ABSTRACT

PAYNE, ANDREW PHILLIP. Understanding Change in Place: Spatial Knowledge Acquired by Visually Impaired Users Through Change in Footpath Materials. (Under the direction of Dr. John O. Tector.)

Throughout time, humans have traveled to new places and experienced unfamiliar territories oftentimes without fear of what lies ahead. However, in today's world any environment outside of our everyday paths of travel can be challenging and intimidating.

This research sets out to investigate the role of typical footpath construction materials in communicating a user's position within an urban environment. While illustrating the importance of detecting changes in materials, it argues that positional information should be available to all users. To examine this phenomenon, this study compares the two components – user and materials. Within the research, a theoretical framework is developed to explain the direct relationship between user and material, and a methodological design is used to elicit detectable values of each material independently and when compared to one another. By doing so, this research produces a means of evaluating the existing and future use of construction materials as a component of larger way-finding systems.

This research will have a practical importance from the standpoint of determining which combinations of footpath construction materials are best detectable, identifiable, and able to be used in way-finding by visually impaired travelers within an urban setting.

Understanding Change in Place: Spatial Knowledge Acquired by Visually Impaired Users Through Change in Footpath Materials

by
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DEDICATION

To my Lord and savior Jesus Christ, through whom, all things are possible. To my wife Ginny, for all that is possible, I will do.

BIOGRAPHY

Andrew Phillip Payne was born in 1972 in Fayetteville, North Carolina. In 1997 Andrew began the first of three degrees to be completed at the College of Design at North Carolina State University. In 2001, Andrew earned a Bachelors of Environmental Design in Architecture, in 2003 his Master's of Architecture, and in 2009 this PhD in Design. Andrew was acknowledged for many accomplishments while at NCSU including the Jenkins-Peer Architecture Fellowship. Andrew was able to expand his education through research and teaching assistantships for the Dean of the College Marvin Malecha, Professor Gail Peter Borden, Dr. Nilda Cosco, and The Center for Universal Design. Through each phase of his education Andrew was able to refine his design interests in areas such as construction materials, universal deign and campus planning and design. In addition to the research and design work at NCSU, Andrew worked with several architecture firms in the North Carolina area.

In 2002, Andrew along with his wife Ginny, Co-founded *Studio GAP*, a Graphic Design, Architectural Design and Photography Studio, where he serves as Principal Designer and Consultant. In 2008 Andrew accepted a position of Professor of Architecture, at Savannah College of Art and Design in the School of Building Arts, Department of Architecture. Andrew focuses his teaching on construction technology, universal design and accessibility and thesis development. Andrew actively conducts research, writes papers and articles, and speaks and conferences.

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Chapter One
Introduction

1.1 The Premise of the Research

Why and to what extent do pedestrians experience difficulty navigating an urban setting?

The emergence of way-finding difficulties, one may think, is a recent phenomenon brought on by the complexity of contemporary buildings and cities (Arthur & Passini, 1992). However, studies by Romedi Passini (1984), Gerald Weisman (1981), and Corlett, Kozub, and Tardif (1989) provide insight into many facets of way-finding behavior such as navigation difficulties and spatial problem solving.

As indicated in the following sections, research literature on way-finding has flourished over the past few decades. Studies exploring the influence of designed environments are greater in number than ever before. If this influence is true, what might the variables of these design features be?

It is proposed that one's mental image, or *cognitive map*, of an environment plays a critical role in way-finding. More generally, such images are seen as mediating between the objective physical characteristics of a setting and the behavior within that setting. The theoretical model of the "cognitive map" proposed by Kaplan, Kaplan, and Ryan (1998) yields several important concepts. These concepts concern the structure of information in the environment, the kinds of information toward which humans have a bias, and the kind of information that, as a consequence, humans may seek in the process of way-finding. Several of these studies are identified and discussed throughout this document.

1.2 General Premise and Concepts of the Research

In reviewing much of the literature on way-finding and orientation, no studies were found to combine visually impaired travelers and construction materials when looking at " … the physical setting within which way-finding occurs, or the extent to which design features contribute to, or might help resolve, difficulties in way-finding" (Weisman, 1981). Thus, three related questions were formed for the structure of this research. First, it was essential to ask

what type of way-finding difficulties are most common; second, which aspects of mobility are most important for travel; and, third, how unfamiliar spaces are perceived. This research proposed an empirical investigation in order to answer these questions, specifically by using visually impaired participants.

Throughout this paper, words are used independently and interchangeably with common terms from the fields of design, psychology, sociology, and others. In building the vocabulary for this research we begin with Long and Hill (1997), who define way-finding as, "The process of navigating through an environment and traveling to places by relatively direct paths." Whereas way-finding is the process of movement, mobility is "the act or ability to move from one's present position to one's desired position in another part of the environment safely, gracefully, and comfortably" (Long & Hill, as cited in Blasch, 1997). These strategic movements from place to place include both orientation and navigation.

This document is an all-inclusive look at how each of the elements necessary for site navigation is intertwined. The term way-finding was first used by architect Kevin Lynch in *The Image of the City* (1960), in which he referred to maps, street numbers, directional signs and other elements as "way-finding devices." The term way-finding is only a few decades old and has been adopted by many industries, including tourism, architecture, urban planning, and computer graphics. Although the term is fairly new, the ideas of navigation and orientation are not, and are generally taught under the title of environmental communications (Arthur, 1988).

Way-finding is not only for people who are lost, but also for tourists in a foreign city, visitors in a hospital, or others. Way-finding is much more personal to each individual and "is the cognitive element of navigation" (Baskaya et al., 2004). Way-finding is not "merely a planning stage that precedes motion, but is intimately tied together with motion" (Baskaya et al., 2004) in a complex negotiating process of thought and decision making exercises that comprise navigation. Part of this complex thought process is the building of a cognitive map to represent the physical environment. Many researchers accept the definition of cognitive mapping as a process composed of a series of psychological transformations by which an individual acquires, stores, recalls, and decodes information about the relative locations and

attributes of the phenomena in his or her everyday spatial environment (Downs & Stea, 1973).

In addition to cognition, there are two main categories of vision that will be described in this research: legally blind and blind. As a general definition in the United States, legal blindness is defined as a maximum corrected visual acuity of 20/200. Total blindness (or blind) is the complete lack of form and light perception. Both categories fall under the umbrella of vision impairment, which is defined as “a person's eyesight which cannot be corrected to a normal level by any means” (Gerberding, 2005), but there may be some residual vision or perception of light. People often think of blindness as the complete and total loss of sight. In fact, a very small percentage of people categorized as “blind” have no sight at all. Many blind people have some degree of functional vision. Their level of sight can vary from the perception of light and dark to being able to read standard print with the help of low vision aids.

Being legally blind does not always mean that a person lives in total darkness. Nearly half of the number of blind people can recognize a friend within an arm’s length (RNIB, 2006). Outside of total vision loss, other people may experience eye conditions with various characteristics such as no central vision or no peripheral vision. Other individuals may see a patchwork of blank and defined areas, or may even see things as a vague blur. Glaucoma, a very common eye disease, can result in tunnel vision, where all side vision is lost and only central vision remains, or total blindness. “Diabetic retinopathy can cause blurred and patchy vision, whereas macular degeneration can lead to a loss of central vision while side vision remains” (RNIB, 2006). It is important not to forget that people are affected by eye conditions in different ways.

1.3 Discussion of the Problem Area

This research is designed to explore spatial knowledge acquired by visually impaired users through the navigation of an environment as a means to orient themselves within a space. More specifically, a large-scale space requires the combination of spatial and temporal information in order to experience it fully (Barlow, 1999). This experience is built through direct navigation, or first-person movement through an environment. Movement and

direction of movement are determined by the user, the paths, and the points of destination throughout the space. The variable, blindness, adds another level of importance when evaluating users' cognitive mapping structures and decision making processes in this research.

"The difficulty of a way-finding task is affected by two major physical factors: the layout of the setting and the quality of the environmental communication" (Arthur & Passini, 1992). The layout, defined by Romedi Passini, is determined by its spatial context, its form, its organization, and its circulation. Passini also states that environmental communication consists of essential information for way-finding such as the architectural, audible, and graphic expressions. To accommodate all pedestrians, it is important to provide information that can be assimilated using more than one sense. Also, redundancy and consistency increase the likelihood that all users will be able to make informed traveling decisions.

Passini (1992) concluded that people finding their way in complex settings will try to understand how they are organized and will identify things to map. The building blocks used for cognitive mapping are spatial entities, and these spatial entities can only be mapped if they are distinct or unique from their surroundings. The same holds true for decision making. Decision making and execution can be successful only if destinations have an identity distinguishing them from other places. "A place has to be recognized before a decision can be transformed into behavior. Distinctiveness giving places their identity is, thus, a major requirement for way-finding" (Arthur & Passini, 1992).

Rapoport (1990) developed three classifications of environmental elements: (a) fixed-feature elements, (b) semi-fixed feature elements, and (c) non-fixed feature elements. Fixed elements or elements that change rarely and/or slowly include streets, buildings, topography, etc. Semi-fixed elements are less permanent such as "the arrangement and type of furniture, signage, decorations, vegetation, weather, etc." (Rapoport, 1990). The final category of non-fixed, ever-changing elements includes cars, people, animals, etc. These classifications include numerous multisensory cues and social cues that are very useful when discussing Kevin Lynch's position on imageability of environments.

Lynch (1960) suggested that identity, structure, and meaning define how imageable an environment can be. Identity, by far the most important of the three, is the extent to which a person can recognize or recall an environment (or its cues) as being distinct from other environments through a unique character of its own. More specifically, identity refers to the noticeability or legibility of individual elements. Structure is the manner in which the environmental elements are ordered and related to each other and the extent to which this structure is comprehensible. Meanings are the messages and other associations that environmental elements are capable of communicating to users.

Lynch continues to express the shear importance of imageability and legibility of everyday spaces in way-finding tasks. In the process of way-finding, the strategic link is the environmental images, the generalized mental picture of the exterior physical world that is held by an individual. This image is the product both of immediate sensation and memory of past experience, and is used to interpret information and to guide action (Lynch, 1960).

This research combines all of the elements of a complex setting, multiple circulation structures, decision making tasks and spatial identity into one complete study. While previous research has considered the effects of these variables individually (Butler, Acquino, Hissong, & Scott, 1993; Levine, Jankovic, & Palij, 1982), this dissertation is one of a few (Weisman, 1981; Brambring, 1982) to combine the visually impaired user and way-finding with the independent variable being foot path material.

1.4 The Significance of the Study

This study has both theoretical and practical significance. The theoretical significance is derived from the multidisciplinary approach and theoretical framework which is discussed in later sections. This study also fills voids in the literature of environmental design, architecture and planning, environmental cognition, and psychology. These disciplines, while concerning themselves with the physical design and mental conceptions of spaces, are rarely combined with such a specific group as visually impaired, adult, independent traveling cane users.

The practical significance of this research is grounded in the underlying premise: that way-finding by visually impaired users within an urban setting can be enhanced through architectural design and planning. “A distinctive and legible environment … heightens the potential depth and intensity of human experience” (Lynch, 1960). The design approach addressed in this research is that of pedestrian paths and construction materials. The relationship between paths and materials was determined to provide a clear basis and rationale for future designs.

1.5 Statement of the Problem

Reginald Golledge in *Environmental Perception and Cognition*, (Garling & Golledge, 1989) stated, “Knowledge gained about perceptual-cognitive processes may improve the quality of human environments through policy, planning and design, to the extent that it tells us how to plan and design environment’s [*sic*] that do not interfere with the proper functioning of these processes.” Kevin Lynch (1976) originally stated, “We can better plan, design, and manage the environment for and with people if we know how they image the world.” Robert Kitchin (1994) reiterated this point by explaining that environments can influence behavior, and explanations of that behavior can be used to influence the make-up of new environments.

Conclusions from this research can help develop design standards as one piece of a more accessible way-finding information system. The completed design will be more inclusive of visually impaired pedestrians, and changes in surface materials will be a method for providing information cues along the journey. It is predicted that with the incorporation of changes in materials at key locations within the footpath network, users will better understand the spatial layout. For example, once the user has learned the overall information system, a detected change in footpath material would indicate one or more of the following: (a) change in path direction, (b) location of signage, (c) building entrance, or (d) a familiar location within the space.

1.6 Statement of the Purpose

This research contains two primary purposes. The first purpose is to investigate and compare the physical characteristics of seven construction materials often used for sidewalks. These characteristics include size, shape, installation methods, vibration, and

sound attenuation. The second purpose of the research is to determine the best combination or “material adjacency” to produce the greatest level of detection of change in materials among the users. As demonstrated by in-depth research studies by Axelson and Chesney (1999), Cooper et al. (2004), and Peck and Bentzen (1987), changes in sidewalk materials can be considered a valid means of conveying information to visually impaired travelers. In order to help architects, landscape architects, planners, and urban designers produce the most accessible environment possible, this research provides a design standard for pathways that can incorporate information cues in the form of changes in materials along the travel path.

1.7 The Structure of the Research

The preceding discussions in this chapter provide the background for the proposed research. The central focus is defined as being the user’s ability to determine his or her position within a space based on cues from changes in footpath materials. The research then outlines the necessity of an empirical study that demonstrates the manner in which this identification of change can be accomplished.

Chapter 2 provides the essential first step for this endeavor. A review of valuable literature from many disciplines, including environmental and behavioral science, psychology, architecture and others, connects the research findings and concepts into a theoretical framework that directs and supports the research. Chapter 3 presents the primary and secondary research questions of the study and assumptions that guide those questions. Chapter 4 gives a detailed description and justification of the research design, data gathering techniques, and data analysis methods. Chapter 5 provides a detailed organization of the data and analysis, whereas chapters 6 and 7 describe and defend the conclusions. (See figure 1.7.a for the overall dissertation structure).

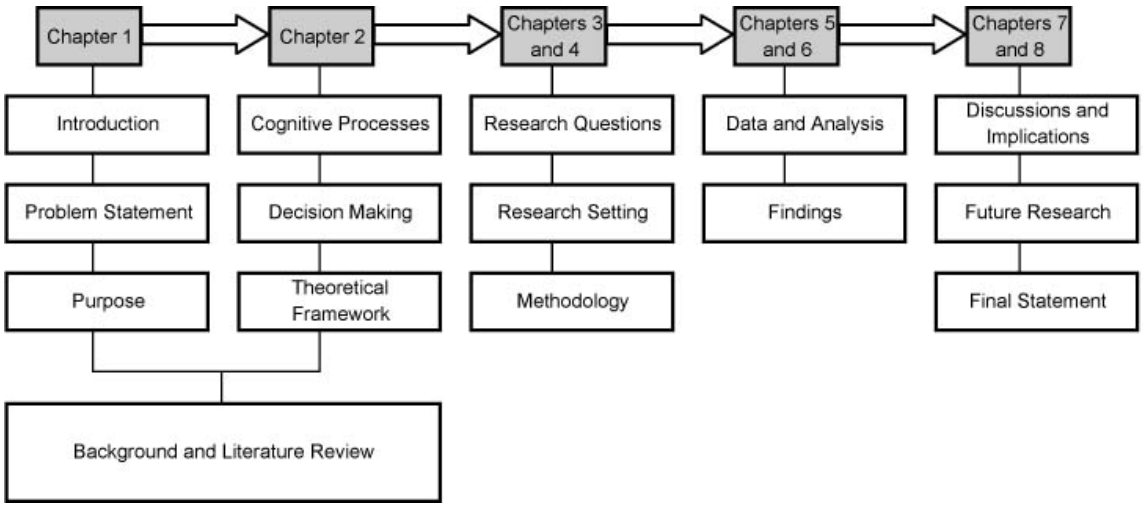


Figure 1.7.a: Dissertation Structure Diagram

Chapter Two
Literature Review and Theoretical Framework

The following sections attempt to answer several questions: What are the cognitive processes of way-finding, and how are they different from other knowledge and learning processes? Secondarily, how are cognitive maps incorporated into decision making?

2.1 Cognitive Processes of Way-finding

Cognitive maps have been called a "picture in the head," although there is significant evidence that the mental view is not purely based on imagery but rather has a symbolic quality. Each individual's ability to visualize, retain, recall, and utilize cognitive maps varies drastically from one person to another. It is the "people with accurate memory for layout or spatial acuity who are more successful way-finders" (Golledge, 1999). The term cognitive map has a long history in psychology. The original connotation of the expression pertains primarily to place-place expectations acquired in differentiated surroundings after ample experience. "Since it is typically impossible that an environment can be seen in its entirety from one point of observation the cognitive map construct is important for users in mentally representing places" (Golledge, 1999). Lynch (1976) originally set the foundation for this theory by stating: "[We] can better plan, design and manage the environment for and with people if we know how they image the world."

2.1.1 Comparisons of Blind and Sighted Users

It has been said that no other sense can identify, gather, and process the same volume of information as quickly and as accurately as sight. It is estimated that up to 90% of all information obtained is through sight. In the greater context of mobility, distant cues obtained through sight mean anticipation. Once the user has the ability to preview the path ahead, he or she is now able to be proactive in travel by avoiding obstacles and the identifying place. Visually impaired pedestrians should have access to the same information as sighted people when traveling in unfamiliar areas. The most effective accessible information is easy to locate and intuitive to understand, even for pedestrians who are unfamiliar with an area. Geruschat and Smith (1997) state:

By way of comparison, the student who is totally blind obtains the information required for independent travel through a combination of the remaining sensory information, principally auditory and tactile. For the purpose of being mobile, auditory, tactile, and other sensory information provides all the critical information required for independent travel. The primary difference between sighted and blind travel is the distance and speed in which environmental information is processed.

2.1.1.1 Case #1

Loomis, Klatzky, Golledge, Cicinelli, Pellegrino, and Fry (1993) conducted a set of navigation tasks with subjects categorized as blindfolded sighted, adventitiously blind (occurs as a result of a disease or an accident), and congenitally blind (blind since birth or up to two years old, typically from a defect). “Effective navigation by humans involves a number of skills, including updating one’s position and orientation during travel, forming and making use of representations of the environment through which travel takes place, and planning routes subject to various constraints” (shortest distance, minimal travel time, maximum safety, etc.) (Loomis et al., 1993). This study originated from the researchers’ interest in the general problem of how blind travelers make their way through natural environments. “Clearly, blind travelers are at a considerable disadvantage relative to the sighted, for vision ordinarily provides information about both the traveler’s motion and the layout of near and far spaces” (Loomis et al., 1993). It has been suggested in other studies that visual experience is required for the development of normal spatial abilities, such as estimating distances and using landmarks. If so, then it can also be said that congenitally blind users are at more of a disadvantage at perceiving space. However, Heller (1989) concludes in his study that “visual imagery is not necessary for texture [and or spatial] perception.”

For the study, Loomis et al. (1993) selected 36 participants to take part in Experiment One, and they were recruited by the Los Angeles Braille Institute or lived in the Santa Barbara, California vicinity. All of the subjects were capable of finding their way around in their respective communities (by walking, public transportation, or both) and were either employed or college students. Three groups of 12 (sighted, congenitally blind and adventitiously blind) were formed and matched based on age, gender, and education level.

The tasks for this experiment were “simple“ and “complex” locomotion exercises. The simple task consisted of reproducing and estimating a walked distance (expressed by verbally declaring the distance in feet), and reproducing and estimating a turn (expressed by verbally describing the rotation of degrees from an established baseline of zero). The complex task involved “completing a triangle by either walking two legs and retracing a two-sided or three-sided figure or completing it with a shortcut” (Loomis et al., 1993). The initial locomotion task lasted 1.5 hours and the reproduction task lasted an additional hour. The tasks were conducted in a darkened 40 foot x 40 foot room, and each subject wore sound-attenuating headphones.

The simple locomotion or distance estimation and reproduction task was completed by each participant being led by a sighted guide (the participant holding the guide just above the elbow as they walked side by side) for a varying distance (6, 12, 18, 24, or 30 feet approximately) in random order. After walking a distance, the participant was to estimate said distance and reproduce the same distance by walking forward without the aid of the sighted guide. Similarly, with the complex locomotion or distance and reproduction task, the subjects were led along two legs of a triangle and were asked to estimate the angle of turn between leg “A” and “B,” and either reproduce the paths in reverse order or complete the third leg “C” of the triangle by returning to the starting point.

The results from the simple locomotion task indicated no differences among groups in the ability to perform simple reproductions of turns and linear segments. Distance estimations varied from overestimation of shorter distances to underestimation of longer distances. Turn reproduction and estimation also varied with overestimation of smaller angles and underestimation of larger angles and with greater accuracy when the angle was a multiple of 90 degrees.

As hypothesized in this study as well as others, blindfolded sighted and adventitiously blind participants performed better than congenitally blind participants on a variety of navigation tasks. In a very popular study, Worchel (1951), participants were also asked to complete triangulation by “path integration.” Worchel (1951) found that sighted participants performed

significantly better than the blind participants; whereas, congenitally blind and adventitiously blind observers did not perform differently. Loomis et al. (1993) concluded that “individuals who lack early visual experience may fail to develop the spatial abilities requisite for independent travel” and that “vision is important for the development of spatial competence.”

2.1.1.2 Case #2

Murakoshi and Kawai (2000) produced a study “exploring way-finding behavior in an unfamiliar environment.” The participants were 24 (sighted) university freshmen who were tasked with returning to the starting point after an 8-minute walk within a complex building. The participants were encouraged to use the shortest path possible. Upon returning to the starting point, the participants went though various other exercises, including a photo memory task, a route memory task, a pointing task, and a sketch map of the route.

Way-finding performance was found to correlate with the performance in the sketch map task, the pointing task, and with route memory. However, “some participants who either drew incomplete sketch maps or had an inaccurate homing vector” (Murakoshi & Kawai, 2000) also were able to return to the starting point with minimal errors. In this study, the behavior of the statistically worst way-finder suggests that poor way-finders focus on irrelevant landmarks, and that sensitivity to the quality of landmarks is a critical factor for successful way-finding.

2.1.1.3 Case #3

Levine, Jankovic, and Palij (1982) produced a research study that focused on the principles of spatial problem solving. The basis for much of this information stemmed from the goal “to characterize the validity of the cognitive map, that is, of acquired spatial knowledge” (Levine et al., 1982). In this exercise, blindfolded college students learned simple 4-point paths by one of three methods: (1) by either moving their fingers over the successive points of a tactile map; (2) by walking along a path diagrammed on the floor; or (3) by temporarily removing their blindfold and viewing a standard cartographic map of the path. The participants were then tested for their knowledge of the path by having to recreate the path in search of a target.

Individually, 24 college students were placed at a starting point (i.e., point 1) on the path and required to move to another point (i.e., point 2, 3, or 4). This required either moving toward the next point in the sequence or taking a shortcut directly to the destination (i.e., from point 1 to point 3).

This experiment set out to determine "if the route learning produced a cognitive map" and "if this map was picture-like" (Levine et al., 1982). The researchers' general strategy was to consider the special properties of pictures as being: (a) simultaneous representations of sequentially placed points, and (b) orientated in relationship to the viewer. The researchers then sought to demonstrate that the behavior of the students reflected the presence of the special properties (a and/or b) noted previously. Levine et al. (1982) stated, "If the students have an internal pictorial map then these properties imply that they should take shortcuts." This was tested and confirmed. "However, the results from the orientation tasks were a surprise," with the participants moving in the wrong direction (angle error greater than 90 degrees) on more than 25% of the specified trials. These results support the thought that cognitive maps are picture-like.

2.1.2 Spatial Knowledge

A person's way-finding performance will improve with increased spatial knowledge of the environment. Many orientation specialists indicate that routines and reenactments best reflect the process of building cognition in the field of spatial knowledge. Thorndyke and Stasz (1980) describe this knowledge in terms of three hierarchical levels of information. Cognitive maps are synonymous with *survey knowledge*, which looks at locations and distances of objects as being measured from a fixed reference and can be thought of as either an overhead map-like view or a first-person walk through view. Lynch (1960) stated that survey knowledge has been found to be essential for skillful way-finding. *Landmark knowledge* is information about the visual details of specific locations in the environment. It is based on notable or easily recognizable features such as a unique building, statue, fountain, and other physical objects. Both survey and landmark knowledge are comprised of multi-dimensional information about the spatial relationships among environmental features. However, *procedural knowledge* is categorized as uni-dimensional information and is insight about the sequence of actions (or procedures) required to navigate particular routes.

Procedural knowledge is constructed by processing multiple pieces of landmark knowledge into a larger more complex structure (see figure 2.1.2.a), and is thought by some theorists to be “a primitive form of cognitive maps while others suggest that it involves a completely different type of learning” (Thorndyke & Stasz, 1980).

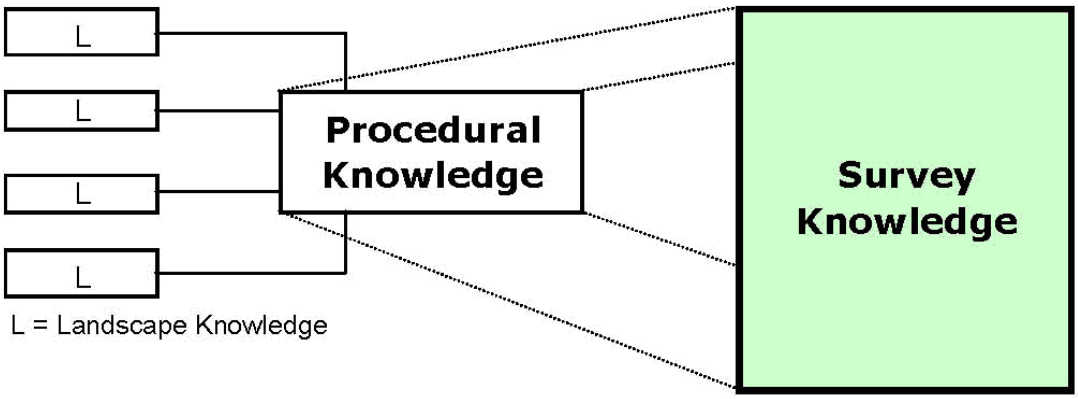


Figure 2.1.2.a: Knowledge Type Diagram

In its advanced stages of development, procedural knowledge becomes survey knowledge, enabling inferences to be made from a single point of view. Alternatively, survey knowledge can also be obtained directly from cartographic-like maps. When information is acquired by this method, the survey knowledge tends to be orientation-specific requiring the user to conceptually rotate his or her mental representation of the space to match the actual environment. It is very important that way-finders be able to identify certain spatial characteristics that allow them to group destinations into common or like zones.

“Distinctiveness, we have seen, can be achieved by outstanding features and by compositional characteristics. The repetition of spaces or architectural features, their rhythmic arrangements, and other proportional relationships can be considered distinctive and thus gain [landmark] quality” (Arthur & Passini, 1992). The authors also identify the most efficient strategy of constructing a mental map as taking note of landmarks and using them as mental anchors. These landmarks in way-finding can be unique physical features, events, and destination zones.

The loco-motor experience utilizes a more orientation-free knowledge where distance and directional estimates are made during navigation and influenced by the amount of environmental information obtained and processed by the traveler. However, “knowledge gained from maps usually differs from the knowledge gained through loco-motor experience” (Golledge, 1999). Siegel and White (1975) suggest that people begin learning about large-scale space by learning landmarks in a new area and then begin to encode the order of landmarks which demarcate routes from specific starting places to salient goals. Montello (1993) states people can acquire all three types of information continuously, improving the accuracy and precision of their data gathering over time. “The use of these knowledge levels depends on the spatial task at hand: we may develop a hierarchically progressing spatial knowledge from landmark-to-route-to-survey schema, or develop a procedural knowledge or use both types of knowledge separately” (Silva, 2004). Another type of perceptual schemata is that of observable activities and events occurring in the environment. The combination of events and order is very important in this research.

Spatial awareness exists simultaneously with spatial knowledge. The awareness aspect refers to the overall environment outside the realm of way-finding and navigation. Elements of the environment in this category include vehicular traffic in outdoor settings, other pedestrians and conversations in crowded areas, and typical distant distractions. Tversky (2003) expresses interaction in space as explicit or implicit. Explicit interaction describes the manner in which we utilize or take advantage of the space, by acknowledging, learning, and using all that the space has to offer. Implicit interaction involves an understanding of the purpose and nature of a particular space. “In order for us to have meaningful, connected experiences that we can comprehend and reason about, there must be pattern and order to our actions, perceptions, and conceptions” (Johnson, 1987).

Previous studies have been inconclusive in determining whether survey knowledge is an outgrowth of procedural knowledge. Rossano and Reardon (1999) examine one factor, goal specificity, as affecting the development of survey knowledge from procedural knowledge. “Goal specificity refers to the extent to which an explicit goal exists, and which problem-solving activities are directed” (Rossano & Reardon, 1999). Using computer-simulated navigation around a 3-D model of the University of California-Riverside, participants were

tasked with developing a cognitive map of building relationships and placement within the environment.

The participants for this study were 50 undergraduate students registered through the Department of Psychology's research sample pool. The group was divided into Group A and Group B through random assignment. Group A observed a 15-minute guided 3-D walk-through simulation of the virtual campus, whereas Group B was allowed to freely explore the virtual campus model by using a computer mouse. However, Group B participants were specifically directed to be constantly mindful of their position within the space in relation to a prominent landmark. Each participant was then tested on his or her identification and placement of a missing building from a campus map. Participants were scored on estimated distances between buildings, orientation in relation to other structures, and the correct naming of selected buildings.

The results of this research determined that participants who watched the guided campus tour (Group A) were found to have more complete and accurate survey knowledge. Group B contended with the interfering task of landmark positioning (identified earlier as goal specificity) which lessened acquisition of survey knowledge. Practically speaking, this research implies that when getting to a goal is of primary concern, the development of survey knowledge may be inhibited even after extensive direct route knowledge.

Ungar, Blades, and Spencer (1997) investigated whether tactile maps can provide visually impaired adults with the information necessary for them to follow a long, complex route through an urban environment, and the extent to which they can gain a coordinated representation of the environment with the aid of the map. In previous research (Ungar, Blades, & Spencer, 1993, 1995, 1996), the researchers have shown that "tactile maps can be a useful means of providing visually impaired people with complex spatial information which is not readily available" to them from direct experience. Route based knowledge of a large space imposes limits on the degree of navigation that a person can achieve. For instance, short cuts and alternate routes cannot easily be deciphered from route-knowledge, but are more readily available in the use of survey knowledge. This can be problematic, especially when a visually impaired person is introduced to an unfamiliar setting.

The participants in this study were 10 blind or partially blind men and women who traveled either by guide dog or the assistance of a long cane. Four of the participants were blind since birth, and all range in age from 20 years 11 months to 47 years 10 months. All participants learned two similar paths (1.2 kilometers with 13 decision points) by one of two methods, either review of a tactile map or by direct experience on-site. The protocol for learning direct experience consisted of allowing the subjects to freely navigate the path and ask questions and receive descriptions of each decision point along the way. The tactile map experience was similar in the fact that the experimenter provided information about each designated symbol along the map route until the participants felt confident with the map. After completing the learning trials, each participant was asked to walk the learned route unguided for Trial 1. Trial 2 was similar, with the addition of distance estimations at designation points along the path.

The results of this study determined that the participants who carried a map performed as well as the others who had already had direct experience of the entire route. Continuing with trial two, the group reviewing the tactile map (now relying on the memory of the map that they carried in Trial 1) still performed as well as the direct experience group (who had the benefit of two complete journeys along the route prior to the second trial).

These results suggest that tactile maps are an effective means for introducing blind and visually impaired people to the spatial structure of an unfamiliar space. Prior to this study, it has been believed that blind people lack the spatial skills to benefit wholly from tactile maps, mainly from the lack of ability to apply a scale necessary to relate the map to the real world. “It had been expected that the use of a tactile map would result in increased ‘Configurational Knowledge’ of the environment, relative to direct experience” (Ungar et al., 1997). This study reinforces the idea that it can be advantageous for the visually impaired to use a tactile map to familiarize themselves with an area. In this way, tactile maps can be thought of as providing more opportunities for independence.

2.1.3 Spatial Language

Giudice, Legge, and Bakdash (2003) compared performance on environmental learning and route finding ability when the available information about layout geometry was conveyed in three verbal conditions: (a) local, (b) enhanced local, and (c) global. Local verbal information describes the layout geometry of the space from the user's current position. Enhanced local verbal information adds the ability to look ahead by giving distance and connectivity information about adjacent intersections. Global verbal information adds a verbal description about the global geometry of the layout.

Eight participants were blindfolded, trained, and tested on all three layout geometries described above. Training and pre-testing were completed individually by having participants find four target locations along a path, indicated by an auditory cue. At each intersection, a verbal description was given to the participant who was then asked to choose a direction to continue walking. After a fixed amount of training, the participants' knowledge of the floor plan was tested by finding routes between pairs of targets (a, b, c, and d).

Preliminary results showed no significant differences between the three verbal conditions. However, target localization accuracy was significantly above chance. The researchers also measured optimal path selection or "the shortest possible path between targets over the route taken" (Giudice et al., 2003) and determined that route efficiency was high for all conditions. The overall result of this study supports the notion that the development of a "spatial language" can be used to learn and navigate an environment in an efficient manner. At some point, when enough routes and landmarks are encoded and interrelated, overall configurations of space (survey knowledge) are formed. In summary, our macro-spatial knowledge is assumed to consist of three levels: landmark knowledge, procedural knowledge, and survey knowledge (Siegel & White, 1975).

2.1.4 Environmental Imaging and Schemata

In the previous section (2.1.3), schemata were introduced when talking about building a mental image of the environment. "While there are many terms that are used to label the mental representations of environment in cognitive science literature, the terms 'image,' 'schema,' 'mental maps,' and 'cognitive maps' are widely adopted to describe the mental

representations" (Silva, 2004). Michel Denis' research into mental imagery has suggested that visual information is mentally represented through "visuo-spatial" cognitive structures, which contain both visual properties of objects and their relative locations. The visuo-spatial memories play key roles in the higher cognitive functions of mental representation and creative thinking, as well as contributing to differences in mental ability (Denis et al., 2003). Other non-visual sensory and motor information such as kinesthetic, auditory, and olfactory cues are encoded as "non-visual sensory-spatial schemata" (Silva, 2004). One way of defining these two mutually dependent perceptual schemata is as visuo-sensory schemata and spatial schemata, respectively. While visuo-sensory schemata mentally encode the perceptual properties of the visual and non-visual sensory information, spatial schemata encode the relative location of these cues. This combined knowledge, known as event schemata, includes both visuo-sensory information of activities and spatial information of activities. Mandler (1984) referred to event schemata as a mental script that characterizes knowledge of organized sequences of events and activities that occur within the environment.

2.2 Way-finding Decision Making

The cognitive map as described previously plays a role in four vital questions: whether to go somewhere, why go there, what is the destination, and how to get there (Kitchin, 1994). The navigator is charged with matching internal information/input (experience) and external information/input (environmental features) as they become available (see figure 2.2.a). Way-finding decision making involves two essential components: environmental cognition and route choice.

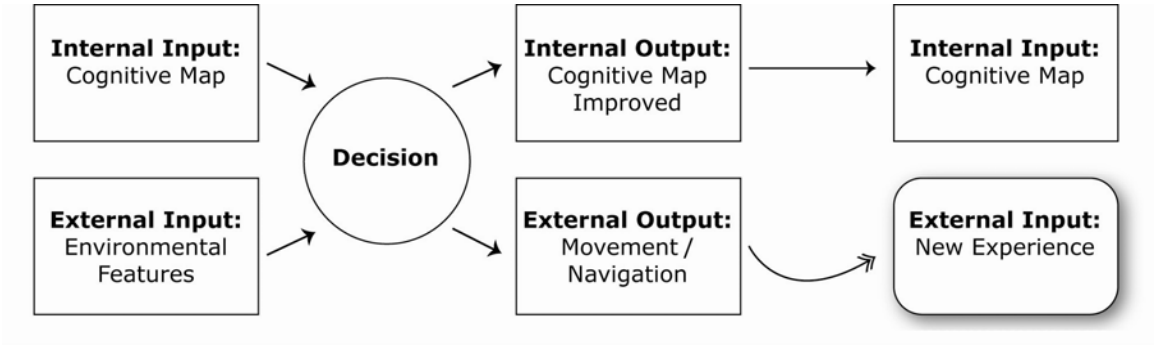


Figure 2.2.a: Way-finding Decision Making Diagram (Payne, 2008)

Portugali (1990) developed a theoretical framework which complements one established earlier by Busemeyer (1979) by declaring, “A person navigating the urban environment does so by using spatial knowledge, [information and experience], as a basis for which navigational decisions are made.”

Likewise, the decision making that supports the navigation of an urban setting is a linear or sequential process concerning route selection between an origin and destination. The navigator, when forced outside of habitual travel routines, is confronted with some level of uncertainty. At this point, internal and external inputs become the decision making tools (see figure 2.2.b). It has been documented that the travel related decision making process is strongly based on the individual’s level of spatial knowledge (e.g., Bovy & Stern, 1990). As the frequency of navigation increases, the relative use of “way-finding information” decreases, and the relative use of “environmental features” increases. Golledge (1999) identifies this maturity in way-finding as “choice behavior.”

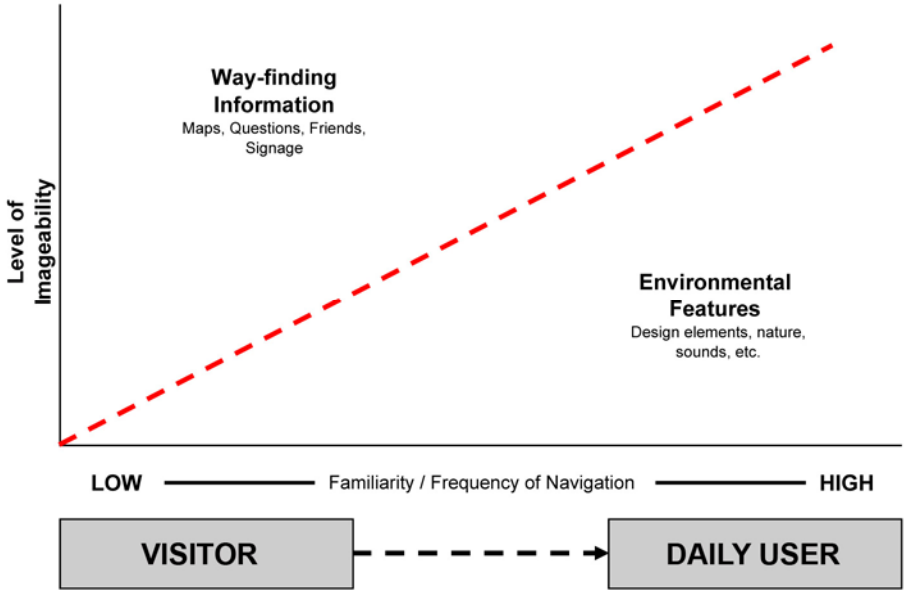


Figure 2.2.b: Frequency Navigation

This “choice behavior” can be affected by four components: (1) purpose, (2) personal characteristics, (3) means, and (4) situation (Golledge, 1999). In the context of this dissertation these four components are defined as follows. (1) **Purpose** involves daily travel

to and from the site (i.e., office, meetings, library, etc.). (2) **Personal characteristics** specifically consider visually impaired and independent travelers. (3) **Means** include pedestrian foot traffic. And (4) **Situation** consists of time spent within the campus boundaries.

2.2.1 Understanding Spatial Layouts

Spatial knowledge theory is well represented in environmental design methodology. Urban planners and architects have long been interested in designing spaces that are easily navigable and, consequently, pleasant places to be. Lynch (1960) describes the urban setting in terms of what he calls urban design elements. These elements include the following. (a) Districts are the mid-sized sections of a city (or community) and are distinguishable as having some common, identifying characteristics which can include particular architectural styles, construction materials, activities, sounds, smells, and even tastes (when considering ethnic restaurants and eateries). (b) Nodes are strategic spots in the city where observers can enter. Nodes are typically linked to travel and may be represented by some type of transportation hub such as a mass transit station, bus stop, or traffic circle. (c) Landmarks are point references that are external to the observer. Landmarks are not entered into but rather are experienced from a distance. A landmark must be distinct from its surroundings and should have directional information associated with it, which is essential to the navigator's ability to remain oriented within the environment. Again, as with districts, these landmark experiences can be unique to a specific location. (d) Paths are channels of movement and include walkways, streets, railroads, expressways, and mass transit lines. An observer typically views the city from this perspective. (e) Edges are linear, not unlike paths, but typically do not facilitate movement. Edges are often boundaries defining a break in continuity between two homogeneous regions. Examples include landscape buffers, walls, rivers, and railroad cuts.

Districts, followed by nodes and landmarks, divide the setting into "places," which are then cross connected by paths and bounded by edges. Lynch developed these principles for city design, although many designers have accepted these ideas as guidelines for large and small space development.

Passini (1984) extends this model to architectural design, adding that a space should have a basic organizational principle. For example, many large cities, such as Manhattan and San Francisco, are laid out on a grid system. Conroy-Dalton (2003), Haq and Zimring (2003), and Werner and Schindler (2004) describe how spatial structure is an overriding principle in route selection and navigation in cities, as well as in complex building designs. Familiarity and sightlines provide the users with a level of comfort in remembering their path.

Architects and designers must begin to develop spaces based on the users' needs and abilities. Merriam-Webster's (1997) dictionary definition of "space" reads as: "A boundless three-dimensional extent in which objects and events occur and have relative position and direction." For designers and researchers, this is true to the extent that one must always be aware of the users, objects, and activities and their physical and mental relationships. By reviewing the literature regarding this relationship between user and environment, we must keep in mind that space is the foundation for design. These are just some examples of how we must observe, understand, and act on the settings in which we place ourselves. Upon reading and reviewing the literature about way-finding and environmental design features, it is more evident that each personal experience is unique and memorable. Both large and small campus settings have been considered comparable to city environments with unique user groups.

2.2.1.1 Campus Plan Configurations

It is fitting, for two reasons, that the research setting for this study is the campus of the Governor Morehead School (GMS) for the Blind in Raleigh, North Carolina. First, the research being conducted among a population of visually impaired students, faculty, staff, and visitors seems fitting. Second, being able to develop and test a means for improving way-finding is most appropriate when done in a semi-controlled setting such as the GMS campus.

The image of the campus setting throughout history has been solidified by preserving its integrity as a self-contained community and its architectural expression of educational and social ideals. GMS began in 1845 and was the first state owned school to provide services for African-American children in the nation. The school has expanded its services ever

since. The preschool program is available for children from birth to 5 years, and full education services are provided for those up to 21 years. Outreach and community training continues to serve adults over the age of 21 (GMS, 2007). The physical campus setting of GMS is varied. There are a total of 30 buildings, including buildings for the Division of Services for the Blind, administration, student dormitories, adult living, preschool classrooms, and adult training workshops. There is something very rich about the spatial layout of the GMS campus environment and the way the users interact. The importance of the number, function, and arrangement of buildings within the campus became evident throughout the research when communicating locational information with the participants.

Several studies have examined facets of the "master plan" as a design precedent that included building plan layout, use of materials, indoor space vs. outdoor space, and typology. The following examples are just a few that relate spatial configuration, campus design, and users to the current research. Throughout history, large architectural compositions had the unity of a single building. Architect Paul Rudolph's master plan for the Southeastern Massachusetts Technological Institute unifies the entire complex in terms of sequence of visual experience, a repetitive structural grid, circulation, and topography. Today, Larson and Palmer's (1933) notion that the character used for campus design is attained "not merely by a blind following of a certain period of style, but rather by faithful interpretation of the specific needs of the individual college," still holds true.

Weisman (1981) explored the impact of plan configuration on way-finding as an environmental variable (whether detected visually or spatially). Two aspects of this variable were identified as: (a) the perceived simplicity of building floor plan configurations, and (b) the respondents' level of familiarity with the buildings. Friedmann, Zimring, and Zube (1978) argue that the legibility of an environment, or "the extent to which it facilitates the process of way-finding," may have significant behavioral consequences.

This particular study by Weisman is structured in three parts. The first part focused on "goodness of form," which is a measurement of plan configuration as established by Alexander and Carey (1968), and takes into consideration symmetry, balance, and ease of understanding. The second part evaluated data gathered through respondents' self-

reporting on their own familiarity with many or all of the 10 sample settings. The third part assessed the influence of the environmental variables upon participants' way-finding behavior.

Ten buildings on the central campus of the University of Michigan served as the study setting. Eight of the 10 buildings were mixed-use (office, classroom, and laboratories), 1 was solely office space, and the last was both academic and administrative offices. The physical characteristics of the buildings also varied in height from 3 stories to 11 stories, and floor plan configurations were simply identified as "I," "L," "V," and "T" shapes.

The research questions and hypotheses for Weisman's research were based on the "nature and pervasiveness of participants' way-finding problems in the 10 sample settings;" the relationship between "way-finding behavior and participants' familiarity" with these settings; and the relationship between "way-finding behavior and various aspects of good plan configurations" of these settings (Weisman, 1981).

The result of this study says, "Way-finding behavior was not reported to be a substantial problem in any of the 10 campus buildings evaluated" (Weisman, 1981). However, the percentage of users reporting themselves lost often or virtually always, varies up to 6% in 5 of the buildings, and from 10% to 26% in the other 5. The most often identified influence upon way-finding behavior was the degree of familiarity an individual had with a given setting. Canter and Canter (1979) state that "in order to comprehend an organization and take advantage of it, it is necessary to understand how it is arranged in space." Also, Lynch (1960) suggests that "a distinctive and legible environment… heightens the potential depth and intensity of human experience." An obvious conclusion would be that the more familiar a person is with a place, the less likely he or she would get lost.

Passini (1984) identified way-finding as being conceptualized in terms of "spatial problem solving," which includes decision making, decision execution and information processing. The hypothesis presented in Passini's study suggested that traveling on routes experienced on previous occasions requires only an act of recognition and not actual recollection of specific environmental features. "To be oriented is equated with having an accurate

representation or cognitive map of the surrounding area" (Passini, 1984). Similarly, Tolman (1948) and Griffin (1948) compare spatial orientation with a person's cognitive ability to represent space accurately, to map environmental information at a large scale, and to determine the position of that person within the map. Passini (1984) also states, "Way-finding decisions are hierarchically structured into plans which not only help to memorize routes in behavioral terms, but help to organize and record environmental information in the form of sequential, route-type representations," and he continued this thought by defining two procedures to aid in the planning of routes. These procedures are "re-enacting previous way-finding experiences and combining them into new suitable arrangements," and "linking departure and destination on a survey-like representation of the setting" (Passini, 1984).

Passini tested these two procedures by observing 100 participants at the downtown commercial center Bonaventure in Montreal, Canada. The research exercise required each participant to sketch the layout of the entire center, at a level that could also be verbally described in relatively simple terms. Of the 100 samples, nearly half of the sketch maps were "unintelligible, or too rudimentary to express any recognizable arrangement" (Passini, 1984). Twenty-five of the samples were developed based on a previously experienced route and showed greatest detail with the more familiar spaces. The final 25 samples developed the sketch map around the Place de la Concorde, a central corridor of Bonaventure, and moved outward with less detail.

Results from Passini's study were varied. During the final evaluations it was obvious that higher levels of detail and accuracy along a travel path were provided by subjects more familiar with the commercial center. Few subjects were able to describe in detail how they planned to reach their destination. Instead, many worked out general ideas on how to begin their travels and dealt with obstacles once they encountered them. The results indicated that "decision plans are the basis of linearly and temporally organized route-representations while spatial organization principles lead to spatial and survey-like representations" (Passini, 1984).

Baskaya, Wilson, and Ozcan (2004) explored spatial orientation and way-finding behavior of newcomers in an unfamiliar environment to emphasize the importance of landmarks and

spatial differentiation in the acquisition of environmental knowledge. The study settings for this experiment were two polyclinics: one with a symmetrical layout and regularly organized, monotonous units on different floors (Polyclinic 1), and another with an asymmetrical layout and repetitive units along one side of a linear corridor of one floor (Polyclinic 2). These spaces were used to explore different strategies for learning large-scale spatial environments. The participants selected for Polyclinic 1 were 73 university students, and the Polyclinic 2 study incorporated 60 university students, all either 19 or 20 years old, and enrolled in the Department of Architecture at their respective schools.

The tasks for both groups of participants included a questionnaire and sketch map. After allowing the participants to walk and explore the polyclinic, they then completed a three part questionnaire that focused on visual accessibility, accuracy of spatial layout, and spatial differentiation. Following the questionnaire, each participant completed a sketch map of the building, which was rated on a 3-point scale for accuracy.

The resulting way-finding performance was found to correlate with performances in sketch-map tasks and with the answers of a questionnaire about each building. Most of the participants of the asymmetrical setting (Polyclinic 2) could complete a sketch map with a minimum of errors. In the symmetrical setting, however, some participants drew incomplete sketch maps but could find their way through the building with minimal errors.

An important fundamental aspect of way-finding communication is the articulation of the circulation paths. The circulation system within and between spaces is the space where people have to find their way. A clear understanding of the direction of movement within the circulation system is what gives users an overall image of space, "… thus it is the space that we try to understand, and it is in this space that we have to make our way-finding decisions" (Arthur & Passini, 1992). The intersection of paths creates nodes (or decision points) which have to contain the appropriate information for decision making.

A common circulation system used in public spaces and buildings is the hierarchical network. This system requires users to be aware of and understand how spaces and paths are linked according to a repetitive order. This hierarchical network is much more

complicated to perceive than a simple grid pattern. The hierarchical network may be more difficult to express than any other organization by architectural means. “In complex settings, where the hierarchical organization is particularly suited, spaces are grouped around paths or circulation nodes,” and it is the combination of paths and nodes that expresses the order (Arthur & Passini, 1992).

2.2.2 Objects in Space

In designed spaces, the paths are typically structured and organized, but for many reasons the structure may not be perceived. Johnson (1987) identifies “the *schema* as a continuous structure of an organizing activity,” and continues by stating that “in every case of *Paths* there are always the same parts: (1) a source, or starting point; (2) a goal, or endpoint; and (3) a sequence of contiguous locations connecting the source with the goal.” In cases where design gives way to chaos, the circulation network becomes illegible. Passini (1992) states that not only do features have to be memorable, but also recognizable by most everybody, in order to function as a cue. “What may be a landmark for one person may not for another” (Arthur & Passini, 1992). It is by designing with redundancy and consistency that spatial communication is the most effective. Arthur and Passini (1992) have argued that some distinct features along a path are necessary to serve as anchor points around which people can build their representations. These anchor points or landmarks can also serve to breakdown a long journey in to manageable units. Intermediate destination points located within a long and/or complex network of paths can serve as a decision point or cue. While directional changes can make it more difficult to map a path, it is the number of intersections (decision points) that affect the difficulty of decision making. For each decision, people have to obtain and process environmental information. Unfortunately, each decision point offers the potential for a mistake. “Of course, there is nothing wrong with decision points. After all way-finding is problem solving and decision making. It is the combination of too many decision points and not enough information that gets people lost” (Arthur & Passini, 1992).

Brambring (1982) identifies “two main problems in street locomotion for the blind: (1) the reliable perception of objects; and (2) adequate orientation.” Object perception simply means the visually impaired person is able to detect and recognize potentially dangerous, confusing, or impeding objects, usually in the path of travel, and is able to avoid the

situation. The identification of landmarks can be described as the perception of recognizable objects that offer locational information along a travel path. With these definitions, objects can be both obstacles and landmarks simultaneously. However, the perception of obstacles is “of central importance to the blind person’s safety,” and perception of landmarks is “essential to his spatial and geographic orientation” (Brambring, 1982). Brambring’s research further compares the spatial perception of both blind and sighted users, and establishes “that information from various sensory modalities can lead to analogous spatial perceptions” (Bach-y-Rita, 1972), and also establishes a baseline for the amount of detail and types of statements used by blind travelers in giving directions.

There have been very few studies completed on the geographic orientation of blind and sighted persons. Yet, the conclusion of these studies are similar in that the blind, just like sighted persons, are able to give directional information on landmark locations within and around a city after learning from a map (McReynolds & Worchel, 1954). Likewise, a study by Bentzen (1972) shows that blind travelers are just as capable as sighted persons of navigating urban paths with the aid of tactile maps or verbal descriptions. The blind population’s largest difficulty is that “they do not have a grasp of large spaces, and thus cannot help themselves to become oriented by the use of distant characteristics of or objects in the locality, such as church steeples or tall buildings” (Brambring, 1982).

“It is presumably much more difficult for sighted persons to give adequate verbal information to the blind about spatial surroundings” (Brambring, 1982), because sighted persons are not familiar with the problems of navigation that blind travelers face or how they solve such problems. For instance, “changes in the consistency or composition of the ground surface, or reflections of sound, can be especially precise means of orientation” (Brambring, 1982).

In the first of two studies conducted by Brambring, four blind students were asked to describe their daily route from “their dormitory to the nearest bus stop.” In the second study, a total of 18 participants, 9 sighted and 9 blind, described 2 different travel routes with which they were familiar. The second experiment concluded with an in-depth evaluation of the language and vocabulary used in verbal walking directions given between two points. This

language evaluation looked for terminology that fell within three categories of statements as defined by Brambring (1982):

> "(a) descriptive statements which serve as a linguistic transliteration of the instructions pertaining to the activity to be performed; (b) commentarial statements which serve as an evaluation for repetition of what was said; [and] (c) interactive statements which serve to establish a social relation between questioner and answerer."

For the actual description of the route, Jarvella and Klein (1982) developed three categories of data: data on distance, data on direction, and data on fixed points as construction units.

In both studies, the researchers were interested in the type and amount of information provided by the participants. The researchers also looked for a relationship between positions and places along the route and how these were described. In helping to identify similar types of data, Brambring further divided the types of statements described above into four specific classes of data. (a) Data on distance statements were categorized as such if distance information was expressed either directly (i.e., about 10–12 paces to the next corner) or indirectly (i.e., continue straight until the corner). (b) Data on direction statements were categorized as such if they expressed an actual change or correction in direction (i.e., make a left turn, 90 degrees). (c) Data on landmarks were categorized as such if they described objects that served an orienting purpose and were not mentioned as something to be avoided (i.e., at the change in surface materials). (d) Data on obstacles were categorized as such if there was something to be avoided (i.e., walk more to the left, in order not to walk into the benches).

The results point to the special importance of landmarks for the blind during street locomotion. This conclusion is further underscored by the quantity of landmarks mentioned in relation to the route length. Brambring's linguistic analysis of route descriptions given by blind persons also reveals that the blind and visually impaired use information that relates to the environment less than that which relates to the user. This is suggested by the less frequent naming of objects outside of the navigation path. "Blind persons tend to use more

temporal and less spatially related words in defining their points of departure and obviously have greater need for information that is person oriented" (Brambring, 1982).

Brambring concluded the study by identifying the difference between route descriptions given by blind and sighted persons as this: "Sighted persons give environment-oriented description, whereas the blind tend to use person-oriented descriptions." Sighted persons more often identify external characteristics of orientation, and the blind, more internal characteristics. In one study, Brambring asked participants to describe a path of 500 meters. Not only did the blind participants include more words to describe the route but also more specific navigation instructions. An example of this might be, "At the traffic light, step to the right, then turn left and proceed until you come to the next street." Compare that to a sighted participant's instructions: "At the traffic light, turn left and go to the next street." Albeit subtle, the clue of "step to the right" was a mobility indicator, not a directional cue.

"In regard to the amount of information given in describing a route, there is naturally a major difference between sighted and blind persons" (Brambring, 1982). The blind subjects provided more than two times the information as the sighted, and the route information was more than twice as detailed. Jarvella and Klein (1982) imply that blind persons may need far more fixed points in such descriptions in order to navigate safely and accurately.

Butler et al. (1993) conducted several experiments to determine the characteristics of an "optional way-finding aid" for new users of a complex building. In Experiment 1, way-finders who used signage were able to find their destinations fastest. Other way-finders using you-are-here maps were measured at a much slower rate than even those way-finders given no aid at all. "The main advantage of signs over you-are-here maps results from information-processing differences" (Butler et al., 1993). Signs provide clear cues about turns and decisions along a route without requiring the high consumption of working memory or advance study time. Contrary to findings of previous research, Butler et al. (1993) did not find complexity to be an important issue.

2.2.3 Way-finding Cues

“Many people think that signs are the most important means of providing way-finding information in an urban or architectural setting. Without downplaying the importance of signs, it is nevertheless easy to show that natural and built environments provide the way-finding person with a great variety of basic way-finding cues” (Arthur & Passini, 1992). Paths and their physical articulation are at the heart of architectural, urban, and landscape design. The vocabulary of a spatial information system is almost infinite. This vocabulary is “provided by the texture of the materials, by the structural and decorative elements of walls and ceilings, by columns and light, vegetations and water” (Arthur & Passini, 1992).

A path can be perceived by markings on the ground, a guiding structure alongside, or a combination of these elements. A common example in today’s environments is that the main circulation route may be marked on the floor by using a material that has a different texture and tone from the surrounding areas, or overhead on the ceiling for interior spaces. “The textured marking improves the legibility of key paths and allows them to be used by the visually impaired population for whom open space arrangements are particularly difficult” (Arthur & Passini, 1992).

“All pedestrians must obtain a certain amount of information from the environment to travel along sidewalks safely and efficiently. Most pedestrians obtain this essential information visually, by seeing such cues as intersections, traffic lights, street signs, and traffic movements” (Kirschbaum et al., 2001). Similarly, people with visual impairments use environmental cues for daily travel. Such cues include changes in surface materials, the sound of vehicular traffic, or a nearby fountain. Some of the most reliable cues for visually impaired users are permanent and can be easily detected, even in unfamiliar environments. Peck and Bentzen (1987) found that people with visual impairments stress the importance of consistency when acquiring accessible information from the environment. This consistency is again evident in studies in the United Kingdom that have shown that “pedestrians with visual impairments can reliably detect, distinguish, and remember a limited number of different tactile paving surfaces and the distinct meanings assigned to them” (Department of the Environment, 1997).

In a similar manner, this current dissertation research begins to assimilate pieces of data that can become a standard system of information when used in consistent locations or situations. This rigid system will allow the traveler to rely more heavily on its existence. “The greater number of sensory qualities [such as color, texture, and sound] the cue has, the more likely it will be detected and understood” (Sanford & Steinfeld, 1985).

2.2.4 Mobility Aids

The long cane is a primary example of an environmental probe that allows blind pedestrians to acquire perceptual information about their immediate environment systematically and efficiently. When using the long cane, visually impaired travelers can better establish and maintain their orientation along a path, as well as detect and avoid hazards. The long cane and the techniques used when traveling are vital to this research.

Cane users typically choose between two techniques when traveling. The first is the 2-point touch method, a repetitive motion of tapping the cane tip on the left side and then across the body on the right side that allows for faster movement by only making contact with the surface momentarily while continuing along the path. The second technique, known as constant contact or sweep method is used by newly independent travelers or when more in-depth exploration of an area is warranted. This technique is performed by sliding or dragging the tip of the cane along the surface, thereby constantly providing the users with information about the surface or pathways.

The cane serves to extend the tactile sense of the user. This is accomplished by transmitting information about the environment either through the tapping sound from the cane tip, vibrations through the cane shaft, or contact with people and objects. The U.S. Access Board (1985) states that adjacent surface materials that make different sounds when tapped by a cane can also serve as navigation cues. In pursuit of similar findings, this research proposes matching pairs of materials with contrasting acoustic and textural qualities to measure detection. See chapter 4 for a full description of the selected materials. Heller (1989) conducted a study in which the results were presented as being inconsistent with the notion that touch is an inferior sense to sight. “There can be advantages to feeling

surfaces over looking at them, especially when vision is limited to low contrast information or when surface textures are especially fine."

Mobility aids such as the long cane, guide dogs, and electronic travel devices provide the user with information about the travel path in advance to allow for decision making. When using the long cane and electronic devices, the individual must be concerned about the type and amount of coverage the specific device provides. The long cane typically provides information about the space around the body, whereas electronic devices are limited to the capability and proximity of the overall system. "The function of a mobility device, such as a cane, is to preview the immediate environment for objects in the path of travel, changes in the surface of travel, and the integrity of the surface upon which the foot is to be placed when brought forward" (Farmer & Smith, 1997).

In deciphering cues (such as pitch, tone, echoes, etc.) as transmitted by the tapping of a long cane, Yost (2001) points out that because sound itself has no spatial properties, sound localization is based on perceptual processing of the sound source. Ungar (2000) mentions that in performing any spatial task, a visually-impaired person has the option of coding spatial information either by reference to his or her own body or relative to some external framework. There are always sounds and smells in the environment, but not all are noticed. Often they are disregarded as not being pertinent during travel.

Cue intensity refers to the strength of the cue, or how strong a cue must be for it to be legible. Closely related to this attribute is the identity of the cue, its uniqueness in contrast to similar cues found in other areas, and its informativeness or the degree to which it communicates information about itself or the associated event. For example, the smell of a particular flower used in a landscape garden might be distinctively different, and hence memorable. Thus, cue identity is an important attribute in the imageability of non-visual cues. Although sounds and smells are formless relative to other visual cues, attributes of cue intensity and cue identity could be placed under the general attribute of form. Spatial reference of these cues relates to the attribute of immediacy, or very specific location identity. Tactile cues are usually tied to visual cues and, therefore, intensity, identity, perceptual access, and location of tactile cues are mostly read in relation to the attributes of

the visual cues. “Research into people with visual impairments suggests that tactile experience effectively substitutes for the lack of visual perception” (Silva, 2004).

2.3 Section Conclusion

In summary, the pedestrian landscape should be conceived as both a spatial and non-spatial entity upon which people impose spatial, temporal, and social orders as they navigate within it. Heller (1989) expands this view by proclaiming that the world of texture is extremely complex and rich, and it was thought that a broader range of textures might shed new light on the relative adequacy of the senses of sight and touch. This mindset can be advanced by accepting environmental cognition as the process by which we make our environment meaningful by knowing, ordering, and relating. “The general model of environment/behavior relationships specifies that the physical characteristics of a built environment are related to users’ perceptions, which in turn determine people’s responses to the environment” (Ozdemir, 2005).

Much of the literature reviewed in the previous sections has proven vital to the overall body of research for this study. A few examples include Romedi Passini’s definition of way-finding and Kevin Lynch’s explanation of spatial characteristics that put identifying tags on the environment. Also, Golledge, Brambring, and Weisman clarify the communication methods for mental imagery and spatial perception. All of these and others will be revisited and identified throughout the remaining chapters of this research. Based on the conceptual framework presented here, the following section identifies the research questions and the research hypotheses.

Chapter Three
Research Questions

3.1 The Primary Research Question

The primary research question is: **What role do changes in footpath materials play in the ability of visually impaired users to locate their position within a space?** The purpose behind this question is to evaluate the pedestrians' understanding of their position within a complex setting based on their ability to detect changes in footpath materials. Since the primary focus of the research question is on one aspect of the built environment, which is change in construction materials, it is necessary for the purpose of this study to compare multiple combinations of materials. Also, an investigation is conducted to determine if travel time and number of errors are improved by using changes in sidewalk materials as way-finding cues.

Sub-questions and hypotheses:

Q1. Do the environmental factors of temperature and humidity affect the detection of material change?

- H1: Environmental factors that physically alter the surface characteristics of the materials will affect the detection of change.

Q2. Is there a correlation between the physical properties of two surface materials that affects the detection of material change?

- H2a: The adjacency of the two surface materials with the greatest difference in vibration levels will be best detected.
- H2b: The adjacency of the two surface materials with the greatest difference in acoustic attenuation will be best detected.

Q3. Is there a correlation between the physical properties of one surface material that, when compared to concrete as a baseline material, affects the detection of material change?

- H3a: The surface material with the greatest difference in vibration level, when compared to concrete as a baseline material, will be best detected.
- H3b: The surface material with the greatest difference in acoustic attenuation, when compared to concrete as a baseline material, will be best detected.

Q4. Is there a correlation between the levels of acoustic attenuation and vibration in two materials that affect the detection of change?

- H4a: The surface material with the greatest level of vibration when measured at the cane grip will also have the lowest level of acoustic attenuation. Therefore, as vibration increases sound level also increases.

As stated above, the identification in change from one material to another while traversing an environment is important from the user's standpoint. However, as designers, it also is important to understand the physical properties of the materials and what may contribute to the more readily detectible materials. Hence, an in-depth study of the physical properties of each of the selected construction materials was necessary.

Likewise, the user's cane tips and shoe types were evaluated as tools to determine the influence these travel aids had on detection. These tests consider the user's ability to detect *underfoot* (using the sensations gathered by walking, scuffing, and tapping the foot) and through the cane tip (using the sensations gathered by tapping, sweeping, and poking with the cane). Each user has a personal preference as to the type of shoe and cane he or she uses while traveling, and these variations were documented and analyzed in the research.

3.2 Theoretical Perspectives and Conceptual Framework

This research begins by considering information processing when based on change of materials as a mechanism leading to way-finding. When new to a setting, the navigator relies on the information provided and oftentimes on instinct. "There is a progression of understanding which increases as we move deeper into a scene, and this is triggered by 'complexity' and 'mystery'" (Southwell, 2002).

3.2.1 Environmental Legibility

Two categories exist within environmental legibility, these being legible and illegible. Legibility in spatial settings has as much to do with the settings' content as with their organization. Kaplan, Kaplan, and Ryan (1998) suggest that environmental information provides cues that enhance a user's ability to explore a setting and understand it. Southwell (2002) identifies a concept of "legibility being a spatial consideration that is interlinked with imageability." This concept is instilled in the researcher's mind even more deeply by Lynch's models of path, edge, node, district, and landmark. Southwell (2002) agrees that this five part model established by Lynch encapsulates how the human brain organizes the urban

landscape into one mental image of the whole (survey knowledge), and designers use this process daily in their analysis of place (see figure 3.2.1.a). Although, Passini (1992) defines legibility as “the ease with which environmental information is obtained and understood,” he also introduces the concept of the *expected image*, which explains that when finding our way through the environment, we are *actively seeking* informational input from the environment setting, but are *passively receiving* it.

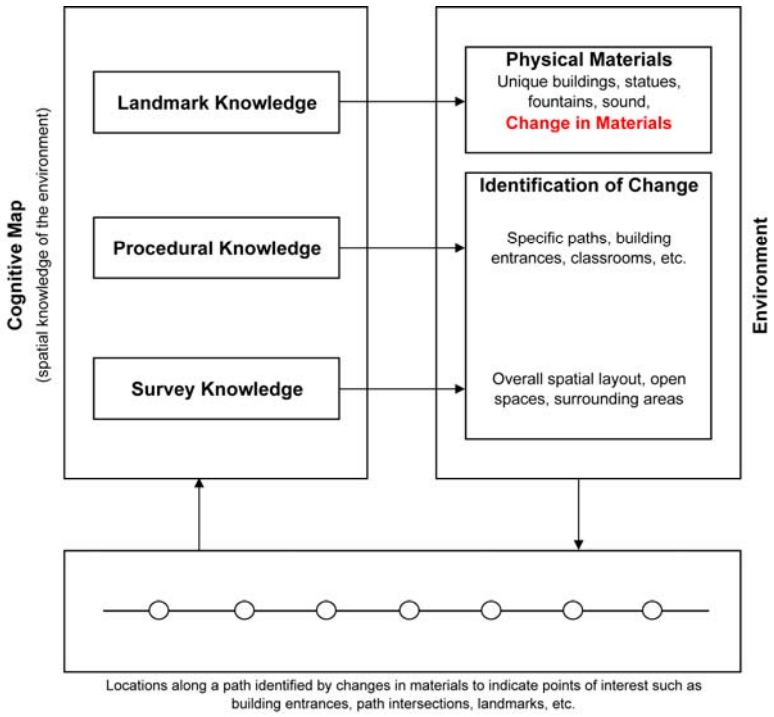


Figure 3.2.1.a: Conceptual Framework Diagram

When considering all of these bits of information, a more concise definition can be described as follows: Legibility of a space is the space’s ability to communicate to the user that the space is usable and what uses it affords. Paths with too many decision points or too few cues, or landmarks that give insufficient environmental information add to a space’s lack of legibility. Ultimately, not integrating function with form results in a setting that conveys an unclear message to the user (Passini, 1992). Therefore, in this research there is one question which is subdivided into four research questions, as diagrammed in figure 3.2.1.b.

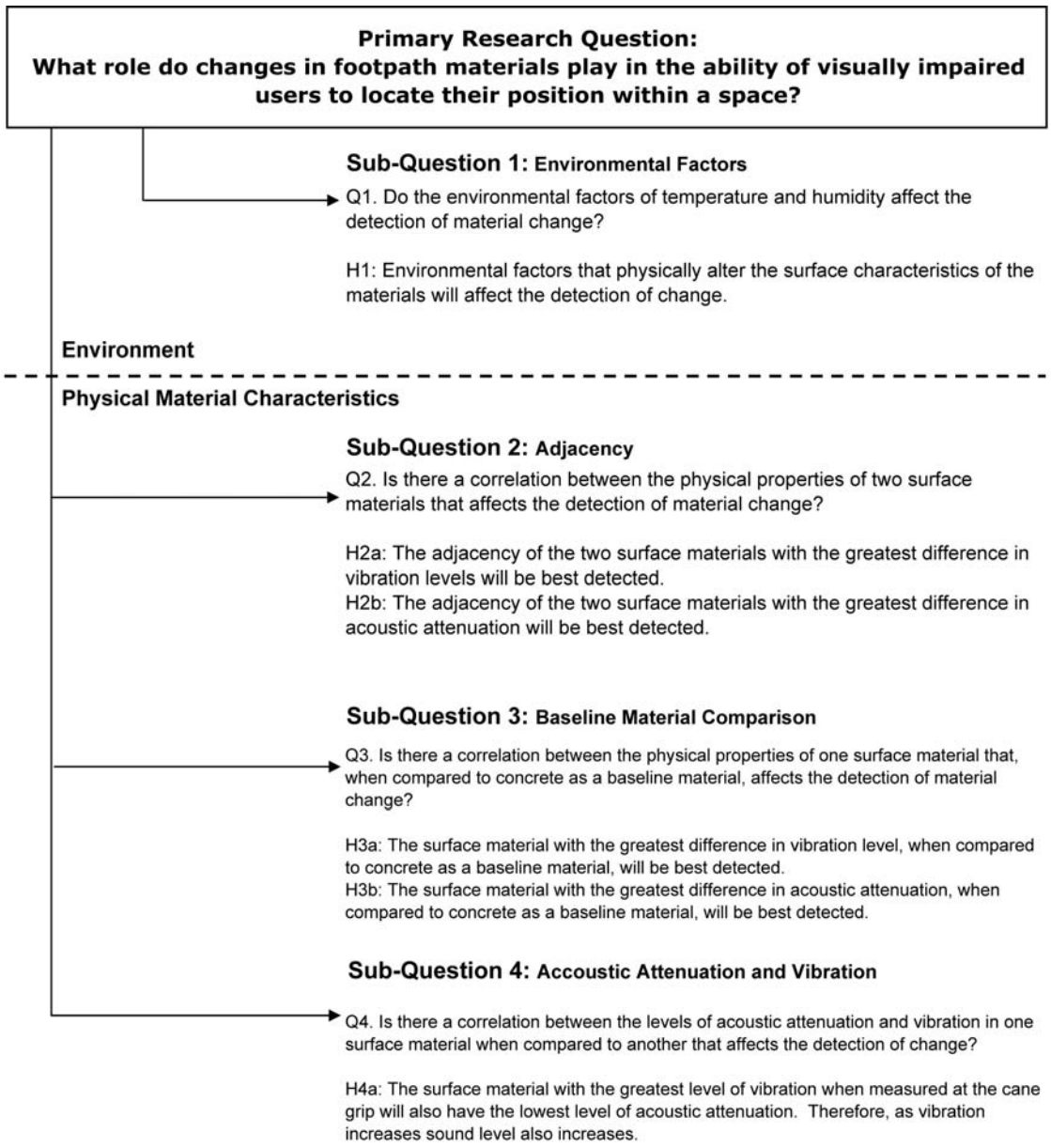


Figure 3.2.1.b – Research Questions

Chapter Four
Research Methods

This chapter discusses the research methods applied in this study. It presents the reasons for selecting the study site, the subjects, sampling procedure, data collection and analysis methods, and the means for establishing the rigor of the study.

4.1 Research Setting

To answer the research questions, this study required an appropriate context: a locus and a group of people who utilize the space, a device to measure physical properties of the individual surface materials, and a rating scale for detecting change in materials. The research questions also required the selection of a site appropriate for field experiments. In order for a test facility to be capable of providing generalizable data results, the site must be active, accessible, local, and atypical. Therefore, the research setting chosen for this study was the Governor Morehead School for the Blind (GMS) in Raleigh, North Carolina (see figure 4.1.a and image 4.1.a).

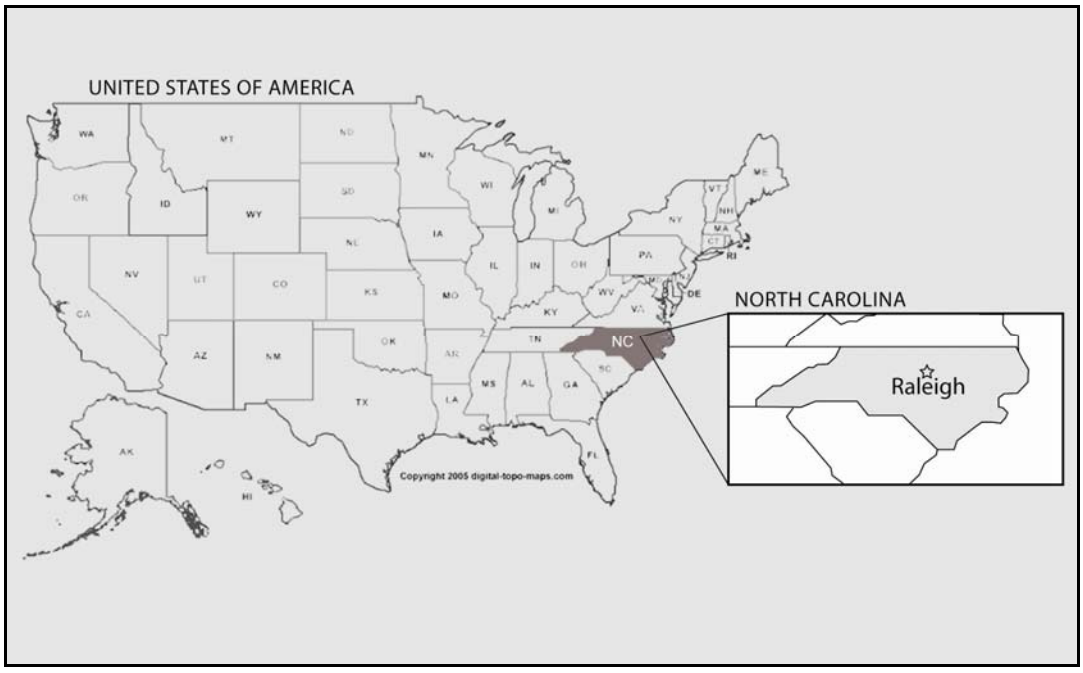


Figure 4.1.a: Vicinity Map (digital-topo-maps.com edited by Payne)



Image 4.1.a: GMS Site Aerial Photo (Google-earth edited by Payne)

The GMS campus is located in southwest Raleigh and is part of the N.C. Department of Health and Human Services. Under the direction of Mr. Dempsey Benton:

> The North Carolina Department of Health and Human Services (DHHS) is the largest agency in state government, responsible for ensuring the health, safety and well being of all North Carolinians, providing the human service needs for fragile populations like the mentally ill, deaf, blind, and developmentally disabled, and helping poor North Carolinians achieve economic independence. (NCDHHS, 2007)

The Governor Morehead School is located on a 40-acre campus that houses several other state departments, including the Division of Services for the Blind, Adult Rehabilitation and Training, and the Vision Impairment and Training Program (which operates in conjunction with N.C. Central University). The school provides preschool and K-12 education with on-campus housing and support facilities for visually impaired students and those with multiple disabilities. Various other services are available daily to visitors of the campus through classes, trainings sessions, meetings, conferences, and a mobility aid's store.

The GMS site was selected for these field tests for its variety of outdoor spaces, diversity of users and visitors to the campus, and the opportunity to permanently install various materials that could serve as a test area and learning tool for all of the students and guests, now and into the future. The data gathering exercises for this research were in four parts: (1) materials analysis, (2) pilot test, (3) matching pairs test, and (4) a 2-part field experiment test. All were conducted at the GMS site. Five locations within the campus with specific site characteristics were chosen (see image 4.1.b).



Image 4.1.b: GMS Site Aerial Photo with Test Paths (Google-earth edited by Payne)

4.1.1 Pilot Test Site

The first of these tests, the Pilot Test, was conducted along an existing 5’ 0” wide concrete sidewalk that provided several changes in surface materials during the 100-foot walk. This path provided the opportunity to evaluate the testing instructions and directives between the researcher and the participants. The various materials were similar to but not the same as the seven materials used in the field studies. One participant was recruited to participate in the Pilot Test and was excluded from the remaining three tests. Discussions with this pilot test participant provided great insight as to the proper techniques to be used when conducting research with visually impaired participants.

4.1.2 Matching Pairs Test Site

The second test, Matching Pairs, used seven materials that are common for sidewalks. Each material was locally available and installed by a professional landscaping crew. The site for the Matching Pairs Test was an existing four-feet-wide mulch path leading from a staff parking lot to the Currin Childcare Building (see images 4.1.2.a and 4.1.2.b). The length, width, and accessibility within the campus made this site location attractive.



Image 4.1.2.a: Matching Pairs Test Site Natural Photo

Much work was required to construct the sidewalk for the Matching Pairs Test. The installation began with excavating the site and preparing and installing a 4-inch concrete sub-base and then was finished with the selected sidewalk materials. The labor and materials were donated by local vendors and contractors, and the concrete sub-base was provided at-cost and funded by the researcher. Each finish material was then installed according to the researcher's plan (see figure 4.1.2.a). One crucial installation detail was that each joint between adjacent materials had to be non-existent or at least minimally detectible (see image 4.1.2.c). The contractor exceeded the researcher's expectations, and the installation was timely and precise (see images 4.1.2.d through 4.1.2.i).



Image 4.1.2.b: Matching Pairs Test Site Natural Photo

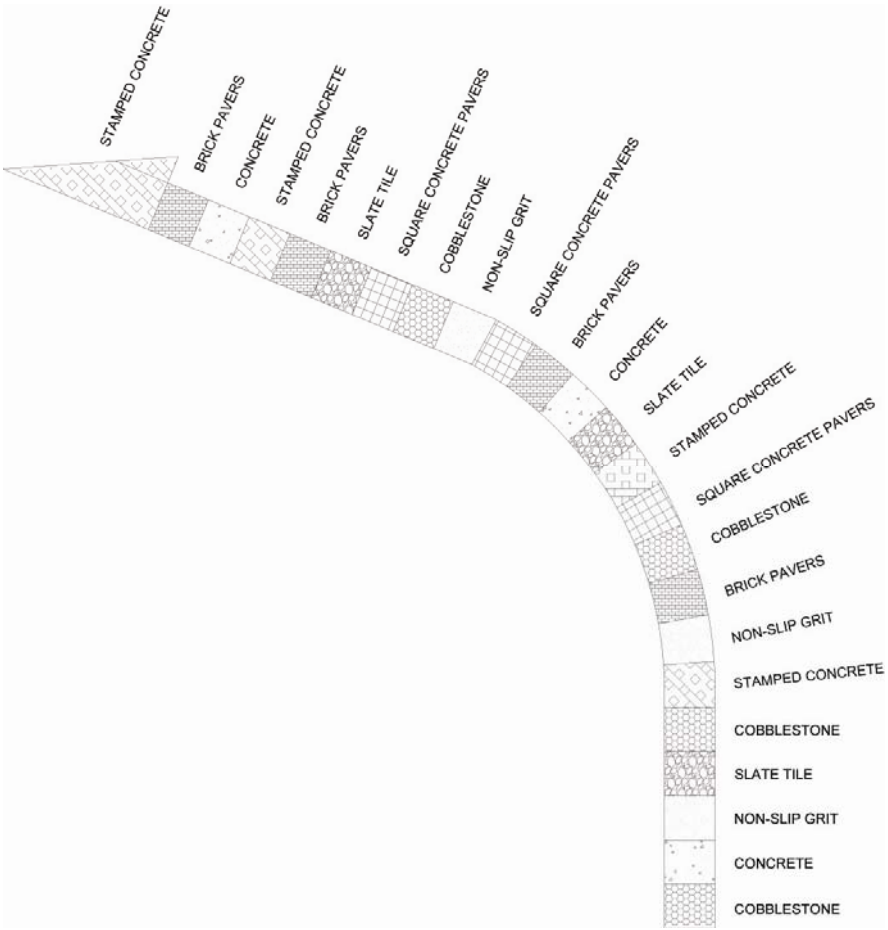


Figure 4.1.2.a: Matching Pairs Test Path Design



Image 4.1.2.c: Matching Pairs Test Path Joint Detail (Payne, 2008)



Image 4.1.2.d: Matching Pairs Test Path Installation Photo



Image 4.1.2.e: Matching Pairs Test Path Installation Photo



Image 4.1.2.f: Matching Pairs Test Path Installation Photo





Image 4.1.2.g: Matching Pairs Test Path Installation Photo



Image 4.1.2.h: Matching Pairs Test Path Installation Photo



Image 4.1.2.i: Matching Pairs Test Path Installation Photo

W. Dennis Thurman (director of GMS), Rod Poole (an orientation and mobility instructor), and Rick Stogner (GMS facilities maintenance director) reviewed this project for approval, and Charles Dixon (grounds supervisor) supported the efforts by providing full access to the school facilities and resources, disposing of the excavated materials and construction debris, and providing continued maintenance. One long-term benefit to GMS is that the permanence of this test path provides the ability to teach future students about various sidewalk materials at an earlier age without leaving the campus setting. The close proximity of the test path to the preschool facilities was well received by the teachers and was cited as being a valuable teaching tool.

4.1.3 Field Experiment Test Paths – Parts 1 and 2

The site for the Field Experiment Test Part 1 was an existing 4 feet wide and 700 feet long concrete sidewalk. This sidewalk began near the main entry of the campus and extended along the front side of three office buildings, the visitors' parking lot, and the principal's house, and ended near the infirmary building (see figure 4.1.3.a). Along the route were several intersecting paths, benches, turns, curves, and gentle slopes. These characteristics along with the length, width, and accessibility within the campus made this path attractive.

The site for the Field Experiment Test Part 2 was the same as Part 1, but the participants' travel direction was reversed. The beginning point was near the infirmary building and ended near the main entrance to the GMS campus. The reuse of the initial path allowed the same number and types of turns, intersecting paths, slopes, and natural surroundings. This path also included the installation of new sidewalk materials in four locations. Non-slip grit was installed atop the existing concrete sidewalk at locations to denote intersections at the main entrances of the office buildings (see image 4.1.3.b). These changes in materials became the variables from Test 1 and Test 2, with all else being equal. The selection of the non-slip grit test material was determined according to the statistical results as described in Table 5.2.1.g: Rank Test Matrix.

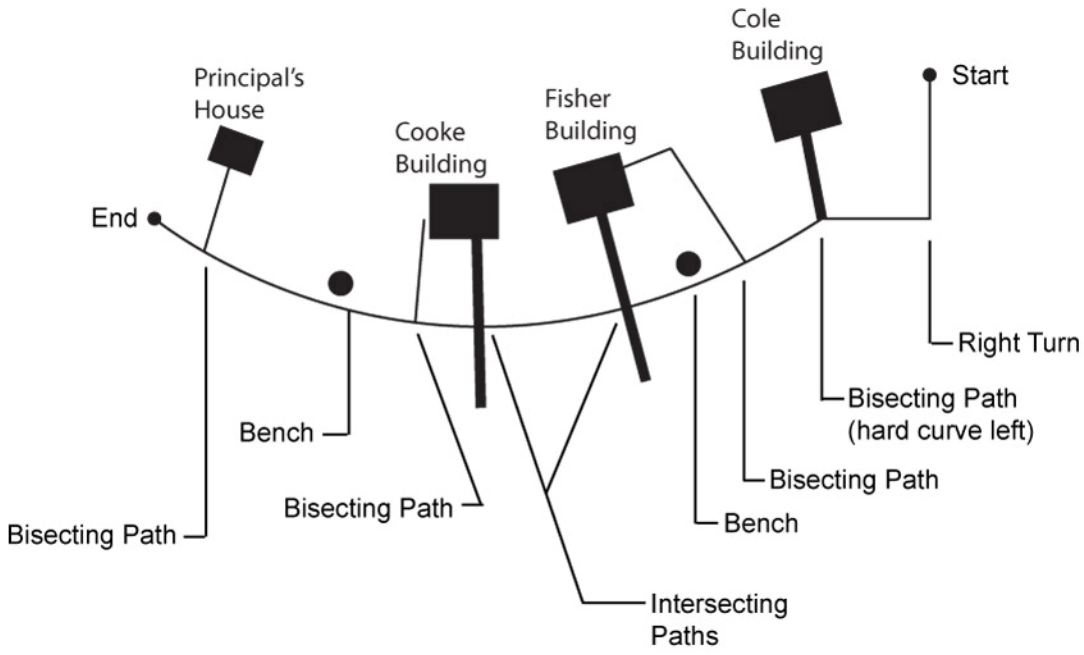


Figure 4.1.3.a: Field Experiment Test One – Route Plan

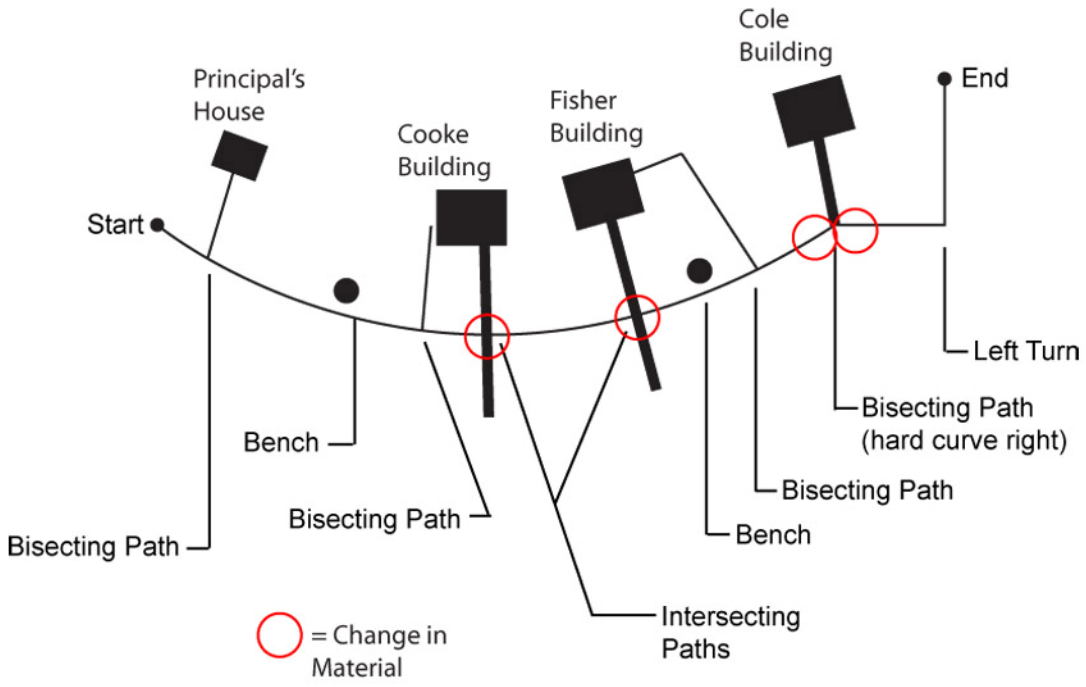


Figure 4.1.3.b: Field Experiment Test 2 – Route Plan



Image 4.1.3.a: Field Experiment Test 2 – Material Change

4.2 Selection of Subjects

Design is a very visual field of art and science. Yet, an important part of way-finding deals with pedestrians who live and travel with the loss of vision. Based on estimates from a study conducted by the American Foundation for the Blind (AFB, 2008), 6.5% (approx. 21.2 million) of the American population has vision loss. This small population relies heavily on the accommodation provided in the physical landscape as well as information provided through way-finding design. Within the legally blind population (and in this study) there are some with varying degrees of light perception, color perception, and usable vision.

One benefit of conducting this research at GMS was the close proximity to North Carolina State University, N.C. Services for the Blind, the Center for Universal Design, and the North Raleigh Lions Club (see figure 4.2.a). Each of these schools and organizations offered a rich resource of information regarding visual impairments and possible research participants. A contact person with each of these organizations was solicited to promote the research study, and many provided the researcher with lists of prospective, willing participants for the study. The researcher contacted possible participants and explained the study, gathered personal information, and determined if the person qualified for the research.

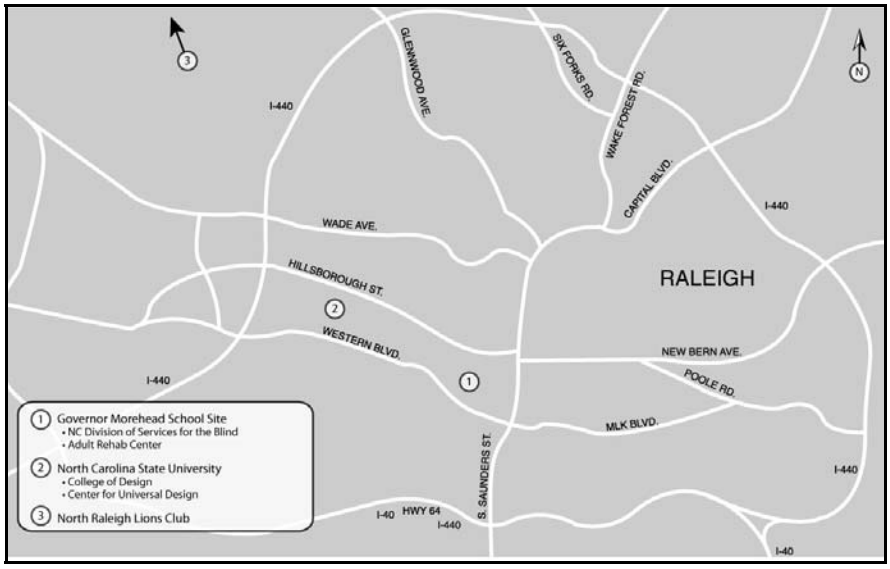


Figure 4.2.a: Local Resources

Of the interested people, 23 visually impaired adults qualified for the study (n=23). Qualifications required that participants be at least 18 years old, and independent and efficient travelers who primarily used the assistance of a long cane. Of these, all were certified as legally blind as determined by the state of North Carolina, and had varying degrees of vision and travel experience (see Section 1.2 for the definition of legal blindness). Due to the limited availability of qualified participants, all 23 participants took part in the Matching Pairs Test and both field experiments. More information about the participants and their responses to the questionnaire appears in Table 4.4.a.

The Matching Pairs Test consisted of a large enough sample of the population to achieve the desired probability and was able to help me assess whether or not the changes in materials resulted in a significant response. A major limitation to the sample size was that the focus of this research was so narrow that a very special population was sought. Of the nearly 21 million Americans who are visually impaired only about 1.3 million are legally blind adults (AFB, 2006). This number is reduced even further when eliminating those with mental or multiple disabilities, or those who cannot travel independently. Therefore, the availability of qualified subjects for this study was very limited. Aspects of this research could be done with a less specific sample group, but the primary thesis would have to change.

4.3 Methodology

This research implemented quantitative measurements and comparisons of various sidewalk surface materials, as well as the participants' performance in field experiments. The two field experiments evaluated the ability of the 23 visually impaired participants to detect changes in sidewalk materials while moving along a path.

The materials selected for comparison were originally identified in a study conducted by Jim Gibbons through the Cooperative Extension System at the University of Connecticut. The result of the study was a technical paper titled *Pavement and Surface Materials* (Gibbons, 1999). Gibbons' paper identifies nine materials used for vehicle and pedestrian thoroughfares and describes the characteristics and procedures for proper construction. Of Gibbons' original nine materials, three were chosen for comparison and testing in this research: (a) concrete, (b) brick pavers, and (c) stamped concrete. In addition to these three

materials, four other surface materials were included: 12-inch slate tiles, 12-inch concrete pavers, manufactured cobblestone, and non-slip grit applied over concrete. The added materials were comparable to the original three in size, installation method, availability, and usability. The decision to introduce materials other than those evaluated by Gibbons was based on local observations of types of sidewalks and materials being used in the southeast region of the United States (see image 4.3.a). Certainly, many other sidewalk materials are used throughout the United States and around the globe. Therefore, similar research could be conducted elsewhere with other materials more suited for those locations. Various materials were eliminated due to their availability, cost, installation procedure, or durability. Wood, for example, although it can be treated for outdoor use, is not viable for long-term constant contact with the earth and not suitable for use in horizontal planes unless elevated.



Image 4.3.a: Non-GMS Comparable Surface Materials

4.3.1 Material Analysis Procedure

The material analysis consisted of evaluating each of the seven materials independently for physical characteristics including installation methods, physical size, acoustic attenuation, and vibration. The user often only interacts with the finished surface of the materials; however, the final performance of the material is a direct result of the installation method and quality of work. This data is not only important when considering the movement from one material to another in detecting change underfoot, but also in considering the transmission of vibrations through a long cane and the generation of sound upon contact. The measurement of sound attenuation in this study was important in conjunction with the long cane because the variation in audible cues was generated by different surface textures.

4.3.2 Matching Pairs Test Procedure

The Matching Pairs Test was approved by the Institutional Review Board of North Carolina State University and administered to all 23 participants. At the initial meeting with each participant, the researcher read aloud the informed consent document (see Appendix A), which described the three tests. The form provided information about the research purpose and procedures and contact information for the researcher and academic adviser. All written information was translated into Braille (and back checked for translation errors), as well as duplicated in large text format before being distributed to the participants for their signature of acceptance of the test procedures. Those who could not sign the form gave verbal acknowledgement, which was documented by the researcher.

The Matching Pairs Test compared mixed pairs of the seven sidewalk construction materials in 23 combinations. The tests were conducted in a semi-controlled outdoor environment to limit distractions. The researcher designed the sidewalk to allow for all seven materials to be arranged in such a way that 21 unique combinations of adjacent materials were provided .

Table 4.3.2.a: *Matching Pairs Matrix (Payne, 2008)*

	Concrete	Brick Pavers	Stamped Concrete	Slate Tile	12-inch Concrete Pavers	Cobblestone	Non-slip Grit
Concrete	**Same**	Concrete & Brick Pavers	Concrete & Stamped Concrete	Concrete & Slate Tile	Concrete & 12-inch Concrete Pavers	Concrete & Cobblestone	Concrete & Non-slip Grit
Brick Pavers		**Same**	Brick Pavers & Stamped Concrete	Brick Pavers & Slate Tile	Brick Pavers & 12-inch Concrete Pavers	Brick Pavers & Cobblestone	Brick Pavers & Non-slip Grit
Stamped Concrete			**Same**	Stamped Concrete & Slate Tile	Stamped Conc & 12-inch Concrete Pavers	Stamped Concrete & Cobblestone	Stamped Conc & Non-slip Grit
Slate Tile				**Same**	Slate Tile & 12-inch Concrete Pavers	Slate Tile & Cobblestone	Slate Tile & Non-slip Grit
12-inch Concrete Pavers					**Same**	12-inch Concrete Pavers & Cobblestone	12-inch Conc Pavers & Non-slip Grit
Cobblestone						**Same**	Cobblestone & Non-slip Grit
Non-slip Grit							**Same**

Each test was conducted by observing one participant at a time. The participant was led to the test area from a neutral meeting place on campus to the starting point of the test route.

Each participant was required to bring his or her own long cane to use during the exercise. Because each individual adapts to the unique sense and feel of his or her own cane, the researcher felt it was important not to dictate the type of cane used. Instead, the type of cane was noted by the researcher and calculated in the data analysis as a variable (nylon tip, roller tip, or metal tip).

The test procedure involved positioning the participant at the first intersection of two materials (see images 4.3.2.a & 4.3.2.b) and explaining the process from that point forward (See Appendix J for verbal instructions). For the determination of textures, the participant chose the sweep method (a side-to-side motion with the cane tip being in constant contact with the ground surface). However, for sound, the 2-point touch approach (a repetitive motion of tapping the cane tip on the left side, and then across the body on the right side) was used. In addition to the long cane, participants also explored sensations underfoot as generated by walking, scuffing, and tapping the foot. This was noted by one participant as “an effective way to determine the stability or permanency of a material” (see Appendix C for Matching Pairs Tally Sheet). As with the cane type, the researcher did not specify a certain quality of shoe, but noted the type of shoes worn by the participants and calculated this i as a variable (tennis, casual, or dress).



Image 4.3.2.a: Matching Pairs Test Procedure



Image 4.3.2.b: Matching Pairs Test Procedure (Payne, 2008)

The participant had a fixed amount of time (30 seconds) to explore the pairs of materials. At the conclusion of each 30-second review period, the participant declared a definitive “Yes” or “No” to two questions asked by the researcher: As detected by the cane, is there a difference between the two materials? As detected underfoot, is there a difference between the two materials? Upon the participant making a determination, the researcher documented the answers and directed the participant to the next intersection and repeated the test.



Image 4.3.2.c: Matching Pairs Test Joint Photo (Payne, 2008)

The researcher also noted (without instigating responses) any descriptive comments the participants made. These comments were noted on the tally sheet as possible keywords and are described later in this document. The total time accounted for during this testing phase was 0.75 hours per participant (see Appendix B for Timeline).

4.3.3 Field Experiment Tests Procedure

The Field Experiment Tests (Part 1 and Part 2) were approved by the Institutional Review Board of North Carolina State University and administered to all 23 participants in two parts. Part 1 was conducted on the same day as and immediately after the Matching Pairs Test above.

4.3.3.1 Part 1

Part 1 of the Field Experiment Tests consisted of 23 individual participants walking a predetermined path (see figure 4.1.3.a) on the campus of GMS. Along this path the researcher identified nine intersections and/or objects for the participants to navigate and identify. These objects included intersecting/crossing paths, bisecting paths, benches, and turns, etc.

Table 4.3.3.1.a: *Test 1 Route Description*

Point	Path Characteristic	Travel Direction	Distance
Start	Start	Straight	45 feet
1	90 degree turn right	Hard curve left	32 feet
2	Bisecting path on right	Straight	58 feet
3	Bisecting path on right	Straight	25 feet
4	Bench on right	Gentle curve right	79 feet
5	Intersecting path	Straight	179 feet
6	Intersecting path	Gentle curve right	53 feet
7	Bisecting path on right	Gentle curve right	138 feet
8	Bench on right	Straight	49 feet
9	Bisecting path on right	Straight	42 feet
10	End	End	700 feet total



Image 4.3.3.1.a: Field Experiment Test Route Obstacle – Intersecting Path

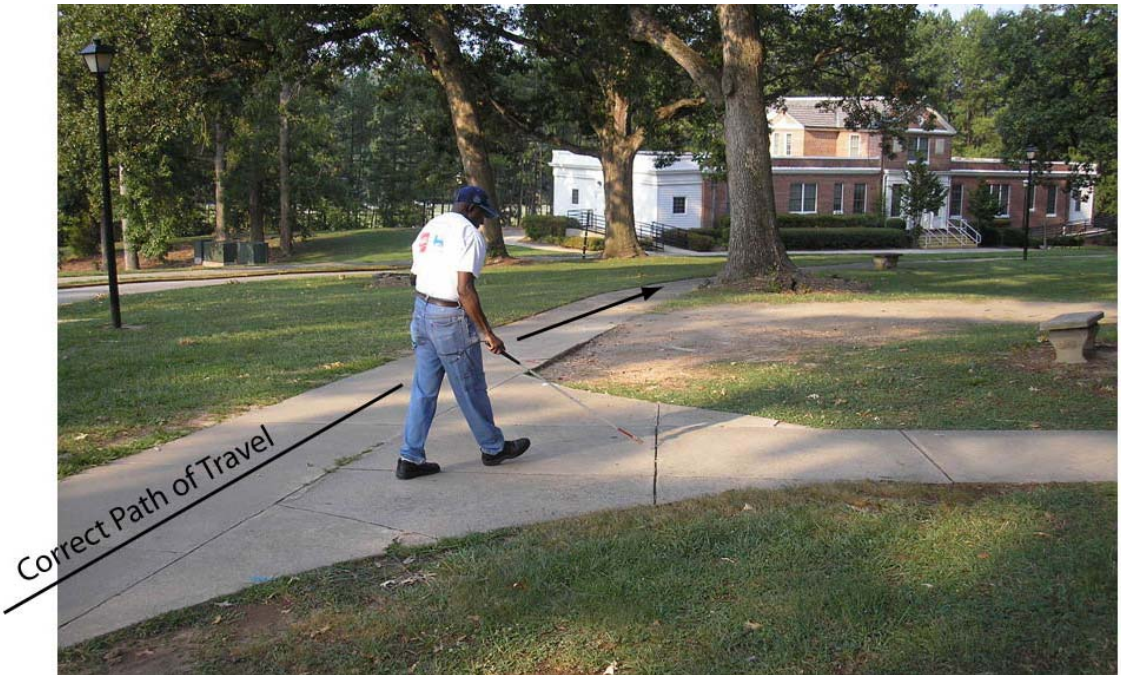


Image 4.3.3.1.b: Field Experiment Test Route Obstacle – Bisecting Path



Image 4.3.3.1.c: Field Experiment Test Route Obstacle – Bench



Image 4.3.3.1.d: Field Experiment Test Route Obstacle – Long Curve and Bench

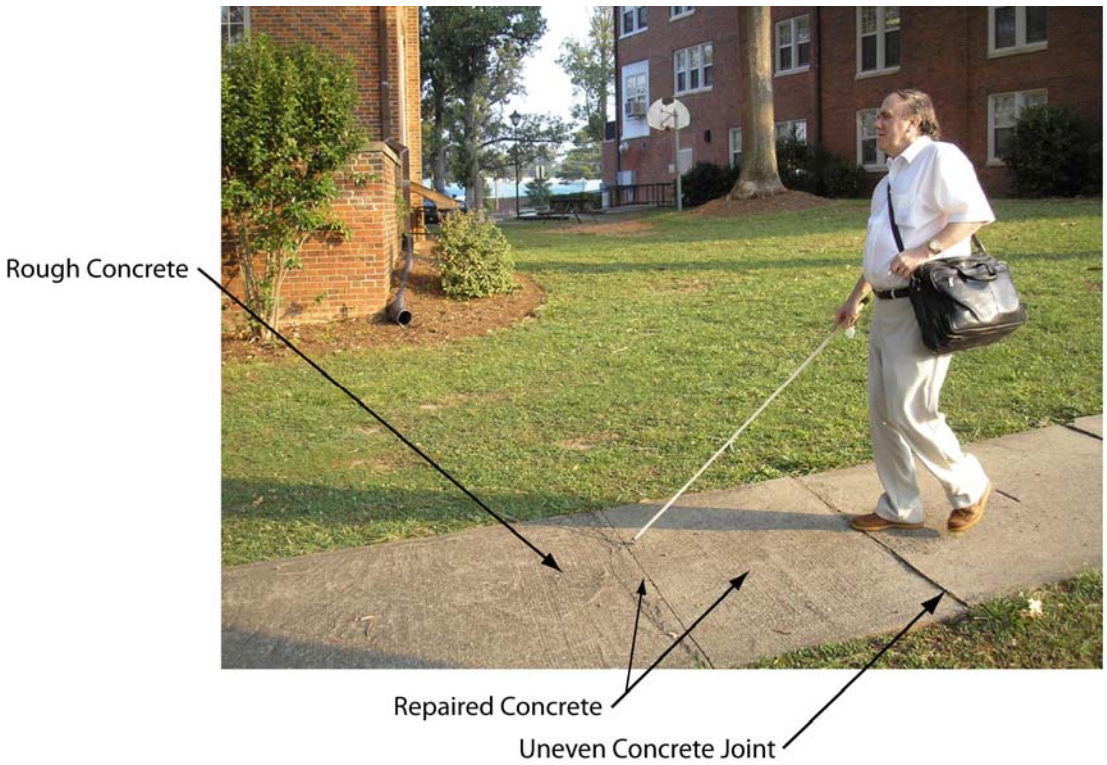


Image 4.3.3.1.e: Field Experiment Test Route Obstacle – Rough Surface Material, no change

At the start of Part 1, each participant was led to the test area from a neutral meeting place on campus to the starting point of the test route and given verbal instructions (See Appendix J for verbal instructions). Once ready, the subject began navigating the path, and the researcher followed nearby to record any identifying statements, document the overall travel time and time from point to point (nine points total), map each participant's travel path and any missed objectives (noted as Errors), and assist in any state of disorientation or confusion (See Appendix D.1 for sample tally sheet).

Upon completion, the participant was advised of his or her performance in regard to the number of correctly identified points along the path, number of errors, and overall travel time. Upon completing the Matching Pairs Test and Field Test Part 1, a tentative meeting date and time was set to conduct the Field Test Part 2. Any comments and suggestions were documented, and the participant was escorted back to the neutral meeting point. The participants were compensated for their time and participation in Part 1. The total time

accounted for during this testing phase was 0.5 hours per participant. (see Appendix B for Timeline).

4.3.3.2 Part 2

Part 2 of the field test took place on a separate day (approximately five months after Part 1) and consisted of the same group of individual participants walking the same path as in Part 1. However, the researcher implemented changes in surface materials at four of the previous nine points along the path (see figure 4.3.1.b). At the start of Part 2, each participant was led to the test area from a neutral meeting place on campus to the starting point of the test route and given verbal instructions (See Appendix J for verbal instructions). It should be noted that the starting point of Part 2 was the finishing point of Part 1 with the participants having to travel the original route in reverse order. This change in direction was made to alleviate the chance of path memorization or experience influencing performance.

Table 4.3.3.2.a: *Test 2 Route Description*

Point	Path Characteristics	Travel Directions	Distance
Start	Start	Straight	42 feet
1	Bisecting path on left	Straight	49 feet
2	Bench on left	Gentle curve left	138 feet
3	Bisecting path on left	Gentle curve left	53 feet
4	Change in surface material	Straight	179 feet
5	Change in surface material	Gentle curve left	79 feet
6	Bench on left	Straight	25 feet
7	Bisecting path on left	Straight	38 feet
8	Double change in surface material	Hard curve right	20 feet & 32 feet
9	90 degree turn left	Straight	45 feet
10	End	End	700 feet total

Once ready, the participant began navigating the path, and the researcher followed nearby to record any identifying statements, document the overall travel time and time from point to point (nine points total), map the participant's travel path, and assist in any state of disorientation or confusion. Specific information was sought from the participants during travel regarding the detection of changes in surface material. The researcher noted on a

map of the route when changes in surface materials were correctly detected and when changes were mistaken (noted as a false ID) or passed over without detection (noted as errors). See Appendix D.2 for sample tally sheet. Upon completion, the participant was advised of his or her performance in regards to the number of correctly identified points along the path, number of false IDs, number of errors, and overall travel time. Any comments and suggestions regarding the field tests were documented. The researcher then conducted a questionnaire, and the participant was escorted back to the neutral meeting point. The participants were compensated for their time and advised that their participation in the study was complete. The total time accounted for during this testing phase was 0.5 hours per participant. (see Appendix B for Timeline).

4.4 Questionnaire

Upon completing the Field Experiment Test 2, the researcher conducted a 14-point questionnaire to gather background information on each participant. Though the questionnaire was optional, there was 100% participation with no unanswered questions (see Appendix E). Table 4.4.a summarizes the participants' responses. Question 14 regarded participants' initials (for coding purposes only) and is not shown in the table.

The sample consisted of 14 (60.9%) males and 9 (39.1%) females and had a mean age of 50 years 3 months (Min = 39; Max = 71), (See Chart 4.4.a). Two (8.7%) reported that they currently work at GMS or Division of Services for the Blind, whereas the other 21 (91.3%) reported having not worked there in the past. Twelve (52.2%) indicated that they were past students at GMS, and almost half (*n* = 11, 47.8%) indicated that they visited the GMS campus a few times each year. The vision levels were varied with 18 (78.2%) being totally blind, with five (21.7%) being blind since birth (congenital blindness), with the mean age (n=18) of vision loss being 13 years 9 months. Travel experience was also varied, with nearly all (n=22, 95.7%) having some formal orientation and mobility training. Of the 23 participants, 15 were traveling independently before the age of 18. Fifteen (65.2%) participants also began traveling with a cane before the age of 18, and 7 (30.4%) travel with mobility aids other than the long cane (i.e., dog guide or sighted guide).

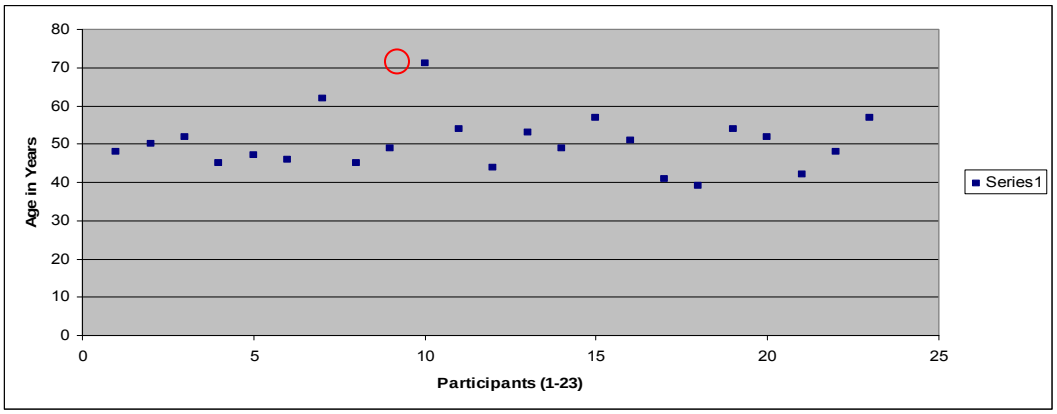


Chart 4.4.a: Participants' Age Range

Although Chart 4.4.a shows a very balanced range of ages for the participants, it should be noted that participant 10 is newly visually impaired and has been blind for only four years (since the age of 67). Therefore much of the information gathered from this participant regarding age and experience can be considered outlier data.

Table 4.4.a: *Questionnaire Tally*

Number of Participants	n=23	Male = 14	Female = 9
Q1 Mean Age of Participants	50 years 3 months	Min. 39	Max. 71

	Yes	No	Now	Past
Q2 Do you (now or in the past) work at GMS or DSB?	2	21	2	21

	Yes	No	Now	Past
Q3 Do you (now or in the past) go to School at GMS?	12	11	0	12

	Daily	Weekly	Monthly	A few times a year	Less than a few times a year
Q4 How often do you visit the GMS campus?	3	4	3	11	2

	Totally Blind	Some Light Perception	Some Usable Vision
Q5 Extent of vision loss?	18	4	1

	Birth	Younger than 18	18 or Older	Mean (n=18)
Q6 If blind, then at what age did you experience total vision loss?	5	8	5	13 years 9 months

	Birth	Under 18	18 or Older
Q7 If not blind, then at what age did you begin to lose your vision?	3	1	1

	Yes	No
Q8 Have you had any formal Orientation & Mobility training?	22	1

	0-6	7-11	12 +
Q9 If Yes, how many months of formal Orientation & Mobility training have you had?	3	19	0

	Up to 18	18-30	31 +	Mean
Q10 At what age did you begin travelling independently?	15	5	3	20 years 9 months

	Daily	Weekly	Less than
Q11 How often do you travel independently?	22	0	1

	Under 18	18-30	31 +	Mean
Q12 At what age did you begin travelling with a cane?	15	4	4	21 years 5 months

	Yes	No	Dog Guides	Sighted Guides
Q13 Do you use any other travel aids?	7	16	4	3

Chapter Five
Data and Analysis

As stated in the hypotheses and research questions, the physical properties of each of the seven surface materials and the participants' ability to detect changes in the materials is what drives this research. As is shown by the data, ***detection*** was most important, whereas ***identification*** and ***action taken*** by the participant was not evaluated.

This chapter reviews the collected data and results based on the methods described in chapter 4. It also presents quantitative reasoning behind the conclusions outlined in the following chapters. The type of data collected during this study is summarized in the following matrix:

Table 5.0.a: *Data Summary Matrix*

Tests	Variables	Data Type	Analysis
Physical Property Tests	Sound Attenuation	Ratio	Descriptive
	Vibration	Ratio	Descriptive
Matching Pairs Test	Shoe Types	Nominal	Logistic Regression, Pearson Correlation, Proportions Correct and Simple Rank Test
	Cane Tip Types	Nominal	
	Temperature	Ratio	
	Humidity	Ratio	
Field Experiment Test One	Time	Ratio	Field Experiment Paired Samples *t* Tests
	Errors	Ratio	
Field Experiment Test Two	Time	Ratio	
	Errors	Ratio	
	False ID's	Ratio	
Questionnaire	Experience	Descriptive	Descriptive

5.1 Physical Property Tests

This section describes the tests and results concerning the physical differences of all the materials and the settings in which they were studied. The Physical Property Tests began with an in-depth study and documentation of the seven chosen materials. In becoming familiar with the materials, the researcher gathered background information including physical size, installation method, manufacturer, product name/number, raw materials, cost, and availability (See Table 5.1.a).

Table 5.1.a: *Materials Summary Matrix*

	Concrete	Brick Pavers	Stamped Concrete (stained)	Slate Tile	12-inch Concrete Pavers	Cobblestone	Non-slip Grit
Physical Size	4" Thick (minimum)	4" x 8" x 2 5/8"	4" Thick (minimum)	12" x 12" x 3/8"	12" x 12" x 1 1/4" w/ 1/4" chamfer edges	5-1/2" L x 2-3/8" D x varying widths (4 3/4, 6 1/4, 8, & 9 1/2")	1/4" (6mm) with +/- 1/32" tolerance
Installation Method	Continuous pour over rough grade	Loose laid pavers on sand base and 4" concrete sub-base	Continuous pour over rough grade	3/8" grout, on one inch mortar bed and 4" concrete sub-base	Loose laid pavers on sand base and 4" concrete sub-base	Loose laid cobbles on sand base and 4" concrete sub-base. (pattern interlocks)	Applied with 1/4" nap roller over 4" concrete sub-base
Manufacturer	Not Applicable	Pine Hall Brick Provided by Oldcastle-Adams Products Co. Raleigh, NC	Scofield Systems, Lithotex, Pavecrafters	Peacock Tile - Provided by Best Tile, Inc. Raleigh, NC	Unknown (Provided by Lowe's Home Improvement)	Oldcastle-Adams Products Co. Bergerac Pavers Provided by Belgard	ITW Resin Technologies, Inc. Provided by Carolina Coatings, Inc. Morrisville, NC
Product Name/Number	Natural Gray (2500 psi)	Pathway Red	Ashler Stone - Random Interlocking	Peacock 1212	Natural Gray	Dublin Modular - Fossil Beige & Silex Gray	Impax 100 - Gray
Raw Material	Cement, Aggregate, Water	Clay	Cement, Aggregate, Water	Natural Slate, (varying grades)	Cement, Aggregate, Water	Cement, Aggregate, Water	Silica, Epoxy Ester, Slurry Resin
Approx. Cost (Turn-key Installed)**	$3.25/sf	$13.35/sf*	$9.65/sf	$ 9.75/sf*	$8.80/sf*	$15.90/sf*	$32/sf*

The following two sections discuss the testing procedures regarding evaluating cane vibration and sound attenuation with each material.

5.1.1 Cane Vibration Test

The long cane is a common tool used as a travel aid by visually impaired and blind people. With the variations in types, lengths, and materials used in today's canes, the researcher had to establish a consistent procedure for testing the amount of vibration generated by the

different paving materials. This method evaluated the levels of vibration at two points along the cane: at the tip and at the grip (see figure 5.1.1.a).



Figure 5.1.1.a: Vibration Test Diagram

The researcher chose one cane type: a 52” long, collapsible, aluminum and graphite shaft with a Golf Pride hand grip and nylon tip. However, this test only measured levels of vibration and did not consider grip or cane technique during use.

5.1.1.1 Precedent and Purpose of Test

In 1998, Morioka and Maeda conducted several studies looking at the affects on the hand and arm as a result of repeated vibration from tapping the long cane against various surface materials. Morioka and Maeda (1998) studied:

> … the vibration at three axes of the cane grip and one axis at the wrist. The pinch forces between an index finger and the grip were also measured using a strain gauge in order to observe how the vibration characteristics depend on the changing forces.

The result of the Morioka and Maeda study, albeit insightful, did not address the information received through the cane, only the grip effects.

Similar to the study conducted by Morioka and Maeda, Rodgers and Emerson (2005) studied vibration transmitted though a long cane. This 2005 study looked specifically at

different cane shaft materials and their flexibility, durability, and sensitivity to tactile information. Rodgers and Emerson identified two correlations: (a) “the less flexible a cane shaft is, the better it transmits vibrations,” and (b) “shafts with less weight transmit energy at higher frequencies.”

In contrast to the two studies above, this current research identified connections between vibration and the detection of changes in surface materials. The generation of vibration in the current tests was not based on cane type or gripping method but simply the texture of the sidewalk surface material.

5.1.1.2 Testing Method and Instrument

This test was performed outdoors at the Matching Pairs Test study site using all seven surface materials. Vibration levels were collected at two points along the cane; six inches above the cane tip and at the base of the cane grip. These locations were determined to best evaluate the initial amount of vibration at the cane tip and the resulting amount of vibration at the cane grip (see table 5.1.1.3.a).

The researcher simulated one method of cane use (constant contact/sweep) while measuring the levels of vibration (see figure 5.1.1.3.a for data sample). Data was recorded by an Actigraph GT1M accelerometer at a rate of 60 samples per second. This data was retrieved and processed using the Actilife Lifestyle Monitoring System software version 3.2.2 as provided by the manufacturer. This study did not consider, nor evaluate, the reduction or transmission rate of vibration along the shaft, although this could be deduced by the difference between the two test points. The data provided insight as to the amount of information available to the user through vibration, as well as opportunities for the generation of sound. (i.e., as vibration level increases, the sound generated increases).

5.1.1.3 Data and Analysis

As shown in Figure 5.1.1.3.a, vibration data gathered for each material was evaluated for spikes (high), sags (low), and frequency in the levels of textural changes. The baseline data of 1952 was established by Dr. Patty Freedman as a point at which moderate activity is detected. Spikes and sags, identified by the high and low points on the chart, represent the

change in detected texture during the sweep method test. Frequency is illustrated by the horizontal range between points. Flat lines in the frequency indicate little to no detected texture, whereas diagonal movement represents varying levels of texture.

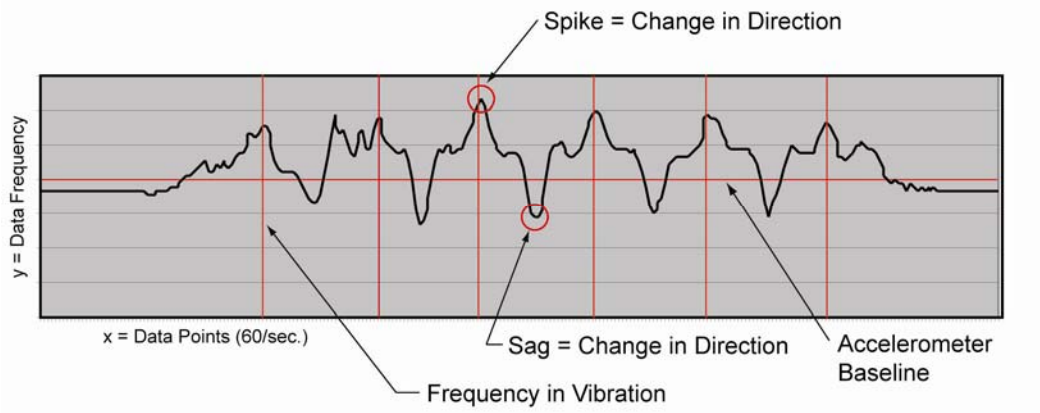


Figure 5.1.1.3.a: Sample Vibration Chart with Labels (Actigraph edited by Payne)

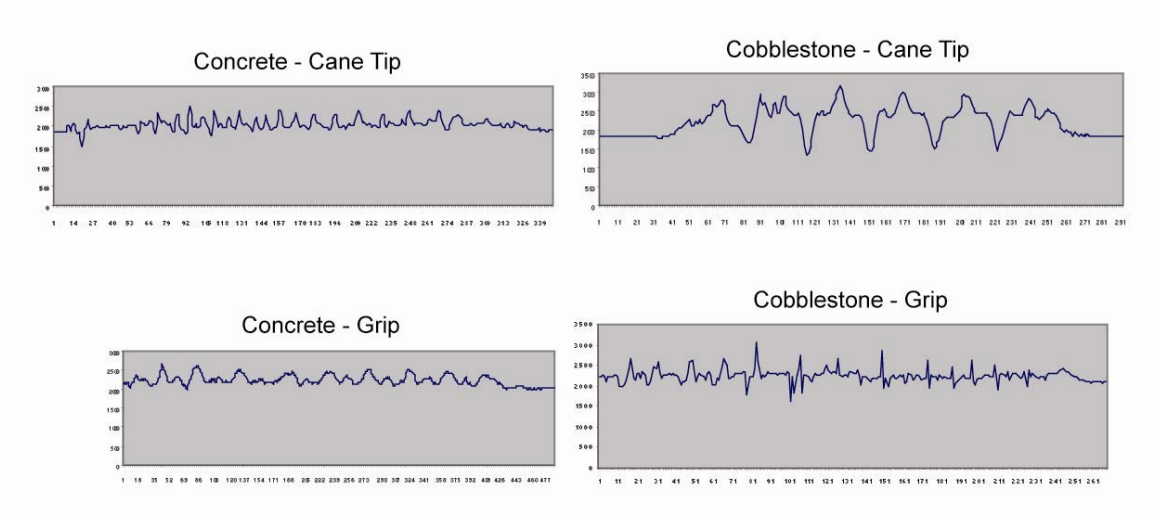


Chart 5.1.1.3.a: Concrete and Cobblestone Data Samples for Comparison (Actigraph edited by Payne)

For the two data samples (concrete and cobblestone) in Chart 5.1.1.3.a, the vibration levels detected at the cane tip show a much more dramatic change in waves, whereas the waves for the cane grip are more regular. This can be attributed to the dissemination of vibration waves through the shaft, where the shaft acts as a filter. The vigorous movement at the cane tip for each sample shows the various opportunities for the generation of sound. Very

active vibration waves demonstrate very active movement in the cane tip during the sweep method. The difference between the two data charts (cane tip and cane grip), for all materials, illustrates the amount of information available to the user through the cane.

Table 5.1.1.3.a shows a comparison of all gathered vibration data. This chart offers the high and low levels, difference between the two, and frequency in detected change in texture. This chart can be read as: Compared to the baseline of concrete, the material with the greatest difference between high and low data points, when detecting vibration, should be the most distinguishable. Therefore, cobblestone pavers with a range of 1433 as measured by the accelerometer provide the greatest difference. Likewise, the material with the greatest difference between cane tip and cane grip levels provides the greatest opportunity for the generation of sound. See Table 5.1.2.3.a for detected sound levels.

Table 5.1.1.3.a: *Vibration Levels Summary Matrix*

Baseline measurement from the Actigraph = 1952			Concrete **(Baseline Material)**	Brick Pavers	Stamped Concrete (Stained)	Slate Tile	12-Inch Concrete Pavers	Cobble-stone	Non-slip Grit
Levels of Vibration (based on difference between high and low and in frequency)	Grip	High	2510	2428	2394	2818	2497	3078	2498
		Low	2004	2109	1991	1755	1830	1645	1821
		Diff.	**506**	319	403	1063	667	**1433**	677
		Freq.	.402 secs	.379 secs	.454 secs	.398 secs	.769 secs	.340 secs	.080 secs
	Cane Tip	High	2497	2828	2787	2847	2639	3162	2141
		Low	1462	1809	1741	1829	2005	1338	1489
		Diff.	**1035**	1019	1046	1018	634	**1824**	652
		Freq.	.196 secs	1.27 secs	.250 secs	.823 secs	.494 secs	.563 secs	.078 secs

5.1.1.4 Section Conclusion

Figure 5.1.1.3.a demonstrates vibration wave signals from the sweep methods on two surfaces at both points on the cane. The difference in the vibration levels and frequencies is what provided cues as to what the material type was and whether or not it was different from the adjacent material. In addition to the variations in the vibration wavelengths, each spike/sag provided an opportunity for the generation of sound to be used as an audible cue. Conclusions regarding vibrations cannot be made independently. Table 5.1.1.3.a is to be compared to the results of the Matching Pairs Test in order to cite correlations of vibration and detection rate.

5.1.2 Sound Transmission Test

This unique test was established to evaluate sound as an aid in determining change in surface materials. The researcher developed a consistent method for producing sounds and measuring the varying results. The following sections describe the tools and methods.

5.1.2.1 Precedent and Purpose of Test

Echolocation entails "a process for locating distant ... objects by means of sound waves reflected to the emitter ... by the objects" (Woolf & Artin, 1981). These sounds are generated by the visually impaired traveler and are typically taps of the foot or cane tips or can be orally produced. These sounds radiate out and strike an object in the environment, and the reflected sounds can be used to determine the object's size, shape, texture, and location (Kellogg, 1962; Rice, 1967).

In a study conducted by Jon Sanford in 1985, the researchers accounted for the ability of users to interpret changes in sound from cane tapping to mean changes in surface materials. In Sanford’s test, the participants were asked to test the same materials a second time while wearing earphones and listening to music. The results of the second test were much poorer, which was attributed to the inability of the subjects to hear the changes in sound generated from the cane tip tapping.

5.1.2.2 Testing Method and Instrument

The sound transmission test for this dissertation was based on the premise that different surfaces produce sounds differently and typical measurements were necessary for comparison. This test was performed outdoors at the Matching Pairs Test site using all seven surface materials. The setting was semi-private with no interaction with anyone outside of the research team, and the sound generated by each material was measured solely by the researcher. Therefore, only the sound generation was measured and not the ability of the user to hear and understand the sounds.

Sound levels were collected at one point in the vicinity of the user; 73” diagonally from the cane tip (See Figure 5.1.2.2.a). This location was determined to best evaluate the resulting levels of sound near the ear of the participant (based on the average height of the 23 participants in this study).

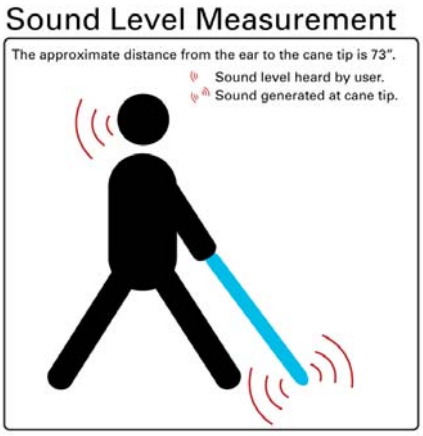


Figure 5.1.2.2.a: Noise Level Test Diagram

Using an American Recording Technologies SPL-8810 sound-pressure level meter, a baseline background noise level was measured before each material test and incorporated into each final noise level tally. The researcher used both the sweep and 2-point touch (as described in section 2.2.4) techniques on all materials to generate the sounds being measured. The noise level tests were conducted within a 10-minute time period with no extenuating circumstances. Data was gathered by testing each material once. Therefore the data in the table was for one instance in time, and uncontrolled variables such as background noise, people talking, wind, etc. were not considered. Only noise level data was

gathered, whereas pitch and tone were not. All efforts were taken to ensure continuity in the gathering of data.

5.1.2.3 Data and Analysis

Table 5.1.2.3.a shows the levels of sound as measured in decibels (dB). The notable difference in the noise generated from the cane tapping was a cue to the user that a change in materials may have occurred. The sound attenuation in this research was compared to the baseline material of concrete, and noted as a difference between the two materials (+/-). The data in the table is to be read as: When using the 2-point touch technique, the material with the greatest difference in noise level when compared to concrete is brick pavers (-2.5dB). Therefore, these two materials would offer the greatest opportunity for detection of change when using sound as an indicator. When using the sweep technique, concrete and cobblestone offer the greatest difference (+3.4dB).

Table 5.1.2.3.a: *Noise Levels Summary Matrix*

* All numbers are reported as db (decibels) unless noted otherwise.			Concrete (Baseline)	Brick Pavers	Stamped Concrete	Slate Tile	12-Inch Concrete Pavers	Cobble-stone	Non-slip Grit
Acoustic Attenuation in Decibels (db)	2-point touch	73 inches	**69.7**	**-2.5** **(67.4)**	0.0 (69.7)	+0.5 (70.2)	-0.3 (69.4)	+0.5 (70.2)	+1.3 (71.0)
(Difference between Concrete and other materials)	Sweep	73 inches	**68.5**	+2.8 (71.3)	+2.2 (70.7)	+2.2 (70.7)	+2.7 (71.2)	**+3.4** **(71.9)**	+3.1 (71.6)

For this test site, concrete was chosen as the baseline material because the sidewalk material in the Field Experiment Tests 1 and 2 is concrete. Therefore any new material introduced into the sidewalk would be compared (in vibration, sound, and texture) to concrete. In future studies, a similar comparison of noise levels could be made for other pairs of materials if the main body sidewalk material (baseline) is known beforehand, and background noise levels are comparable.

5.1.2.4 Section Conclusion

It was evident that sound cues vary depending on many factors including the listener's familiarity with the source, the ambient/background noise levels, and the consistency of noise/cue generation (Wightman & Kistler, 1997). This data clearly showed the wide range of noise levels generated by the simple tapping and sweeping of the long cane. The noise-measuring approach proved to be valuable in better understanding the difference between the sound generation of materials and at what level the sound travels to the ear of the subject. We are able to determine the attenuation by measuring the differences between the baseline noise level of concrete (69.7dB for 2-point touch and 68.5dB for sweep) and the noise level for each of the other materials. The greater the difference, positive or negative, the greater the chance that sound will contribute to the detection of change. Conclusions regarding sound attenuation, just like vibration, cannot be made independently. Table 5.1.2.3.a should be compared to the results of the Matching Pairs Test in order to cite correlations of vibration and detection rate. When doing so, correlation between sound and vibration is evident. When compared to concrete, the materials that provided the greatest level of vibration and detectible sound were cobblestone pavers when sampled by the sweep method, and brick when sampled by the 2-point touch method.

5.2 Matching Pairs Test

Way-finding by visually impaired travelers has been described as a combination of art and science and is often mastered over a long period of time. For this research, the way-finding aid of choice was the long cane. Cane traveling techniques are as unique as the user, and various detection methods were observed during testing. This section offers the discussion and explanation of the data and analysis for the Matching Pairs Test.

Table 5.2.a: *Temperature, Humidity, Shoe Type, and Cane Tip Type Matrices*

	Matching Pairs Test and Field Test One	Field Test Two
Mean Temperature	84.6	68.3
Mean Humidity	59.8	66.7

Table 5.2.a: Continued

	Number of Users	Matching Pairs Test
Metal Tip	n=23	4
Nylon Tip		15
Roller Tip		4
Dress Shoes	n=23	1
Tennis Shoes		16
Casual Shoes		6

The variables considered in the Matching Pairs Test included temperature, humidity, cane tip type, and shoe type. Temperature and humidity were gathered at the start time of each test. Tests were brief so the initial temperature and humidity levels were sufficient as data points. Also, shoe types were identified and categorized as either tennis, casual, or dress. Cane tip types were also identified and categorized as nylon, roller, or metal. (see table 5.2.a).

5.2.1 Data and Analysis

Matching Pairs Test Data: Cane and Underfoot

As noted in Section 2.2, visually impaired travelers are able to understand their surroundings by analyzing various sources of environmental input. Two inputs (cane tip and underfoot) were evaluated in these tests. The data for these inputs were separated into two distinct sets of results because the participants were asked to evaluate the materials with their cane and then with their feet. Data was organized and tallied using Microsoft Excel v.2007, and statistical data was analyzed using the SPSS Statistics v.16.0 on a PC platform.

Matching Pairs Test Data: Cane

A series of binary logistic regression analyses using simultaneous entry were conducted to determine whether cane tip type, temperature, and humidity would predict accuracy in detecting changes in sidewalk materials while en route. Regression results indicate that for

[Brick Pavers – Concrete], the overall model was significant in classifying participants' responses as correct or incorrect, $\chi^2(4) = 9.38$, $p = .05$, $R^2 = .34$. The model correctly classified 78.3% of the cases as correct or incorrect. Regression results also indicated that for [Concrete – Stamped Concrete], the overall model approached significance in classifying participants' responses as correct or incorrect, $\chi^2(4) = 8.67$, $p = .07$, $R^2 = .31$. The model correctly classified 78.3% of the cases as correct or incorrect. Regression results continued by indicating that for [Slate Tile – Stamped Concrete], the overall model was again significant in classifying participants' responses as correct or incorrect, $\chi^2(4) = 11.01$, $p = .03$, $R^2 = .38$. The model correctly classified 73.9% of the cases as correct or incorrect. However, examination of regression coefficients revealed no significant individual predictors in any of these models (see table 5.2.1.a).

Table 5.2.1.a: *Summary of Logistic Regression: Cane Tip (N = 23)*

Matching Pairs Test *Criterion:* Cane Tip	*p*	R^2	$X^2(4)$	*Freq.*
[Brick Pavers – Concrete]	.05**	.34	9.38	78.3
[Concrete – Stamped Concrete]	.07*	.31	8.67	78.3
[Slate Tile – Stamped Concrete]	.03**	.38	11.01	73.9

* denotes trend toward significant *p* value
** denotes significant *p* value

1. [Brick Pavers – Concrete], ($p = .05$): $R^2 = .34$, 78.3% classified accurately, no significant individual predictor
2. [Concrete – Stamped Concrete], (approached significance, $p = .07$): $R^2 = .31$, 78.3% classified accurately, no significant individual predictor
3. [Slate Tile – Stamped Concrete], ($p = .03$): $R^2 = .38$, 73.9% classified accurately, no significant individual predictor

In addition to looking at the logistic regressions, the researcher examined the proportion of correct decisions for each of the matched pairs to see which pairs yielded the most correct

responses as detected by the cane tip, as well as the ones that yielded the most mistakes, or difficulty in distinguishing between the materials. The results indicated that the three most correctly detected pairs of materials were [Non-slip Grit – Square Concrete Pavers] with 91.3%, along with [Concrete – Slate Tile] and [Concrete – Cobblestone] with 87.0% each. The least correctly detected pairs of materials were [Slate Tile – Square Concrete Pavers] and [Square Concrete Pavers – Cobblestone] with 52.2%, and [Stamped Concrete – Cobblestone] with 43.5%. See Table 5.2.1.b for the corresponding frequency table.

Table 5.2.1.b*: Summary of Frequency: Proportions Correct (All Cane Tips) (N = 23)*

Criterion: Matched Pairs	*Frequency*	*Valid Percent*
Most Correctly Detected		
[Non-slip Grit – Square Concrete Pavers]	21	91.3
[Concrete – Slate Tile]	20	87.0
[Concrete – Cobblestone]	20	87.0
Least Correctly Detected		
[Slate Tile – Square Concrete Pavers]	12	52.2
[Square Concrete Pavers – Cobblestone]	12	52.2
[Stamped Concrete – Cobblestone]	10	43.5

The researcher examined the proportion of correct decisions for matched pairs to see which cane tip type yielded the most correct responses. The results indicate that cane tips correctly distinguished pairs of materials at the rate of: metal (87.0%), nylon (68.4%) and roller (59.8%) (see table 5.2.1.c).

Table 5.2.1.c*: Summary of Frequency: Proportions Correct (Cane Tips) (N = 23)*

Predictors: Cane Tips	*Frequency of use*	*Valid Percent*
Metal Tip	4	87.0
Nylon Tip	15	68.4
Roller Tip	4	59.8

Matching Pairs Test Data: Underfoot

Another series of binary logistic regression analyses using simultaneous entry were conducted to determine whether shoe type, temperature, and humidity would predict accuracy in detecting changes in sidewalk materials while en route. Regression results indicate that for [Concrete – Slate Tile], the overall model was significant in classifying participants' responses as correct or incorrect, $\chi^2(4) = 12.24$, $p = .02$, $R^2 = .41$. The model correctly classified 91.3% of the cases as correct or incorrect. Regression results also indicate that for [Cobblestone – Brick Pavers], the overall model approached significance in classifying participants' responses as correct or incorrect, $\chi^2(4) = 8.92$, $p = .06$, $R^2 = .32$. The model correctly classified 78.3% of the cases as correct or incorrect. However, examination of regression coefficients revealed no significant individual predictors in any of the models (see table 5.2.1.d).

Table 5.2.1.d: *Summary of Logistic Regression: Underfoot (N = 23)*

Matching Pairs Test *Criterion: Underfoot*	*p*	R^2	$X^2(4)$	*Freq.*
[Concrete – Slate Tile]	.02**	.41	12.24	91.3
[Cobblestone – Brick Pavers]	.06*	.32	8.92	78.3

* denotes trend toward significant *p* value
** denotes significant *p* value

1. [Concrete – Slate Tile], (p = .02): R^2 = .41, 91.3% classified accurately, no significant individual predictor
2. [Cobblestone – Brick Pavers], (approached significance, p = .06): R^2 = .32, 78.3% classified accurately, no significant individual predictor.

In addition to looking at the logistic regressions, the researcher examined the proportion of correct decisions for each of the matched pairs to see which pairs yielded the most correct responses as detected underfoot, as well as the ones that yielded the most mistakes, or difficulty distinguishing between the materials. The results indicate that the three most correctly detected pairs of materials were [Concrete – Cobblestone] with 91.3%, along with [Slate Tile – Non-slip Grit] and [Concrete – Slate Tile] with 87.0% each. The least correctly detected pairs of materials were [Square Concrete Pavers – Brick Pavers], [Square Concrete Pavers – Cobblestone], and [Stamped Concrete – Cobblestone] with 47.8%, and [Slate Tile – Square Concrete Pavers] with 43.5%. See Table 5.2.1.e for the corresponding frequency table.

Table 5.2.1.e*: Summary of Frequency: Proportions Correct (All Shoe Types) (N = 23)*

Criterion: Matched Pairs	*Frequency*	*Valid Percent*
Most Correctly Detected		
[Concrete – Cobblestone]	21	91.3
[Slate Tile – Non-slip Grit]	20	87.0
[Concrete – Slate Tile]	20	87.0
Least Correctly Detected		
[Square Concrete Pavers – Brick Pavers]	11	47.8
[Square Concrete Pavers – Cobblestone]	11	47.8
[Stamped Concrete – Cobblestone]	11	47.8
[Slate Tile – Square Concrete Pavers]	10	43.5

The researcher examined the proportion of correct decisions for matched pairs to see which shoe type yielded the most correct responses, as well as those which yielded the most mistakes, or difficulty distinguishing between the materials. The results indicate that shoe types correctly detected pairs of materials at the rate of: dress (78.3%), tennis (67.6%), and casual (62.3%).

Table 5.2.1.f*: Summary of Frequency: Proportions Correct (Shoe Types) (N = 23)*

Predictors: Shoe Types	*Frequency of use*	*Valid Percent*
Dress Shoes	1	78.3
Tennis Shoes	16	67.6
Casual Shoes	6	62.3

Matching Pairs Test Data: Simple Rank Test

Data sheets were kept for all 23 participants and tallied upon completion. The initial data was analyzed for the material most often detected in the Matching Pairs Test. During each of the participant's evaluations of a pair of materials, if the response was "Yes," each material in that pair received a score of one. At the conclusion of all tests, the material scores were totaled and ranked according to the highest number of correct detections (see table 5.2.1.g). This Simple Rank Test was able to determine which individual material (when matched with other materials) was most often detected as being different. The result was [Non-slip Grit] with a score of 211 (or 16.1%). This material was chosen to be implemented in the Field Experiment Test Part 2.

Table 5.2.1.g: *Rank Test Matrix*

	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Total Score
STAMPED CONCRETE	32	28	29	31	35	21	176
BRICK PAVERS	32	30	27	25	34	33	181
CONCRETE	30	28	30	40	41	32	201
SLATE TILE	27	22	40	29	29	39	186
COBBLESTONE	23	35	34	21	29	41	183
NON-SLIP GRIT	35	39	33	35	39	30	**211**
12 INCH SQUARE CONCRETE PAVERS	22	23	39	25	31	32	172

5.2.2 Section Conclusion

The combination of cane tip, temperature, and humidity significantly predicted correct decisions for the [Slate Tile – Stamped Concrete] distinction and approached significance for the [Brick Pavers – Concrete] and [Concrete – Stamped Concrete] pairs. The combination of shoe type, temperature, and humidity significantly predicted correct decisions for the [Concrete – Slate Tile] pair, and approached significance for the [Cobblestone – Brick Pavers] pair. The range of responses (correct and incorrect) in Tables 5.2.1.b and 5.2.1.e shows that materials are not easily distinguishable. This is contributed in part to the user, detection devices (canes, shoes, etc.), and the similarity of some materials.

As noted in the two regression analyses, agreements between cane and underfoot tests were not always made. However, correlations between vibration, sound, and detection rates are evident in several instances.

5.3 Field Tests (Part 1 and Part 2)

The field tests were divided into two parts. Part 1 consisted of 23 participants walking a predetermined path as described in section 4.3.3. This test allowed the collection of travel time and scored the users' ability to detect obstacles along the route (see Appendix D.1 for tally sheet). Data types for this test included travel times between nine checkpoints along the path with "Yes/No" marks for correctly identifying the obstacles. Behavior maps were also diagrammed by the researcher to identify possible patterns in travel. If patterns in the users' travel routines were detected at a significant level, the researcher would have had to justify the similarities. After review of the diagrams, no patterns were detected (see Appendix D.3 and D.4 for samples).

Part 2 was similar in execution and again collected data for the participants' travel time and scored their ability to detect obstacles along the route, this time including four changes in surface materials (the four instances of new materials were non-slip grit). Data types for this test also included travel times between nine checkpoints along the path, "Yes/No" marks for correctly identifying the obstacle/surface changes, and notations of any point along the path the participant falsely identified a change in materials. Again, behavior maps were diagrammed to identify patterns in travel, with no patterns being detected.

5.3.1 Data and Analysis

A series of paired samples *t* tests were run to determine whether participants improved or worsened from Test 1 to Test 2 on errors (misses) and their overall times. Results indicated that participants made more errors ($M = 1.65$, $SD = 1.15$, $t(23) = 2.07$, $p = <.05$) on Test 1 than they did on Test 2 ($M = 1.08$, $SD = 1.12$). Results also indicated that participants traveled at a faster time ($M = 330.96$, $SD = 70.30$) on Test 1 than they did on Test 2 ($M = 348.35$, $SD = 97.90$). Due to the nature of Test 1 (field test prior to changes in materials) data was only gathered for false IDs during Test 2 (see table 5.3.1.a).

Table 5.3.1.a
Summary of Paired Samples t Tests for Errors, Overall Time and False Identifications

Dependent Variable/Test	*M*	*SD*	*t*	*p*
Errors				
Test 1	1.65	1.15	2.07	.05*
Test 2	1.08	1.12		
Overall Time (in seconds)				
Test 1	330.96	70.30	-1.11	.28
Test 2	348.35	97.90		
False Identifications				
Test 1	NA	NA	NA	NA
Test 2	1.26	1.01		

* denotes significant *p* value

A comparison was made to determine whether participants improved or worsened from Test 1 to Test 2 on their times between each of the nine checkpoints. Results indicated that participants improved their travel times between 6 of the 9 checkpoints. For checkpoints 3, 4, and 5, the travel times were drastically increased. Two of these checkpoints contained changes in materials to be detected in Test 2. It should also be noted that in Table 5.3.1.c, these two checkpoints (4 and 5) resulted in the greatest number of false IDs (9 and 12, respectively).

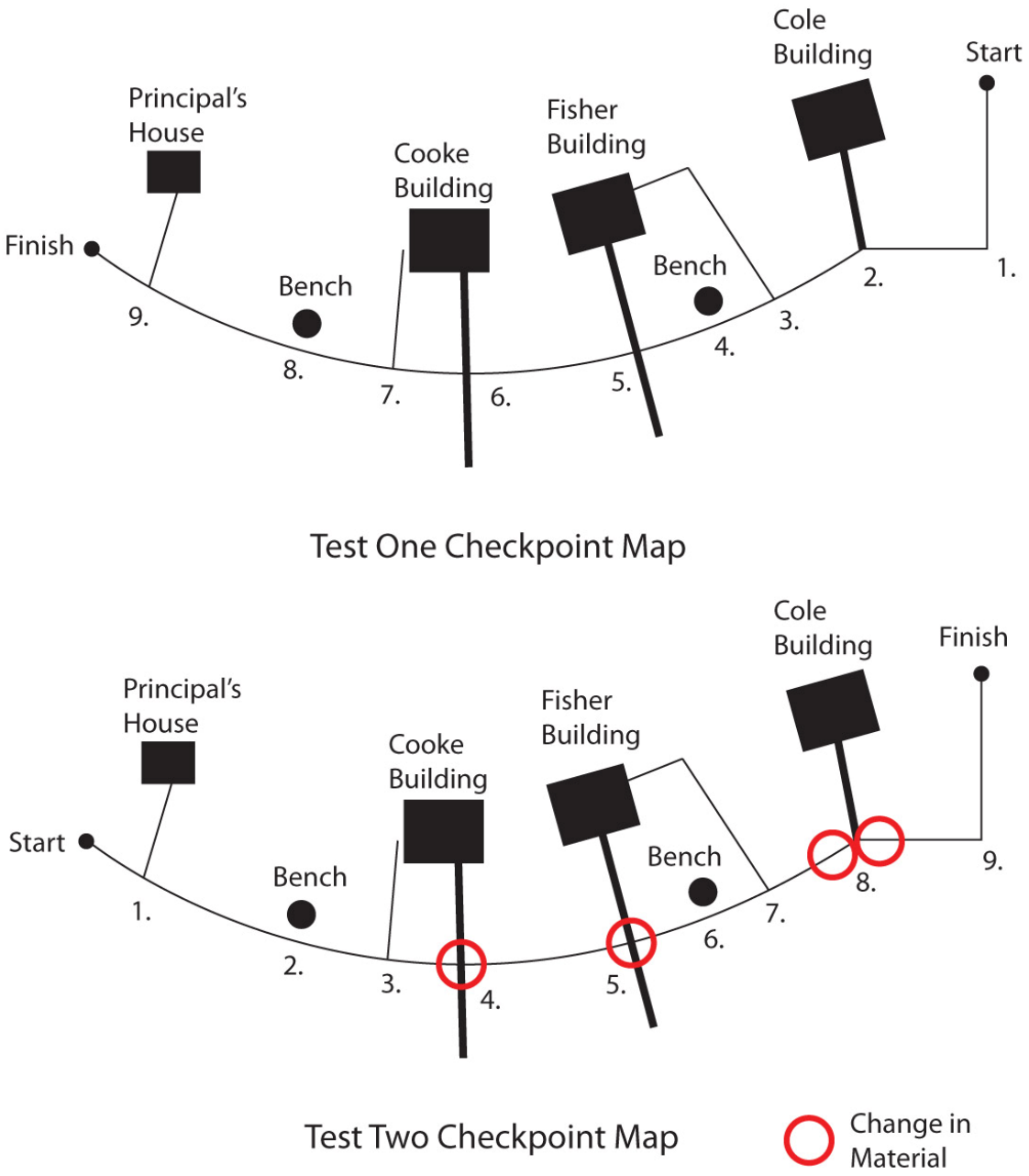


Figure 5.3.1.a: Checkpoint Maps

Within the same series of paired samples *t* tests analyses were run to determine whether participants improved or worsened from Test 1 to Test 2 on their cumulative times to each checkpoint. Results indicated that, at several checkpoints, participants took significantly longer on Test 2 than on Test 1. For instance, participants took more time to reach

Checkpoint 3 on Test 2 (*M* = 96.91, *SD* = 32.44) than they did on Test 1 (*M* = 81.04, *SD* = 30.09), *t* (23) = -2.02, *p* < .055*.

Likewise, participants took more time to reach Checkpoints 4, 5, 6, 7, and 8 on Test 2 than they did on Test 1. For Checkpoint 4 on Test 2, the times were (*M* = 142.00, *SD* = 46.34), whereas Test 1 was (*M* = 102.13, *SD* = 37.34), *t* (23) = -4.17, *p* < .001**. For Checkpoint 5 on Test 2, the times were (*M* = 199.47, *SD* = 65.74), whereas Test 1 was (*M* = 145.65, *SD* = 49.13), *t* (23) = -3.97, *p* = .001**. For Checkpoint 6 on Test 2, the times were (*M* = 247.56, *SD* = 76.40), whereas Test 1 was (*M* = 198.70, *SD* = 47.56), *t* (23) = -3.45, *p* = .002**. For Checkpoint 7 on Test 2, the times were (*M* = 274.65, *SD* = 74.92), whereas Test 1 was (*M* = 230.30, *SD* = 55.90), *t* (23) = -3.30, *p* = .003**; and for Checkpoint 8 on Test 2, the times were (*M* = 314.34, *SD* = 97.03), whereas Test 1 was (*M* = 277.70, *SD* = 60.45), *t* (23) = -2.26, *p* = .034**. Although various times within the field tests produced significant results, Table 5.3.1.a shows that the overall times were not significantly different. Although points of confusion or hesitation along the travel path were not documented, one could infer that increases in travel time between checkpoints may be a result.

Other results indicated that, for Checkpoints 1 and 2, participants improved their travel time during Test 2 as compared to Test 1. For Checkpoint 1 on Test 2, the times were (*M* = 21.96, *SD* = 8.40), whereas Test 1 was (*M* = 28.87, *SD* = 18.22), *t* (23) = 1.76, *p* = .09; and for Checkpoint 2 on Test 2, the times were (*M* = 49.13, *SD* = 14.62), whereas Test 1 was (*M* = 58.30, *SD* = 23.89), *t* (23) = 1.79, *p* = .09 (see table 5.3.1.b).

Table 5.3.1.b: *Summary of Paired Samples t Tests for Checkpoints (1-10)*

Dependent Variable/Test	*M (secs)*	*SD*	*t*	*p*
Checkpoint (1)				
Test 1	28.87	18.22	1.76	.09
Test 2	21.96	8.40		
Checkpoint (2)				
Test 1	58.30	23.89	1.79	.09
Test 2	49.13	14.62		
Checkpoint (3)				
Test 1	81.04	30.09	-2.02	.055*
Test 2	96.91	32.44		
Checkpoint (4)				
Test 1	102.13	37.34	-4.16	<.001**
Test 2 (*Change in Material*)	142.00	46.34		
Checkpoint (5)				
Test 1	145.65	49.13	-3.97	.001**
Test 2 (*Change in Material*)	199.47	65.74		
Checkpoint (6)				
Test 1	198.70	47.56	-3.45	.002**
Test 2	247.56	76.40		
Checkpoint (7)				
Test 1	230.30	55.90	-3.30	.003**
Test 2	274.65	74.92		
Checkpoint (8)				
Test 1	277.70	60.45	-2.26	.034**
Test 2 (*Two Changes in Material*)	314.34	97.03		
Checkpoint (9)				
Test 1	306.13	62.57	-1.71	1.01
Test 2	333.39	96.89		
Checkpoint (10– finish line)				
Test 1	330.96	70.30	-1.11	.28
Test 2	348.35	97.90		

* denotes trend toward significant *p* value
** denotes significant *p* value

Table 5.3.1.c: *Summary of Responses for Checkpoints (1-10)*

Dependent Variable/Test	*Errors*	*False ID*
Checkpoint (1)		
Test 1	2	NA
Test 2	5	0
Checkpoint (2)		
Test 1	3	NA
Test 2	1	0
Checkpoint (3)		
Test 1	6	NA
Test 2	1	0
Checkpoint (4)		
Test 1	4	NA
Test 2 (*Change in Material*)	6	9
Checkpoint (5)		
Test 1	4	NA
Test 2 (*Change in Material*)	5	12
Checkpoint (6)		
Test 1	4	NA
Test 2	2	3
Checkpoint (7)		
Test 1	8	NA
Test 2	2	0
Checkpoint (8)		
Test 1	4	NA
Test 2 (*Two Changes in Material*)	2	0
Checkpoint (9)		
Test 1	4	NA
Test 2	0	2
Checkpoint (10– finish line)		
Test 1	0	NA
Test 2	0	2

Table 5.3.1.d: *Summary of Time Between Checkpoints (1-10)*

Dependent Variable/Test	*M (secs) from point to point*	*Difference*
Checkpoint (1)		
Test 1	28.87	
Test 2	21.96	-6.91
Checkpoint (2)		
Test 1	29.43	
Test 2	27.17	-2.26
Checkpoint (3)		
Test 1	22.74	
Test 2	47.78	+25.04
Checkpoint (4)		
Test 1	21.09	
Test 2 (*Change in Material*)	45.09	+24.00
Checkpoint (5)		
Test 1	43.52	
Test 2 (*Change in Material*)	57.47	+13.95
Checkpoint (6)		
Test 1	53.05	
Test 2	48.09	-4.96
Checkpoint (7)		
Test 1	31.60	
Test 2	27.09	-4.51
Checkpoint (8)		
Test 1	47.40	
Test 2 (*Two Changes in Material*)	39.69	-7.71
Checkpoint (9)		
Test 1	28.43	
Test 2	19.05	-9.38
Checkpoint (10 – finish line)		
Test 1	24.83	
Test 2	14.96	-9.87

Chapter Six
Findings

This chapter states the overall conclusions and findings based on the methods and analyses described previously. It also is a basis of recommendations for the future research described in chapter 7.

6.1 Summary Overview

The aim of way-finding information systems is to assist people in travel by easing the burdens of navigating in unfamiliar environments. With this as a goal, the person(s) doing the travel will fall into one of two categories: a one-time user, or a repeat user who, over time, learns the information system. In both cases, the information provided must be obvious, understandable, and unchanging.

Way-finding methods by visually impaired and blind persons are no different than those who are sighted. Both groups must be able to identify their initial location, have knowledge of their destination, be able to interpret environmental information, and make decisions during travel. However, visually impaired and blind travelers often do so with very little information provided by their surroundings. This was the driving force of the dissertation, the need to provide adequate information to all who travel no matter their familiarity with a space and means of perception. This research approached way-finding from a different perspective than those in the past. Instead of signage, maps, diagrams, audible signals, etc., the outcome is a successful use of sidewalk textures as informational cues.

The topic of changes in materials as a way-finding aid has not been well researched in the past. Similar studies of tactile materials have been done but only from the perspective of a warning system not a way-finding information system. Also, much of today's designs dealing with accessibility revolve around wheelchair users. Therefore, the visually impaired and blind population will certainly benefit from the results in this study.

This dissertation evaluated seven sidewalk materials for their physical properties which were then tested by 23 participants to determine if they were distinguishable from one another.

Also, one material was implemented within a travel path and tested by the participants to determine if the change was detectable while en route. The materials for these tests were described in chapter 4, and the results were provided in chapter 5. In this chapter, the major findings are summarized by first addressing the questions raised in the General Premise Section 1.2. Conclusions to the research questions are also provided, and relationships to keywords throughout the study are made.

6.2 Relationship Between General Premise and Study

In chapter 1, section 1.2, the researcher asked three questions pertinent to the overall premise of this study. These questions were: What types of way-finding difficulties are most common; which aspects of mobility are the most important for travel; and how are unfamiliar spaces perceived?

Before looking at the type of way-finding difficulties that are most common, we must first look at the two variables: user and environment. Related to this study, it must be stated again that “the primary difference between sighted and blind travel is the distance and speed in which environmental information is processed” (Geruschat & Smith, 1997). With this, comes the concern about the quality of the information, how the information is made available, what the information means, and for whom the information is intended.

When navigating a space, the user is tasked with detecting the usable cues and determining or assigning meaning. If the meaning is assigned by the individual user, then that person becomes disconnected from the greater way-finding information system. And, if the meaning is to be understood and used similarly by everyone, then that piece of information must be clearly indentified and explicit. When providing elements in space that will serve as cues, redundancy and consistency become very important and increase the likelihood that all users will be able to make informed traveling decisions based on the same environmental input. Arthur and Passini (1992) make a valid point in that what may be a landmark for one person may not for another. Peck and Bentzen (1987) also found that people with visual impairments stressed the importance of consistency when acquiring accessible information from the environment.

As determined in this study the detection of change between materials along a path depended upon the degree of contrast between one material and another. For example, Bentzen et al. (1994a) cite that raised detectable surfaces (truncated domes) had been shown to be significantly less detectable when located adjacent to coarse aggregate concrete, but much more effective when placed next to smooth paving materials such as brushed concrete. In Bentzen's example, the meaning of detectible surface was understood by most as a warning or hazard. This level of detection of change in surface materials was what this dissertation research focused on.

Prior to evaluating the participant's performance, Question 1 asked whether environmental factors of temperature and humidity affected the detection of material change. Therefore, at the time each task was performed, the researcher documented temperature and relative humidity (see Chart 6.2. a). Once complete, the environmental data was analyzed alongside the field test performance results. With no evidence of change in the characteristics of the materials' surfaces, it was concluded that there was no significant difference in performance based on the variables of temperature, humidity, or the combination of the two.

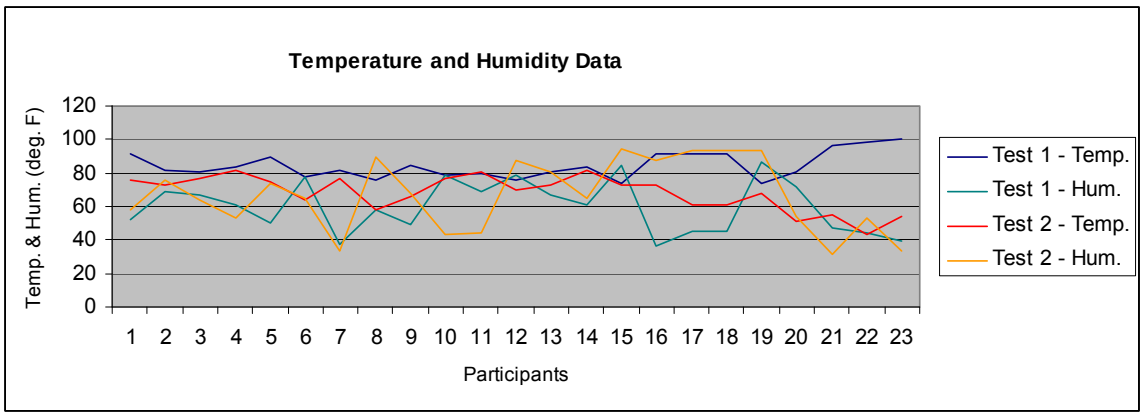


Chart 6.2.a: Temperature and Humidity Data

Question 2 asked which aspects of mobility are the most important for travel. Again this can be addressed from two perspectives: the planning of travel and the act of movement. In planning for travel, a destination must be evident, and its relation to the starting point should be known. Before navigation begins, progression along the route should be able to be tracked, and points which require decision making must be sought. "A place has to be

recognized before a decision can be transformed into behavior. Distinctiveness giving places their identity is, thus, a major requirement for way-finding" (Arthur & Passini, 1992).

Another very important aspect of mobility is being able to continuously build upon the cognitive map. Routines for frequently traveled paths are very useful, and the ability to perceive, store, and retrieve environmental information is vital to improving travel performance. "When enough routes and landmarks are encoded and interrelated, overall configurations of space (survey knowledge) are formed" (Siegel & White, 1975). Survey knowledge, procedural knowledge, and landmark knowledge are equally important to being able to build a complete and accurate cognitive map of any space, large or small. Especially since, during travel, objects can be both obstacles and landmarks simultaneously. "For the purpose of being mobile, auditory, tactile, and other sensory information provides all the critical information required for independent travel" (Geruschat & Smith, 1997). Again, returning to points made in addressing question 1 above, the perception of recognizable objects that offer locational information along a travel path is crucial for the traveler to stay oriented.

Question 3 moves directly to the spatial attributes of way-finding in asking: How are unfamiliar spaces perceived? Earlier in this dissertation, the researcher described two keys to understanding space. One is Lynch's urban design elements (districts, nodes, landmarks, paths, and edges), and the other is the three knowledge types (landmark, procedural and survey). How these two groups of information were used in this study will be explained, as well as the cross connections between the two as a means of moving forward from here.

Lynch's urban design elements, although not thoroughly used in this study, provided a very important contribution. Understanding the environment and being able to dissect it into Lynch's five elements provides a greater level of detail of understanding. Also, detecting and learning smaller chunks of environmental information have been proven to be more successful than full emersion. In using Lynch's elements, the travel route for the field experiments in this study can be diagrammed as:

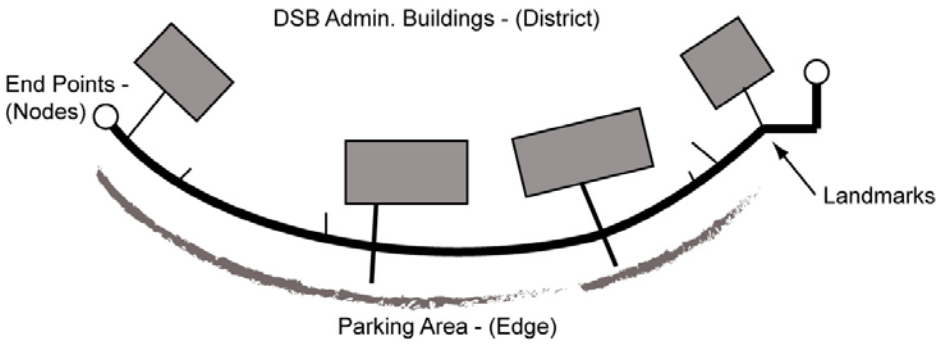


Figure 6.2.a: Use of Lynch's Urban Design Elements Diagram

The district can be identified as the Division of Services of Blind portion of the GMS campus. This area of the campus contains four main administration buildings and various other structures primarily used by the division. The nodes are the beginning and end points of the travel paths. For this test, the entire path along the building fronts was used. Landmarks varied from benches, branch paths, bisecting paths, and even trees or sound. Along the path were two edges. One edge was provided by the building fronts, and the other was the edge of the parking area. Several participants were able to identify aspects of the elements such as the edge and the landmarks without being prompted.

Part of the exercises performed by the participants required them to identify intersections of paths. Appropriate environmental/spatial information had to be available at these junctures in order for the travelers to be able to navigate accurately and in a timely way. Often, during Field Test 1, participants paused at the intersections before continuing on to the destination. These pauses and hesitations were identified in the researcher's notes but were not highlighted in the data results. Instead, one could infer that increases in travel time between points (from Test 1 to Test 2), as well as errors/false IDs could be a point of confusion. As noted previously, the decision making points along a path had to be clearly demarcated and understandable. During Field Test 2, the changes in surface materials helped identify the intersections with less hesitation, therefore resulting in improved travel time and accuracy.

The second key element in understanding new spaces is the knowledge types described in section 2.1.2. The ability to connect landmark knowledge and procedural knowledge

enables a person to use his or her cognitive map in the sense of survey knowledge. Many participants in this study were able to build a comprehensive cognitive map as they progressed along the route during the field experiments. Whether it is the bench that represents a landmark or an intersecting path that represents the entrance of a building, the subjects were able to make multiple relationships at a time. Many used a system known as the hierarchical network. Arthur and Passini (1992) feel that this system requires users to be aware of and understand how spaces and paths are linked according to a repetitive order. In Field Test 2, the repetition of architectural features (changes in footpath materials), and their rhythmic arrangements and other proportional relationships (locations at key points along a path) can be considered distinctive and thus provide the user with the necessary landmark cues.

The use of changes in materials in this dissertation was reinforced by Brambring (1982), who states, “Changes in the consistency or composition of the ground surface, or reflections of sound, can be especially precise means of orientation.” This supports both the detection of change and the acoustic attenuation hypotheses.

6.3 Research Questions and Hypotheses Addressed

In this section, results of statistical tests that measured the degree of relationships between research variables are described. The aim of conducting such tests was to answer the research questions asked in chapter 3.

Research question 1 asks: **Do the environmental factors of temperature and humidity affect the detection of material change?** The logistic regressions analyses did include humidity and temperature as variables; however there were no indications that these variables affected the response rate. As a result, research question 1 was **untested**.

Research question 2 asks: **Is there a correlation between the physical properties of two surface materials that affects the detection of material change?** As identified in the Simple Rank Test (table 5.2.1.g), non-slip grit and concrete were the two most often distinguished materials in the Matching Pairs Test. According to the vibration test and sound attenuation levels, these material are very similar. Also, the installation methods and final

appearance are consistent with each other. However, in comparison to the other five materials, these two are very distinct. These two materials are installed as single-pour products. There are no joints, and the final product is not made up of smaller individual pieces. Although stamped concrete is also a single-pour product, the applied pattern provides ridges and gaps that are unlike broom-finished concrete. Hypothesis 2a states that the adjacency of the two surface materials with the greatest difference in vibration levels (brick pavers and cobblestone) will be best detected. However, when evaluating the most correctly detected pairs of materials in Tables 5.2.1.b and 5.2.1.e, these materials did not appear, so hypothesis 2a is **not supported**. Similarly, hypothesis 2b states that the adjacency of the two surface materials with the greatest difference in acoustic attenuation will be best detected. When measuring acoustic attenuation with the 2-point touch, the two materials with the greatest difference in sound levels were brick pavers (67.4dB) and non-slip grit (71.0dB), a difference of 3.6dB. This combination of materials was not among the most correctly detected pairs by either (cane tip or underfoot) method. Therefore, hypothesis 2b can be considered **not supported**.

Research question 3 asks: **Is there a correlation between the physical properties of one surface material that, when compared to concrete, affects the detection of material change?** As identified in the Simple Rank Test (table 5.2.1.g) non-slip grit was the material most often distinguished in the Matching Pairs Test. According to the vibration test and sound attenuation levels, non-slip grit and concrete properties are somewhat mixed. When considering acoustic attenuation, non-slip grit has the second highest difference in sound level when compared to concrete. Also, vibration levels are not significantly different between the two materials. Hypothesis 3a states that the material with the greatest difference in vibration level (measured at the cane grip), when compared to concrete (506), will be best detected. In fact, cobblestone (1433) was in the top three for most correctly detected by cane (87.0%) and underfoot (91.3%). Likewise, Hypothesis 3b stated that the material with the greatest difference in acoustic attenuation, when compared to concrete, will be best detected. The two materials that ranked highest in the acoustic attenuation tests were brick pavers (-2.5dB with the 2-point touch method) and cobblestone (+3.4dB with the sweep method). Cobblestone and concrete were among the most correctly detected pairs of materials in the Matching Pairs Test. Therefore, hypotheses 3a and 3b are **supported**.

Research question 4 asks: **Is there a correlation between the acoustic attenuation and vibration of two materials that affects the detection of change in material?** To best answer this question the following hypothesis needs to be considered. Hypothesis 4a states: The surface material with the greatest level of vibration when measured at the cane grip will also have the lowest level of acoustic attenuation. Therefore, as vibration increases, sound level also increases. This hypothesis is **partially supported**. When evaluating vibration level at the cane grip, cobblestone (1433) has the highest level of vibration difference. When calculating acoustic attenuation using the sweep method, again cobblestone had the highest level (+3.4dB) as compared to concrete. However, when using the 2-point touch technique, brick pavers had the highest level of acoustic attenuation (-2.5dB). According to the Simple Rank Test, cobblestone ranked fourth and brick pavers fifth of the seven materials in overall detection. Therefore, when considering the two variables of vibration and acoustic attenuation, this hypothesis proves to be **supported**.

6.4 Relationship to Key Words

When discussing the findings, information gathered via the questionnaires and informally during the field tests needs to be considered. During the Matching Pairs Test, many participants commented frequently about the various sounds given off by different materials. “Hollow” and “solid” were terms frequently used to describe the 12-inch concrete pavers and slate tiles. These particular terms were mentioned by participants nine and seven times respectively. However, these terms did not directly relate to the detection responses by the participants, and this connection between descriptive terms and detection rates was not evident in the results. For instance, while testing two adjacent materials, the participants would offer two different terms but would answer the question as if there were no difference. Many of the respondents also made comments about the various amounts of traction or texture they felt underfoot. In hearing words such as “rough”, “smooth,” and “bumpy,” the researcher noted many different terms used for similar materials. During the underfoot portion of the test, many participants commented on the texture of several materials.

Chapter 7
Discussions, Implications, and Future Research

This chapter discusses the results in the context of research findings, as well as the practical implications of this dissertation. The chapter is organized into four sections. The first section discusses quality considerations, including generalizability and reliability. Section two identifies the limitations of the research and discusses possible remedies as well as strengths of the study. Section three describes the implications of the research, and the final section looks to future research, and provides directions and insight for conducting similar experiments.

7.1.1 Generalizability

Generalizability refers to the extent to which research findings and conclusions from a study, conducted on a sample population, can be applied to the population at large. The generalizability of the experiments was outlined in the methodology section of chapter 4. The methods of the experimental design were simple, explicit and fully replicable. Participants were identified as appropriate for participation, tasks were fully explained, and the goals and purpose were clearly defined.

The selection of the sample population came from the general public with explicit qualifiers being: (a) adult (18 years or older), (b) independent travelers, and (c) cane users. Implicit qualifications also included: (a) ability to understand and follow verbal instructions, (b) ability to fully communicate with the researcher, and (c) willingness to participate.

The influences of context (GMS campus), audience (visitors to or attendees of the school), and the form of the application (field tests and questionnaires) were not compromised or mediated. All of the surface materials are typical, readily available, everyday sidewalk materials that were installed by professionals using standard practices. The data recording instruments, when used, provided clear, concise, and accurate results. The output of these instruments was clearly defined and other devices with comparable output would have been acceptable. No special circumstance arose.

7.1.2 Reliability

Reliability is the extent to which a procedure will produce the same results under constant conditions. If a study is to be reliable, one must show that repeated measurements with the same methods, variables, and instruments, under unchanged conditions, will yield the same results (Zeisel, 1984). To ensure the reliability of the design of this research, great care was taken into consideration at the planning, implementation, and analysis stages. For this reason, a clear description of the data sources and methods used to gather those sources was provided in chapters 4 and 5.

In all phases of research design, the same strategies were kept constant for reliability purposes. These included the participant requirements, the use of one sole data collector, the required tasks, the research instruments for the digital data, and the questionnaire design. This strategy assured that the data collection procedures were consistent throughout the study.

For reliability purposes, instruments were tested before the actual fieldwork commenced. A pilot test was conducted for the Field Experiments, including the verbal descriptions and instructions. (The pilot test was described in Section 4.1.1). The questionnaire and the Braille translations were tested with two visually impaired persons. This process prompted some changes in the questionnaire: The order of the questions was rearranged, and the term “low-vision” was changed to “visually impaired and blind” to be more consistent. Much consideration was taken when choosing words and phrases used when describing the tests, giving instruction to the participants, and in answering their questions during the tests so as not to contradict any other information. Some participants were very inquisitive, and the researcher was careful not to offer too much or too little information so as not to influence the outcomes.

7.2.1 Limitations of the Study

- This study focused on the relationships between a limited number of materials and only the ***detection of change*** in surface materials, not ***detection*** and ***action*** by the users. The results cannot be generalized to all surface textures but can be considered for materials with similar physical characteristics.

- The choice of settings was another limitation of the study. The researcher chose a small educational campus with controlled access and gathered data during times with limited possible distractions. As noted previously, results could vary dramatically in another setting at another point in time with the same sample.

- As often cited in research containing participants with disabilities, the affects and extent of the impairments are hard to evaluate. Without a thorough personal medical review of all subjects, a researcher is often unable to fully understand the subject's limitations. Also, with older adults, multiple disabilities become an issue. One particular concern for this study was the variations in sensitivity in the participants' feet and/or hands and how this may affect the detection rate through the cane and underfoot. No instances of reduced sensitivity were noted, nor was this information sought.

- Even though the researcher designed, developed, and had installed a unique and well planned Matching Pairs Test site, questions arose concerning the repetitive interval (48" +/-) of the changes in surface material (see figure 4.1.2.a). Although each pair of materials was tested individually and not as a whole, the researcher recognizes this variable in the study and will revisit the layout and placement of material when the next opportunity to conduct this research arises.

- As with most uncontrolled research settings, the natural environments vary from day to day and at different times throughout the day. That was the case with the sound attenuation test. Data was gathered on one day in a brief window of time so as not to allow much variation in the natural environment. However, the researcher feels the data is valid for the current research. Similar tests for noisy or busy settings may have to be reevaluated.

Limitations exist in this study with regard to its application for evaluating materials for purposes other than simple detection. As noted in the Future Research section to follow, the detection with an expected action could add valuable information to this study. However, the researcher felt it was important first to determine if detection is even possible.

7.2.2 Strengths of the Study

This study was designed in a simple, straightforward manner with everyday sidewalk materials. The selection of participants was clear, and the required tasks were typical of independent travelers who use a long cane. The duration of tests was brief, and participants were asked to commit less than two hours of their time over two days of testing. Their time was compensated, and the schedule was flexible so as not to interfere with their daily activities. This study was well received by the participants and resulted in 100% participation for both days of testing. This study was limited to the GMS campus, an adult population, and seven surface materials. These decisions proved to be broad enough to include a great portion of the local, visually impaired/blind population, while at the same time providing clean data with exacting results.

7.3 Implications

This section discusses the practical implications for future design of similar built environments. These suggestions include strategies for the improvement of existing sidewalks and any new construction.

7.3.1 Practical Implications

The findings of this study reveal some conclusions that can be developed as recommendations for the design of way-finding systems in built environments. These recommendations are defined based on the study results that have been discussed in previous chapters. To improve the design of current and future environments, these findings suggest some guidelines for more accessible paths of travel.

Passini (1984) identifies a major information-structuring factor that contributes to the legibility and imageability of architectural settings as ***spatial organization***. Spatial organization is “the principle by which an order among various spaces and architectural elements is established.” According to Weisman (1981), ***architectural differentiation*** contributes to more effective way-finding and orientation. This differentiation can be accomplished by separating areas structurally or via colors, graphics, lighting, and furnishings. In this context, implementing changes in surface materials to act as way-finding

cues would serve as the architectural difference to manage and direct the movement of users along a path.



Identify Building Entrances



Identify Branch Paths

Figure 7.3.1.a: Design Suggestions

Spatial correspondence or coherence is the extent to which there is image continuity between and within spaces (Weisman, 1981). The process of designing similar types of settings in different locations deserves special attention. Space organization, layout, and way-finding aids such as surface materials should not be considered as a specific design solution but more of a system of solutions. If one design schema (in regards to the use of changes in materials) is developed, tested, accepted, and implemented as a standard, then many users would be able to understand and react to this information system wherever they travel.



Primary and Seconday Paths



Direction Change and Stair Warning

Figure 7.3.1.b: Successful Material Change Examples

Like so many other design solutions, acceptance and use by the masses determines success.

7.4 Recommendations for Future Research

This study included a number of variables in order to assess their relationship to the detection of changes in surface materials. Future research should perhaps include physical characteristics that were not part of this study, such as coefficient of friction, hardness of materials, and performance in damp conditions. Inclusion of these characteristics would enable a better understanding of physical characteristics that may have roles in person-environment interactions. Also, any future research could include materials from other regions of the world and materials of color for users with some usable vision.

Investigating users' detection of materials in various settings such as public spaces, populated urban areas, and large open outdoor spaces can also make for very valuable future research. Detection rates for these environments could then be compared with the detection rate in this study of a semi-controlled setting.

The intention of this body of research is to develop an in-depth way-finding information system that can benefit all travelers. In further studies, other age groups, newly blind users, users with varying degrees of travel experience, wheelchair users and persons with some usable vision could be studied to compare their responses. Also, travel paths may include indoor and outdoor (urban and suburban) environments, paths of varying lengths, and tests during different weather conditions (i.e., ice, snow, rain) that would provide a vast array of data and results.

Future research could also include more qualitative methods of assessing users' opinions regarding the design characteristics and selection of surface materials. A researcher may also design a more active study, one which requires the participants to receive travel directions and execute the route using changes in surface materials as landmarks. These activities may reveal the users ability to *detect* and *react* to the changes in materials. The type of feedback for design characteristics of a setting cannot be gathered by simple interviews, questionnaires, or material comparisons alone.

With regard to more general issues in the design of travel paths, including user responses to various sidewalk materials, many other types of inquiry could be helpful. Formal, semi-structured, and spontaneous interviews with daily users can provide valuable additional information. These people interact with many types of surface materials on a daily basis and, without a doubt, use changes in materials as way-finding aids. This type of subjective or qualitative input might prove very useful.

Chapter Eight
Final Statement

This study compared and evaluated seven sidewalk surface materials and measured detection rates by visually impaired users in field tests. The process of field testing provided a sense of real-life application to this research study that is often obscured in a sterile laboratory setting. This study focused on several very specific characteristics ranging from adults to the closed-campus setting of GMS. Each of the restrictions imposed by the researcher narrowed the focus to a level that provided very clear and complete results. Due to the type of data needed for this type of research, any future studies will have to be as equally focused.

Restrictions in the generalizability of findings may apply to its implications. However, the study's methodology and results are valid and should be used to inform future designs of sidewalks with the visually impaired population in mind. Credible conclusions can be drawn from the empirical evidence found within the study. As stated previously, through the means of an applied quantitative analysis strategy, the findings provided evidence to support changes in footpath materials being used to improve way-finding.

Although the materials chosen for this research were described to each participant, participants gave common suggestions as to how the different materials could be used as way-finding cues. It was noted that three people suggested the use of stamped concrete and non-slip grit texture to identify important locations along a path. This suggestion brings up two new questions which can be asked in future research: What points along a path need to be identified, and how many points are reasonable before the information becomes overwhelming?

The success of this research is evident in the positive response and performance of the participants at each phase of testing. With such a reduction in the number of way-finding errors in Field Test 2, the researcher feels that this method of providing cues along a path can dramatically enhance the independent travelers way-finding success in both familiar and unfamiliar environments.

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Appendices

Appendix A.1
North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study: **UNDERSTANDING CHANGE IN PLACE:** Spatial knowledge acquired by visually impaired users through change in footpath materials.

Principal Investigator: Andrew P. Payne
Faculty Sponsor: Dr. John O. Tector

PURPOSE OF THIS STUDY

We are asking you to participate in a research study. This research contains two primary purposes. The first purpose is to investigate and compare the physical characteristics of seven typical sidewalk construction materials. The second purpose of the research is to determine the best combination of materials to produce the greatest level of detection of change in materials among the users. In order to help landscape architects, campus planners and university administrators produce the most accessible environment possible this research will provide a design standard for sidewalks which can incorporate information cues in the form of changes in materials along the travel path at key intersections and destinations. You are being asked to participate in this study because you are a visually impaired adult.

PROCEDURES

This research will implement quantitative measurements and comparisons of various sidewalk surface materials as well as a field experiment to evaluate the ability of visually impaired users to identify changes in materials while moving along a path. If you agree to participate in this study, you will be asked to be a part of three activities. Any of these activities may be photographed.

Pre-experiment test procedure (Activity One):

The pre-test will compare mixed pairs of the seven sidewalk construction materials. The pre-test will be conducted in an outdoor controlled environment at the campus of the Governor Morehead School.

Each test will be administered by the researcher and will contain one pair of materials to be compared at a time. The subjects will be led to the test area and allowed a fixed amount of time (30 seconds) to explore the pairs of materials with their own personal long cane. (Each participant will be required to bring his/her own long cane for use during the exercise). At the conclusion of each 30 second review period the participant is to declare a definitive “Yes” or “No” to the question: “Are these sidewalk materials different”? The participant’s response will be recorded by the researcher at each test area. The total time allocated for this testing phase is 1.0 hour per subject.

Field experiment control test procedures (Activities Two and Three):

Field experiment two will consist of individual subjects walking a predetermined path on the campus of the Governor Morehead School. The subject’s journey will be timed and recorded for accuracy in following travel directions. The researcher will trail each subject

and record the subject's statements and overall travel time, as well as assist in any state of disorientation or confusion. The total time allocated for this testing phase will be 30 minutes per subject. This test will be conducted on the same day as Activity One above.

Part three of the experiment will take place on a separate day and will consist of the same group of individual subjects walking a similar path in length, number of turns and changes in grade, as in field experiment two. This path will include changes in surface materials at key intersections and will require the subjects to: a) verbally declare when changes in materials are detected, b) perform a travel task (i.e. turn left, turn right, etc.) and c) continue to the destination. This task will be timed and recorded for accuracy in following travel directions and detecting changes in sidewalk materials. The researcher will trail each subject and record the subject's statements and overall travel time, as well as assist in any state of disorientation or confusion. The total time allocated for this testing phase will be 30 minutes per subject.

RISKS
There should be no risks from participating.

BENEFITS
Your participation in this research will help determine better combinations of sidewalk paving materials that are more easily identifiable and can provide wayfinding cues to visually impaired pedestrians.

CONFIDENTIALITY
The information in the study records will be kept strictly confidential. Data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. For clear communication in the field only your initials and an assigned number will be identified. No other references will be made in written or oral reports that could link you to the study. Any photographs obtained during the field exercises can be blurred to conceal your identification upon your request.

Do you want your identity concealed in photographs?
Yes___ No____

If yes, the researcher is to write a brief description of the participant to ensure the correct identity is concealed. (i.e. gender, shirt color, etc.).

DATA GATHERING and MANAGEMENT
The Principal Investigator will be responsible for the security of all data gathered in each phase of the research. Outside persons who may have limited access to portions of data include (but are not limited to), research assistants, statisticians, research committee members, writer/editor, Governor Morehead School administrator's and faculty, and the Dean of the College of Design.

COMPENSATION

You will be compensated $20.00 (cash) for your participation in this study. (Ten dollars will be paid at the completion of parts one and two, and ten dollars will be paid at the completion of part three).

EMERGENCY MEDICAL TREATMENT

There is no provision for free medical care in the event that you are injured during the course of this study. In the event of an emergency, medical treatment may be available through the 911 emergency response service.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Andrew P. Payne, at Campus Box 7701, NCSU College of Design, Raleigh, NC 27695-7701, appayne@ncsu.edu or (919/467-8845). If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. David Kaber, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/515-3086) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed at your request.

CONSENT

“I have read and understand the above information. I have received a copy of this form in large print format or Braille. I agree to participate in this study with the understanding that I may withdraw at any time.”

Subject's
Signature_____ Date _____

Subject’s
Name (Print)_____

Researcher's
Signature_____ Date _____

Appendix A.2
IRB Approval/Exemption Letter

North Carolina State University is a land-grant university and a constituent institution of The University of North Carolina

Office of Research and Graduate Studies

NC STATE UNIVERSITY

Sponsored Programs and Regulatory Compliance
Campus Box 7514
1 Leazar Hall
Raleigh, NC 27695-7514

919.515.7200
919.515.7721 (fax)

From: Debra A. Paxton, Regulatory Compliance Administrator
North Carolina State University
Institutional Review Board

Date: May 15, 2007

Project Title: Understanding Change in Place: Spatial Knowledge Acquired by Visually Impaired Users Through Change in Footpath Materials

IRB#: 215-07-5

Dear M. Payne;

The research proposal named above has received administrative review and has been approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101.b.2). Provided that the only participation of the subjects is as described in the proposal narrative, this project is exempt from further review.

NOTE:

1. This committee complies with requirements found in Title 45 part 46 of The Code of Federal Regulations.
   For NCSU projects, the Assurance Number is: FWA00003429; the IRB Number is: 01XM.

2. Review de novo of this proposal is necessary if any significant alterations/additions are made.

Please provide your faculty sponsor with a copy of this letter. Thank you.

Sincerely,

Debra Paxton
NCSU IRB

Appendix B
Research Timeline Breakdown

Design and Installation	Discussion with GMS	14 Days
	Schematic Design	7 Days
	Approval by GMS	7 Days
	Preliminary meeting with GMS and Contractor	7 Days
	Material Order and Delivery	25 Days
	Installation	21 Days
	Sound Attenuation and Vibration Tests	30 Days
Pilot Test	Invitation to participate in the Pilot Test	7 Days
	2 Participants/Tests	5 Days
	Invitation to participate in the research	21 Days
	23 Participants/Tests	45 Days
Matching Pairs Test	Meet at Neutral Lcoation	
	Walk to Tet Area	5 Minutes
	Introduction to the Research (Informed Consent)	5 Minutes
	Testing of Matching Pairs (1-12)	10 Minutes
	Break	5 Minutes
	Testing of Matching Pairs (13-23)	10 Minutes
	Testing of Matching Pairs (15-20)	10 Minutes
	Return to Neutral Location	5 Minutes
	Total Test Time	**45 Minutes**
Field Test 1	Meet at Neutral Lcoation	
	Walk to Test Area & Introduction	5 Minutes
	Instructions	5 Minutes
	Route Navigation Exercise	15 Minutes
	Conclusion	5 Minutes
	Total Test Time	**30 Minutes**
Site maipulation		4 weeks
Field Test 2	Meet at Neutral Lcoation	
	Walk to Test Area	5 Minutes
	Instructions	5 Minutes
	Route Navigation Exercise	15 Minutes
	Conclusion	5 Minutes
	Total Test Time	**30 Minutes**
Questionnaire		5 Minutes

Appendix C
Matching Pairs Test Tally Sheet

As detected with the cane, is there a difference between the two materials? (YES or NO) and As detected underfoot, is there a difference between the two materials? (YES or NO)

Matching Pairs	Cane	Under-foot
STAMPED CONCRETE / BRICK PAVERS		
BRICK PAVERS / CONCRETE		
CONCRETE / STAMPED CONCRETE		
STAMPED CONCRETE / BRICK PAVERS		
BRICK PAVERS / SLATE		
SLATE / SQUARE PAVERS		
SQUARE PAVERS / COBBLESTONE		
COBBLESTONE / GRIT		
GRIT / SQUARE PAVERS		
SQUARE PAVERS / BRICK PAVERS		
BRICK PAVERS / CONCRETE		
CONCRETE / SLATE		
SLATE / STAMPED CONCRETE		

Matching Pairs	Cane	Under-foot
STAMPED CONCRETE / SQUARE PAVERS		
SQUARE PAVERS / COBBLESTONE		
COBBLESTONE / BRICK PAVERS		
BRICK PAVERS / GRIT		
GRIT / STAMPED CONCRETE		
STAMPED CONCRETE / COBBLESTONE		
COBBLESTONE / SLATE		
SLATE / GRIT		
GRIT / CONCRETE		
CONCRETE / COBBLESTONE		

Participant:

Date: Temp.

Time: Hum.

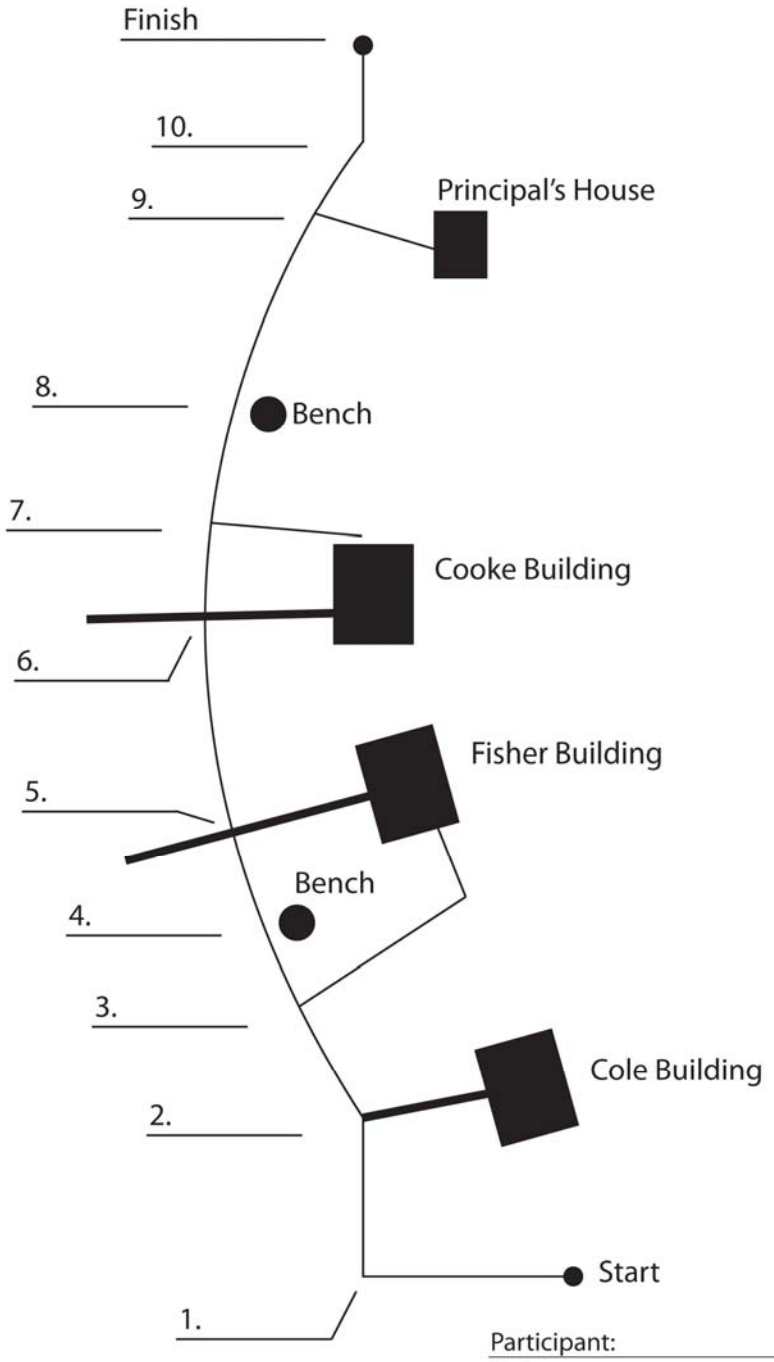
Shoe: D C T **No:**

Cane: N R M

Shoe Codes: D = Dress, C = Casual, T = Tennis

Cane Tip Codes: N = Nylon, R = Roller, M = Metal

Appendix D.1
Field Experiment Test One Tally Sheet

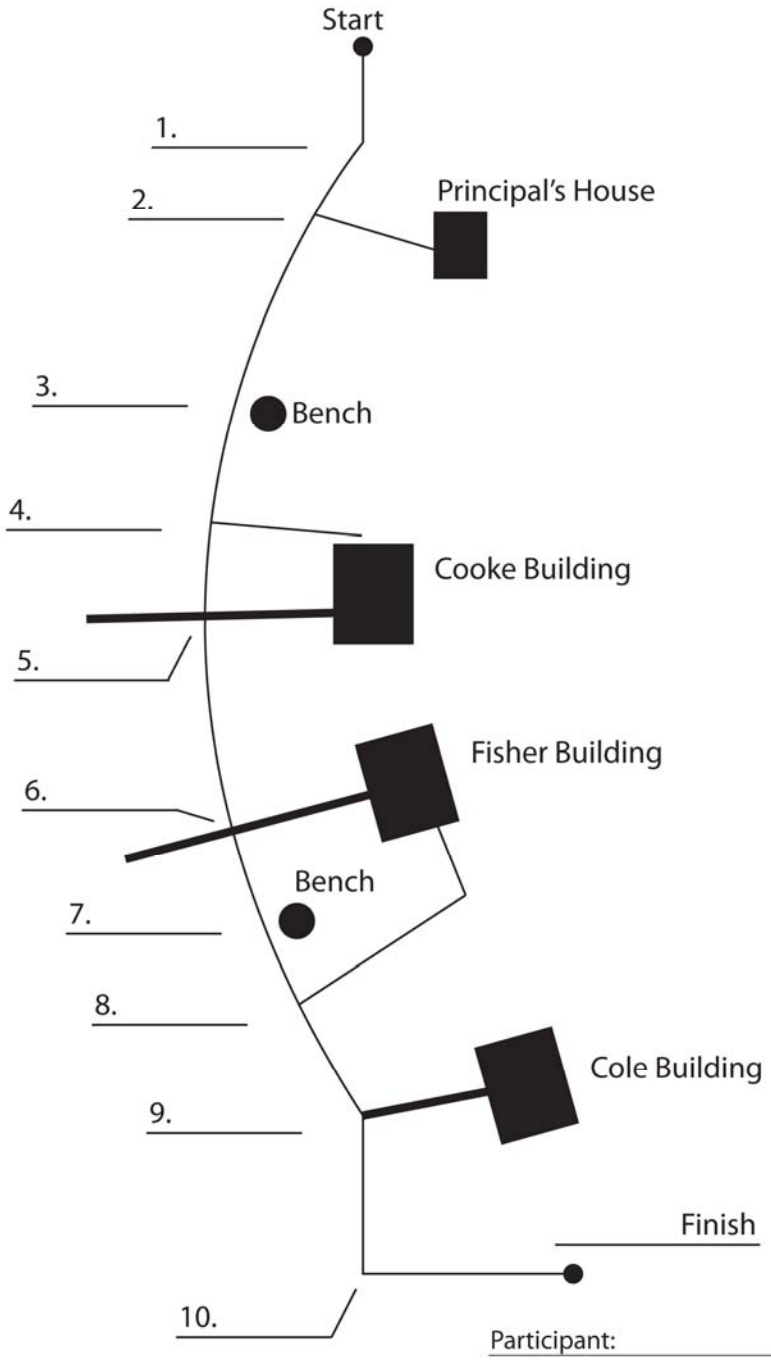


Participant:
Date: Time:

Shoe: D C T **NO:**
Cane: N R M

Test One Tally Sheet

Appendix D.2
Field Experiment Test Two Tally Sheet

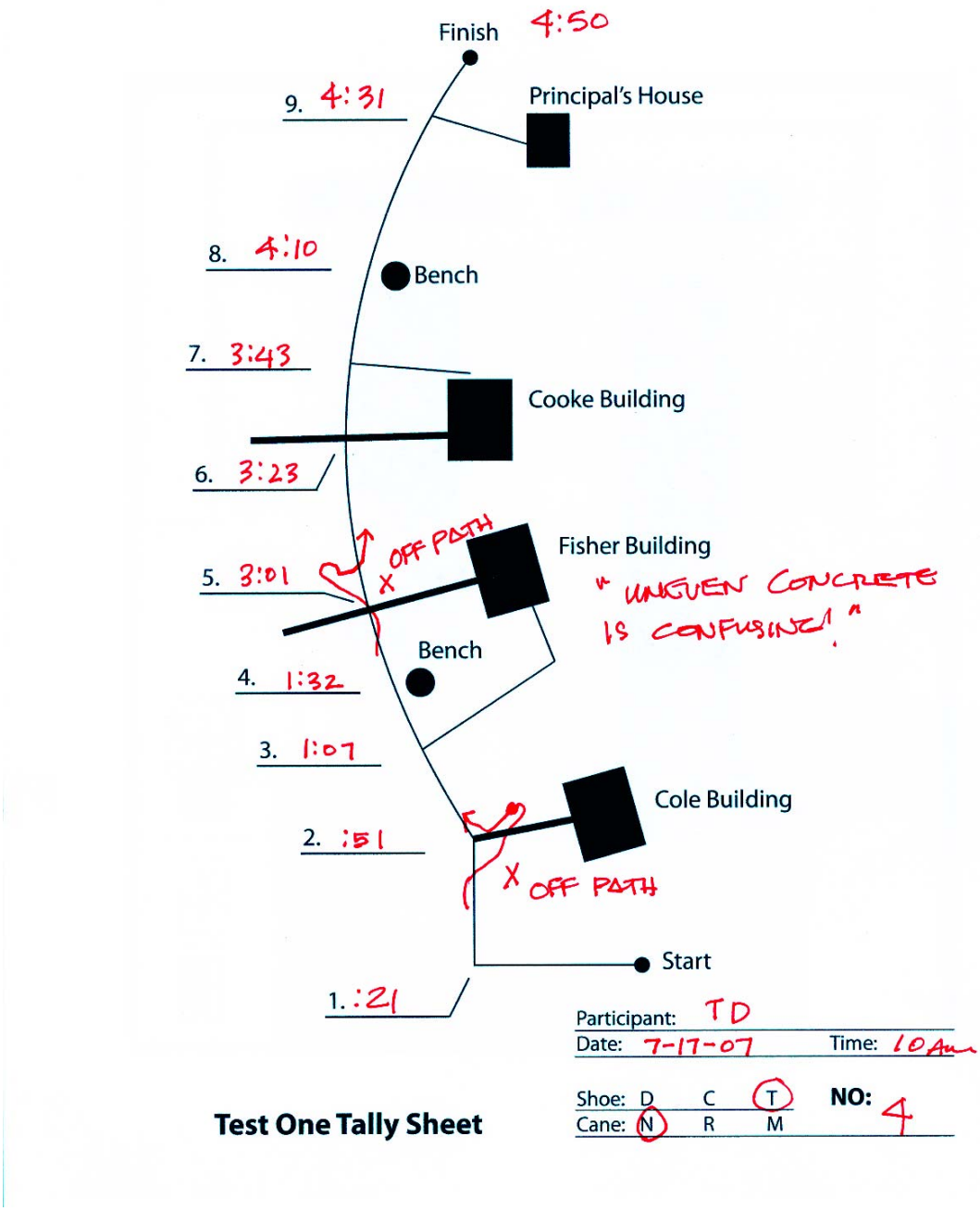


Participant:
Date: Time:

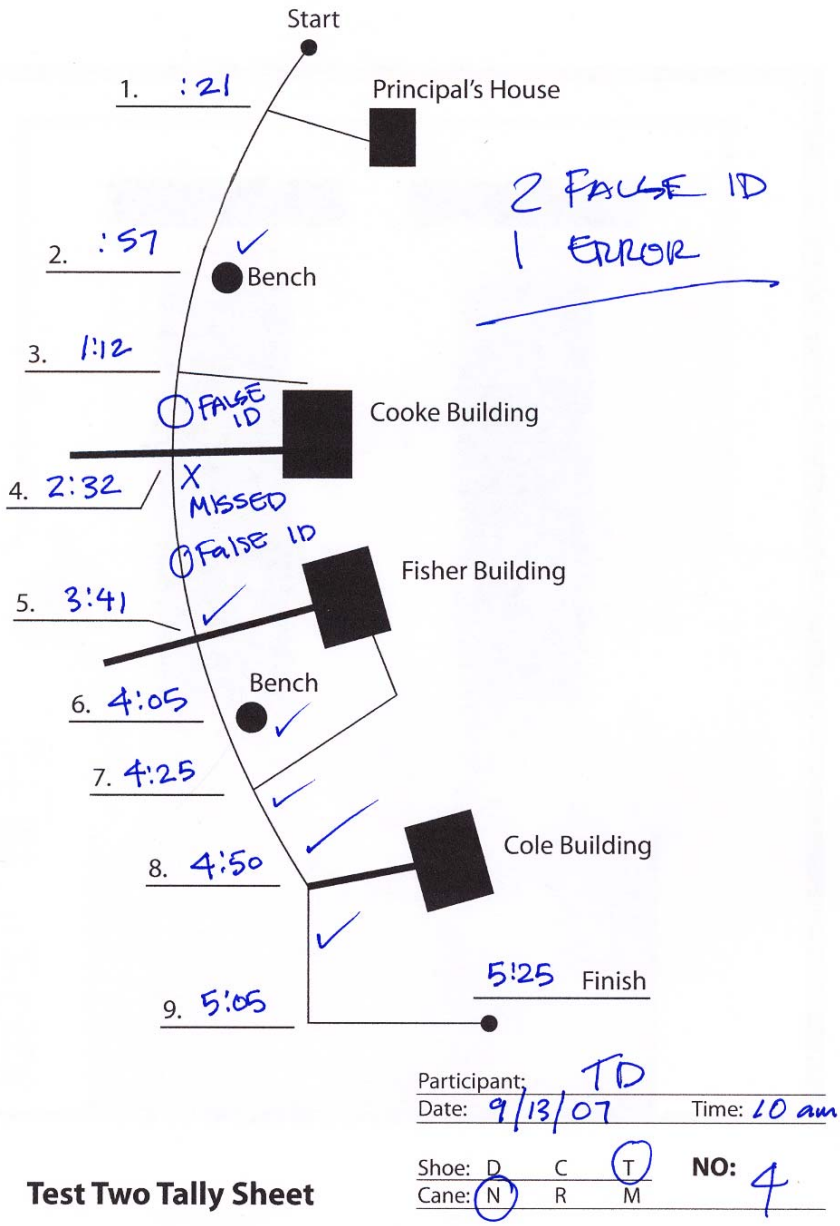
Shoe: D C T **NO:**
Cane: N R M

Test Two Tally Sheet

Appendix D.3
Field Experiment Test One Tally Sheet (Sample)



Appendix D.4
Field Experiment Test Two Tally Sheet (Sample)



Appendix E
Questionnaire

Assigned Number		Date
Q1 Age		

	Yes	No	Now	Past
Q2 Do you (now or in the past) work at GMS or DSB?				

	Yes	No	Now	Past
Q3 Do you (now or in the past) go to School at GMS?				

	Daily	Weekly	Monthly	A few times a year	Less than a few times a year
Q4 How often do you visit the GMS campus?					

	Totally Blind	Some Light Perception	Some Usable Vision
Q5 Extent of vision loss?			

	Birth	Younger than 18	18 or Older	Mean (n=18)
Q6 If blind, then at what age did you experience total vision loss?				

	Birth	Under 18	18 or Older
Q7 If not blind, then at what age did you begin to lose your vision?			

	Yes	No
Q8 Have you had any formal Orientation & Mobility training?		

	0-5	6-11	12 +
Q9 If Yes, how many months of formal Orientation & Mobility training have you had?			

	Up to 18	18-30	31 +
Q10 At what age did you begin travelling independently?			

	Daily	Weekly	Less than
Q11 How often do you travel independently?			

	Under 18	18-30	31 +
Q12 At what age did you begin travelling with a cane?			

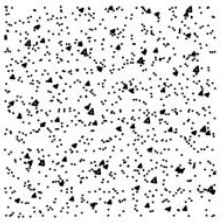
	Yes	No	Dog Guides	Sighted Guides	Other
Q13 Do you use any other travel aids?					

Q14 Participant Initials	

Appendix F.1
Material Installation Details

Non-slip Grit Texture

Surface Pattern



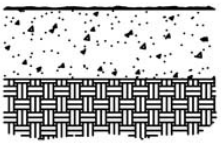


Surface Pattern Photo

Applied Non-slip Grit

4" Concrete Base

Natural Soil



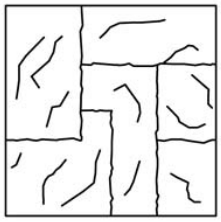
Construction Section



48" wide Sample Pattern

Stamped Concrete

Surface Pattern



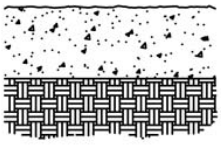


Surface Pattern Photo

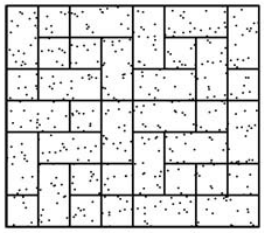
Stamped Patterin in Concrete

4" Concrete Base

Natural Soil



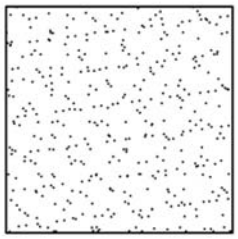
Construction Section



48" wide Sample Pattern

Concrete

Surface Pattern



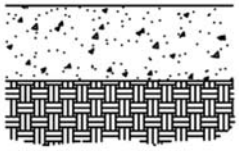


Surface Pattern Photo

Broom Finished Concrete

4" Concrete Base

Natural Soil



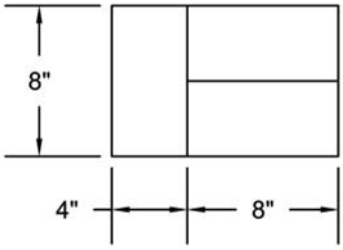
Construction Section



48" wide Sample Pattern

Brick Pavers

Surface Pattern





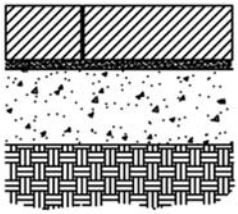
Surface Pattern Photo

Solid Brick Pavers

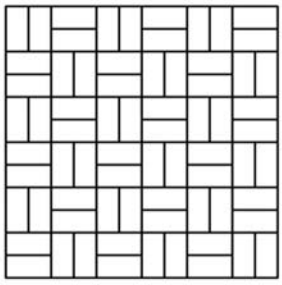
1/2" Sand Base

4" Concrete Base

Natural Soil



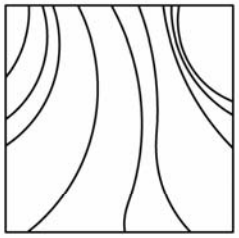
Construction Section



48" wide Sample Pattern

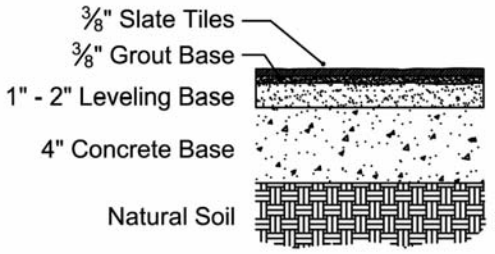
12" Slate Tiles

Surface Pattern

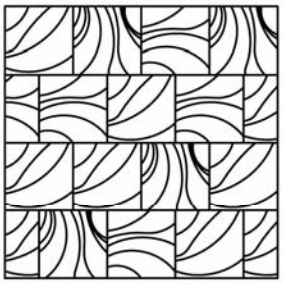




Surface Pattern Photo



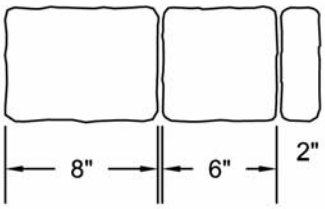
Construction Section



48" wide Sample Pattern

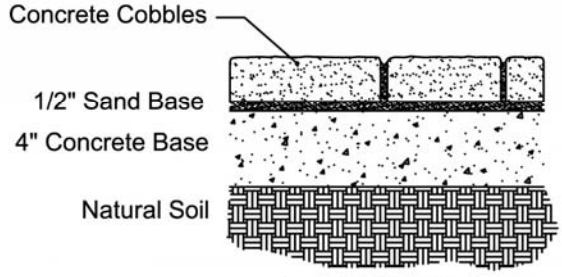
Concrete Cobblestone Pavers

Surface Pattern

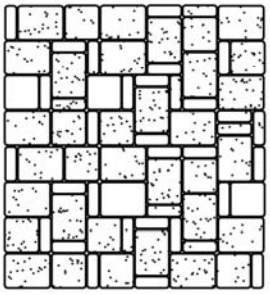




Surface Pattern Photo



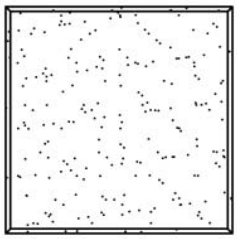
Construction Section



48" wide Sample Pattern

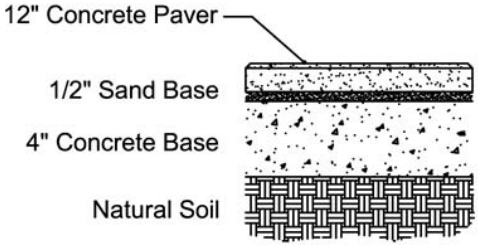
12" Concrete Pavers

Surface Pattern

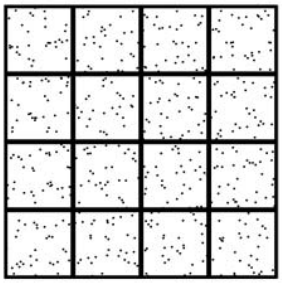




Surface Pattern Photo



Construction Section



48" wide Sample Pattern

Appendix F.2
Material Installation Photos












MYATT
LANDSCAPING
CONCEPTS





Appendix F.3
Testing Photos with Subjects










COLE
BUILDING



Appendix G
Literature Review Matrix

	Cognitive Input								Physical Characteristics								
	Cognitive Maps	Decision Making	Environmental Input	Knowledge Types	Perception	Degree of Vision Impairment	Travel Experience	Orientation and Mobility Training	Cane Detection	Ease of Installation	Maintenance and Durability	Vibration	Noise Levels	Texture	Material Hardness	Slip Resistance Value	Structural Stability
Alexander, C., & Carey, S. (1968)		•	•		•												
Arthur, P. (1988)	•	•	•		•		•										
Arthur, P. & Passini, R. (1992)		•	•		•		•										
Barlow, S. T. (1999)			•	•	•												
Baskaya, A. Wilson, C.S., and Ozcan, Y.Z. (2004)																	
Bentzen, B. L. (1972)	•			•		•	•	•									
Bentzen, B. L.; Nolin, T. L. & Easton, R. D. (1994a)			•		•	•		•	•		•			•			
Bovy, P. H. L. and E. Stern, (1990)	•	•	•				•										
Burton, G. (2000)								•	•			•	•	•			
Busemeyer, J. R. (1979)		•	•	•	•			•									
Butler, D., Acquino, A., Hissong, A, and Scott, P. A. (1993)	•	•	•		•		•	•									
Corlett, J., Anton, J., Kotzub, S., & Tardif, M. (1989)	•	•		•	•		•	•									
Downs, R. M. & Stea, D. (1973)	•	•	•	•	•												
Garling, T. & Golledge, R. G. (1989)			•		•												
Gerberding, J.L. (2005)					•	•		•	•								
Geruschat, D. and Smith, A. J. (1997)			•		•	•	•	•	•								
Giudice, N., Legge, G. E., & Bakdash, J. Z. (2003)	•		•	•	•	•	•	•	•			•	•	•	•		
Gibbons, C. James. (1999)			•							•	•			•	•		•
Golledge, R. (1999)	•	•	•	•	•												
Hart R. A. & Moore, G. T. (1973)	•	•	•	•	•												
Haq, S., & Zimring, C. (2003)	•		•		•												
Heller, M. A. (1989)			•		•			•	•			•	•	•	•	•	
Kellogg, W. N. (1962)			•		•			•	•			•	•	•	•		
Kitchin, R. M. (1994)	•		•	•	•		•										
Levine, M., Jankovic, I., and Palij, M. (1982)	•	•	•	•	•												
Lynch, K. (1960)			•		•												
McReynolds, J. and Worchel, P. (1954)	•		•		•	•											
Morioka, M., and Maeda, S. (1998)					•				•			•	•	•			
Passini, R. (1984)	•		•		•		•										
Passini, R. (1992)	•		•		•		•										
Peck, A. F. & Bentzen, B. L. (1987)						•		•	•		•	•		•		•	•
Rice, C. E. (1967)			•		•							•	•	•			
Rodgers, M., D., and Emerson, R. W. (2005)		•		•	•				•			•	•	•			
Rossano, M. and Reardon, W. P. (1999)																	
Schenkman, B. N., & Jansson, G. (1986)			•		•	•	•	•	•			•	•	•			
Silva, K. D. (2004)			•		•		•										
Thorndyke, P. W. and Statz, C. (1980)	•			•	•												
Tversky, B. (2003)	•		•	•			•										
Ungar, S. (2000)	•		•		•	•	•										
Ungar, S.J., Blades, M. & Spencer, C. (1993)							•	•									
Weisman J. (1981)		•	•		•		•										
Werner, S., & Schmidt, K. (1999)	•		•		•		•	•									
Wightman, F. L., & Kistler, D. J. (1997)					•			•	•			•	•				

Appendix H
Letter of Support

North Carolina State University is a land-grant university and a constituent institution of The University of North Carolina

College of Design
Brooks Hall / Campus Box 7701
Raleigh, North Carolina 27695

NC STATE UNIVERSITY

Office of the Dean / 919.515.8302
Architecture / 919.515.8350
Art and Design / 919.515.8315
Graphic Design / 919.515.8326
Industrial Design / 919.515.8322
Landscape Architecture / 919.515.8340
Fundamentals / Design Studies / 919.515.8315
Graduate and PhD Studies / 919.515.8308
Fax: 919.515.7330
www.design.ncsu.edu

February 2, 2007

To whom it may concern:

I am writing to confirm that Andrew Payne is a student in good standing in the PhD in Design program in the College of Design at NC State University. Andrew is conducting research on the use of sidewalk materials for pedestrians with visual impairments. His work is under Dr. John Tector, Associate Dean of the college and has the full approval of his graduate dissertation committee.

Andrew is seeking the support of the construction industry for this work, which will likely yield valuable information on strategies for universal design. We encourage you to consider his requests and are willing to provide donation documentation for any materials or services contributed to this project.

Sincerely,

MEREDITH DAVIS

Meredith Davis
Director, PhD in Design Program

Appendix I
Verbal Instructions

Matching Pairs Test:

[Introduction to test] – This portion of the research is to determine the rate of detection of changes in various surface materials. There have been seven sidewalk materials chosen to be tested and these materials have been installed in a new sidewalk. This new sidewalk is approximately 48" wide and 110 feet long. Along the path are joints, approximately every 4 to 5 feet, where changes may or may not occur. There are a total of 23 pairs of materials, such as brick and concrete, slate tiles and brick, etc., which you will be required to make a response.

You will be positioned direction in line with a joint between two materials (similar or different) and you are to perform two tasks: First, test the materials with you cane, by tapping or sweeping, and answer the question "As detected by the cane, is there a difference between the two materials?". [The researcher documented the response and directed the participant to perform the next task]. Next, you are to test the materials with you feet, by stepping, stomping or scuffing, and answer the question "As detected underfoot, is there a difference between the two materials?".[Upon the subject making a determination, the researcher documented the answers and directed the participant to the next intersection and repeated. This process was continued for all 23 pairs of materials. Over the 45 minute time period with each participant, much of the formal repetitive terminology was dropped, typically due to the participant quickly offering a response before the researcher asked the questions.]

[The participant was led to the starting point for Test One and provided the following information].

Field Test One:

[Introduction to test] – This next test for today will require you to walk a predetermined path with a length of approximately 700 feet. Along this path will be various bisecting paths, intersecting paths, and obstacles you will be asked to detect and identify (such as benches

etc.). You will be timed and correct responses and detections of the obstacles will be noted in order to compare to the next phase of testing.
You are now at the starting point for Test One. We are near the front gate of GMS at Ashe Avenue with the Cole Building on your right side and the Security/Administrative Building across the street on your left side. You are facing the Auditorium Building.

[The researcher felt it was important to provide locational information to the subjects in order to not raise concerns of disorientation. This information had no bearing on the responses being sought in the testing].

I will be walking slightly behind you and to the left for the entire test, if you need to stop at any point please do so. I will be making notes of your actions and comments along the route so if there is anything interesting about the path please feel free to share it with me. Also, along the route, I will ask you to detect certain items or obstacles. You can simply respond when you make the detection and continue along the path. I will also be making note of your overall travel time and time from point to point. The idea behind this research is to install new materials which makes travelling from point to point easier and possible improve travel time and reduce travel errors. Are there any questions? [Any questions were addressed before beginning the test]. You will hear a beeping noise as we begin down the path and that is simply me starting the stop watch. Feel free to begin travelling down the path when ready. [Once commenced the researcher stated commands].

[The following is a sample of small bursts of instructions from the researcher to the participant. Often there was little conversation during the testing. There was however positive responses from the researcher to the participant when a task was successful and there was doubt from the participant (i.e. Did I do that right? Yes – Good job, now let's continue.]

You are to turn right at the first intersection. You are to follow the path around to the left. You are to detect a bisecting path. You are to looking for a bench, etc.

[Upon completion of the test the following conversation was typical]. You have completed the testing for today. [In a few cases, some subjects inquired as to where the end point was on campus – The researcher identified the Principal's House as nearby.]
In a month or so I will be in contact with you for Test Two. The next test will involve you walking a similar path that has had changes in materials installed at specific points and you will have to detect the changes along the path. Do you any questions? [Any questions were addressed before returning to the neutral location – Payment was made upon arrival].

Field Test Two:

You are now at the starting point for Test Two. We are at the End Point for Test One, near the Principal's House with the Parking Lot on your right.

[Again, the researcher felt it was important to provide locational information to the subjects in order to not raise concerns of disorientation. This information had no bearing on the responses being sought in the testing].

Similar to Test One I will be walking slightly behind you and to the right for the entire test, if you need to stop at any point please do so. I will be making notes of your actions and comments along the route so if there is anything interesting about the path please feel free to share it with me. Also, along the route, I will ask you to detect certain items or obstacles, and specifically the changes in materials that have been installed. You can simply respond when you make the detection and continue along the path. There are four locations of changes in materials. I will also be making note of your overall travel time and time from point to point to compare to Test One to see if there was a difference.
As I mentioned last time you were here, the idea behind this research is to determine if changes in materials makes travelling from point to point easier and improve travel time and reduce travel errors. Are there any questions? [Any questions were addressed before beginning the test]. You will hear a beeping noise as we begin down the path and that is simply me starting the stop watch. Feel free to begin travelling down the path when ready. [Once commenced the researcher stated commands].

[The following is a sample of small bursts of instructions from the researcher to the participant. Often there was little conversation during the testing. There was however positive responses from the researcher to the participant when a task was successful and there was doubt from the participant (i.e. Did I do that right? Yes – Good job, now let's continue.]

You are to follow the path around to the left. You are to detect a bisecting path. You are to looking for a bench, etc.

[Upon completion of the test the following conversation was typical]. You have completed the testing for today. You successfully detected 3 of the 4 changes in materials and mistakenly identified 1 change that did not occur. [The researcher felt sharing the performance with the participant had no bearing on the data]. Do you any questions? [Any questions were addressed before returning to the neutral location – Payment was made upon arrival].

Appendix J.1
Large Print Informed Consent Form for Research

Title of Study: **UNDERSTANDING CHANGE IN PLACE:** Spatial knowledge acquired by visually impaired users through change in footpath materials.

Principal Investigator: Andrew P. Payne

Faculty Sponsor: Dr. John O. Tector

PURPOSE OF THIS STUDY

We are asking you to participate in a research study. This research contains two primary purposes. The first purpose is to investigate and compare the physical characteristics of seven typical sidewalk construction materials. The second purpose of the research is to determine the best combination of materials to produce the greatest level of detection of change in materials among the users. In order to help landscape architects, campus planners and university administrators produce the most accessible environment possible this research will provide a

design standard for sidewalks which can incorporate information cues in the form of changes in materials along the travel path at key intersections and destinations. You are being asked to participate in this study because you are a visually impaired adult.

PROCEDURES

This research will implement quantitative measurements and comparisons of various sidewalk surface materials as well as a field experiment to evaluate the ability of visually impaired users to identify changes in materials while moving along a path. If you agree to participate in this study, you will be asked to be a part of three activities. Any of these activities may be photographed.

Pre-experiment test procedure (Activity One):

The pre-test will compare mixed pairs of the seven sidewalk construction materials. The pre-test will be conducted in an outdoor controlled environment at the campus of the Governor Morehead School.

Each test will be administered by the researcher and will contain one pair of materials to be

compared at a time. The subjects will be led to the test area and allowed a fixed amount of time (30 seconds) to explore the pairs of materials with their own personal long cane. (Each participant will be required to bring his/her own long cane for use during the exercise). At the conclusion of each 30 second review period the participant is to declare a definitive “Yes” or “No” to the question: “Are these sidewalk materials different”? The participant’s response will be recorded by the researcher at each test area. The total time allocated for this testing phase is 1.0 hour per subject.

Field experiment control test procedures (Activities Two and Three):

Field experiment two will consist of individual subjects walking a predetermined path on the campus of the Governor Morehead School. The subject’s journey will be timed and recorded for accuracy in following travel directions. The researcher will trail each subject and record the subject’s statements and overall travel time, as well as assist in any state of disorientation or confusion. The total time allocated for this testing phase will be 30 minutes per subject.

This test will be conducted on the same day as Activity One above.

Part three of the experiment will take place on a separate day and will consist of the same group of individual subjects walking a similar path in length, number of turns and changes in grade, as in field experiment two. This path will include changes in surface materials at key intersections and will require the subjects to: a) verbally declare when changes in materials are detected, b) perform a travel task (i.e. turn left, turn right, etc.) and c) continue to the destination. This task will be timed and recorded for accuracy in following travel directions and detecting changes in sidewalk materials. The researcher will trail each subject and record the subject's statements and overall travel time, as well as assist in any state of disorientation or confusion. The total time allocated for this testing phase will be 30 minutes per subject.

RISKS

There should be no risks from participating.

BENEFITS

Your participation in this research will help determine better combinations of sidewalk paving materials that are more easily identifiable and can provide way-finding cues to visually impaired pedestrians.

CONFIDENTIALITY

The information in the study records will be kept strictly confidential. Data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do otherwise. For clear communication in the field only your initials and an assigned number will be identified. No other references will be made in written or oral reports that could link you to the study. Any photographs obtained during the field exercises can be blurred to conceal your identification upon your request.

Do you want your identity concealed in photographs?

Yes ____ No_____

If yes, the researcher is to write a brief description of the participant to ensure the correct identity is concealed. (i.e. gender, shirt color, etc.).

DATA GATHERING and MANAGEMENT

The Principal Investigator will be responsible for the security of all data gathered in each phase of the research. Outside persons who may have limited access to portions of data include (but are not limited to), research assistants, statisticians, research committee members, writer/editor, Governor Morehead School administrator's and faculty, and the Dean of the College of Design.

COMPENSATION

You will be compensated $20.00 (cash) for your participation in this study. (Ten dollars will be paid at the completion of parts one and two, and ten dollars will be paid at the completion of part three).

EMERGENCY MEDICAL TREATMENT

There is no provision for free medical care in the event that you are injured during the course of

this study. In the event of an emergency, medical treatment may be available through the 911 emergency response service.

CONTACT

If you have questions at any time about the study or the procedures, you may contact the researcher, Andrew P. Payne, at Campus Box 7701, NCSU College of Design, Raleigh, NC 27695-7701, appayne@ncsu.edu or (919/467-8845). If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. David Kaber, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/515-3086) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty. If you

withdraw from the study before data collection is completed your data will be returned to you or destroyed at your request.

CONSENT

“I have read and understand the above information. I have received a copy of this form in large print format or Braille. I agree to participate in this study with the understanding that I may withdraw at any time.”

Subject's
Signature_____
Date _____

Subject’s
Name
(Print)_____

Researcher's
Signature_____
Date _____

Appendix J.2
Braille Format INFORMED CONSENT FORM for RESEARCH

INCLUDED IN FINAL PRINT COPY