair while being administered the treatment.

Copies of the Study Descriptor (see Appendix C) and the Participant Sign-in Sheet (see Appendix B) were placed in the research area. Several pens were brought for participants to use for the different assessments. The researcher also had business cards that were to be given to students to take back to their instructor for possible extra credit for participating in the study.

Large manila envelopes were used to store the different data collection instruments and to track individual participant data. Copies of the SUS© and VEPQ were numbered, stapled and placed in each of the envelopes. Each envelope was then placed in the research area. All of the different instruments were numbered including the top of each of the large envelopes to correspond to the number assigned to each of the different participants in both the pilot study and the final study. The numbers were the only identifiers of individual students as was done as part of the exempt status of the IRB. The researcher was in the room with the students but did not interact with them. The door was left open and other participants waited outside of the research area in a common space of the hallway that had chairs and a sofa.

Computer Equipment Used in the Research

The researcher's laptop computer, eye tracking equipment and traditional PC computer tower were used for the study as discussed. Both the laptop and traditional computer were needed for the research to accommodate the eye tracking system hardware. The computer systems were comprised of a Dell Vostro 1400™ laptop computer and a Gateway Multimedia PC™ tower with supporting monitor, keyboard and mouse. Specific eye tracking equipment related to both systems was installed prior to the treatments being administered to participants. Participants used the researcher's laptop computer to view and use the virtual environment treatments.

Setup of the Eye Tracking System Equipment

An Ethernet crossover cable and supporting script specific to the eye tracking system was installed between the laptop computer and traditional PC tower. This allowed the participants to access the virtual environment on the laptop while the traditional PC tower communicated with the display of the laptop computer and ran the supporting eye tracking software and numeric calculations. The lipstick eye camera used by the eye tracking system and support was set up on the table in front of the laptop. The supporting eye tracking data was feed through the lipstick camera and into the PC tower where the data packets were calculated by the system software. A frame grabber card that converted the eye tracking data was installed on a PCI slot on the back of the PC tower and the supporting software was installed. The mouse was connected to the laptop so that participants had access to the laptop and mouse while using the virtual environment. Specifics of the eye tracking system and data collection are discussed later in this write-up.

Instrumentation and Data Collection Tools

Several instruments and tools were used for data collection purposes. The following section discusses each of the instruments used in the study. This includes the prescreening Phase I and the actual study instruments used in Phase II.

Mental Rotations Test (MRT)

The Mental Rotation Test (MRT) developed in 1978 (Vandenberg & Kuse, 1978) is designed to measure an individual's spatial ability and has been used to study the development of spatial ability. The instrument is a paper-based test that is composed of a series of 3-dimensional cubes represented as rotated two-dimensional drawings. The test includes 20 items. Each test item includes a sample criterion test image and four possible rotated outcomes, two of which are correct representations of possible rotations of the criterion image; the other two depict outcomes that are not possible rotations of the criterion image. Test takers are asked to identify which two of the four outcomes presented are represented rotations of the outcome image. They are instructed to put a check mark in the checkboxes located under the correct image rotations. 2.0 points are awarded for each correct answer which must include two correct responses for each item.

Raw scores are compared to a normed centile group by age and gender to obtain individual user's spatial ability score. The norm percentiles for the development of the MRT was based on scores obtained by participants in age groups ranging from 14 – 70. Groups were broken down into five different age ranges for both males and females. For males, age group 14 – 20 had an N = 1198, age group 21 – 30 had an N = 123, age group 31 – 40 had an N = 566, age group 41-50 had an N = 676 and age group 51- 70 had an N = 124. For females, age group 14 – 20 had an N = 1228, age group 21 – 30 had an N =

94, age group 31 – 40 had an N = 449 , age group 41-50 had an N = 932 and age group 51- 70 had an N = 303.

Possible raw score ranges are from 1 to 40. The maximum score possible for the instrument is the 100th percentile the norm group as reflected by specific age and gender. A high score on the MRT indicates a high level of spatial ability and spatial problem solving ability. The distribution of the participant MRT scores appear in Appendix R. For the purposes of this research, volunteers who scored above the 50th percentile based on the normal sample score description were considered to demonstrate acceptable levels of spatial ability performance for the participation in the experimental study.

Reliability of the MRT Test

The MRT has been used with high reports of reliability (Vandenberg, and Kuse's, 1978). Their findings of reliability and consistency with the MRT include a Kuder-Richardson 20 = .88 reliability, indicating high internal consistency, and a test – retest reliability of .83.

Quabeck (1997) also reported reliability ratings for the MRT, but noted differences in gender scores related to time differences. He evaluated the Mental Rotation Test for sex differences, performance, and split-half reliability, with 52 female and 55 male undergraduate psychology students. Spearman-Brown reliability coefficients were reported for attempted items obtained during a timed six-minute time period; .93 and .85 were reported for ratio items score and .86 for item scores (Quabeck, 1997). Differences in gender performance were reported only in one section and attributed to performance factors. This may relate to research with time constraints and the degree of completion of test items among female participants. Differences were reduced further when ratio scores were used. Voyer (1997) reported additional research on the impact of time constraints in using the MRT. Two hundred and seven females and 155 males were given the MRT, in both timed and in untimed conditions. Results indicate significant gender differences on timed tests, but not on the untimed test.

Validity of the MRT Test

Evidence to support the validity of the MRT has also been reported in several research studies. Sanders, Soares and D'Aquila (1982) used the Mental Rotations Test to evaluate 672 female and 352 male college participants between the ages of 17 to 25 in one of two studies to examine spatial visualization. Results indicate male participants scored significantly higher than female participants, with gender accounting for 16% of the total variance of scores. However, additional studies, such as those conducted by Peters (2005) found that gender differences in scores on the MRT were related to time. Three studies were conducted with large participant groups. Group one with 1,765 participants using standard time limits to complete the instrument shows that fewer female participants finished the assessment than males. Additional studies examined time to complete the instrument based upon the hypothesis that females use more time to evaluate and verify that visual items that do not match do indeed not match, than do males, which affected completion times (Peters, 2005).

Other support of validity in using mental rotation tests as indicators in areas of education and training have been reported. Forty-four pilot trainee's visual-spatial abilities were evaluated using a mental rotation test to predict training of pilots. Reported scores had a significant correlation with scores of actual pilot navigation and navigation training indicating the test's predictive validity (Singh, Thakur, & Gurmukh, 1994).

Interestingly, the MRT has been used to evaluate the relationship between differences in the SAT mathematics assessments and mental rotation ability among 760 students planning for college. Math aptitudes scores were predicted for all females by the MRT score results. This varied for males because of differences in the sample. These findings indicate that spatial ability may indicate and predict differences in math aptitude.

The Mental Rotations Test in this study was used to minimize differences in the spatial ability of participants. Significant differences in spatial ability among the participants could have affected their ability to use and to navigate in a virtual environment which would have impacted their wayfinding performance. The MRT has been used in a number of studies to examine the difference in spatial ability between gender and overall student performance and to evaluate the development of spatial ability in high school and college age students. The researcher purchased a copy of the Mental Rotation Test (Vandenberg & Kuse, 1978) from Educational Testing Services. Copies were made for the researcher's own use in the study and to comply with copyright restrictions. A copy of the instrument was not allowed to be included in the Appendix.

Time-on-Task Performance Measure

Time-on-task scores were directly calculated by the computer system and the virtual environment developed in Unreal Tournament™. Time-on-task scripting calculated participant's individual time-on-task performance scores in seconds from the time they began navigating through the environment until they navigated around and entered the figure 8-conference room. There was not a specific score range for these data. A high time-on-task performance score indicates that a participant was taking longer to complete the virtual wayfinding treatment.

Eye Tracking System Measure

An *Arrington Research Total Quick Clamp*® eye tracker system was used to obtain data on participant's eye movements in viewing the desktop interior virtual wayfinding environment including saccade movements and gaze fixation detections. This equipment was used to collect and evaluate eye movements and pauses and to calculate response of the eye to the different image resolution groups in support of object-based visual attention. The *Arrington Research Total Quick Clamp System*® eye tracker system is developed by Arrington Research®. Dr. Karl Arrington developed some of his first eye tracking systems in the early and mid 1990's as part of his postdoctoral research at MIT prior to launching a business devoted to eye movement analysis systems. This system is composed of a combination of hardware and specialized software installed on a computer. This system is a total off-the-shelf system that includes all hardware and supporting software to allow for easy set up and the analysis of discrete calculations of eye movements. The system is a monocular system that uses infrared video and the dark pupil method for tracking eye movements. Specifics of the setup, calibration and operation of the system are discussed in the procedures portion of this chapter.

Eye movements for each participant were recorded by the system's video lipstick camera. The camera tracks the dark pupil of the eye with an infrared light source and this movement is recorded into the computer system by using a frame grabber card. These data were converted and analyzed with the system's *Viewpoint Data Analysis*® software to create individual numeric scores for each participant's saccade movements and gaze fixation detection scores. The equipment provides for a variety of eye movement data collection and does not have a specific range or response scale.

It is also important to note that the system allows for recalibration of the eye and blink suppression both of which can occur when any research is done with eye movements. Blink suppression and recalibration are two of the types of enhancements that help to filter data. Purely summing saccade movements and gaze fixation detections does not necessarily provide accurate time-on-task measures for a specific task as wayfinding.

Validity and Reliability of Eye Tracking Equipment

The validity and reliability of eye tracking equipment and applied use of subsequent data from eye tracking equipment has increased, as equipment and technology have been refined. Ongoing studies support the high level of validity in eye tracking scores and output from the data gathered by using this type of equipment. Studies have used eye tracking equipment with schizophrenia patients and validated the use of eye tracking systems and the scores obtained. A better understanding of smooth pursuit eye movements has been the focus to determine genetic risks of schizophrenia. Hong, Avila, Wonodi, McMahon and Thacker (1995) evaluated data using a head mounted system and a portable eye tracking system. Measures of pursuit performance and gain suggest that both devices were comparable (ICC = .96).

As discussed in the literature, there is a wide variety of different types of eye tracking equipment. Nevalainen and Sajaniemi (2004) measured the accuracy of three eye tracking devices by calculating mean distances between recorded points of gaze (in the data files) and requested points of gaze measured with the different tracking software. Two remote systems and one head mounted system were used. Findings report 8.1% to 3.0% of invalid data with using an eye tracker. Reports include that random errors were rare and that the results from the eye tracker are reliable with good repeatability and low standard deviations. Many eye tracker products have controls that allow for monitoring the quality of the data and for recalibrating the system if the eye moves out of the range of the initial settings. Systems can also filter out uncertain data caused by head movements, blinking or distractions by either providing stabilizing bars or head fixed cameras.

System Usability Scale

The System Usability Scale (SUS©) (Brooke, 1996) was developed to evaluate the participants' perceived usability of the computer system that was used in the research. The SUS© is a 10-item pencil and paper measure that uses a 5-point Likert-type response scale ranging from "1 = strongly disagree" to "5 = strongly agree". Ratings are summed to yield a composite score for each respondent's perception of the usability of the computer system. The instrument yields a total score of each respondent that ranges from 0 to 100. High system usability is reported with scores that are closer to 100. Low system usability is reported with scores that are closer to 0. Each test item's score ranges were from 0 to 4. For odd numbered test items (1, 3, 5, 7, 9), the score was the scale position minus 1. For even numbered test items (2, 4, 6, 8 and 10), the score is 5 minus the scale position. The sum of the individual scores were then multiplied by 2.5 to obtain the overall value of the system's usability. The researcher obtained a copy of the instrument from the author. Copyright considerations prohibited electronic duplication of the instrument without the author's consent. For this reason a copy was not provided in the Appendix.

Validity of the SUS©

The validity evidence for the SUS© instrument includes high content face validity because the questions cover areas of usability such as support, training and complexity. *The American Institute of Research* (2001) used the SUS© as part of an evaluation of PC based operating systems. Thirty-six participants' SUS© scores strongly correlated with task T test scores of completion rates and completion times and supported the overall findings of user preference. Hart, Chaparro and Halcomb (2004) used the SUS© in conjunction with guidelines developed by the *National Institute on Aging* and the *National Library of Medicine* (2002) to evaluate seniors' response to websites. Findings indicate strong correlations (.77) between the measures of what seniors rated as the most preferred and easiest of the websites evaluated.

Virtual Environment Presence Questionnaire (VEPQ)

As is indicated in the literature, presence is a key determiner in evaluating learner's virtual environment experience and perception of usability of a virtual environment. The VEPQ was originally created to evaluate presence in virtual environments for the military. The design of the instrument is based upon the concept that the more user control and engagement that occurs in a virtual environment, the more participants feel a sense of presence. Presence is also a sign of attention and sensory and environmental factors as indicated by Witmer and Singer (1998). The VEPQ was used to assess participant's perception of presence and in turn usability in using the virtual environment. Several virtual environment tasks have shown that presence is related to task performance.

Development of the instrument included identifying factors that influence presence in a virtual environment such as user control and sensory and realism factors that may affect this. The instrument was developed to test subscale factors that influence presence with individual items. All of the test items for the instrument measure perception as the single construct. Subscale factors include involvement and control, naturalness, resolution and interface quality (Witmer & Singer, 1998).

The original instrument consisted of 32 items which were refined over time. The version of the instrument used for this research was the revised version which consists of 20 items. The different items are designed to obtain information on participants' approach to using the environment, their level of engagement, usefulness and interest in the VR interface. The instrument uses a 7 – point Likert-type response scale with options ranging from "1 = not compelling" to "7 = very compelling". Item scoring involves analyzing responses to each of the questions and calculating the overall score average. The researcher obtained a copy of the instrument with the understanding that it would be used only for personal research and would not be duplicated electronically. For this reason a copy is not provided in the Appendix.

Reliability of the VEPQ

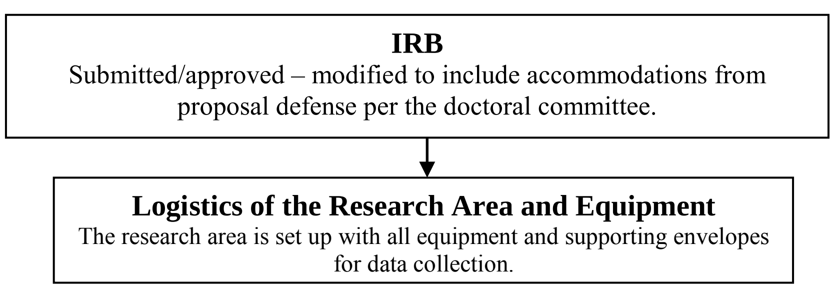
The current version of the instrument was refined to contain 20 items after comprehensive testing and item analysis on the instrument. Total item analysis scores for the instrument show high reliability for the questionnaire. Internal consistency as measured by Cronbach's Alpha was reported as 0.88 (n = 132), (Witmer & Singer, 1998). Reliability of the VEPQ indicates that the instrument has high reliability.

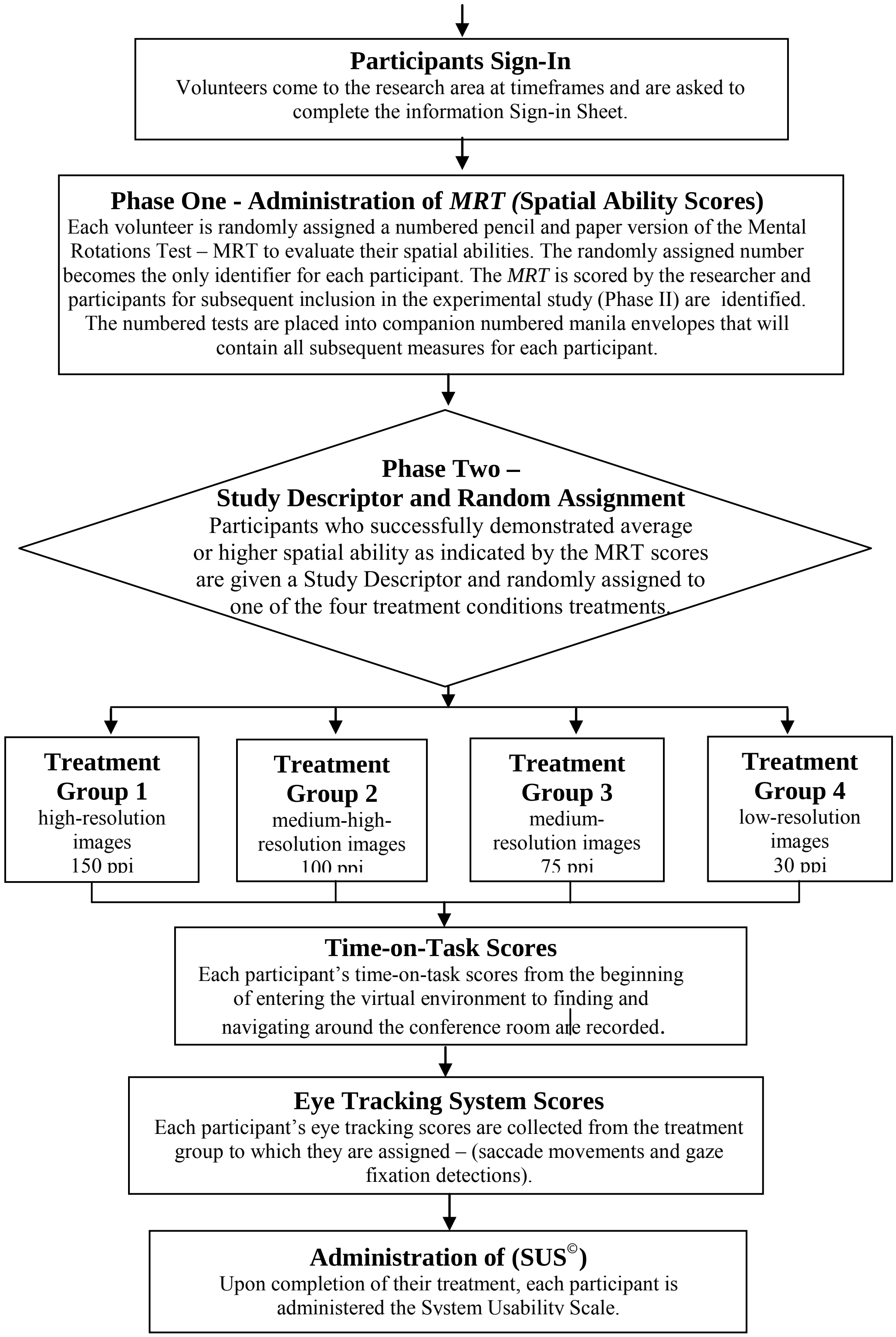
Research also indicates that design considerations for the instrument relate to presence as a sign of attention. The basis of the questionnaire is on motivation and factors that promote involvement (Witmer & Singer, 1998). The more immersed participants are in a virtual environment, the more they should feel that they are interacting and the more usable the environment may appear. One hundred thirty-two participants in four experiments were used in the development of the instrument. The VEPQ has been used in virtual environment research as a post treatment questionnaire to further evaluate participants' reactions to virtual environments and overall level of immersion and engagement.

Each of the instruments and tools that have been discussed were used in the research study. The distribution and use in the data collection of the research are discussed in depth in the procedures portion of this chapter.

Research Procedures

Figure 2 illustrates the process and flow for the overall research procedures. The specific details of each of the steps involved are discussed in the following write-up. Each instrument and data collection tools that was previously discussed and how they were distributed and used is refined with more detail.




Participants Sign-In
Volunteers come to the research area at timeframes and are asked to complete the information Sign-in Sheet.
Phase One - Administration of *MRT (*Spatial Ability Scores)
Each volunteer is randomly assigned a numbered pencil and paper version of the Mental Rotations Test – MRT to evaluate their spatial abilities. The randomly assigned number becomes the only identifier for each participant. The *MRT* is scored by the researcher and participants for subsequent inclusion in the experimental study (Phase II) are identified. The numbered tests are placed into companion numbered manila envelopes that will contain all subsequent measures for each participant.
Phase Two –
Study Descriptor and Random Assignment
Participants who successfully demonstrated average or higher spatial ability as indicated by the MRT scores are given a Study Descriptor and randomly assigned to one of the four treatment conditions treatments.
Treatment Group 1
high-resolution images
150 ppi
Treatment Group 2
medium-high-resolution images
100 ppi
Treatment Group 3
medium-resolution images
75 ppi
Treatment Group 4
low-resolution images
30 ppi
Time-on-Task Scores
Each participant's time-on-task scores from the beginning of entering the virtual environment to finding and navigating around the conference room are recorded.
Eye Tracking System Scores
Each participant's eye tracking scores are collected from the treatment group to which they are assigned – (saccade movements and gaze fixation detections).
Administration of (SUS©)
Upon completion of their treatment, each participant is administered the System Usability Scale.

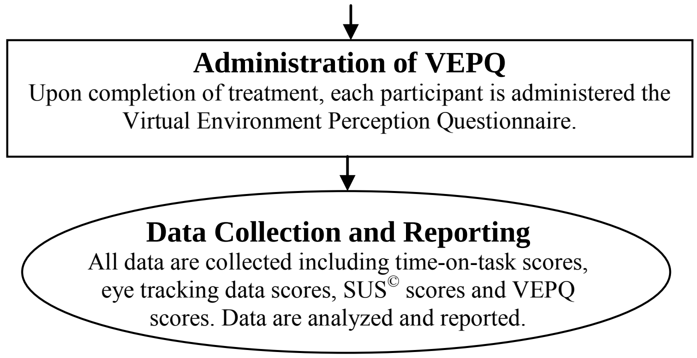


Figure 2. *Procedures of the Research Design*.

Institutional Review Board

An initial Institutional Review Board exempt research application for the study was submitted to the university. The initial approval was obtained with the researcher providing samples of the different instruments to the IRB office for review. An IRB modification form was also completed, submitted and approved by the IRB office after the proposal defense to accommodate modifications to the study per the researcher's dissertation committee. These changes are mentioned in the pilot study discussions. Only after the IRB modification was approved did any of the research begin.

Phase I Administration of the MRT

Students who volunteered to participate in the study were asked to come to the office where the research was being conducted at specific time frames over a five-day period. These times included morning and afternoon hours during and directly after the basic teacher education technology course that students were enrolled in on Monday through Friday of week ten of the spring 2008 semester. Volunteers did not have specific appointments but could come at anytime during the preset times. As individual students came to the research area, they were greeted and randomly assigned a pre-numbered paper-based copy of the MRT test and a pencil. Volunteers were asked to read the test instructions and to ask the researcher if they had any questions prior to starting their test. They were to follow the test instructions and to check the two correct checkboxes that indicated the correct rotations of the criterion image for each of the 20 items. Each item that represented the criterion image rotated in a different position. Participants sat in chairs and completed the MRT.

As mentioned, each copy of the MRT was pre-numbered. In this manner, each participant was identified only by the randomly assigned supporting number on the MRT instrument. Each MRT number also correlated to a numbered manila envelope with copies of the other instruments used in the research. Each of these copies had the same corresponding number written on the top of each instrument by the researcher. By assigning random numbers to participants and correlating envelopes with the other instruments that were pre-numbered, the confidentiality requirements for each participant and for the exempt status of the IRB was maintained. The only demographic information provided by participants on the MRT instrument was their age and gender, which was recorded on each supporting numbered manila envelope which was used to correlate scores with the normed percentile group provided in the MRT key.

On the completion of the MRT, volunteers were asked to hand in their test to the researcher and to wait for a few moments outside of the research area. A small commons area with chairs and a coach was located directly across from the research area. As each volunteer completed the MRT, each test was scored by the researcher and placed into the supporting envelope. Those volunteers who did not score in the 50^{th} percentile were thanked and told that they were free to return back to their classes or other activities. Volunteers whose scores were in the 50th percentile or higher were selected to participate in the experimental study. Only volunteers who scored higher than 50% compared to the normed percentile by their age and gender from the MRT key were selected for participation in the final study. A score of less than 50% as indicated by the MRT would indicate less than average spatial ability. Four students who volunteered from the classes did not score in the 50th percentile or higher on the MRT and did not participate in the experimental study. These specifics are discussed in Chapter IV of the research. To reduce potential for significant gender differences in performance among participants, the test was administered in an untimed format. This, as indicated by research, minimized potential confounding differences in the gender and amount of completion time.

Phase II Experimental Study

Participants who met the spatial ability criteria for participation in the study were advanced to Phase II of the study. The Study Descriptor (see Appendix C) was given to each of the participants who were asked to read it prior to their participation in the study. The descriptor noted that speed counted in the environment and that participants should move as quickly as possible through the environment to the conference room. Each participant was asked if he or she had any questions about the research or purpose of the study after reading the Study Descriptor. Participants were told that they would be given additional instruments to complete after the virtual environment treatment.

After reading the Study Descriptor, each participant was assigned one of the pre-numbered packets that corresponded to the randomly assigned and numbered MRT test that was previously completed by the participant. This allowed the supporting SUS© and

VEPQ instruments that were previously placed by the researcher into each envelope to correspond to the numbered MRT number test. The instructor wrote the gender of the participant on the supporting envelope and recorded his or her age. Spaces were left on the outside of each envelope to record each participant's time-on-task score and the treatment group to which he or she was randomly assigned to. This information was recorded by the researcher on each envelope as participants progressed through the study.

Next, participants were asked to sit in the chair and to adjust the equipment as needed. The researcher described the eye camera and how the equipment calculated the eye movements and recorded these into the computer. Adjustments were made to the eye camera equipment placement as needed and to ensure that the crossover cable, laptop image and eye tracking software were functioning properly. After each participant was comfortable, and positioned himself or herself in front of the laptop and adjusted the mouse, the participant was provided with an opportunity to use the mouse and arrow keys in the virtual environment and to become familiar with navigating.

Participants were instructed to let the researcher know when they were ready to begin the actual treatment. Once participants were ready, they were randomly assigned a fresh image of one of the four virtual environment treatment groups. A script randomly spooled one of the four treatment group options and limited the number of times that any one treatment could be administered. The maximum number that each treatment could be randomly spooled was 15 times, which accommodated for the 60 participants across the four treatment groups. This script was adjusted as each of the four students who asked to stop the study dropped out, so that students were still randomly assigned and the cap was kept at 15 participants per each of the treatment groups. The treatment group each participant was randomly assigned to was recorded by the researcher on the individual participant's envelope.

Time-on-Task Performance Scores

Time-on-task scores were directly calculated by the computer system and the virtual environment developed in Unreal Tournament™. The virtual environments developed for this research were programmed to calculate and record participant's time-on-task scores from the time they began their treatment until they completed their treatment in cumulative seconds. As each image of the virtual treatments loaded, a ghosted versions of the main interface displayed the words "Ready" and "Go" sequentially. The interface became full color as participants began their treatment environment and a preset timing script began to calculate time-on-task for each participant. Time-on-task scripting calculated participant's individual time-on-task in seconds from the time they began navigating through the environment until they navigated around and entered the figure 8-conference room. Time-on-task scores displayed on screen once participants found the conference room. Participants were able to view their scores and they could also continue moving in the environment after their score appeared on screen if they desired; however, this additional time was not calculated by the system. Individual time-on-task scores were recorded by the researcher on the appropriate space of each envelope as each participant completed their treatment.

Administration of the Eye Tracking System

Simultaneously, as participants moved through the virtual environment on the researcher's laptop computer, eye movement data were calculated and recorded in the *Arrington Research Total Quick Clamp System*™ supporting eye tracker software on the

PC computer tower that was assigned to the eye tracking system. The data gained from saccade eye movements and gaze fixation detections examined participant's responses to the different image resolution groups and the impact to their overall object-based visual attention. Each participant's eye was calibrated to the eye tracking system by having them position themselves properly in front of the lipstick camera. The supporting equipment was adjusted for each participant. Saccade movements and gaze fixations were selected from the menu of available options when the system was set up. Blink suppression and eye drift recalibration were also used to ensure the accuracy of the participant's eye movements.

Participant's eye movements registered through the lipstick camera and into the special frame grabber card installed on the empty PCI slot on the traditional PC tower. As the eye moved, packets of numeric data indicating the movements and pauses of the eye were sent in real time in ASCII format to the computer system. Plots of the x and y positions of the eye for each participant as they viewed their specific environment were recorded in the software as a separate file. Each of these files were later analyzed through the special *ViewPoint Data Analysis*™ software that accompanies the system and output into numeric data as a text file format at the completion of the study. Each participant's data were saved into a file and numbered to coincide with their randomly assigned participant number.

Administration of the SUS©

Upon completion of the virtual treatment, each participant was given a pen or pencil and asked to complete the SUS© questionnaire. Participant were given their pre-numbered copy of the SUS© and asked to sit either in a chair away from the computer or in the chairs outside of the door of the research area to complete the instrument. They were told that they would have one additional questionnaire to complete after they finished the SUS© in order to obtain a business card to show their instructors that they had participated in the study. Participants were instructed to let the researcher know when they completed the SUS© so that they could obtain the last questionnaire.

Administration of the VEPQ

The pencil and paper version of the Virtual Environment Presence Questionnaire (VEPQ) was administered to each of the participants upon the completion of the SUS©. After completing the VEPQ, participants handed their copy in to the researcher along with their SUS© instrument. The researcher placed these two instruments into the supporting numbered envelope to be scored at the completion of the research. Participants were given a business card to validate that they had participated in the study and to take back to their instructor to obtain the possible extra credit points for participation from their instructors.

Data Collection and Reporting

Upon completion of the research, all of the envelopes that contained the supporting instruments were collected and the computer systems taken to the researchers home. The data files for each of the participant's eye tracking scores were analyzed with the *ViewPoint Data Analysis*™ software and output into numeric data as a text file format. Each file was then output into an Excel spreadsheet and evaluated using SPSS version 16 for statistical analysis. The different instruments were scored.

Supporting tables and graphic representations for each of the data measures and the overall analysis are reported in Chapter IV of the research. From these findings, an analysis of each of the research questions and supporting hypothesis were synthesized and discussed. Final considerations include discussions for follow on research opportunities and an overall reporting on the research design and findings.

Pilot Study

Prior to conducting the formal study, a pilot study was undertaken in the spring of 2008. Specifics of the pilot study research and findings are reported in Appendix A. Participants in the pilot study were 12 volunteers drawn from the same 2000 level teacher education technology course from which the final sample was selected. The purpose of the pilot study was to assess the feasibility of the research procedures and design and to address several changes and refinements requested by the dissertation committee after the researcher's proposal defense. The virtual environment was modified to eliminate any directory map image and research on navigating in game environments was added to the literature review. The committee suggested the inclusion of a questionnaire to evaluate learner responses to the virtual environment. For this reason, the VEPQ was added to the study.

The pilot study followed all procedures that were discussed and used all of the different instruments in Phase 1 and Phase II of the study. The pilot allowed the researcher to evaluate the instruments and logistics, use the virtual environment and analyze the data. In addition, the pilot study validated the feasibility of the research, logistics in using the equipment and the different research instruments. For these reasons there were no modifications made to the design for the final study. The analysis of the pilot data showed trends that time-on-task scores were affected by differences in image resolution and that participant's perception of the usability of the virtual environment was high. More detailed information of the pilot study findings are discussed in Appendix A.

Chapter Four

Results

Description of the Participant Sample

The experimental study was conducted in the spring of 2008 with 60 participants from a sample of education majors at a major research university in the southeastern portion of the United States who were enrolled in a 2000 level teacher education technology course. The age range of the participants in the sample was 18 to 38 years old. To ensure that an equal number of male and female participants were assigned to each of the four different treatment groups as requested by the dissertation committee, four males and eleven females were randomly assigned to each of the four treatment conditions. Four additional students beyond the final 60 participants participated in the experimental study, but their data was not used as discussed later in this chapter. The demographic data of the participant sample are reported in Table 1.

Table 1. *Characteristics of the Participant Sample by Image Resolution Group*.

	IR^1	IR^2	IR^3	IR^4
Gender				
Females	11	11	11	11
Males	4	4	4	4
Age Range (years)				
Age 18 - 21	7	6	8	7
Age 22 - 27	5	7	6	6
Age 27 - 32	2	1	1	1
Age 32 - 38	1	1	0	1

IR^1 = image resolution group one (150 ppi) IR^2 = image resolution group two (100 ppi)
IR^3 = image resolution group three (75 ppi) IR^4 = image resolution group four (30 ppi)
N = 60

The age range of participants as indicated in Table 1 shows a fairly equal age distribution across each of the four different resolution treatment groups.

Minimizing for Confounding Variables

Minimizing confounding variables as discussed earlier in the method section such as prior knowledge was insured by having students complete the participant Sign-In Sheet. Students were asked to sign on the Sign-In Sheet (see Appendix B) and to check the appropriate check boxes if they had any prior experience, courses, or training in architecture, perspective drawing or drafting prior to participating in the study. None of the 60 participants in the final sample reported any prior experience in or architecture, perspective drawing or drafting which could have had an effect on their performance in using the virtual wayfinding treatment. Since all participants were from the same basic teacher education technology course, each had basic skills in computer usage since the study was done mid-term in the semester after several weeks of applied computer skills were taught in their classes. The gender distributions across treatment groups also assured that the ratio of male and females were evenly distributed as reported in Table 1. Four male and eleven females students were randomly assigned to each of the four different treatment groups.

Phase I Mental Rotation Test Scores (MRT)

As discussed earlier, the Mental Rotation Test was administered in Phase I of the research study. The MRT was used to screen volunteers' spatial ability. All participants in the experimental study had to score above the 50^{th} percentile of the norm group (considered average) or higher to participate in the study as an indicator of average or better than average spatial ability. Individual participant Mental Rotation Test scores for the participant sample are reported in the Appendix R. As is shown, the total percentage earned on the test ranged from 50% to 100%.

As previously discussed, four of the initial volunteers did not score in the 50^{th} percentile and were not participants in the experimental study. These students were thanked for their time and told they were free to go back to their classes. Individual scores were compared to a normed percentile group by age and gender. As discussed, the percentiles of spatial ability as measured by the MRT fluctuate with gender and increasing age. Table 2 reports the mean percentage MRT score by treatment group.

Table 2. *Means and S.D. of Mental Rotation Test Scores by Image Resolution Group*.

Group	Mean	S.D.	Min.	Max.
IR[1]	74.66	0. 043	0.50	1.00
IR[2]	73.46	8.053	0.52	95.64
IR[3]	72.46	6.620	0.52	100.00
IR[4]	69.53	0.036	0.52	0.94

IR[1] = image resolution group one (150 ppi)   IR[2] = image resolution group two (100 ppi)
IR[3] = image resolution group three (75 ppi)   IR[4] = image resolution group four (30 ppi)
N = 60

As is indicated in Table 2, the mean MRT scores for each group were 74.7% for Group 1, 73.5% for Group 2, 72.5% for Group 3 and 69.5% for Group 4. The group mean scores represent the spatial ability of the participants, represented as the norm percentile by age. The skill levels were similar. In treatment Group 4 the spatial ability skill levels were slightly lower (69.53). To determine if there was a significant difference in mean scores between the groups, a one-way ANOVA was computed. The results of the ANOVA are reported in the Table 3.

Table 3. *Analysis of Variance for Mental Rotation Test Scores by Image Resolution Groups*.

Source	df	Sum-of-Squares	Mean-Squares	*F*	*p*
Between Groups	3	1466.5297	488.8432	1.1995	.3184
Within Groups	56	22822.2196	407.5396		
Total	59	24288.7493			

The results from the one-way ANOVA indicate that there is not a statistically significant difference in MRT mean scores of the image resolution groups $F(3, 56) = .1.1995$, $p > .05$. The effect size is 0.25. This is important because the MRT means indicate that the groups had similar spatial abilities and that none of the group means was statistically significant from the others.

Phase II

As discussed, volunteers had to score above the 50^{th} percentile of the MRT test as an indicator of average or higher spatial abilities to be selected for participation for Phase II of the research and to participate in the experimental study. The results of the study addressed the three research questions and supporting hypothesis. Each of these questions and their supporting hypothesis are discussed separately.

Results of Research Question I -Differences in Time-on-Task Performance Scores Based on Image Resolution

The first research question and hypothesis evaluates time-on-task performance scores in the desktop interior virtual wayfinding treatment as a function of the differences in image quality in the different image resolution groups:

R_1: Is there a significant difference in time-on-task performance in a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

H_1: Changes in image resolutions of 150, 100, 75 and 30 ppi significantly affect user performance as measured by time-on-task in a desktop interior virtual wayfinding environment.

To answer the research question participant time-on-task scores were compared across treatment groups. Data reporting includes individual scores of time-on-task performance, summary data of time-on-task performance scores by treatment group, a one-way ANOVA to evaluate the significant effect of the different image resolution groups on time-on-task performance and Tukey's post hoc analysis to compare group means and identify which group's time-on-task performance scores were significantly different from the others. All data analysis was conducted using SPSS and reported in the supporting discussion, tables, and Appendix.

Time-on-task performance scores for each of the 60 participants are reported in Appendix S. Means and standard deviations of time-on-task performance scores by participant group are reported in Table 4. Measures reported by group were 67.46 seconds for treatment Group 1 (150 ppi), 86.06 seconds for treatment Group 2 (100 ppi), 175.73 seconds for treatment Group 3 (75 ppi), and 217.46 seconds for treatment Group 4 (30 ppi).

Table 4. *Means and S.D. of Time-on-Task Performance Scores by Image Resolution Group.*

Group	Mean	S.D.	Min.	Max.
IR^1	67.46	29.43	26.93	119.00
IR^2	86.06	32.01	21.30	156.60
IR^3	175.73	45.10	74.00	233.74
IR^4	217.46	63.10	123.70	318.09

IR^1 = image resolution group one (150 ppi) IR^2 = image resolution group two (100 ppi)
IR^3 = image resolution group three (75 ppi) IR^4 = image resolution group four (30 ppi)

N = 60

The data represented in Table 4 suggests the mean time-on-task performance scores varied considerably between the different image resolution groups with the highest resolution group (Group 1) completing the task in the least amount of time and the lowest resolution (Group 4) completing the task in the most amount of time. Treatment Group 4 also showed the largest variability in scores (S.D. 63.1). Observations of participants during the research study indicate that all participants in treatment Group 4 had a tendency to take more time to complete the test and that they had a wider range of scores, but they are still normally distributed. Minimum and maximum scores were similar for treatment group one and two with considerable differences between treatment groups three and four.

It is important to note that four participants in the experimental groups asked to stop the study. Specifics of this are discussed in the following chapter. One participant was randomly assigned to treatment group three and three participants were randomly assigned to treatment group four. Since the experimental task was to be completed by each individual participant. Additional participants were added and randomly assigned to one of the four treatment groups as discussed until each of the four treatment groups had 15 final participants and a total N of 60 was achieved.

To determine if there was a significant difference in time-on-task performance scores between image resolution groups, data were subjected to one-way ANOVA. Time-on-task scores were normally distributed and did not contain any significant outliers within each treatment group. The standard deviations reported were more or less similar among the different treatment groups and the homogeneity of variances was satisfied.

Based on these data and that all assumptions were met, data were entered into SPSS to evaluate the statistical significance. The results of the ANOVA are reported in Table 5.

Table 5. *Analysis of Variance of Time-On-Task Performance Scores by Image Resolution Group.*

Source	df	S.S.	M.S.	*F*	*p*
Between Groups	3	231046.492	77015.497	38.967	.000
Within Groups	56	110679.001	1976.411		
Total	59	341725.493			

The results from the one-way ANOVA indicate a statistically significant effect of image resolution levels on participants' time-on-task performance scores $F(3,56) = 38.967$, $p < .05$. The effect size is large with a value of 3.37.

A scatter plot of the time-on-task performance scores by image resolution group is shown in Figure 3. This visually represents the distribution of the time-on-task performance scores by image resolution groups.

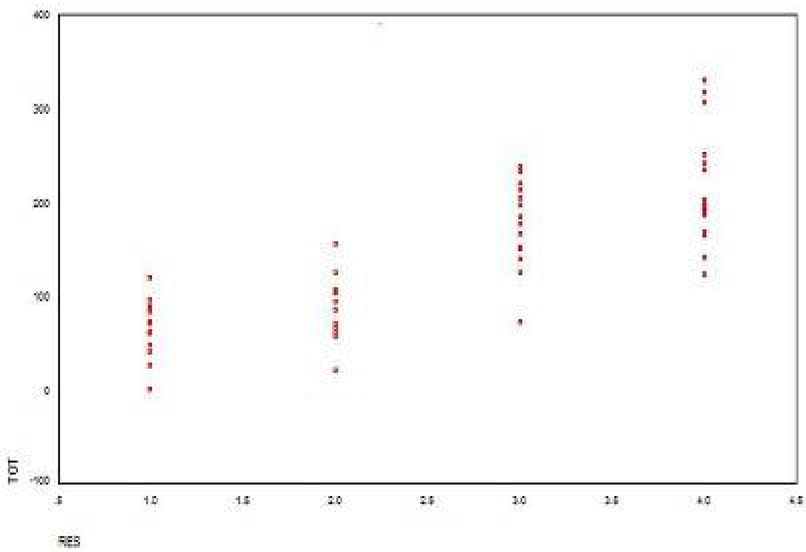


Figure 3. *Final Study - Scatter Plot Analysis of Variance for Time-On-Task Performance Scores by Image Resolution Group.*

Tukey's post hoc test was used to determine the treatment groups between where there were significant differences in time-on-task performance. Results of the Tukey test are reported in Appendix. Results of these analysis reveal time-on-task performance mean scores for image resolution Group 1 was significantly less ($p < .05$) than the mean score for image resolution Groups 3 and Groups 4. In addition, time-on-task performance mean score for Group 2 was also less than the mean scores for image resolution Groups 3 and Groups 4. However, there was no difference in the time-on-task mean scores between Groups 1 and Groups 2 and between Groups 3 and Groups 4. These findings suggest that participants in the treatments with higher resolution images, Groups 1 and Groups 2 took less time to complete the wayfinding task. Images that were at resolution ranges of 150 ppi (Group 1) to 100 ppi (Group 2) aided participant's locomotion and wayfinding time-on-task performance. These participants were able to complete the wayfinding tasks more quickly than participants in groups with lower resolution images. Group 3 (75 ppi) and Group 4 (30 ppi) which had lower resolution images took longer for participants' to complete the wayfinding task. The data also suggests that there is a clustering of time-on-task performance scores related to higher resolution ranges of Groups 1 (150 ppi) and Groups 2 (100 ppi) from the lower resolution ranges of Groups 3 (75 ppi) and Groups 4 (30 ppi).

Results of Research Question II - Differences in Visual Attention as Reported by Eye Tracking Response Scores Based on Image Resolution

The second research question and hypotheses addressed object-based visual attention as measured by eye movement scores in the virtual wayfinding treatment (obtained by the eye tracking system) as a function of the differences in image resolution in the different image resolution groups:

R_2: Is there a significant difference on object-based visual attention in a desktop interior virtual wayfinding environment based upon individual eye tracker data as a function of the change in image resolution of 150, 100, 75 and 30 ppi?

H_2: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect user visual attention as measured by the eye tracker data.

$H_{2.1}$ Changes in image resolution of 150, 100, 75 and 30 ppi in an desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by the saccade movements obtained by eye tracker data.

$H_{2.2}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by gaze fixation obtained by eye tracker data.

Results of the data that address this question and hypothesis include eye movement data collected and analyzed through the *Arrington Research Total Quick Clamp*™ system as discussed in Chapter III. The individual eye data scores for this research are reported in Appendix T and Appendix U of the study. These scores were used to evaluate the overall eye movements for each participant and to compare the different eye movement scores for each of the four different image resolution groups. Data used includes individual scores of saccade movements and gaze fixation detection. A one-way ANOVA was used to determine if there was a significant effect of different levels of image resolution on saccade eye movements scores and object-based visual attention. A one-way ANOVA to evaluate the significant effect of different levels of image resolution on fixation detection scores and object-based visual attention and a Tukey's post hoc test was used as a follow-up test to the ANOVA.

The selection criteria and setup of the study with the *Arrington Quick Clamp System*™ included saccade movements and gaze fixation detections options selected from the system interface prior to the dark pupil calibration of the eye for each participant. Final data packets of the eye movement information for each participant were collected through the software and output into ASCII file format. These data were then calculated through the specialized *ViewPoint Data Analysis*™ software that accompanied the system and output into an Excel file format. Each of the 60 participants' overall saccade movements scores are reported in Appendix T and gaze fixation detections are reported in Appendix U respectively. Table 6 reports overall saccade movement and Table 7 reports overall gaze fixation mean scores by image resolution group.

Table 6. *Summary Data on Saccade Movement Score Averages by Image Resolution Group*.

Group	Mean	S.D.	Min.	Max.
IR^1	0.17	0.24	0.01	0.59
IR^2	0.56	0.39	0.02	1.13
IR^3	0.23	0.24	0.03	0.27
IR^4	0.48	0.43	0.04	1.81

IR^1 = image resolution group one (150 ppi) IR^2 = image resolution group two (100 ppi)

IR^3 = image resolution group three (75 ppi) IR^4 = image resolution group four (30 ppi)

N = 60

Table 7. *Summary Data on Gaze Fixation Detection Score Averages by Image Resolution Group*.

Group				
IR^1	0.65	0.60	0.21	2.42
IR^2	1.18	0.50	0.88	2.46
IR^3	1.34	1.07	0.05	3.65
IR^4	2.56	1.14	0.76	3.84

IR^1 = image resolution group one (150 ppi) IR^2 = image resolution group two (100 ppi)

IR^3 = image resolution group three (75 ppi) IR^4 = image resolution group four (30 ppi)

N = 60

Both types of eye data scores approximated normal distribution of scores. The standard deviations reported were more or less similar among the treatment groups and the homogeneity of variance assumptions was satisfied. A one-way ANOVA was conducted to determine if there were statistically significance differences in eye data scores between treatment groups. Data were entered into SPSS. The results of the ANOVA are reported in Table 8.

Table 8. *Analysis of Variance for Saccade Movement Scores by Image Resolution Group*.

Source	df	SS	MS	*F*	*p*
Between Groups	3	4318.524	4318.524	.742	.393
Within Groups	58	337406.969	5817.362		
Total	59	341725.493			

These findings indicate that there is not a statistically significant difference in saccade movements of the eye based on image resolution levels (with the four different image resolution groups), $F(3,58) = 0.742$, $p > .05$. The effect size is .005. This rejects the $H_{2.1}$ hypothesis that changes in image resolution significantly effects participant's object based visual attention as measured by saccade movements obtained by the eye tracking system. This scanning eye patters indicated by saccade movements was not statistically different between the four different image resolution treatment levels.

To further assess the effect of resolution levels on eye movement, a one-way ANOVA was conducted on gaze fixation detection scores. Assumptions of normality and homogeneity of variance were met. Data were entered into SPSS. The results of the ANOVA are reported in Table 9.

Table 9. *Analysis of Variance on Gaze Fixation Detection Scores by Image Resolution Groups.*

Source	df	SS	MS	*F*	*p*
Between Groups	2	31777.9912	15888.9956	3.662	.036
Within Groups	45	195241.3748	4338.6972		
Total	47	227019.3660			

These findings indicate that there is a statistically significant effect of image resolution level on gaze fixation detection of the eye, $F(2,45) = 3.662$, $p < .05$. The effect size is small with a value of .02.

Tukey's post hoc test was used to determine where the significant differences in fixation detection scores occurred between the different resolution groups. The results of the Tukey test are reported in the Appendix. The results of these analyses reveal that gaze fixation detection mean scores for image resolution Group I was significantly lower ($p < .05$) than the mean scores of Group 3 and Group 4. In addition, the gaze fixation detection mean scores for Group 2 was significantly lower ($p < .05$) than the means scores of image resolution Groups 3 and 4. However, there was not a significant difference in fixation detection scores between Group 1 and Group 2 and between Groups 3 and Group 4. These findings suggest that participants in the treatments with higher resolution images, Groups 1 and Groups 2 took less time to fixate upon an image and had lower fixation scores. Images that were at resolution ranges of 150 ppi (Group I) to 100 ppi (Group 2) were easier for participants to focus on. Images that were at lower resolution ranges of 75 ppi (Group 3) to 30 ppi (Group 4) were more difficult for participants to focus on, took longer to fixate on and had higher fixation scores. The data also suggests that there is a clustering of fixation detections scores related to higher resolution ranges of Groups 1 (150 ppi) and Groups 2 (100 ppi) from the lower resolution ranges of Groups 3 (75 ppi) and Groups 4 (30 ppi).

Results of Research Question III - Perception of Usability of the Virtual Desktop Environment as a Function of Image Resolution

The third research question and supporting hypotheses evaluate the usability of the virtual desktop wayfinding treatment as measured by SUS© and VEPQ scores as a function of the differences in image resolution in the treatment groups:

R_3: Is there a significant difference in the perception of the usability of a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

$H_{3:}$ Changes in image resolution of 150, 100, 75 and 30 ppi in an desktop interior virtual wayfinding environment significantly affect participant’s perception of the usability of the virtual environment.

$H_{3.1}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant’s perception of the system usability of the virtual environment as measured by scores obtained by the System Usability Scale (SUS©).

$H_{3.2}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment as measured by scores obtained by the Virtual Environment Presence Questionnaire (VEPQ).

Data used to answer this research question were collected from participant scores on the System Usability Scale (SUS©) and the Virtual Environment Performance Questionnaire (VEPQ). Individual participant scores for the SUS© were averaged and reported in Appendix V. These data were used to report group averages and an overall usability score for the computer system that was used for the treatment groups.

System Usability Scores

Individual SUS© scores for the 60 final participants are reported in Appendix V. Table 10 reports participant SUS© summary data by treatment group.

Table 10. *Summary of System Usability Scores by Image Resolution Group*.

Group	Mean	S.D.	Min.	Max.
IR[1]	81.80	11.27	62.50	100.00
IR[2]	81.00	11.74	66.40	97.50
IR[3]	79.26	12.41	60.00	95.00
IR[4]	78.26	12.15	60.00	100.00

IR[1] = image resolution group one (150 ppi) IR[2] = image resolution group two (100 ppi)
IR[3] = image resolution group three (75 ppi) IR[4] = image resolution group four (30 ppi)

N = 60

Composite scores for each participant were obtained by calculating scores for each item. Mean SUS© scores by group are reported in Table 11. The overall rating of the usability of the computer system was 80.3% indicating a high participant rating of the system usability.

SUS© score distribution was approximately normal. The standard deviations reported were more or less similar among the treatment groups and the homogeneity of variances were satisfied. A one-way ANOVA was conducted to determine if there was a the statistically significant effect of different image resolution groups on participants' perceived usability of the system as measured by SUS© scores. Data were entered into SPSS. The results of the ANOVA are reported in Table 11.

Table 11. *Analysis of Variance for SUS© Scores by Image Resolution Groups.*

Source	df	Sum-of- Squares	Mean-Squares	*F*	*p*
Between Groups	3	144.727	48.242	.340	.796
Within Groups	56	7939.143	141.770		
Total	59	8083.870			

These findings indicate that there is not a statistically significant difference in the perceived usefulness of the virtual environment as related to the system usability based on SUS© scores of the different image resolution groups $F(3,56) = .340$, $p > .05$. The effect size is .29. Thus, hypothesis $H_{3.1,}$ which states that the system usability of the virtual environment is significantly affected by differences in image resolution groups as indicated by SUS© scores is rejected.

Virtual Environment Presence Questionnaire Scores

Presence suggests attention, which is the result of exchanges and environmental factors that promote involvement (Witmer & Singer, 1998). Individual VEPQ scores are reported in Appendix W. Among the several sub factors under which the individual items fall, the sub factors of Interface Quality (IFQ) and Resolution (RES) are relevant to this study. The questionnaire as discussed earlier consists of 20 items under different sub-factor categories. Appendix W shows the scores obtained by participants for each of the 20 items by treatment groups (IR^1, IR^2, IR^3, and IR^4). The mean scores were also reported for each group.

In order to evaluate the effect of image resolution on each participants' perception of virtual presence, a repeated measures ANOVA using the items (I) as a within subjects' variable and treatment group (G) as the between subjects variable was conducted. All of the 20 items in each of the treatment groups were included in the ANOVA. Results of the repeated measures ANOVA are shown in Table 12

Table 12. *Repeated Measures ANOVA with VEPQ Items.*

Source	df	Type III SS	MS	*F*	*p*
Between Subjects					
Group	3	42.320	14.10	.971	.413
Intercept	1	27763.320	27763.32	1911.275	.000
Within Subjects IT	19	1645.280	86.594	19.382	.000
IT * Group	57	322.013	5.649	1.264	.093

Two sub factors, Interface quality (IFQ) and Resolution (RES) were relevant to the study. The RES sub factor included item #12 and the IFQ sub factor included Items #18, 19 and 20. Since the two sub factors included unequal number of items (1 and 3) the means of each of these group scores could not be compared. Hence, for this analysis, all the items for each of the four treatment groups were considered.

Repeated measures ANOVA showed significant item score main effects and no item score/group interaction effects. This indicates that the way in which the items were answered could have an effect on the way the participant moved through the virtual environment. The perception of presence affects the way participants behave and move around in the virtual environment which can affect the perceived usability of the environment. The between groups repeated measure results does not show any significant group effects. As a result, the different image resolution groups do not have any effect on participant's perception of presence or usefulness of the virtual environment. This rejects hypothesis $H_{3.2}$ that changes in image resolution affect perception of engagement as measured by the *VEPQ*. Individual *VEPQ* scores were reported in Appendix W.

The mean scores by treatment groups were also reported. Table 13 reports the overall item averages of the VEPQ results by treatment group.

Table 13. *Summary of Virtual Environment Presence Questionnaire Overall Item Averages by Treatment Group.*

	IR^1	IR^2	IR^3	IR^4
Virtual Environment Presence Questionnaire Overall Item Averages	5.06	4.49	4.78	4.60

IR^1 = image resolution group one (150 ppi) IR^2 = image resolution group two (100 ppi)
IR^3 = image resolution group three (75 ppi) IR^4 = image resolution group four (30 ppi)
N = 60

As reported in Table 14, the overall item averages for participants out of a scale of 1 - 7 was 5.06 for treatment Group 1, 4.49 for treatment Group 2, 4.78 for treatment Group 3 and 4.60 for treatment Group 4. On an average, participants of Group 1, the highest resolution group, scored slightly higher on the questionnaire than the other treatment group participants. The range of average scores for treatment Group 2, Group 3 and Group 4 were close 4.49 – 4.78. The average scores of treatment group one indicated a slightly greater sense of engagement and presence in using the virtual treatment with higher resolution wayfinding images.

As discussed, a variety of subscale factors are used as modifiers of presence in the VEPQ. Items 18, 19, 20 in particular are sub-factors of interface quality in indicating virtual environment presence and directly related to this research on differences in image quality. Items 18 and 19 are worded so that lower scores indicate higher presence. Item 18 score averages among each of the four treatments were identical for treatment group one, two and three with an average score of 2.06. Treatment Group 2 was slightly lower with an average score of 1.86.

Item 19 average scores ranged more among the different treatment groups. Treatment Group 1 average scores were 1.60, treatment Group 2 average scores were 1.73, treatment Group 3 average scores were 2.46 and treatment Group 4 average scores were 2.73. Treatment groups one and two with higher image resolutions had average scores that were similar. Also, treatment group three and four which had lower image resolution had average scores that were similar. This indicates a slight relationship of participant scores to differences in higher vs. lower interface quality.

Item 20 average scores among the different treatment groups varied. Treatment Group 1 average scores were 5.66, Group 2 were 5.20, Group 3 were 4.86 and Group 4 were 4.93. Again, treatment groups one and two with higher resolution images had similar scores and treatment groups three and four with lower resolution images had similar scores.

Item 12 is considered a sub-factor of resolution in indicating virtual environment presence and is related to this research on differences in image resolution. Average scores of treatment Group 1were 6.0, Group 2 were 5.46, Group 3 were 4.80 and Group 4 were 4.60. Again similar groupings of average scores among the higher resolution images of treatment group one are indicated and the average scores of lower resolution images of treatment groups three and four. This indicates slightly higher participant scoring averages of resolution for the higher resolution treatment groups one and two.

Summary of Findings

The study examined the effects of image resolution on locomotion tasks through a desktop interior virtual wayfinding environment as measured by time-on-task performance scores. The study also examined the role of image resolution to object based visual attention on participants' physical eye movements and the perceived usability of the virtual environment as these relate to locomotion tasks. The following is a summary of the results of the analysis for each of the research question and hypothesis.

Results of research question one and the supporting hypothesis address the effect of image resolution on locomotion tasks through the virtual environment related to time-on-task performance scores.

R_1: Is there a significant difference in time-on-task performance in a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

H_1: Changes in image resolutions of 150, 100, 75 and 30 ppi significantly affect user performance as measured by time-on-task in a desktop interior virtual wayfinding environment.

Data from the one-way ANOVA of time-on-task performance scores by image resolution indicates that there was a statistically significant difference between treatment groups and that there was a large effect size. A Tukey post hoc analysis showed that there was a significant difference for time-on-task performance scores for image resolution groups IR^1 and IR^2 from time-on-task performance scores of image resolution groups IR^3

and IR^4. Resolution had an effect on time-on-task performance in the virtual desktop wayfinding environment. There was also clustering that occurred with similar scores for treatment Groups 1 and Groups 2 from treatment Groups 3 and Groups 4.

Results of research question two and the supporting hypotheses address the inquiry of the effect of image resolution to object-based visual attention in the participant's physical eye movements as attention relates to locomotion tasks.

R_2: Is there a significant difference on object-based visual attention in a desktop interior virtual wayfinding environment based upon individual eye tracker data as a function of the change in image resolution of 150, 100, 75 and 30 ppi?

H_2: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect user visual attention as measured by the eye tracker data.

$H_{2.1}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by the saccade movements obtained by eye tracker data.

$H_{2.2}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by gaze fixation obtained by eye tracker data.

The data from the one-way ANOVA saccade movement scores by image resolution level did not show a statistically significant difference between groups. The hypothesis was rejected. Changes in image resolution did not significantly affect participant's object-based attention as measured by saccade scores. The rapid eye scanning movements of the saccade scores were not significantly different in the four treatment groups.

However, the data from the one-way ANOVA between gaze fixation detection scores and image resolution groups did indicate a statistically significant difference between groups. Tukey post hoc analysis showed that there was a significant difference for gaze fixation detection scores for image resolution Group 1 and Group 2 from gaze fixation detection scores of image resolution Group 3 and Group 4. Even though the rapid eye scanning patterns of saccade movements were not statistically different among the treatment groups, there was a statistically significant difference in fixation detection scores of the different treatment groups. The hypothesis was retained as changes in image resolution affected participant's object-based visual attention as related to eye fixation scores. Resolution had an effect on eye fixation scores in the desktop interior virtual wayfinding environments but not on saccade scores.

Results of research question three and the supporting hypotheses address the inquiry of the effect of image resolution on the perceived usability of the virtual environment as this relates to locomotion tasks.

R_3: Is there a significant difference in the perception of the usability of a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

H_3: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment.

$H_{3.1}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the system usability of the virtual environment as measured by scores obtained by the System Usability Scale (SUS©).

$H_{3.2}$ Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment as measured by scores obtained by the Virtual Environment Presence Questionnaire (VEPQ).

The data from the one-way ANOVA between SUS© scores and image resolution did not show a statistically significant difference between groups. Hypothesis $H_{3.1}$ was not supported by the findings and was rejected. Changes in image resolution did not significantly affect participant's perception of the usability as indicated by the system usability as measured by SUS© scores.

The data from the repeated measure ANOVA showed significant item main effects and no item group interaction effects. The image resolution groups did not have a significant effect of the perception of the usability of the virtual environment by presence as measured by the VEPQ. Hypothesis $H_{3.2}$ was not supported by the findings and was also rejected. Changes in image resolution did not significantly affect participant's perception of the usability of the virtual environment. A comprehensive synthesis of these results and implications are discussed in Chapter Five.

Chapter Five

Discussion

This dissertation study assumed the effects of differences in image resolution on time-on-task performance, object-based visual attention as reported by saccade and fixation eye movement scores, the perception of the usability of the computer system as reported by SUS© scores and the perception of the usability of the virtual environment as reported by presence scores from the VEPQ. Each of these relates to locomotion tasks in virtual environments.

While the specific research results were previously discussed, it is important to synthesize these data to the context of the particular research questions and past findings from literature. A deeper understanding of the inference of the dissertation findings relative to past and possibly future research will also provide a more comprehensive evaluation. This chapter is arranged so that each of the research questions and the supporting findings are discussed. Supporting literature relative to each question is also presented. Future areas of research and recommendations are also presented along with final considerations.

Results and Implications of Research Question One and the Supporting Hypothesis - Differences in Time-On-Task Performance Based on Image Resolutions

The findings of this research indicate that different resolutions affect time-on-task performance scores in a virtual wayfinding environment. A significant difference ($p < .05$)

was reported in the one-way ANOVA of time-on-task performance scores by image resolution groups. There was also a strong effect size. Tukey's post hoc analysis indicates that time-on-task performance significantly differed in image resolution Groups 1 (150 ppi) and Group 2 (100 ppi) from image resolution Group 3 (75 ppi) and Group 4 (30 ppi). The supporting hypothesis was retained as a result of these findings. Changes in image resolutions significantly affect user performance as measured by time-on-task performance in a virtual desktop wayfinding environment.

R_1: Is there a significant difference in time-on-task performance in a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

H_1: Changes in image resolutions of 150, 100, 75 and 30 ppi significantly affect user performance as measured by time-on-task in a desktop interior virtual wayfinding environment.

The ability of a person to move through a desktop interior virtual wayfinding environment was effected by the resolution of wayfinding images as supported by the research findings. The data indicates that time-on-task performance scores were lower for participants with higher image resolution, Group 1 (150 ppi) and Group 2 (100 ppi) than in lower resolution groups Group 3 (75 ppi) and Group 4 (30 ppi). Participants in the lower image resolution groups took longer to navigate though the virtual environment treatment. A review of the previously discussed literature must also be noted as the findings supports these studies.

Support of Literature on Differences of Image Resolution and Performance

The dissertation findings support the inference that performance within virtual environments is influenced by design considerations and the effectiveness of navigation as supported by the quality of image resolution. These findings reinforce research studies reviewed in the literature of this dissertation. Several are important to note as they relate to aspects of the design of this dissertation and support that resolution differences in virtual worlds reinforces the findings of past research with resolution in other types of media. The work of Vidmar et al., (1999) found a significant effect among the high-resolution image groups verse the low to medium resolution image groups in this research. Vidmar et al., research also used a broader range of image resolution levels unlike many past studies, which only used two image resolution levels. All participants in this research also used the same computer system. Both of these aspects, broader ranges of image levels and the use of a single computer system to control for system variances mirror the research study.

Knoche et al., (2005) research on variances in mobile TV resolution also supports the research findings. This research reported participant's acceptable level of resolution among the four different resolution groups used in the research was for images that had higher resolution. Babcock et al., (2002) research also indicated that increased time was spent in looking at a more visually rich environment as reported with wearable eye tracking equipment.

Support of Literature on Differences in Image Resolution and Wayfinding and Navigation Performance

Wayfinding in the virtual environment developed for the dissertation was impacted as reported by time-on-task performance scores. This supports the work of Lynch (1960) and the need to transfer considerations for what promotes and enhances human navigation in the real world to human navigation in virtual worlds. The decreased time-on-task scores reported in treatment group one with high-resolution images supports Lynch's premise that specific landmarks acting as distinctive objects (the wayfinding signage used in the dissertation environment) can affect the paths taken and channels of movement in wayfinding. Time-on-task scores reported by the dissertation findings indicate that wayfinding and navigation are enhanced by higher resolution images. Participants were able to select paths and navigate more quickly with higher resolution landmark images. Passini's (1984) research also supports the findings that navigation is promoted by the design and selection of signage. The higher resolution images of treatment Group 1 and Group 2 reported lower time-on-task performance scores than treatment Group 3 and Group 4 indicating that resolution and clarity of design of the wayfinding signage images promoted increased ease of navigation and in turn lower time-on-task scores.

The research time-on-task performance score findings also support the work of Darken and Sibert (1996). The wayfinding images acting as visual clues in the dissertation treatment were essential to prompting the effective navigation in a large-scale virtual environment. When the resolution of the wayfinding images was compressed, there was an effect of the time-on-task performance scores as indicated in the findings reported for treatment group three and four of the dissertation research. Visual clues that had more compressed resolutions and were subsequently not as clear, increased participant's viewing time and time-on-task performance scores. Seemingly, route knowledge among the participant in the higher-level resolution groups of the dissertation was increased as indicated by decreased time-on-task performance scores when the wayfinding images acting as landmarks had higher resolutions as indicated in Witmer and Signer's (1995) research. Time-on-task findings of the dissertation may also support Foo et al., (2006) findings that knowledge in a VE is critical to wayfinding and gained by landmarks and signs. Higher resolution sign images may have increased knowledge and in turn improved wayfinding and time-on-task performance scores.

Branching points and spatial problem solving also seem to be supported by the time-on-task findings of treatment groups one and two in the dissertation, which used higher resolution images. Raubal and Egonhofer's (1998) research indicated that successful wayfinding that utilizes true decision or branching points is predicated by the readability of visual clues at intersections. The higher resolution images in treatment group one and two were more readable and may have promoted increased wayfinding problem solving as the participants could more readily find the conference room and make choices more quickly as indicated by time-on-task performance scores.

Support of Research on Virtual Environments Relating to Vision and Space

Additional visual information as reported by the Matto Laboratories substantially improved wayfinding performance. The visual information was increased in the images in groups 1 and 2 because of the higher resolution of the images used in these groups. Increased visual information may have been a key factor for improved time-on-task performance scores as reported by the image resolution group one and image group two, which had higher resolution images.

Results and Implications of Research Question Two and the Supporting Hypothesis - Differences in Object-based Visual Attention as Reported by Eye Tracking Response Scores Based on Image Resolutions

The findings of this research indicate that different image resolutions significantly affect object-based visual attention in the virtual desktop environment as measured by gaze fixation scores. However, different image resolutions did not significantly affect object-based visual attention in the virtual desktop environment as measured by saccade scores.

R_2: Is there a significant difference on object-based visual attention in a desktop interior virtual wayfinding environment based upon individual eye tracker data as a function of the change in image resolution of 150, 100, 75 and 30 ppi?

H_2: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect user visual attention as measured by the eye tracker data.

$H_{2.1}$: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by the saccade movements obtained by eye tracker data.

$H_{2.2}$: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's object-based visual attention as measured by gaze fixation obtained by eye tracker data.

As reported in the previous chapter, data from the one-way ANOVA of saccade scores by image resolution groups did not show a significant difference. The supporting $H_{2.1}$ hypothesis was rejected. Changes in image resolution in the environment did not significantly affect participant's object-based visual attention as measured by the saccade movements obtained by the eye tracker.

However, the one-way ANOVA between image resolution and gaze fixation detections scores did indicate a statistically significant difference between groups. Tukey's post hoc analysis indicates that there was a significant difference in gaze fixation detection scores of image resolution groups one and two from image resolution groups three and four. The supporting $H_{2.2}$ hypothesis was retained as a result of these findings. Changes in image resolution in the environment did significantly affect participant's object-based visual attention as measured by gaze fixation scores obtained by the eye tracker. What is important to consider is why there might not be significant differences in one type of eye movement pattern with different resolution images as opposed to another type of eye movement pattern.

What is known from the findings is that time-on-task performance scores were affected by the different types of resolutions, and that differences between the image resolution groups were statistically significant for gaze fixation detections scores. Gaze fixation detections occur when the eye pauses to focus on an object. The findings indicate that there is a relationship of the resolution of the images to how long participant's eyes were fixating on them, which in turn may have affected time-on-task performance. Treatment Group 3 and Group 4 used lower resolution images (75 ppi and 30 ppi respectively) and had higher gaze fixation detection scores indicating that participants took longer to focus their attention or took longer to decipher the images, which already had their attention. This impacted their time-on-task performance in navigating in the virtual environment. Treatment Group 1 and Group 2 used higher resolution images (150 ppi and 100 ppi respectively) and had lower time-on-task performance scores. These higher resolution images indicated shorter fixation periods and lower time-on-task scores. Seemingly, the higher resolution images were easier for participants to focus on and react to in performing desktop virtual wayfinding tasks.

It is also important to note past research findings. As discussed in the literature review, saccade movements occur before gaze fixation detections. There is an increase in saccade scores before gaze fixation occurs. Salah, et al., (2005) reported that the fovea collects high-resolution information while the periphery eye collects low-resolution information. This would indicate that the periphery eye would collect low-resolution information faster in the higher resolution groups. However, the data indicates that the difference between high resolution and low-resolution group saccade scores was not statistically different. Perhaps there is a consistent amount of saccade movements that occur that are related to the task and not dependent on the image.

Researchers also discussed in the literature report that attentional movements in complex tasks are coupled (Duebel & Schneider, 1996; Knowler et al., 1995). There is limited research on eye tracking in desktop interior virtual environments that relates to interior virtual wayfinding tasks that can provide guidance on attentional movements. Perhaps attentional mechanisms such as pre-attentive and attentive processing like saccade and fixation detections are coupled in wayfinding tasks and that the task itself may impact the attentional mechanisms.

The exact reasons as to why the data for saccade movements in this research was not statistically significant are not known. Perhaps the overall size of the interior virtual environment was a factor or that participants' were performing complex tasks such as moving (wayfinding and locomotion tasks) as well as searching for and viewing images. Yarbus (1967) noted that saccade movements were a way for the eyes to select task relevant information. The findings may indicate that saccade eye patterns may be fairly consistent even with different image resolutions if the actual task involved such as wayfinding is consistent. If in fact attentional mechanisms in complex tasks such as virtual wayfinding are coupled, as mentioned, this may explain the difference in the results of saccade movements and gaze fixation scores. Perhaps, saccade movements act as pre-attentive processes that react consistently when specific tasks are involved that require the eyes to collect information regardless of the image resolution. These movements may be more physical in nature and more consistent and predictable with some types of tasks. While gaze fixations may differ depending on image resolution as the eyes must cognitively process and understand what they take in. There may be more of a flow of information from the brain to the eyes during fixations that require additional scrutinizing when an image cannot be adequately deciphered (such as those having lower resolution) and in turn produce higher fixation scores. This may explain why lower resolution images had higher fixation scores and participants took longer amounts of time to view the images and perform wayfinding tasks in the environment. Additional research would need to evaluate specifics of how both saccade scores and gaze fixation scores relate in complex tasks.

Observations made by the researcher as participants moved through the environment indicate that subjects in treatment Group 4 (the lowest resolution group) experienced increasing frustration with the task. Participants moved repeatedly in circles around the environment and viewed images for longer periods unable to clearly navigate through the virtual environment. What is interesting to note is that the environment was held constant for all four of the groups with exactly the same resolution for all of the supporting environment imagery and only the wayfinding image resolutions were altered. The images played a key role in providing additional information in the locomotion tasks. These observations support the research findings and that the tendency for humans to look for signs and clues as they make decisions to complete a task was influenced by image resolution.

Four additional students participated in the experimental study above the final group of sample of 60 as previously discussed. Each of these participants asked to stop the study during their research treatment. Three of these participants were from treatment group four and one of the participants was from treatment group three. Each of the participants asked to stop their participation when they were well into 300 or more cumulative seconds and had gone around the environment several times. These students were not aware of their specific time-on-task scores but became increasingly frustrated with themselves showing increased agitation, verbally expressing frustration and moving restlessly in their seat. The virtual environment was stopped as soon as each student requested that they stop. Each of these four students were provided with a business card to present to their instructors to retrieve possible credit points as discussed, but their data was not included in the research.

What is interesting to consider is why frustration was occurring for these students and in particular why within a consistent range of 300 or more cumulative seconds. Particularly, since these students did not have any frame of reference for what their exact time-on-task score was and since they were individually experiencing a treatment condition and were not in competition or in a room with other participants who were working at the same time. Perhaps this is some indication that for some types of virtual environment tasks such as the wayfinding and locomotion tasks of the study, there may be a threshold of performance that participants must innately achieve to avoid frustration. Perhaps there is a relationship to lower resolution images that triggers specific responses related to performance that exceeds a time frame threshold. This threshold would need to be further evaluated particularly with cumulative scores that replicate those that caused these participants' frustration and with lower resolution images to verify this. Additional considerations related to this are discussed later in this write-up.

Results and Implications of Research Question Three and the Supporting Hypothesis

Differences in the Perception of the Usability of the Virtual Environment Based on Image Resolutions

The findings of this research indicate that different resolutions did not significantly affect participants' perception of the usefulness of the virtual desktop environment. There was not a significant difference reported in the one-way ANOVA between SUS© scores and the different image resolution groups. The supporting hypothesis was rejected. Changes in image resolution did not have a significant effect on the participant's perception of engagement in the virtual environment. However, a repeated measures ANOVA using the individual item scores as within subject variables indicates an item score main effect. The way participants answered the question in the VEPQ has a significant effect on their perception of engagement.

R_3: Is there a significant difference in the perception of the usability of a desktop interior virtual wayfinding environment as a function of the effect of image resolutions of 150, 100, 75 and 30 ppi?

H_3: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment.

$H_{3.1}$: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the system usability of the virtual environment as measured by scores obtained by the System Usability Scale (SUS©).

$H_{3.2}$: Changes in image resolution of 150, 100, 75 and 30 ppi in a desktop interior virtual wayfinding environment significantly affect participant's perception of the usability of the virtual environment as measured by scores obtained by the Virtual Environment Presence Questionnaire (VEPQ).

As discussed, the scores of the SUS© and the VEPQ indicate that participant's virtual world experience did not preclude their perception of their ability to effectively use the computer system to navigate through the virtual environment or their perception of the usability of the virtual environment based on presence. Literature that can guide research on participants' perceptions of the usability of desktop interior virtual wayfinding environments is limited as noted in the Chapter II and oftentimes involved treatments that do not replicate authentic environments. These studies do not relate directly to the image resolution used in this research, however, several are important to note as they relate to perceptions in virtual environments.

Phillips (1986) reported that participants did not indicate any significant differences in perceived object size in virtual worlds. Waller and Hunt (2001) concluded that there was only a small difference in size estimation among three different versions of a room maze. Thompson, et al. (2004) research investigated if image resolution had an effect on distance perception and estimation in different virtual environments. Findings reported that image resolution did not play a role in distance estimation. Seemingly, from these studies, the perception of elements in different types of virtual environments did not impact the usefulness of the environment or the objects. Additional research would provide further guidance on the effects of image resolution to the perceived usefulness of virtual environments.

Recommendations

There are several recommendations for further research that are a result of this study. One important area is the further evaluation of image resolution in the range of 100 – 75 ppi. The goal of developing many virtual environments also focuses on the most effective compression techniques for images. From this study, there was cluster of data that occurred for Groups 1 and Groups 2 from Groups 3 and Groups 4 as discussed. 100 ppi was the compression from Group 2 while 75 ppi was the compression from Group 3. As a result of this clustering, the scores between the highest resolution Group 1 (150 ppi) from Group 2 (100 ppi) were marginal. Similarly, the scores between the lowest resolution Group 4 (30 ppi) and Group 3 (75 ppi) were marginal. Further research on desktop interior virtual wayfinding images needs to evaluate the lowest acceptable image resolution that does not have an impact on time-on-task performance, object-based visual attention as measured by eye movements including saccades and fixation scores, and the perceived usability of the computer system. Only by further studying these ranges, can an effective metrics be refined.

Different types of images is also important to evaluate in future research. Additional studies should focus on a broad range of image types that are used in virtual environments beyond wayfinding signs. This research may also provide additional clues for how best to effectively balance the different types of images areas in a virtual environment including rich areas that may be comprised of sophisticated images used a bump map textures vs. more stark areas with single images or more monotone patterns. The design of this research replicated both types of areas in the same environment to mirror the authentic environment. Some areas such as the lobby were visually rich with patterns and textures that were on plants, chairs and couches while other areas were starker such as white walls that had only a single image at some locations. Additional research should evaluate what may occur in environments that more rich visual patterns and less rich visual patterns.

Additional research recommendations also include evaluating larger and smaller virtual environments. Conducting research with image resolution in different size environments may yield supporting data for the eye tracking scores and refine the overall resolution metrics. Research should focus on a smaller virtual environment perhaps the size of a room that does not involve images used in connection with a complex task such as wayfinding. This would allow more concentrated analysis of the response to the images themselves without the association of complex tasks. This information may yield additional clues with the eye tracking system and object-based visual attention relative to images and image resolution.

Follow-on research to additional smaller studies should also increase the size of the virtual environment to evaluate the effect of a larger virtual space. This may include different types of delivery methods such as a multi-player environment or a web-based environment. Over time different types of smaller tasks such as object manipulation or retrieving cued information in relationship to image resolution may also be beneficial. It is important to evaluate smaller tasks and different types of tasks relative to different size environments to understand if there is a relationship of images to task performance in virtual environments.

Another consideration as discussed would be the further evaluation of when a frustration threshold is reached for participants that are using low-resolution images in desktop interior wayfinding treatments. It is important as metrics are refined with additional research on image resolution ranges that further evaluations of any potential thresholds in using low-resolution images and performance tasks are more clearly understood. As this research indicated, some of the initial participants in the low-resolution groups (1 from Group 3 and 3 from Group 4) became frustrated when their time-on-task performance scores reached ranges over 300 cumulative seconds. Additional research may help to have a clearer understanding so that environments can be designed to minimize user frustrations. Additional tools or support feedback may also be considerations upon further evaluating how to minimize user frustration. Future studies that focus on these considerations may help to build more useful environments that more learners can effectively use.

Affordable eye tracking systems are now available. Possible considerations may be the evaluation of images in virtual environment that are not coupled with complex tasks such as locomotion as discussed. This would allow for programming the eye tracker to evaluate the specific regions of interest of images that vary in resolution without the impact of locomotion tasks. This would allow for a more comprehensive evaluation of saccade movements and gaze fixation scores. These types of studies may yield useful information to evaluate if saccade movements are indeed physical responses to related tasks in virtual environments and if there is any relationship to the type of tasks with average saccade movements per participant. This information would also refine how fixation detection scores are related to cognitive processing and how this may be impacted by the different types of tasks in virtual environments.

The research findings of this study have provided some insight into the design of interior virtual environments relative to image resolution and locomotion tasks in virtual desktop wayfinding in an interior floor plan environment. Additional research should be conducted to evaluate the role of images as discussed and to further refine a scale of metrics for using image compression in virtual environments. This is a vast and growing area of instructional design and learning that needs more research and guidance for how best to make design considerations for learners and how to evaluate the transfer of research in other areas of media to virtual environments.

Final Conclusions

From the research, a better range of resolution metrics can be validated for images in desktop interior virtual wayfinding environments that involve complex tasks such as wayfinding. The findings indicate that time-on-task performance scores with complex tasks such as wayfinding decreased when images resolutions used in the environment were at 150 ppi to 100 ppi. Object-based visual attention was also enhanced with image resolutions used in the environment at 150 ppi to 100 ppi as indicated by lower gaze fixation times that participants took to focus on images when making navigation decisions. The perceived usability of the virtual environment as indicated by the system usability scores (SUS©) and the sense of virtual environment usability as related to presence in the virtual treatment (VEPQ scores) was not significantly affected by differences in image resolution.

Based on these findings, compression metrics for images in complex tasks such a wayfinding in virtual environments should range between 100 ppi to 75 ppi where signage is necessary for successful locomotion task completion. Image resolutions in these ranges allowed for participants to effectively focus their attention in a timely manner that did not compromise their time-on-task performance skills, nor attention in wayfinding and using the environment.

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Appendices

Appendix A: Pilot Study

Pilot Study

A pilot study was conducted in the spring of 2008 with 12 participants over a period of two days. The purpose of the pilot study was to demonstrate the feasibility of the research methodology and design, evaluate the instruments that were proposed and to address several changes and refinements requested by the dissertation committee after the researcher's proposal defense. The virtual environment was modified to eliminate any directory map image. The committee also requested that an equal distribution of gender among participants be maintained in the study because of the difference in male and female students in the class populations. Also, the committee suggested the inclusion of a questionnaire to evaluate learner responses to the virtual environment. For this reason, the Virtual Environment Performance Questionnaire (VEPQ*)* was added to the pilot and final study. A description of the eye tracking system and data collection and additional details of the logistics of the study were also requested. These were incorporated into the previous methodology discussion. All requests were implemented prior to the researcher running the pilot study.

Pilot Study Sample

Participants' ages ranged from 18 to 30 years old. Participants were solicited from the same 2000 level undergraduate teacher education technology course at a major research university as the final study in the spring of 2008. One male and two female participants were randomly assigned to each of the four treatment groups. Two additional participants participated in the experimental study but their data was not used as discussed later. None of the students reported prior exposure to classes in architecture, perspective drawing or drafting as indicated on the Participant Sign-In sheet (Appendix B).

Pilot Study Logistics and Methodology

The logistics and set up of the computer equipment, eye tracking system, room procedures, control for extraneous variables and virtual environment development are identical to those discussed in the final research, and for these reason are not reported in-depth in the pilot study. Rather, these discussions will focus on the processes, procedures used and evaluation of instruments and data that were evaluated during the pilot study.

To screen for individual differences, volunteers were asked to complete the Mental Rotation Test (MRT) before being selected for participating in the experimental study. This was scored first to verify if the volunteers had average or better spatial ability prior to selection for participation in the experimental study. This was Phase 1 of the pilot. Participants who successfully scored in the 50% or better on the *MRT* (indicating average or higher spatial abilities) were allowed to participate in Phase II of the study. Only one of the volunteers did not score in the 50% on the MRT and was not selected to participate in the experimental study.

Participants in Phase II of the pilot study were randomly assigned a number when they were administered the MRT test with a pre-numbered copy. The Study Descriptor (see Appendix C) was given to each participant to be read and reviewed. Participants were asked if they had any questions and manila envelopes containing copies of the System Usability Scale (SUS©*)* and the Virtual Environment Performance Questionnaire (VEPQ*)* were then matched to each participant has pre-numbered MRT test as their identifier. The researcher recorded the gender and age of each person on the outside of each envelope.

Participants were randomly assigned to one of the four virtual environment treatment groups. The treatment group number was recorded on their supporting envelope. Scripting for the pilot study allowed each of the four treatments to be randomly spooled three times to accommodate the 12 participants. After completing the study, participants were given a business card to present to their instructor for five extra credit points.

Findings of the Pilot Study

Mental Rotation Test Scores

Individual MRT scores for the pilot study are reported in Appendix L. MRT scores were used as a control for extraneous variables as mentioned, with participants having to score higher than 50th percentile to participate in the research. The averages of the MRT scores reported by the different treatment groups were 73.66% for treatment group one, 76.33% for treatment group two, 78% for treatment group three and 67% for treatment group four. One volunteer did not score in the 50th percentile indicating that they had lower than average spatial ability. They were told that they were free to go back to their classes and were given a business card to present to their instructor for possible extra credit.

A Pearson product correlation coefficient was computed between participants' time-on-task performance scores and the MRT scores. Table 14 reports these findings.

Table 14. *Pilot Study - Correlation Coefficient Between Time-On-Task Performance Scores and Mental Rotation Test Scores.*

	Mental Rotation Test	Time-On-Task Performance Scores
Mental Rotation Test	1.00	-.19
Time-On-Task Performance Score	-.19	1.00

N = 12, $p < .05$

These data indicate that there was a weak negative correlation (-.19) between MRT scores and time-on-task performance scores. These data indicate that there was not a statistically significant correlation between time-on-task performance scores and MRT scores.

Time-on-Task Scores by Treatment Group

Individual time-on-task performance scores for the pilot study are reported in Appendix H. Time-on-task scores averages reported by group were 67.69 seconds for treatment group one, 106.42 seconds for treatment group two, 198.34 seconds for treatment group three, and 248.19 seconds for treatment group four. Time-on-task score averages per treatment group varied considerably with the highest resolution (group one) completing the task in the least amount of time to the lowest resolution (group four) completing the task in the most amount of time.

A one-way ANOVA was conducted to determine if there was a significant difference in time-on-task scores by treatment group. Normality assumptions were met for each treatment group for time-on-task scores. The standard deviations reported were more or less similar among the different treatment groups and the homogeneity of variances were satisfied. Data were entered into SPSS. The results of the ANOVA are shown in Table 15.

Table 15. *Pilot Study - Analysis of Variance for Time-On-Task by Image Resolution Group.*

Source	df	Sum of Squares	Mean Square	*F Value*	*p*
Between Groups	3	85494.4005	28498.1335	27.7726	.0001
Within Groups	8	8208.9843	1026.1230		
Total	11	93703.3848			

The results from the one-way ANOVA indicated a statistically significant effect for resolution level $F(3,8) = 27.7726$, $p < .01$.

Eye Tracker Data Scores

Each participant's eye movement scores including fixation detections and saccade movements are reported in Appendix J and Appendix K respectively. Graphical representations of the eye movements are also visible in Appendix H. The assumptions for conducting a one-way ANOVA were met and the ANOVA was conducted between image resolution and saccade movements using SPSS. The findings of the ANOVA are shown in Table 16.

Table 16. *Pilot Study - Analysis of Variance for Saccade Movements by Image Resolution Group*.

Source	df	Sum-of-Squares	Mean Square	*F Value*	*p*
Between Groups	3	.0006	.0002	1.6378	.2562
Within Groups	8	.0009	.0001		
Total	11	.0014			

Findings indicate that there was not a statistically significant difference in the number of saccade movements of the eye as a function of image resolution levels (with the four image resolutions), $F(3,8) = 1.6378$, $p < .26$.

A one-way ANOVA was conducted to determine if there was a difference between image resolution and gaze fixation detection scores to evaluate the effect of image resolution levels to participant's eye movements and to support the Object Based Visual Attention theory. The assumptions for conducting the ANOVA were satisfied and the results are reported in Table 17.

Table 17. *Pilot Study - Analysis of Variance for Gaze Fixation Detection Scores by Image Resolution Group*.

Source	df	Sum-of-Squares	Mean-Square	*F Value*	*p*
Between Groups	3	.4511	.1504	2.0504	.1912
Within Groups	8	.5867	.0733		
Total	11	1.0378			

Pilot study findings indicate that there was not a statistically significant difference in gaze fixation detection of the eye as a function of image resolution levels (four image resolutions), $F(3,8) = 2.0504$, $p < .19$.

System Usability Scores

Individual SUS© scores for the pilot study are reported in Appendix P. Single composite scores for each participant were obtained by calculating the score contributions for each item and then summing the total score per participant since individual items are not meaningful predictors of usability. The SUS© score averages by group included 91.16% for treatment group one, 85% for treatment group two, 75.83% for treatment group three and 80% for treatment group four. Treatment group four was higher than treatment group three indicating that even the lowest resolution is not an indicator for reduced system usability to participants. The overall rating of the usability of the computer system was 82.99% indicating the usability of the computer system was high.

A Pearson product moment correlation was computed between time-on-task performance scores and participants' SUS© *scores to* determine the relationship between satisfaction of the system usability and time-on-task performance scores. These data are reported in Table 18.

Table 18. *Pilot Study - Correlation Coefficient Between Time-On-Task Performance Scores and System Usability Scores 1 - tailed.*

	Time-On-Task Performance Scores	System Usability Scores
Time-On-Task Performance Scores	1.00	-.48
System Usability Scores	-.48	1.00

N = 12, $p < .05$

These da ta i ndicated that t here w as ne ither a s tatistically s ignificant weak nor strong negative correlation (-.48) between SUS© and time-on-task performance scores.

Pilot Study Virtual Environment Presence Questionnaire Scores

Individual VEPQ performance scores for the pilot study are recorded in Appendix Q. Overall item averages for participants were 5 out of a scale of 7. On an average, participants of group one, the highest resolution group, scored the highest in the questionnaire, which indicated a greater sense of engagement.

A Pearson product moment correlation was computed between participants' VEPQ scores and time-on-task performance scores to determine the relationship between participants' sense of engagement in using the virtual environment and time-on-task performance scores. Table 19 reports these data.

Table 19. *Pilot Study - Correlation Coefficient Between Time-On-Task Performance Scores and Virtual Environment Presence Questionnaire Scores 1 – tailed.*

	Virtual Environment Presence Questionnaire	Time-On-Task-Performance Scores
Virtual Environment Presence Questionnaire	1.00	-.17
Time-On-Task-Performance Scores	-.17	1.00

N = 12, $p < .05$

These data indicated a weak negative correlation (-.17) between VEPQ scores and time-on-task performance scores.

Summary of Pilot Study

The pilot study results indicated that resolution had a statistically significant effect on time-on task performance in desktop virtual wayfinding. The data from the one-way ANOVA between time-on-task performance scores and resolution indicated that there were statistically significant difference between groups. This is visually represented in a scatter plot of the time-on-task performance scores by resolution shown in Figure 4.

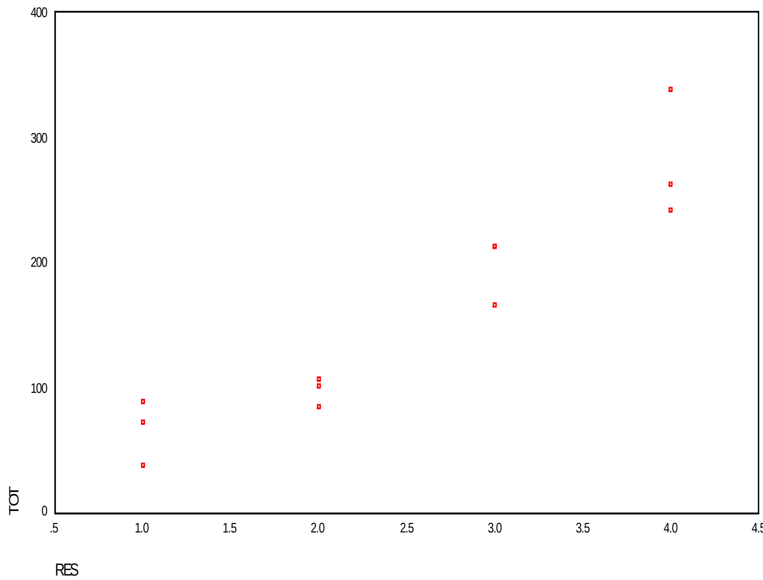


Figure 4. *Pilot Study - Scatter Plot Analysis of Variance for Time-On-Task Performance Scores by Resolution..*

Resolution however, did not have a statistically significant effect on saccade movement and gaze fixation scores. The data from the one-way ANOVA between time-on-task performance scores and saccade movements and the one-way ANOVA between time-on -task performance and gaze fixation detection did not indicate that there were statistically significant difference between groups.

Two additional participants were not included in the final 12 participants from the pilot study. Both participants asked to stop the study after becoming frustrated with how long they felt it was taking them to complete the treatment. Each of the participants not included in the final 12 was still given a business card to present to their instructor for participating in the study for extra credit. Interestingly, both of these participants had been randomly assigned to treatment group four – the lowest resolution group. One student asked to stop the study after his/her time-on-task score reached 352 seconds and the other student asked to stop the study after his/her time-on-task score reached 347.2 seconds. Each of these two participants did complete the MRT test and showed above average spatial ability. Also, each completed the supporting instruments and showed high SUS© satisfaction and a high sense of presence as indicted by the VEPQ.

Another interesting observation is that nine of the final twelve participants felt that they were very comfortable in using and navigating in the VE before they saw it and were ready to begin the treatment at once without having additional time to practice. The pilot study also provided support for the logistics involved in conducting the formal research study and the flow of the research method and supporting assessment measures.

Appendix B: Participant Sign-in Sheet

Student Name	**Meeting Time**	**Classroom Visited**	**Age**	**Please check if you have had Previous Courses in:**		
				Perspective Drawing	Drafting	Architecture

Appendix C: Study Descriptor

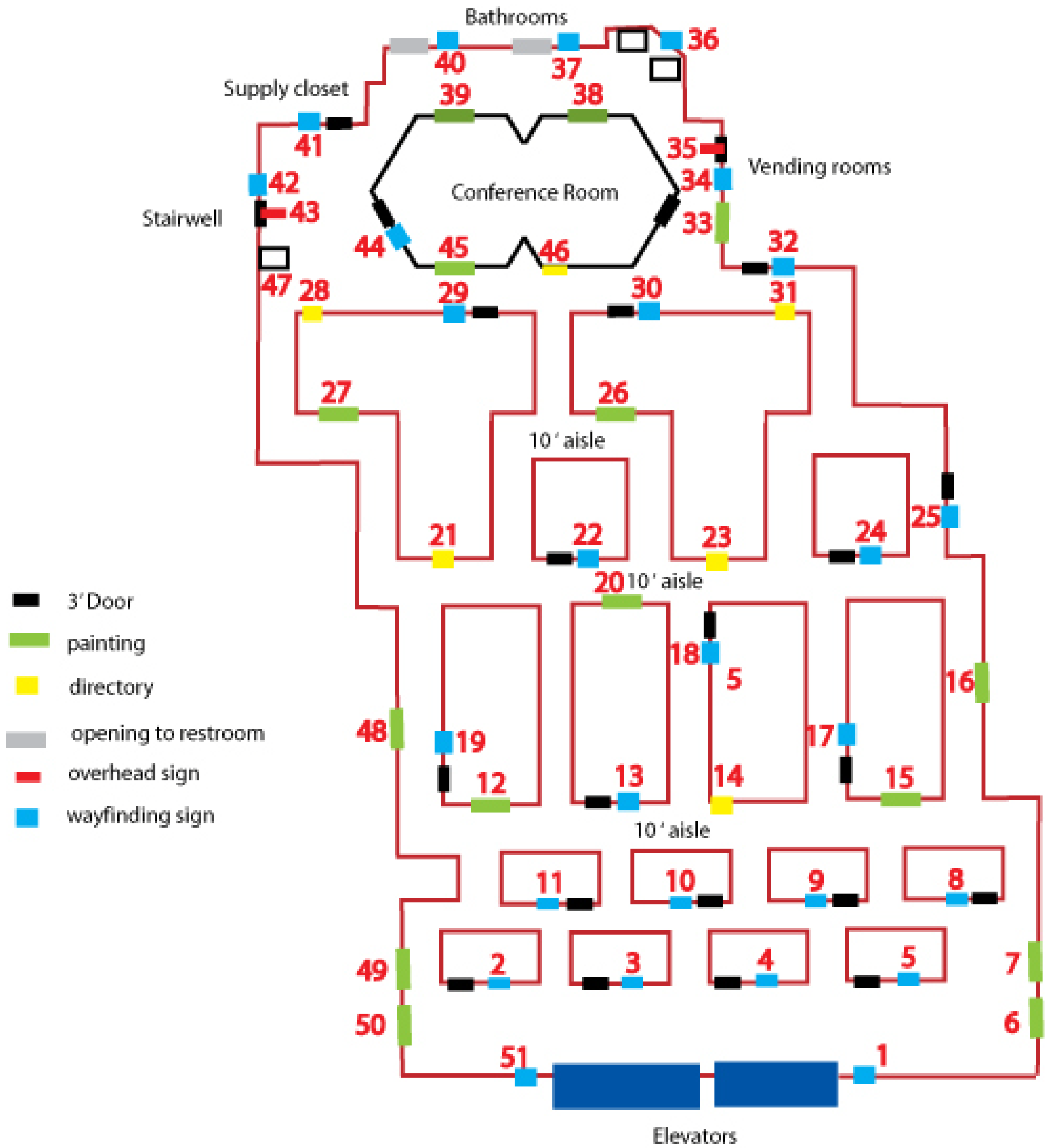
You will be exploring and navigating through a virtual 3-dimensional interior environment. An eye tracking system will also be used to record the movements of your eyes as you move through the environment. The eye tracker is made up of special equipment and software that records the movements of your eyes into different types of data in the computer system. The environment will allow you to turn and move through an office building by using the arrow keys on the keyboard of the computer. You may stop at any time while you are moving through the environment to move forward, backward, left, or right. Images in the office space will assist you in navigating. A floor plan directory will be visible to you once you enter the setting.

Your task will be to progress through the interior hallways as quickly as possible until you find a conference room and to navigate all the way around the conference room and enter the conference room. How long it takes you to find the conference room and enter it will be timed. After you find the conference room, you will be asked to complete a series of short questions about your experience with using the system.

You will now be given an opportunity to view a sample area of the environment and to use the arrow keys from your keyboard to practice moving and navigating. Once you have used all of the arrow keys and are comfortable moving in the environment, please let the proctor know and then select the enter button to begin.

Thank you for your time and participation in this study.

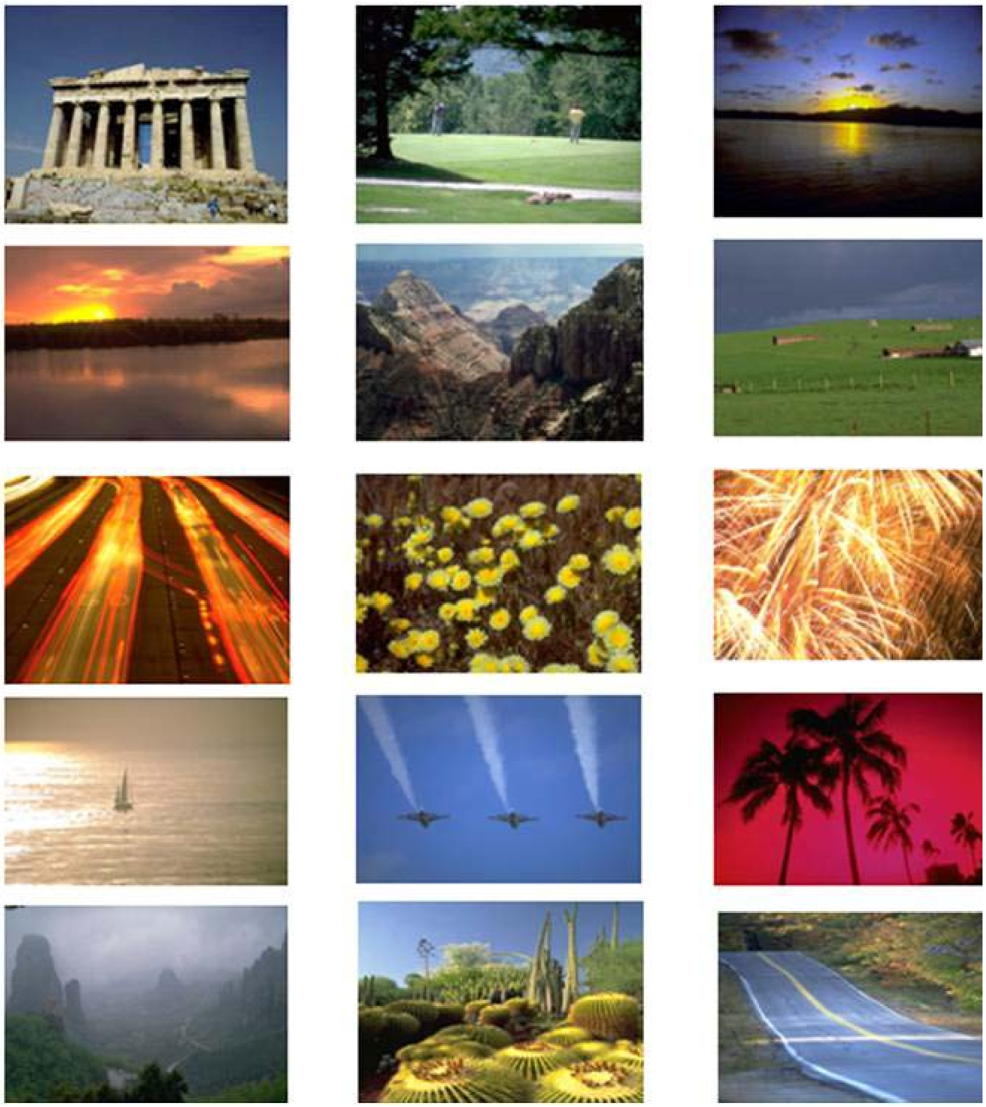
Appendix D: Floor-plan of 3-D Model and Placement of Images with Legend



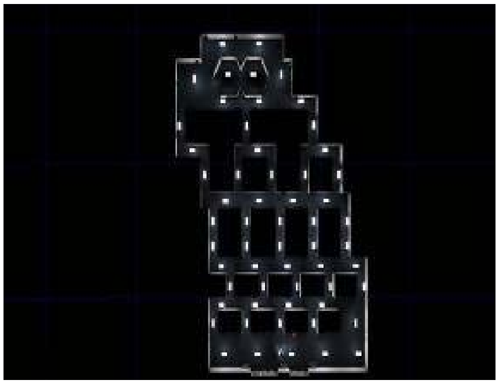
Appendix E: Sample Images in the Virtual Environment

* Please note these are the native images that have not been compressed or altered for each treatment

Appendix F: Sample Images in the Virtual Environment

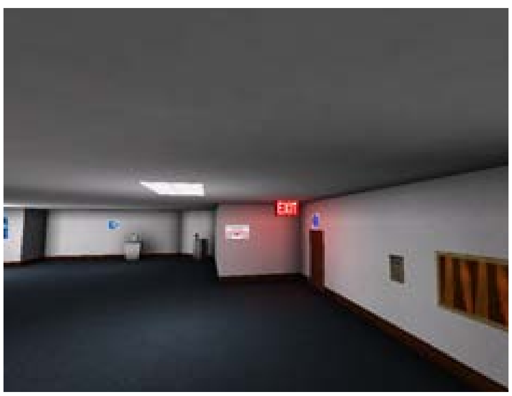


Appendix G: 3-D Environment Screen Shots



Model floor plan in 3-D virtual environment

Model environment – oblique view



Model environment –corridor near conference room

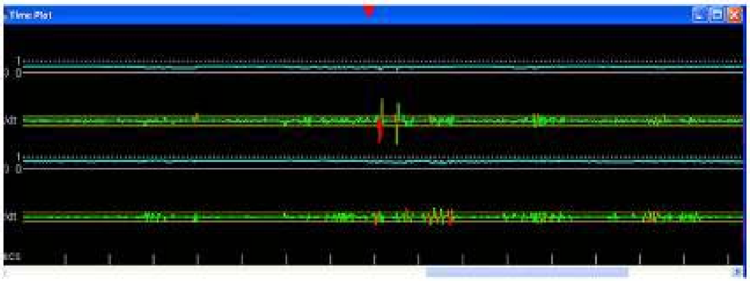
Model environment – looking from elevator entry point of lobby

Model environment – looking down typical corridor

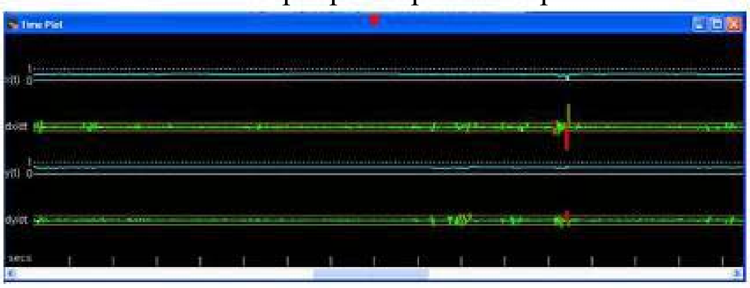
Model environment – looking down typical corridor

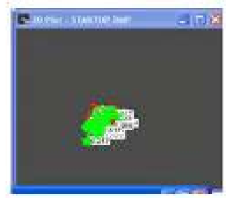
Appendix H: Screen Shots of Sample Eye Tracking Data

Sample participant Group 1

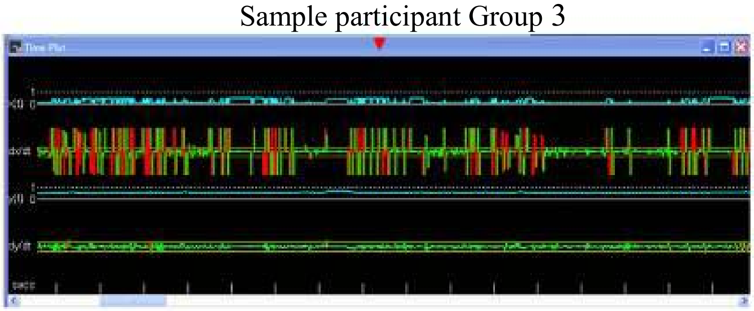


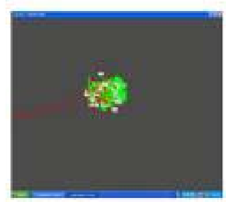
Sample participant Group 2



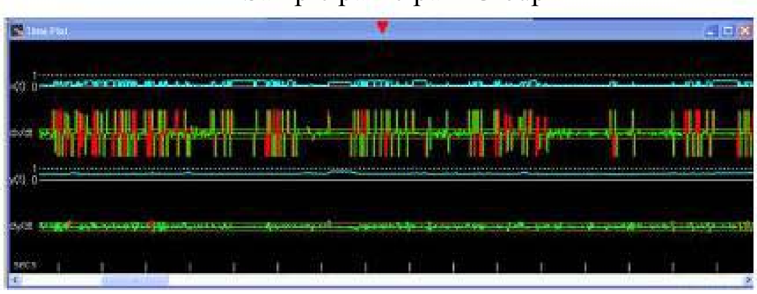


Sample participant Group 3





Sample participant Group 4



Appendix I: Pilot Study - Time-On-Task Descriptive Statistics –

Frequency Distribution

Participant	Value	Frequency	Percent	Percent	Percent
1	39.43	1	8.3	8.3	8.3
2	73.82	1	8.3	8.3	16.7
3	86.34	1	8.3	8.3	25.0
4	89.84	1	8.3	8.3	33.3
5	102.60	1	8.3	8.3	41.7
6	107.34	1	8.3	8.3	50.0
7	167.43	1	8.3	8.3	58.3
8	213.56	1	8.3	8.3	66.7
9	214.03	1	8.3	8.3	75.0
10	242.32	1	8.3	8.3	83.3
11	263.04	1	8.3	8.3	91.7
12	339.21	1	8.3	8.3	100.0
Total		12	100	100	100

Appendix I: (Continued)

Mean	161.580	Median	137.385	Mode	39.430
Std. dev.	92.296	Variance	8518.490	Kurtosis	-.732
S E Kurt	1.232	Skewness	.528	S E Skew	.637
Range	299.780	Minimum	39.430	Maximum	339.210

* Multiple modes exist. The smallest value is shown.

Percentile	Value	Percentile	Value	Percentile	Value
25.00	87.215	50.00	137.385	75.00	235.248

Pilot Study - One Sample t-test

Variable	Number of Cases	Mean	SD	SE of Mean
TOT	12	161.5800	92.296	26.643

Test Value = 0
Mean 95% CI

Difference	Lower	Upper	t-value	df	2 Tail Sig
161.58	102.938	220.222	6.06	11	.00

Appendix J: Pilot Study – Gaze Fixation Detection Scores – Descriptive Statistics

Participant	Value	Frequency	Percent	Percent	Percent
1	.10	1	8.3	8.3	8.3
2	.10	1	8.3	8.3	16.7
3	.16	1	8.3	8.3	25.0
4	.18	1	8.3	8.3	33.3
5	.25	1	8.3	8.3	41.7
6	.39	1	8.3	8.3	50.0
7	.45	1	8.3	8.3	58.3
8	.71	1	8.3	8.3	66.7
9	.71	1	8.3	8.3	75.0
10	.72	1	8.3	8.3	83.3
11	.89	1	8.3	8.3	91.7
12	.89	1	8.3	8.3	100
Total		12	100	100	100

Variable	Mean	Std Dev.	Minimum	Maximum	N Label
FIXATION	.46	.31	.10	.89	.12

Appendix K: Pilot Study - Saccade Scores – Descriptive Statistics

Participant	Value	Frequency	Percent	Percent	Percent
1	.02	1	8.3	8.3	8.3
2	.03	1	8.3	8.3	16.7
3	.03	1	8.3	8.3	25.0
4	.03	1	8.3	8.3	33.3
5	.03	1	8.3	8.3	41.7
6	.03	1	8.3	8.3	50.0
7	.03	1	8.3	8.3	48.3
8	.03	1	8.3	8.3	66.7
9	.03	1	8.3	8.3	75.0
10	.04	1	8.3	8.3	83.3
11	.04	1	8.3	8.3	91.7
12	.07	1	8.3	8.3	100
Total		12	100	100	100

Variable	Mean	S. D.	Minimum	Maximum	N Label
SACCADE	.03	.01	.02	.07	.12

Appendix L: Pilot Study - Mental Rotation Test (MRT) Scores

		Participant 1	Participant 2	Participant 3
Independent Variable Resolution	IR[1] Resolution 150 ppi	70% (f)	51% (f)	100% (m)
	IR[2] Resolution 100 ppi	84% (f)	57% (m)	88% (f)
	IR[3] Resolution 75 ppi	98% (f)	70% (f)	66% (m)
	IR[4] Resolution 30 ppi	58% (f)	52% (m)	91% (f)

Appendix M: Pilot Study - Time-On-Task Performance Scores

		Participant 1	Participant 2	Participant 3
Independent Variable Resolution	IR[1] Resolution 150 ppi	39.43 (f)	73.82 (f)	89.84 (m)
	IR[2] Resolution 100 ppi	107.34 (f)	86.34 (m)	125.60 (f)
	IR[3] Resolution 75 ppi	167.43 (f)	214.03 f)	213.56 (m)
	IR[4] Resolution 30 ppi	242.32 (f)	339.21 (m)	263.04 (f)

Appendix N: Pilot Study - Eye Tracker Data Scores - Saccade Movements

		Participant 1	Participant 2	Participant 3
Independent Variable Resolution	IR[1] Resolution 150 ppi	0.0362 (f)	0.0404 (f)	0.0278 (m)
	IR[2] Resolution 100 ppi	0.0263 (f)	0.0349 (m)	0.0279 (f)
	IR[3] Resolution 75 ppi	0.02632 (f)	0.02402 (f)	0.03215 (m)
	IR[4] Resolution 30 ppi	.03296 (f)	0.06639 (m)	0.03522 (f)

Appendix O: Pilot Study - Eye Tracker Data Scores – Gaze Fixation Detection

		Participant 1	Participant 2	Participant 3
Independent Variable **Resolution**	**IR[1]** **Resolution** **150 ppi**	0.45 (f)	0.2467 (f)	0.7233 (m)
	IR[2] **Resolution** **100 ppi**	0.8860 (f)	0.7144 (m)	0.3892 (f)
	IR[3] **Resolution** **74 ppi**	0.70585 (f)	0.8876 (f)	.09723 (m)
	IR[4] **Resolution** **30 ppi**	0.1839 (f)	0.0979 (m)	0.15802 (f)

Appendix P: Pilot Study System Usability (SUS©) Scores

		Participant 1	Participant 2	Participant 3
Independent Variable Resolution	**IR[1]** **Resolution** **150 ppi**	81% (f)	92.5% (f)	100% (m)
	IR[2] **Resolution** **100 ppi**	97.5% (f)	87.5% (m)	88% (f)
	IR[3] **Resolution** **75 ppi**	72.5% (f)	75% (f)	80% (m)
	IR[4] **Resolution** **30 ppi**	70% (f)	70% (m)	100% (f)

Appendix Q: Pilot Study - Virtual Environment Presence Questionnaire (VEPQ) Scores

Item Numbers	Participants											
	IR[1] 150 ppi			IR[2] 100 ppi			IR[3] 75 ppi			IR[4] 30 ppi		
	1	2	3	1	2	3	1	2	3	1	2	3
1	6	7	7	6	6	6	7	4	7	4	5	7
2	6	7	6	7	5	5	6	5	5	5	5	3
3	6	7	4	4	4	2	4	4	5	2	6	7
4	5	7	5	6	6	2	3	4	4	6	5	7
5	5	7	6	6	6	3	6	5	5	6	5	4
6	5	7	4	3	3	3	4	5	5	4	6	4
7	6	7	5	2	3	3	3	5	5	4	5	7
8	5	7	7	1	1	3	7	4	4	4	5	7
9	7	7	6	5	3	2	6	4	6	5	4	7
10	4	7	4	4	4	6	5	4	6	3	4	7
11	4	7	4	4	6	6	5	5	5	3	5	7
12	5	7	5	4	4	3	5	5	2	5	6	7
13	6	7	5	4	4	3	5	1	2	2	5	2
14	6	7	3	3	4	3	3	5	4	6	4	7
15	6	4	5	5	4	5	1	4	4	2	5	7
16	6	7	6	3	4	3	6	2	1	3	5	4
17	6	7	7	6	4	6	7	2	6	3	2	4
18	6	4	5	5	4	5	5	2	2	2	4	7
19	6	1	6	3	5	2	5	2	2	4	5	7
20	6	7	5	3	5	2	5	5	6	3	4	3

Appendix R: Mental Rotation Test (MRT) Scores

I. V. Resolution	Participant														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
IR[1] 150 ppi (%)	97 (m)	55 (f)	99 (f)	50 (m)	73 (f)	63 (f)	62 (f)	87 (f)	53 (f)	76 (m)	72 (f)	85 (f)	100 (m)	84 (m)	64 (f)
IR[2] 100 ppi (%)	58 (f)	57 (f)	60 (m)	52 (m)	94 (f)	52 (m)	79 (f)	84 (f)	88 (f)	84 (m)	72 (f)	82.5 (f)	63 (f)	82 (f)	95.64 (f)
IR[3] 75 ppi (%)	70 (f)	53 (m)	66 (f)	88 (f)	100 (f)	52 (f)	60 (f)	55 (m)	68 (m)	61 (f)	66 (f)	98 (f)	82 (f)	77 (f)	84 (f)
IR[4] 30 ppi (%)	84 (f)	94 (f)	79 (f)	60 (f)	55 (m)	92 (f)	61 (f)	52 (f)	52 (m)	73 (f)	57 (f)	68 (m)	82 (f)	72 (m)	62 (f)

Appendix S: Time-On-Task Performance Scores

I. V. Resolution	Participant														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
IR[1] 150 ppi (seconds)	74.17 (m)	103.7 (f)	85.19 (f)	62.30 (m)	72.70 (f)	71.2 (f)	97.6 (f)	119.8 (f)	73.02 (f)	40.63 (m)	49.26 (f)	26.93 (f)	89.84 (f)	87.45 (m)	61.3 (f)
IR[2] 100 ppi (seconds)	71.35 (f)	86.34 (f)	72.3 (m)	66.40 (m)	71.3 (f)	58.15 (m)	62.81 (f)	106.34 (f)	125.6 (f)	107.3 (f)	21.30 (m)	86.5 (f)	156.6 (f)	104.0 (f)	95.64 (f)
IR[3] 75 ppi (seconds)	214.03 (f)	150.99 (m)	204.92 (f)	185.62 (f)	153.16 (f)	239.2 (f)	74.0 (f)	150.92 (m)	221.8 (m)	198.0 (f)	177.72 (f)	167.43 (f)	125.1 (m)	139.42 (f)	233.7 (f)
IR[4] 30 ppi (seconds)	203.66 (f)	242.36 (f)	199.54 (f)	308.12 (f)	331.19 (m)	164.5 (f)	251.3 (f)	318.09 (f)	123.70 (m)	141.04 (f)	192.3 (f)	169.52 (m)	236.12 (f)	193.90 (m)	187.2 (m)

Appendix T: Eye Tracker Data Scores - Saccade Movements

I. V. Resolution	Participant														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
IR[1] 150 ppi	0.048 (m)	0.041 (f)	0.041 (f)	0.064 (m)	0.015 (f)	0.04 (f)	0.576 (f)	0.587 (f)	0.471 (f)	0.04 (m)	0.478 (f)	0.041 (f)	0.012 (f)	0.013 (m)	0.024 (f)
IR[2] 100 ppi	0.598 (f)	0.042 (f)	0.85 (m)	0.654 (m)	0.354 (f)	0.541 (m)	0.978 (f)	0.845 (f)	0.025 (f)	1.125 (f)	0.021 (m)	0.457 (f)	0.048 (f)	0.894 (f)	1.023 (f)
IR[3] 75 ppi	0.196 (f)	0.258 (m)	0.265 (f)	0.458 (f)	0.03 (f)	0.035 (f)	0.235 (f)	0.034 (m)	0.024 (m)	0.847 (f)	0.524 (f)	0.432 (f)	0.032 (m)	0.042 (f)	0.045 (f)
IR[4] 30 ppi	0.066 (f)	0.521 (f)	0.458 (f)	0.421 (f)	0.365 (m)	0.042 (f)	0.055 (f)	1.813 (f)	0.312 (m)	0.8 (f)	0.581 (f)	0.345 (m)	0.31 (f)	0.361 (f)	0.795 (m)

Appendix U: Eye Tracker Data Scores – Gaze Fixation Detection

I. V. Resolution	Participant														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
IR[1] 150 ppi	0.315 (m)	0.384 (f)	2.418 (f)	1.546 (m)	0.847 (f)	0.25 (f)	0.897 (f)	0.247 (f)	0.587 (f)	0.451 (m)	0.567 (f)	0.316 (f)	0.214 (f)	0.345 (m)	0.32 (f)
IR[2] 100 ppi	1.548 (f)	1.374 (m)	1.325 (f)	0.986 (f)	0.88 (f)	0.635 (f)	0.789 (f)	1.352 (m)	1.254 (m)	1.654 (f)	0.985 (f)	2.458 (f)	0.693 (m)	0.458 (f)	1.256 (f)
IR[3] 75 ppi	2.596 (f)	0.365 (f)	2.03 (m)	0.085 (m)	1.235 (f)	3.654 (m)	0.054 (f)	1.352 (f)	0.389 (f)	0.784 (f)	0.064 (m)	1.562 (f)	2.315 (f)	2.015 (f)	1.654 (f)
IR[4] 30 ppi	0.971 (f)	3.326 (f)	2.263 (f)	3.48 (f)	1.235 (m)	0.552 (f)	0.976 (f)	3.35 (f)	3.25 (m)	2.107 (f)	2.78 (f)	3.86 (m)	2.713 (f)	3.575 (f)	3.839 (m)

Appendix V: System Usability (SUS©) Scores

I. V. Resolution	Participant														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
IR[1] 150 ppi (%)	72.5 (m)	62.5 (f)	85 (f)	82.5 (m)	62.5 (f)	97.5 (f)	77.5 (f)	92 (f)	92 (f)	90 (m)	75 (f)	80 (f)	100 (f)	78 (m)	80 (f)
IR[2] 100 ppi (%)	72.5 (f)	87.5 (f)	87.5 (m)	66.4 (m)	100 (f)	67.5 (m)	87.5 (f)	92.5 (f)	70 (f)	97.5 (f)	95 (m)	82.5 (f)	75 (f)	66 (f)	80 (f)
IR[3] 75 ppi (%)	75 (f)	95 (m)	60 (f)	65 (f)	100 (f)	87.5 (f)	77 (f)	95 (m)	82 (m)	87 (f)	67.5 (f)	72.5 (f)	85 (m)	78 (f)	62.5 (f)
IR[4] 30 ppi (%)	90 (f)	94 (f)	60 (f)	60 (f)	68 (m)	100 (f)	72 (f)	85 (f)	67 (m)	77.5 (f)	80 (f)	75 (m)	72.5 (f)	82.5 (f)	91 (m)

Appendix W: Virtual Environment Presence Questionnaire (VEPQ) Scores

Group	Item Number																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	4	5	3	6	7	5	5	2	4	6	6	4	4	6	2	7	6	2	2	7
1	4	4	4	4	7	5	5	4	3	4	4	4	4	4	3	5	6	1	2	4
1	7	7	6	6	7	6	7	5	7	6	7	7	2	4	1	6	7	2	1	7
1	7	7	5	6	4	5	4	4	7	7	4	5	3	2	1	7	6	1	1	7
1	4	7	2	3	7	2	3	6	3	7	5	5	7	5	1	3	2	3	2	5
1	4	3	6	6	7	7	7	4	7	6	4	7	6	7	2	7	7	2	2	7
1	6	6	6	6	6	5	6	3	6	5	5	6	5	6	2	4	4	2	2	7
1	7	7	7	6	7	7	6	6	5	5	5	7	6	6	1	6	7	1	1	6
1	7	7	5	5	5	4	6	6	7	7	7	7	7	7	1	5	7	3	2	6
1	7	7	6	3	3	7	3	3	7	7	3	7	7	4	2	7	7	3	1	7
1	7	7	7	3	5	6	6	3	6	6	6	7	6	7	1	7	7	1	1	4
1	4	3	4	3	7	3	7	7	3	6	4	3	7	7	1	7	7	3	2	1
1	7	7	7	7	7	7	7	7	7	7	7	7	7	7	4	7	7	4	1	7
1	7	7	7	3	5	6	6	5	6	6	6	7	6	7	1	7	7	1	1	4
1	7	6	7	4	6	3	3	7	6	6	7	7	7	7	3	7	6	2	3	6
2	6	6	5	3	4	3	3	4	4	5	5	4	3	6	5	2	4	1	2	4
2	5	5	5	5	5	4	7	5	5	4	7	7	2	4	1	4	2	3	1	4
2	7	7	7	7	7	7	7	6	6	7	7	7	4	5	1	7	7	2	2	3
2	7	6	4	7	7	5	5	4	5	4	4	6	5	6	1	6	4	1	1	4
2	6	7	6	5	5	5	6	5	6	6	6	7	7	5	6	2	7	1	1	7
2	4	5	4	3	4	4	4	4	6	6	6	6	6	6	1	5	4	2	1	5
2	7	7	7	7	7	7	7	6	7	7	7	7	7	7	1	7	7	1	1	7
2	6	6	3	3	4	3	3	4	3	4	4	4	3	2	5	4	4	4	4	4
2	3	6	4	7	4	5	5	2	4	3	4	4	5	4	3	5	4	3	2	5
2	6	5	4	6	6	3	3	1	3	4	5	6	4	6	2	4	4	3	3	3
2	7	7	7	6	6	6	7	6	4	4	7	7	4	4	2	7	7	1	2	7
2	7	6	6	6	5	5	3	4	4	6	6	5	2	3	3	6	6	1	1	7
2	6	4	5	4	6	6	6	4	6	4	6	7	7	6	3	6	6	2	2	6
2	2	2	4	4	6	3	2	2	1	2	1	1	3	5	6	1	2	2	1	3
2	3	6	4	7	4	5	5	2	4	3	4	4	5	4	3	7	6	1	2	7

Appendix W: (Continued)

Group	Item Number																			
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
3	4	5	4	4	5	5	5	4	5	4	4	4	4	5	1	4	5	2	4	5
3	7	7	7	7	7	6	7	7	7	7	7	7	7	7	2	7	7	2	2	7
3	4	7	4	4	5	4	4	4	4	3	3	3	4	5	1	4	4	2	3	3
3	3	4	3	4	4	3	5	5	4	4	4	3	2	4	1	5	3	2	1	4
3	4	7	4	7	6	4	7	4	6	7	7	7	4	7	1	6	7	1	1	4
3	6	7	6	7	7	6	6	6	7	7	6	6	6	6	5	7	6	1	4	4
3	7	6	6	6	6	6	7	6	7	7	7	7	6	1	2	7	7	2	2	5
3	7	7	7	7	6	7	6	7	7	7	7	7	7	7	1	7	7	3	2	7
3	7	6	6	5	6	6	6	5	7	7	6	3	5	5	2	7	7	3	3	7
3	6	7	4	5	4	5	3	3	7	7	3	6	3	6	3	3	7	2	3	4
3	3	3	2	4	4	6	3	3	1	4	3	3	2	4	2	3	3	2	3	2
3	5	7	6	4	3	6	4	3	7	6	5	5	5	3	1	6	7	3	3	5
3	6	7	6	6	7	4	4	4	6	6	4	3	6	7	1	7	7	2	2	7
3	7	7	7	6	5	4	6	4	7	7	6	5	1	5	2	7	7	2	2	2
3	4	5	4	4	3	3	3	6	4	3	3	5	5	5	1	3	2	2	2	7
4	7	7	7	7	7	6	6	6	7	7	7	7	5	7	1	6	6	1	1	7
4	5	7	2	5	5	4	4	5	4	4	3	4	4	5	3	3	3	2	2	5
4	5	4	3	4	5	5	3	4	7	6	4	5	5	5	2	5	5	3	3	5
4	3	7	4	6	7	4	4	5	4	4	3	6	3	6	1	3	3	1	1	4
4	5	5	7	6	6	7	6	6	5	5	6	4	6	6	4	6	6	3	4	5
4	7	4	7	7	5	5	7	7	7	7	7	7	7	3	3	5	5	2	3	4
4	4	5	2	6	6	4	4	5	3	3	5	6	3	5	2	3	3	2	4	3
4	3	6	2	6	4	6	6	6	6	6	7	4	2	5	2	5	7	3	3	7
4	5	4	5	4	5	5	7	4	5	4	5	4	5	4	2	7	7	2	3	3
4	5	5	5	5	5	5	4	7	5	5	4	7	5	5	4	7	7	2	2	4
4	6	7	6	6	4	4	6	6	6	4	6	3	4	4	3	4	7	4	3	6
4	7	7	7	5	7	3	6	6	7	7	7	3	3	7	5	6	6	3	2	7
4	6	3	3	6	6	4	2	3	3	2	1	7	2	6	1	7	1	1	3	3
4	5	6	6	4	4	2	6	6	6	3	6	3	3	3	6	0	6	0	2	6
4	7	6	5	5	6	3	6	6	6	6	6	2	5	6	4	5	5	2	5	5

Appendix X: Tukey Post Hoc Analysis of Time-on-Task Performance Scores Between Image Resolution Groups

(I) res	(J) res	Mean Difference (I - J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
IR[1]	IR[2]	-31.06333	26.15496	.651	-114.8207	52.6941
	IR[3]	-130.64333*	26.15496	.005	-214.4007	-46.8859
	IR[4]	-213.82667*	26.15496	.000	-297.5841	-130.0693
IR[2]	IR[1]	31.06333	26.15496	.651	-52.6941	114.8207
	IR[3]	-99.58000*	26.15496	.022	-183.3374	-15.8226
	IR[4]	-182.76333*	26.15496	.001	-266.5207	-99.0059
IR[3]	IR[1]	130.64333*	26.15496	.005	46.8859	214.4007
	IR[2]	99.58000*	26.15496	.022	15.8226	183.3374
	IR[4]	-83.18333	26.15496	.052	-166.9407	.5741
IR[4]	IR[1]	213.82667*	26.15496	.000	130.0693	297.5841
	IR[2]	182.76333*	26.15496	.001	99.0059	266.5207
	IR[3]	83.18333	26.15496	.052	-.5741	166.9407

*. The mean difference is significant at the 0.05 level.

IR[1] = image resolution group one (150 ppi) IR[2] = image resolution group two (100 ppi)

IR[3] = image resolution group three (75 ppi) IR[4] = image resolution group four (30 ppi)

N = 60

Appendix Y: Tukey Post Hoc Analysis of Gaze Fixation Detection Scores Between Image Resolution Groups

(I) res	(J) res	Mean Difference (I - J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
IR^1	IR^2	-.69667	.61973	.676	-2.3377	.9443
	IR^3	-4.13307*	.61973	.000	-5.7741	-2.4921
	IR^4	-3.53713*	.61973	.000	-5.1781	-1.8961
IR^2	IR^1	-.69667	.61973	.676	-.9443	2.3377
	IR^3	-3.43640*	.61973	.000	-5.0774	-1.7954
	IR^4	-2.84047*	.61973	.000	-4.4815	-1.1995
IR^3	IR^1	4.13307*	.61973	.000	2.4921	5.7741
	IR^2	3.43640*	.61973	.000	1.7954	5.0774
	IR^4	.59593	.61973	.772	-1.0451	2.2369
IR^4	IR^1	3.53713*	.61973	.000	1.8961	5.1781
	IR^2	2.84047*	.61973	.000	1.1995	4.4815
	IR^3	-.59593	.61973	.772	-2.2369	1.0451

* The mean difference is significant at the 0.05 level.

IR^1 = image resolution group one (150 ppi) IR^2 = image resolution group two (100 ppi)

IR^3 = image resolution group three (75 ppi) IR^4 = image resolution group four (30 ppi)

N = 60

About the Author

Lisa Anderson is an instructional designer, past college department chair and faculty of new media and graphic design. She is a lifelong artist, illustrator and graphic designer. She has received numerous consecutive year awards in education and industry including; Outstanding Faculty, Faculty of the Year, Who's Who in the World, Who's Who in America, Who's Who Among American Women, Who's Who Professional Executives Registry – Lifetime Inductee, and Who's Who Among America's College Teachers. Lisa has co-written five books with topics ranging from specific software skills, technology integration to faculty development and student success strategies with media. She has presented at numerous educational conferences, written articles and been a guest speaker on education and technology integration at national conferences.

Lisa has worked in major national corporations as a manager. She has owned her own educational, instructional design and faculty development consulting business working with numerous clients including Pearson Education, Prentice Hall, Cengage Learning, IBM, the National Center for Medicare and Medicaid, school districts, colleges and universities. She is currently a manager of instructional design technology in the Educational Methods Division of a fortune 100 company.