AN ANALYSIS OF THE USE OF SOUNDS FOR COGNITIVE ENHANCEMENT

OF TOPOGRAPHIC MAPS FOR PEOPLE WITH VISUAL IMPAIRMENT

by

PAPORN THEBPANYA

(Under the Direction of Thomas W. Hodler)

ABSTRACT

This research evaluates the implementation of two sound variables, pitch and duration, with regard to their effect on the interpretation of spatial features and contour lines on topographic maps. The study aims to provide an initial investigation into the use of multimodal (e.g., haptic and auditory) representation for exploring topographic data. The objectives of this research are to design and develop a user-friendly interface in which topographic maps can be examined in a more efficient manner than traditional maps allow, and to investigate the application of sound variables to enhance the interpretability of topographic maps. The sonically enhanced maps are designed as a prototype to explore the possibilities for communicating geographic information in a "touch-audio" manner. The creation of tactile user interfaces and audio cues are applied to convey spatial information for people with sight and those with visual impairment or blindness.

The findings from this research reveal that an integration of sound variables with topographic data provides a multi-sensory approach to access information, thus allowing the people with visual impairment to explore and correctly answer questions pertaining to topographic maps (e.g., relative elevation, profile, and landform). These findings support the difference theory and indicate that persons with visual impairment and blindness are able to acquire and develop their spatial representations with alternative coding and designing strategies. They are able to learn and develop spatial knowledge equivalent to that of people who are sighted if they are provided with subsequent experience, such as training as to how the environment is represented on topographic maps.

INDEX WORDS: Visual impairment, Sonically enhanced map, Cognitive map, Sound variables, Multimodal display, Difference theory

AN ANALYSIS OF THE USE OF SOUNDS FOR COGNITIVE ENHANCEMENT OF TOPOGRAPHIC MAPS FOR PEOPLE WITH VISUAL IMPAIRMENT

by

PAPORN THEBPANYA

B.S., Chulalongkorn University, Thailand, 1994

M.A., The University of Georgia, 1999

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2003

AN ANALYSIS OF THE USE OF SOUNDS FOR COGNITIVE ENHANCEMENT OF TOPOGRAPHIC MAPS FOR PEOPLE WITH VISUAL IMPAIRMENT

by

PAPORN THEBPANYA

Major Professor: Thomas W. Hodler

Committee: Lynn E. Usery
Hilda E. Kurtz
Clifton W. Pannell
Lloyd P. Rieber

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
August 2003

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1
INTRODUCTION

Cartographers have developed methods and formulated theories of map construction and map use for centuries. The predominant method for presenting spatial information in cartography was and still is the map. Recent developments in multimedia techniques have provided a wide range of hardware and software enhancements that enable cartographers and map users to create and use cartographic multimedia presentations. Different media, such as maps, pictures, text and sound can be combined to show various aspects of a spatial object or phenomenon, and thus enhance or accentuate information (Dransch 1999). A common view within the field of multimedia application is that inclusion of varied media, and thus more use of the senses, aids in the perception of information, and provides for a qualitatively better result.

Sound has been used in human-system interfaces for many years (Patterson 1982; Pollack and Ficks 1954). Although applications increasingly use sound to convey information, there are still no general guidelines for mapping data dimensions (e.g., temperature) onto display dimensions (e.g., pitch). Investigation of the use of sound in multimedia maps is still in its beginning stages. Usually, sound is integrated as a means toward achieving a good atmosphere by playing background music or to provide verbal explanations. In the real world, sound also supports orientation and navigation in three-dimensional space (Buziek 1999). For example, the typical announcement that is made when the underground stops at the station is played to help travelers identify the right train stop to exit. The location of the station is known by studying the map, and the acoustical advice helps to construct sptail knowledge. In this case, sound is used for double encoding and to reinforce complementary information.

Data sonification is a useful technique for displaying data to users whose visual attention must be devoted elsewhere, for revealing data properties that are not easily rendered by visual graphics, and for presenting information to individuals who are visually impaired. Hardware improvements in today's computers (multimedia readiness) have the potential to vastly increase the availability of auditory data display formats for general users. Providing sound-based software enhancements to encourage exploration of symbolic data representation lead to useful creative developments for a variety of applications.

Geographers have recently begun to turn their attention to issues of people with disabilities. Indeed, vision impairment has received the most attention of all the sensory and physical impairments explored by geographers (e.g., Dacen Nagel and Coulson 1990; Golledge and Costanzo 1997; Jacobson 1998; Jacobson and Kitchin 1997; Kitchin *et al*. 1997; Wiedel and Grooves 1970). Prior to 1990, there were only a handful of geographic studies that explicitly focused upon disability. The number of empirical studies has grown significantly since 1990, both in numbers and in the range of issues addressed (Park *et al*. 1998). However, most prior research on spatial ability in the absence of vision has concentrated on performing tasks within relatively small-scale spaces, such as a room (Hill *et al*. 1993), or a building (Passini and Proulx 1988), or otherwise within artificial spaces such as a purpose-built maze within a room (Passini *et al*. 1990). With some limited exceptions, little research has focused upon large-scale geographic spaces such as an urban environment or residential area.

People who have complete loss of sight have limited accessibility to physical environment, and have to rely on their remaining auditory, tactile, olfactory, and kinesthetic senses to gather information about the world. In addition, there is a need to develop effective methods of communicating spatial information using a non-visual medium. The development of novel representations of geographic space allows access to spatial information without vision. For those people with visual impairment, the communication can be processed through other modalities (i.e. haptic and auditory). By expanding the presentation of geographic information to multiple modalities there will be considerable benefits for many disciplines. It also has the potential to offer novel ways of interacting with data, providing opportunities for visualization, understanding and analysis. Multimodal representations offer the user with sight an opportunity for greater interpretation and immersion. For the user with no sight, they represent an unparalleled opportunity for information to be presented in a manner that is highly accessible. This research aims to provide an initial investigation into the use of multimodal information for exploring topographic data.

1.1 Research Objectives

This research will evaluate the implementation of two sound variables, pitch and duration, with regard to their effect on the interpretation of spatial features and contour lines. The use of audio cues and visual simulation will be applied to enhance the ability of topographic map reading and interpretation for people who have sight and those who have visual impairments and blindness. Although there is limited research on this task in the field of geography, the researcher hopes this study will offer a new perspective and add depth to the discipline. The objectives of this research are:

1) To design and develop a user-friendly interface in which topographic maps can be examined in a more efficient manner than traditional maps allow.
2) To determine whether the sound variables, pitch and duration, help improve the spatial learning of geographic environments for people who are sighted and those who are visually impaired or blind.
3) To determine how well participants respond to map questions on sonically enhanced maps* as compared to maps without sound in terms of accuracy and response time. Accuracy is determined by the total numbers of correct answers obtained from each task and the response time is the length of time taken to answer each question. Timing is recorded automatically by the program. The clock starts when the participants click the button on the screen to view the question, and stop when the answer is selected.

1.2 Research Hypotheses

According to the objectives of this research, the hypotheses to be tested are:

1) The combination of sound variables pitch and duration enhances the cognitive knowledge of topographic maps for participants who are sighted and those who are visually impaired or blind, allowing more accuracy and faster speed of response to map questions than when only one sound variable is used (i.e. pitch).

---

* The sonically enhanced maps refer to topographic maps in which the sound variables of pitch and duration are incorporated.

2) The participants who interpret topographic maps based on sound obtain higher scores than when they view the traditional topographic maps.
3) The participants who are sighted and perform tasks on the sonically enhanced maps answer questions pertaining to the topographic data, such as relative elevation, slope, slope profile, landform, and distance, faster than when they learn from the traditional maps.

1.3 Null Hypotheses

Based upon the objectives and the research hypotheses, the null hypotheses to be examined are:

Ho_1: Using the combination of sound variables pitch and duration will **not** increase **accuracy** for participants who are sighted and those who are visually impaired or blind when compared to using on sound variable.

Ho_2: An integration of the sound variables pitch and duration with contour lines will **not** affect the ability of participants who are sighted and those who are visually impaired or blind to **correctly answer** questions pertaining to topographic maps.

Ho_3: An integration of the sound variables pitch and duration with contour lines will **not** affect the **speed of response** to map questions in the group of participants who are sighted.

CHAPTER 2

LITERATURE REVIEW

For learning a geographic environment from primary sources or secondary sources such as maps, vision is the most effective sense, and sight is often quoted as the sense *par excellence* (Foulke 1983). Vision allows spatial information to be easily collected and processed. It provides immediate perception of objects within an environment and allows oneself to maintain orientation, to differentiate perspective and scale, and to locate objects in relation to one another and the perceiver (Morrongiello *et al*. 1995; Scholl 1996). Consequently, it is generally contended that people with visual impairment or blindness experience a world different from those who are sighted, because the former must rely on other senses (i.e., tactile and auditory), as other modes of learning which are sequential in nature (see Spencer *et al*. 1989). It is widely thought that spatial knowledge and behavior are substantially restricted for the people who are blind. However, our understanding of the spatial world experienced by people with visual impairments remains relatively limited. Cognitive mapping research and other allied techniques allow an insight into the *mental landscapes* of people with blindness or visual impairments and have the potential to provide clues as to how spatial information is learned, processed, and stored (Golledge *et al*. 1996; Pick 1980). These studies can also contribute to increased mobility and independence for individuals with visual impairments, thus helping to improve their quality of life.

The research in cognitive mapping is of considerable theoretical and practical importance. Since the inception of geography, a concept of “space” has been at its core; space is crucial to geographic inquiry. In the following sections, the cognitive processes that humans used to analyze geographic environments are introduced. Two theoretical cognitive structures (an object file and a mental model) for encoding spatial information are also discussed. In part two, the discussion is narrowed and focused to issues relating to the spatial abilities of the people with visual impairment and blindness. Before addressing these issues, it is necessary to review the diversity of blindness in order to illustrate the prevalence of this occurrence. There is much debate in the literature as to the ability of people who are congenitally blind to comprehend space. In addition, three theories of blind spatial ability proposed by Fletcher (1980), along with the evidence used to support those theories are presented. Past and current research in cognitive mapping for individuals with visual impairment is reviewed and methods for communicating spatial information to people who are blind are also discussed. In part three, an exploration of issues relevant to perception in sound is introduced. The discussion begins with a review of auditory perception versus visualization. Abstract sound elements and the auditory presentation of graphical user interfaces (GUI) are illustrated. Finally the applications of sonification are investigated.

2.1 Part One: Spatial Cognition

Spatial cognition is an important research area in both geography and psychology (Figure 2.1) with the two disciplines sharing a fundamental theoretical interest in (1) the processes used to encode spatial information into memory; (2) the nature of the internal representations; and (3) the decoding processes used with internal representations for making decisions (Garling and Golledge 1993). In the past, geographic information related to both human and physical environments was observed, recorded, described, classified, and analyzed, but relatively little concern was given to processes that directly connected humans with their environments. This required new assumptions to be made about both geographic environments and the humans living in them.

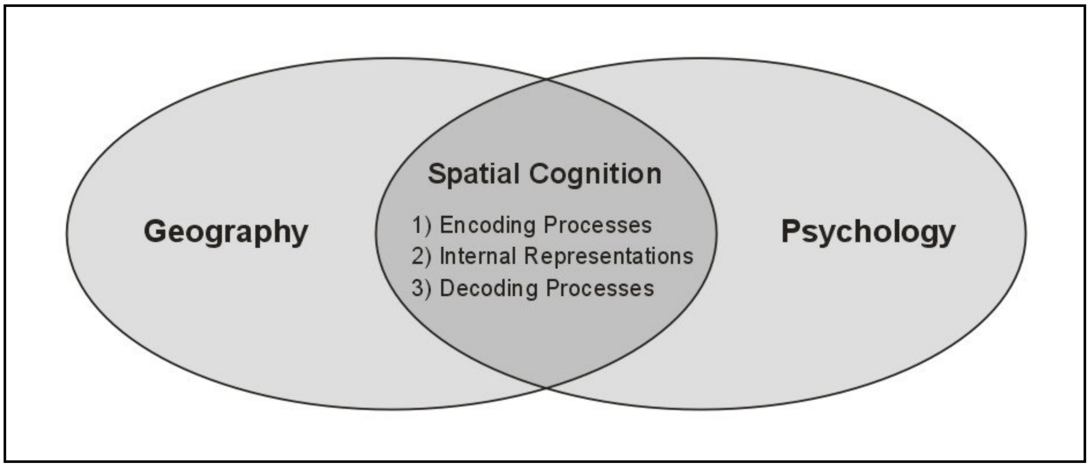


Figure 2.1 Spatial cognition. Spatial cognition is a research area of interest for both geography and psychology. Both disciplines are interested in fundamental ideas related to encoding processes, internal representations, and decoding processes (After Lloyd, 1997).

The current interest that geographers have in spatial cognition has directly evolved from the behavioral paradigm established in geography in the late sixties and early seventies (Downs and Stea 1973). Early landmark studies in this era by researchers, such as Lynch (1960) on images of cities, Gould (1966) on mental maps, and Lowenthal (1961) on environmental images, had established a cognitive perspective that attracted attention of geographers in a variety of topics. As ideas related to spatial cognition became known to a greater number of geographers, their proper place within geography became the subject of some debate. Geographers have always been interested in exploring environments and representing them on maps. In addition, this new interest in spatial cognition was a natural extension of this tradition. Since the basic concepts of spatial cognition focus on the environmental information ones have stored in their memories, these concepts have a broad range of applications in many sub areas of geography.

2.1.1 Cognition and Visual Perception

Cognitive psychology deals with questions about how people learn, store and use information. Psychologists consider cognition a general concept that is concerned with acquiring information about the world, representing and transforming this information as knowledge, and using this knowledge to direct our attention and behavior (Solso 1979). These three components of cognition, (1) Acquisition, (2) Representation, and (3) Use, reflect the theoretical interests shared by geography and cognitive psychology through spatial cognition. Geographers are interested in asking specific questions about the acquisition, representation and use of information for specific geographic environment (see Figure 2.1).

Perception is a cognitive process that is directly involved with the detection and interpretation of sensory information. Perception requires a direct connection between a person and the object being perceived so that sensory signals can be directly processed. For example, viewing a map and acquiring information about the sizes of cities is perception. Hearing an animal in a forest running ahead of us is a direct sensory experience and, therefore, involves perception. However, acquiring information about Boston while reading a novel is not perception because we are not in direct contact with Boston.

Visual cognition includes all the mental processes involved in the perception and memory of visual information (Pinker 1984). Visual perception is the process of being able to selectively attend to and then perceive some meaning from a visual display. It is largely concerned with visually recognizing shapes and patterns of objects directly in our visual field. Thus, visual perception is far from an objective process and instead is based on all our previous knowledge and experiences (Levie 1987).

2.1.1.1 Mental Images

Mental images can involve any of the senses, but geographers usually study the environment using visual images. Representing spatial information as images has an intuitive appeal because images can function like cartographic maps. Imagery involves reactivating information that has already been coded and stored in long-term memory. Kosslyn and Swartz (1978, p.223) argued "images are spatial representations that occur in active or short-term memory." They also claimed "the image we experience is not simply 'retrieved', but is generated from a more abstract representation in long-term memory." They further contended that images were constructed using both perceptual and conceptual information that have been previously encoded and stored. Therefore, a person could experience an image of an object that was not physically present (e.g., a map of Georgia) in a bare room with the lights out and his/her eyes closed. A person could generate a visual image of a place that he/she never directly experienced or even one that did not actually exist because information about the place was acquired through verbal and auditory coding.

2.1.1.2 Schemata

A schema is another type of internal structure that represents spatial information. Schemata are internal representations of common relationships among familiar objects in the environment. The schemata help to organize and give meaning to real-world settings (West and Morris, 1985). Spatial schemata are seen as distinctly different from images and as a framework for organizing past and present experiences within an environment (Tuan 1975). Spatial schemata are more directly associated with behavior taking place in the everyday environment and are able to easily accommodate environmental information currently being experienced. It requires concentrated attention to construct images in the visual cortex from information in long-term memory stored in a more abstract format. Forming images requires such concentration that the person forming the image may become temporarily oblivious to current sensory information while spatial schemata may be used without a conscious effort (Gold 1980). For example, people navigating a familiar route in a well-learned environment while concentrating on non-environmental information frequently report arriving at a destination without being able to recall a trip. This suggests that we can use some spatial information without making a conscious effort.

2.1.1.3 Conceptual - Propositions

Some researchers argued that all verbal and visual knowledge is stored as abstract conceptual propositions (see Anderson and Bower 1973; Rumelhart *et al*. 1972). The raw information that one acquired is abstracted, summarized, and interpreted before it was stored. A "concept" is a class or category that subsumes a number of individual instances. An important way of relating concepts is through propositions, which make some assertion that relates a subject (e.g., the Rocky Mountains) and a predicate (e.g., are in Colorado). Conceptual propositions are assertions that make a statement about the nature of the world. Simple examples are *the Empire State building is tall* or *Wyoming is square*. Semantic examples like these two are normally used to illustrate propositions, but visual information can also be depicted in memory using conceptual propositions. It has been suggested that abstract verbal inputs are rather simple when compared with visual information (Raaijamakers and Shiffrin 1981). The basic difference between an internal representation that encodes a verbal description of a map and one that encodes a visual depiction of the same map would be the amount of detail. It is argued that imaginable material is better remembered because it has a rich and detailed network of related propositions. To illustrate that a map can be encoded as a visual depiction and as a description of conceptual propositions consider the following example (Figures 2.2 and 2.3).

The map is for the hypothetical state of Dyland (Lloyd 1997). Dyland consists of two counties, Stone and Hardrain. It has two major cities, Tambourine and Heaven's Door, and two transportation arteries, 4th Street and Highway 61 (Figure 2.2). One can see the absolute and relative locations of these various elements on the map. Quick references, such as the graphic scale and north arrow, allow one to know that Tambourine is about 35 miles north of Heaven's Door on 4th Street. One can also encode most of the basic spatial information for the objects on the map as a network of conceptual propositions (Figure 2.3). The conceptual-proposition network can tell one that Tambourine is north of Heaven's Door on 4th Street, but cannot provide the distance between the two cities.

The main arguments of the image theory and the proposition theory are illustrated in Table 2.1. Anderson (1978) suggested that the question of which position was correct and which was incorrect could not be answered since the similar internal representations were the basis of both perceptual and imaginal visual experiences. The same processes may be activated when one is using perception to look at the map or long-term memory to imagine a map. The obvious implication of this is that similar behavioral effects could occur with either the map or map image.

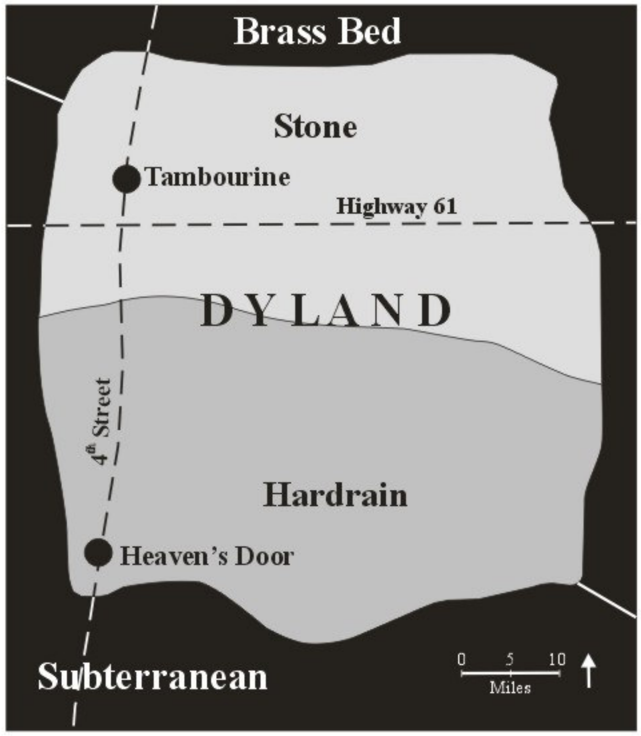


Figure 2.2 A hypothetical state of Dyland. A map that depicts a hypothetical state (Dyland), counties (Stone and Hardrain), cities (Tambourine and Heaven's Door), and transportation arteries (4th Street and Highway 61) (After Lloyd, 1997).

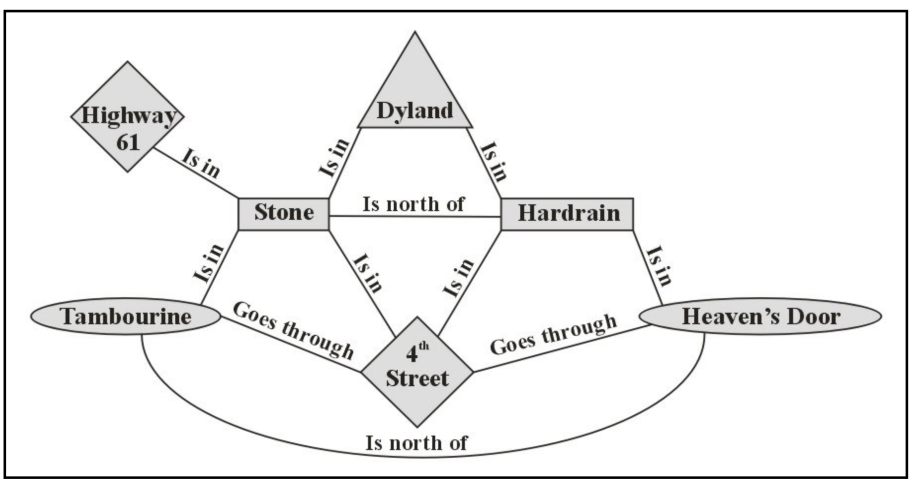


Figure 2.3 Conceptual propositions. Network of conceptual propositions that describe the map depicted in Figure 2.2. Nodes represent hypothetical state (Dyland), counties (Stone and Hardrain), cities (Tambourine and Heaven's Door), and transportation arteries (4th Street and Highway 61). Nodes are connected by a statement of their relationships, such as Is in, Is north of, and Goes through (After Lloyd, 1997).

Table 2.1 The main ideas of the image theory and the proposition theory.

Image Theory	Conceptual Propositions
1) Images are spatial representations Images are generated from underlying abstract representations, but the contents of the underlying representations are accessible only when a surface is generated to experience the image.	1) There are no pictures (images) stored in memory Any information stored in memory is only represented by networks of conceptual propositions.
2) Images have a capacity limit Only fixed amount of memory resources is available for processing with images are constructed and represented. This limits the details that can be activated for an image at any pointof time.	2) Propositions have a capacity limit Active memory can only process a finite number of conceptual propositions at one time. Both time and effort are needed to make propositional structures active.
3) Images are whole entities Once images are formed they are experienced as a wholes that may be compared to percepts in a template-like manner.	3) Both serial and parallel processes can access conceptual proposition networks Networks may be serially searched for information by accessing nodes in a specified ordered. Pairs of networks may be compared in parallel to assess their similarity by accessing all their nodes simultaneously.
4) The visual system supports imagery The same structures in the brain that represent spatial information being extracted during vision also are available to support images.	4) Visual information can be represented as conceptual propositions Networks can be constructed so that any desired spatial relationship can be represented.
5) Images are functionally equivalent to the objects they represent Many if the same cognitive processes that are used to analyzing percepts also can be used to investigate images.	5) Propositional networks can be compared to determine the relative similarity of the entities they represent Networks or parts of networks are similar or different to the extent that their elements and relations are similar and different.

2.1.2 Storing Spatial Information in Memory

The environments we encounter everyday contain many objects. We selectively focus attention on some of the objects and wish to store important information associated with them. This information includes 'where' information, recording the object's location, and 'what' information, recording other characteristics such as the object's shape, color, or size. Encountered objects vary in their relative importance to the person experiencing the objects (Figure 2.4). Many objects that exist in the environment are completely ignored because we never focus attention on them, while others may attract our attention long

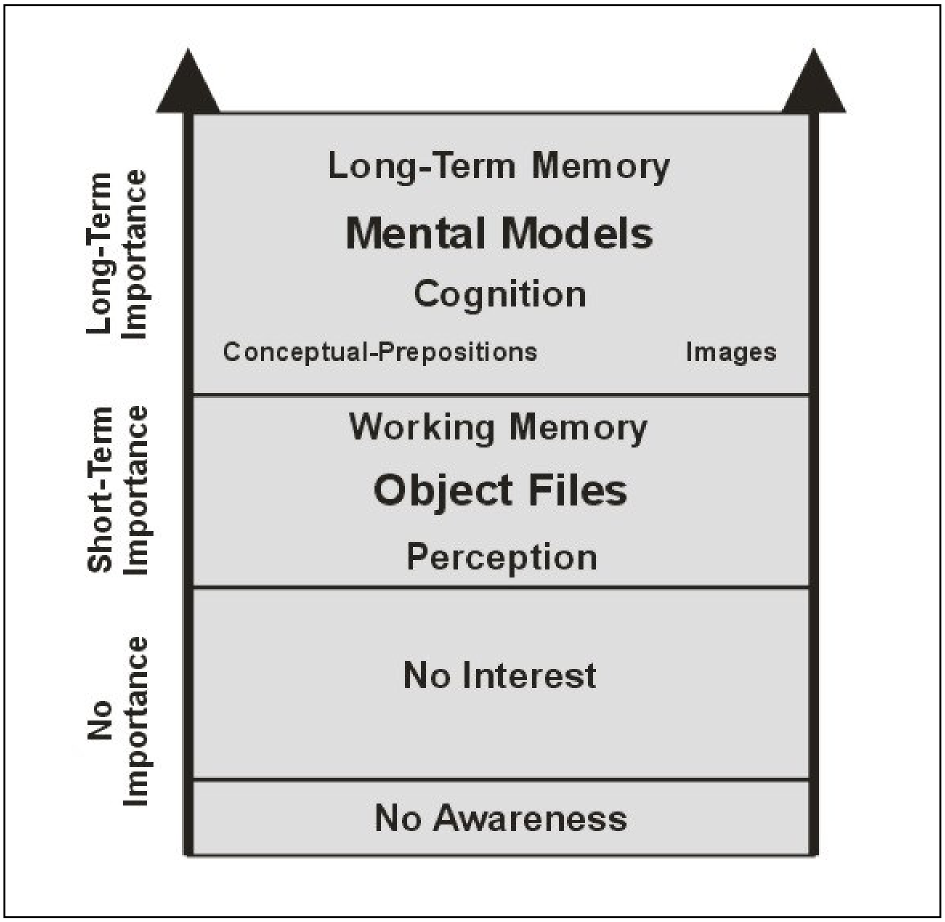


Figure 2.4 Object files. Object files are created by perceptual process as temporary structures for objects in working memory and mental models are created to encode spaces in long-term memory (After Lloyd 1997).

enough to make us briefly aware of their existence. We may be forced to abandon objects we have focused on as we shift our attention to new objects because our working memory has a limited capacity (Baddeley 1986). Sometimes the focus is not on a specific object, but on a space that contains a number of objects. We want a cognitive structure that can be used to store relationships among specific objects. This structure should allow us to relate a set of objects embedded in a common space. Two theories that accounted for encoding spatial information were proposed. The first theory, an object file (Kahneman and Treisman 1984), explained how we kept temporary track of information about objects encountered in the environment. The other theory, a mental model (Johnson-Laird's 1983), explained how we integrated verbal and visual information into a model of the environment.

2.1.2.1 Object File Theory

Object files were first discussed as the temporary episodic representations of real world objects by Kahneman and Treisman (1984). An object file is used to encode and update information about an object in our immediate environment that has temporarily attracted our attention, but will be forgotten when our attention shifts to other interesting objects. Object files were separated and distinct from representations stored in long-term memory that could be used to identify and classify objects. Kahneman and Treisman (1984) made a distinction between the specific and temporary object files, which they called "tokens", and the generalized and permanent structures used to label the object's identity, which they called "types". For example, suppose we are attempting to find our car in the parking lot and there are a number of objects (cars) in the space (parking lot). As we scan the space we open an object file for each car in view and store information (e.g., color, shape, size, etc.) about the object in file. These are *tokens* in immediate environment and one of the tokens is our car (Figure 2.5). We have viewed the car as an object many times and have encoded generalized information about that object (car) in our memory. This is a *type* because it represents all the views of the car as an object not any particular one.

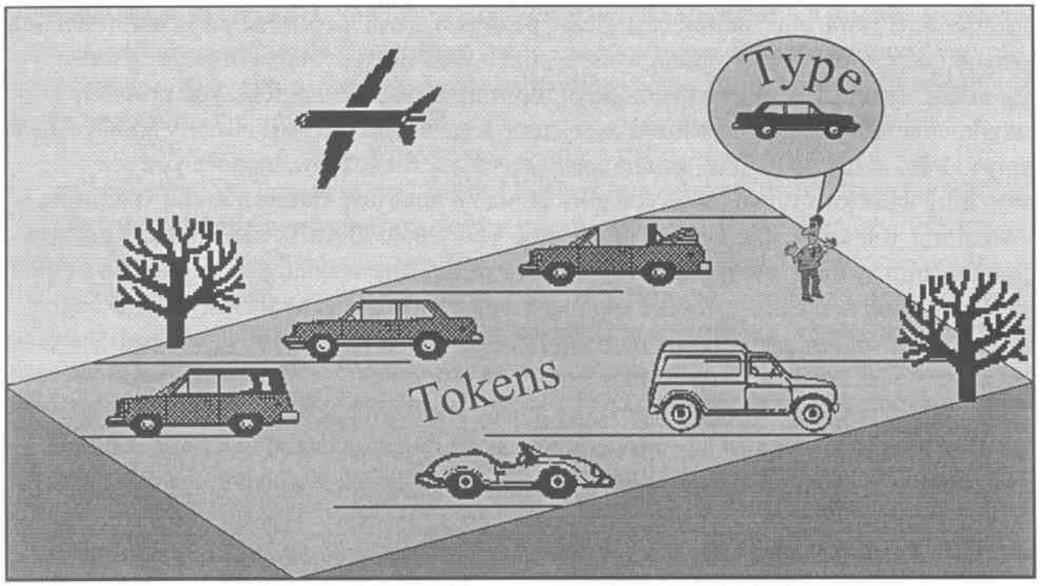


Figure 2.5 A type and a token. A type refers to a representation of an object based on many views of the objects stored in long-term memory and a token refers to a particular view of an object at a particular time (From Lloyd, 1997).

An object file is opened for use by the perceptual system once we have focused attention on the object. Information is put into the file to record the changes occurring to the object over time. Normally the perceptual system can maintain the continuity of a single file and keep it open or know when to close the first file and create a second file with relatively little difficulty. A process called "reviewing" causes a current object to evoke an item previewed in a previous visual field, thus maintaining the perceived continuity of an object as it moves, changes characteristics, or momentarily disappears from sight by relating its current state to its previous states. The reviewing process facilitates recognition when the current and previous states of an object match, but hinder it when they do not match.

2.1.2.2 Mental Model Theory

An image is a mental model whose source is visual imagination. It presents a viewer-centered representation of the visible characteristics for a spatial model. A mental model is used to encode and update information about spaces that have objects. Mental models are stored in long-term memory so that they might be used at a later time. Some mental models contain tokens that are entities in the real world (physical models) while others have tokens that are abstract concepts (conceptual models). Johnson-Laird (1983) identified a “spatial model” as a model that only encoded the physical relationships among tokens as spatial relationships. This type of mental model locates the tokens in a two- or three- dimensional space with metric properties. Distances between locations have to be accurate enough to satisfy the triangular inequality assumption of metric spaces. The distance of any two points must always be less than the sum of the distances between the two points and any third point.

The nature of mental models that represent geographic environments can be expressed in three basic principles developed by Johnson-Laird (1993). First, each object in the environment is represented by a corresponding token in the mental model. Since geographic spaces can be represented at various scales, it is assumed that a particular model is at an appropriate scale and that only important objects relevant at the scale will be encoded in the model. Second, the characteristics of objects are represented by the properties of their tokens. These properties include any characteristics of the objects that are relevant to modeling the environment. Third, relations among objects are represented by relations among tokens. The spatial location of tokens in the model corresponds to the spatial locations of objects in geographic space. Mental models organize and store spatial information as cognitive structures in our memory. Cognitive maps of environments that have been encoded from both verbal and visual information can integrate this information and store it as mental models that are thought to be perspective-free structures.

2.2 Part Two: The Cognitive Map Knowledge of People with Visual Impairment and Blindness

Geographers were naturally drawn to discussions of environmental learning and spatial behavior that related to maps stored in the brain. The cognitive map then became a central issue in spatial cognition research. Cognitive mapping is a technique that has been developed over a period of time. The most widely accepted definition of cognitive mapping is 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 this everyday spatial environment” (Downs and Stea 1973, p.7).

In its broadest sense, cognitive map knowledge can be thought of as an internal model of the world in which we live (Golledge and Stimpson 1997). It relates not only to how we perceive, store, and recall information about our spatial environment, but also how we think and feel about our larger geographic environment. Cognitive mapping is therefore used in spatial decision-making, in navigation, and in learning new environments via maps (Jacobson 1998). Over the past thirty years researchers in geography, psychology, planning, architecture and cognitive science have made significant advances in understanding spatial thought. A number of cognitive theories have been developed to account for how knowledge is learned, stored, and structured.

2.2.1 Heterogeneity of Blindness

Blindness carries with it certain misconceptions and stereotypes that influence how the people who are blind interact within society. There remains a barrier to the acceptance of the person who is blind as simply a person who cannot see. Visual impairments, like other disabilities in general are highly heterogeneous. No two people who are visually impaired will see the same thing. Visual impairments can range from mild, such as an individual wearing contact lenses or glasses, to severe, such as someone who is totally blind with no light perception, representing what Martin *et al*. (1988) called a "continuum of severity". In the United States, to be registered legally blind, requires a vision of less than 20/200 in one eye and/or a visual field of 20 degrees of visual angle or less in the better eye (Tuttle, 1984). Twenty degrees of visual angle is about the size of a one-foot ruler held at arms length. This standard, which is set forth by the Social Security Administration, indicates that a person with 20/200 vision on the Snellen scale would see at 20 feet while a person with 20/200 vision would see at 200 feet. Snellen scale is the most common scale used to represent acuity. The Snellen fractions (e.g., 20/20, 20/30, etc.) are measures of sharpness of sight. They relate to the ability to identify a letter of a certain size at a specified distance. Some people who are visually impaired are affected in both eyes equally, some in both eyes unequally, and others only in one eye. People can develop a vision impairment later in life through an accident or illness, or they may be congenitally (from birth) visually impaired.

Some of the variability of different visual impairments is illustrated in Figure 2.6. These pictures depict what the experience of certain eye diseases are like. The normal view of the teenager is shown in Figure 2.6 (a) and the subsequent pictures are simulated with fixation on the nose. Figure 2.6 (b) represents a vision loss caused by diabetic eye disease. This is the number one cause of blindness in the white population. In diabetic retinopathy, the blood vessels in the back of the eye (retina) are ruptured and leaked. This causes parts of the retina to die and results in a loss of vision where the leaking occurred. Figure 2.6 (c) is an example of a vision loss caused by age-related macular degeneration (ARMD). Macular degeneration is a disease in which the macula, which is the center part of the eye and retina, degenerates and dies-off, leaving a black hole or "scotoma" right where that person is looking. Figure 2.6 (d) illustrates a vision loss caused by cataracts. A cataract is an opacity or cloudiness of the eyes internal focusing lens. As the opacity gets larger or denser, vision is gradually more blurred and visual acuity is reduced. Figure 2.6 (e) represents a vision loss caused by glaucoma and retinitis pigmentosa (RP). Glaucoma is the number one cause of blindness in the black population. It is a disease in which the optic nerve fibers are damaged. Both glaucoma and RP cause a loss of side vision, leading to "tunnel vision". Figure 2.6 (f) depicts a left field homonymous hemianopia. In this case, the person cannot see anything in the entire left or right visual field in both eyes. However, sometimes one may be able to fixate or look directly at or point to a visual object located in the affected visual field, even though he/she does not consciously "see" the object. This condition is referred to as "Blind Sight" (Ohio LIONS Eye Research Foundation, 2003).

2.2.2 Current Theories of Blind Spatial Ability

Vision is generally determined to be the central sense in many aspects of our daily lives such as reading, writing, and navigating through an environment. In fact, Zeevi and Kronauer (1975) estimated that as much as 60 percent of environmental information acquired by a human arrives through the visual pathway, and Wieskrantz (1972) suggested that 50 percent of the nerve fibers entering the brain originate in the eyes. Accordingly, it is commonly understood

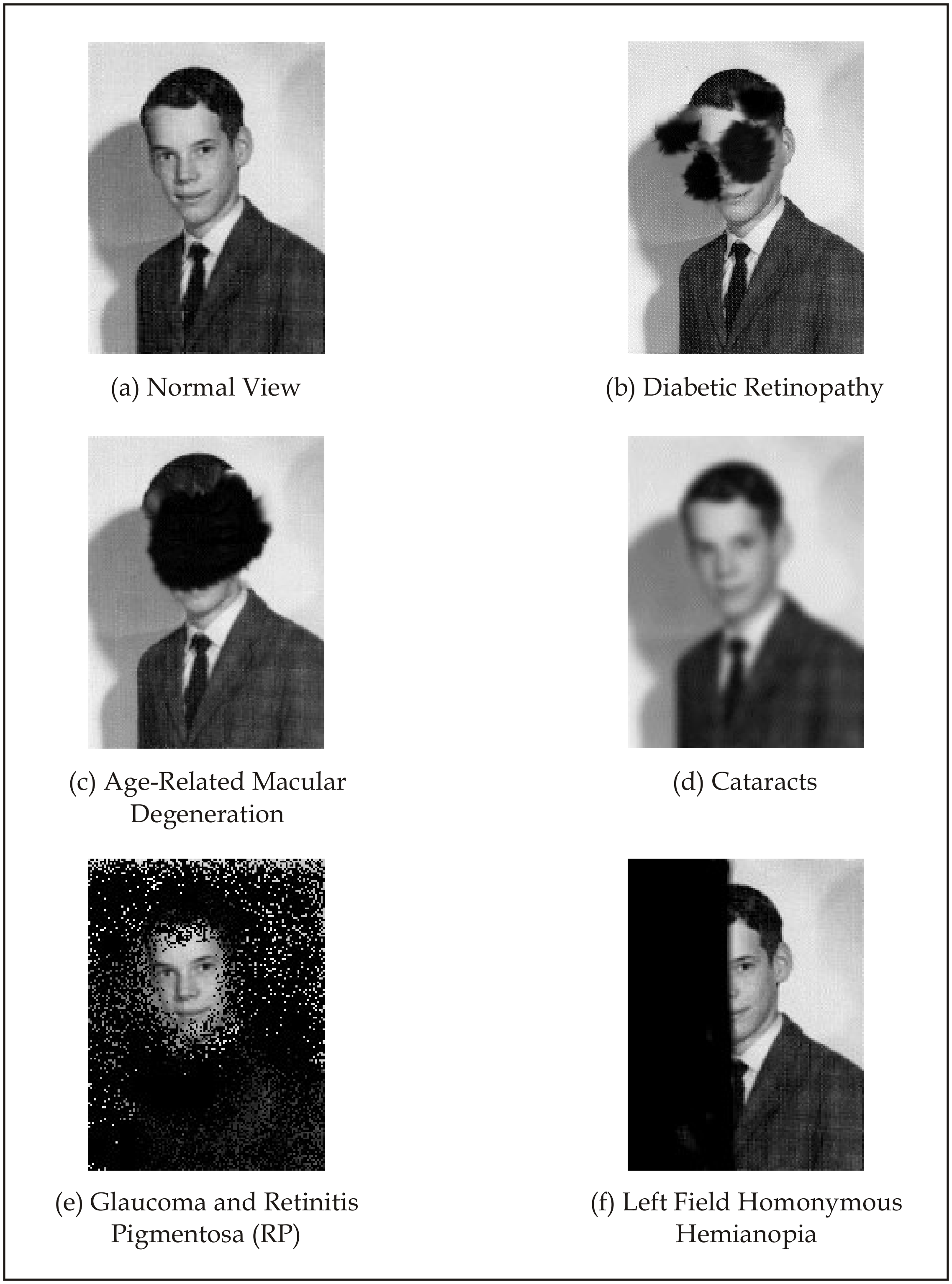


Figure 2.6 Visual examples of vision impairments (After Ohio LIONS Eye Research Foundation, 2003).

that the spatial abilities of the people with visual impairment are underdeveloped in comparison to sighted individuals.

Research and thought relating to blindness has a long historical precedent. Plato, the Greek philosopher, debated approaches and models as to how people came to know spatial structure and how they developed the capacity to know it (Morgan 1977). Plato taught that regardless of sight, each human possessed the same abilities to understand spatial relations. This was because the soul before birth knew concepts in their pure form; they only had to be uncovered afterward. Descartes (1637), based upon the ability of people with visual impairment to learn shape tactually, theorized that the capacity to form a mental representational framework was an innate property of human minds, and was not derived from a residue of experience. Therefore, a process of constructing a representational framework was viewed as being amodal, rather than being rooted in any sensory modality. In contrast, John Locke (1689) argued that concepts of space were derived from perceptual experience and that the mind was a *tabula rasa*, a blank tablet onto which the experience was written. Similarly, Berkeley (1709) in studying distance perception argued that the knowledge of spatial structure originated in perceptual learning and experience. He later explained that the apprehension of spatial relations arose from awareness of the body's own movement, thus providing the structure for tactile and visual sensations. Diderot, the philosopher in the late eighteenth century, concluded that touch was able to give his informant a sense of three-dimensional objects. He argued that changes in scale presented few problems for his subject, and that the people who are blind could enlarge or shrink shapes mentally. He also believed that tactile representations could be as useful for the people without sight as visual representations were for the sighted (Kenedy *et al*. 1992).

By the beginning of 1900s, there was considerable debate as to whether a person with no sight was able to hold or cognitively process any kind of spatial concept (Morgan 1977). Although these debates have continued throughout the century, it is now generally believed that people without sight are able to hold spatial concepts, to perceive spatial relations, and to form spatial representations through their intact senses. However, there is still a great deal of debate about the nature and extent of these processes. In 1980, Fletcher categorized the long history of research into three broad theoretical positions concerning the spatial abilities of people who were blind. Fletcher termed these the *deficiency*, *inefficiency* and *difference* theories.

2.2.2.1 Deficiency Theory

The *Deficiency Theory* literally holds that the spatial skills of people without sight are deficient compared to those of people with sight. This theory has its roots in the work of von Senden (1960). He contended that the individual who is congenitally blind lacked everything that would enable one to speak of a tactile awareness of space. In other words, spatial comprehension is not possible through touch alone. The deficiency theory assumes that spatial information received via senses other than vision cannot form an adequate base to formulate a coherent, sophisticated, mental spatial schema. Therefore, individuals who are congenitally blind are unable to develop a general spatial understanding because they have never experienced the perceptual process (e.g. vision) necessary to comprehend complex spatial arrangements. This theory is mainly of historical interest as more recent work has discredited von Senden's extreme position. It is now accepted that the spatial abilities of the people who are blind are not lacking, but severely underdeveloped. As the people who are visually impaired have much weaker spatial skills and competence than those who are sighted, they lack the ability to perform complex mental spatial problem solving involving rotation and transformation.

2.2.2.2 Inefficiency Theory

The *Inefficiency Theory* states that the spatial abilities of individuals who are blind from birth are weak, underdeveloped and functionally inferior to those of the sighted and late blind. It is determined that the potential for spatial knowledge by people with blindness is approximately comparable to the sighted, but that the cognitive functioning and encoding spatial abilities is poorer in the blind population. They are able to comprehend and mentally manipulate spatial concepts, but their knowledge of the spatial environment is based upon auditory and haptic cues because of their absence of vision (see Spencer *et al*. 1989). Individuals who are blind may have difficulty in estimating and making short cuts as they have difficulty identifying proximity relations between points of places. Research has shown that spaces traveled by congenitally blind tend to be re-constructed as linear routes consisting of sequences of paths linked by decision points (Casey 1978). The participants who are blind showed a basic understanding of spatial relations, however, inefficient processing was cited as the reason for a lack of configural representation (knowledge of where places were in relation to each other).

2.2.2.3 Difference Theory

The *Difference Theory* states that the spatial abilities and knowledge of people with visual impairments are different than those of individuals with sight. This theory proposes that individuals who are visually impaired possess the same abilities to process and understand spatial concepts as individuals who are sighted, but they may be developed more slowly, by different means, and consist of different structures (Juurmaa 1973). Passini and Proulx (1988) stated that any differences in spatial competence between sighted and blind, such as a cognitive mapping task, either in quantitative or qualitative terms, could be explained by intervening variables such as access to information (e.g. maps), experience, or stress. Millar (1988) argued that although non-visual senses were inferior at coding spatial relational information, people with visual impairment did not have less potential than those with sight for developing a fully integrated representation of space. It was contended that lack of vision slowed down spatial development, but visual impairment did not prohibit it. The people who were congenitally blind were able to develop spatial representations based on non-visual inputs from information supplied by their haptic, tactile, kinesthetic, and auditory senses. Most researchers now acknowledge that the persons who are congenitally or adventitiously blind and those who are visually impaired can process spatial data, although their ability is variable and generally poorer than that of sighted individuals.

2.2.3 Research in Cognitive Mapping

Since the late 1990s a number of researchers have begun to examine the geographies of blindness through four inter-related research threads (Kitchen *et al*. 1998). The most developed of these threads concerns measurement and assessment of the ability of people with visual impairments to process, learn, and store spatial information gained directly from primary interaction (i.e., when learning a route) and secondary sources, such as tactile maps (see Golledge *et al*. 1998; Kitchen 1997). A second research thread involves assessment of basic spatial abilities, such as manipulation, transformation and rotation of objects, and remembering of layouts on a micro scale within a controlled laboratory. These experiments attempt to determine the nature of spatial mental processing for people with severe vision impairments (Klatzky *et al*. 1990; Loomis *et al*. 1993). The third research thread examines the viability and success of different media in communicating spatial information. The media assessed include tactile maps (e.g., Ungar *et al*. 1994), tactile strip maps (e.g., Golledge 1991), personal guidance systems (e.g., Jacobson and Kitchen 1997), talking signs (e.g., Golledge *et al*. 1998a), and sound maps (e.g., Jacobson 1998). The fourth, and least developed thread, explores the spatial experiences of people who are visually impaired, setting these within a wider socio-spatial and cultural framework, such as how they read their physical environment (Cook 1996).

The representation of space or cognitive maps is not directly observable, it is one's subjectively internalized knowledge of the environment. There are two main options for assessing the cognitive map knowledge of people who are blind: an externalization of a cognitive map, such as a sketch map, is extracted, measured, and studied, or participants are asked to complete a task appropriate for their environment (Jacobson 1998). Traditionally, the accuracy of a spatial product and its correlation to a map has been used to assess cognitive map knowledge. The implication is that the greater the accuracy, the greater the utility. However, there are problems with this paradigm, as a cognitive map may not correspond to the same metrics (e.g., Euclidean) as the map used for comparison. The main options for assessing cognitive map knowledge are summarized in Table 2.2 (see Kitchin and Jacobson 1997 for detail).

Currently we are unsure whether people with visual impairments differ from individuals who are sighted in what they know about geographic space, or in how their knowledge is structured. Cognitive mapping research may provide a baseline for further research, suggesting what information is needed by people with visual impairment, and how this information can best be presented.

Table 2.2 Tests to measure configurational knowledge (From Kitchin 1995).

Category	Variations
Graphic tests	Basic Normal Cued Longitudinal Language
Partially graphic and reconstruction tests	Spatial cued response Cloze procedure Reconstruction
Uni-to-multidimensional tests	Metric multidimensional scaling Mnonmetric multidimensional scaling Projective convergence
Recognition	Map/configuration recognition Aerial photograph recognition

2.2.4 Communicating Geographic Space to People who are Blind

Our language and thinking is imbued with spatial constructs and metaphors that shape our ways of acting and communicating (Jacobson 1999). However, for people with little or no vision, who have limited access to the world, mobility within the geographic world is severely limited. Even more restricted is their access to representations of the environment (e.g., maps), and more abstract concepts, such as tables and graphs that are fundamental in education and daily life. These representations are frequently inaccessible for people who are blind because they primarily rely on the medium of vision.

With the rise of mass media and the accelerating development of computer technology, information is becoming a more valuable commodity. Computer interfaces, from textual interfaces to graphically based Windows, allow people with no sight to access this information more readily. At present there appear to be two possible means in which to develop a non-visual medium of spatial communication (Jacobson and Kitchin 1997). One method is to develop a system based upon *touch* that conveys relative spatial relations. The second method is to develop a system based upon *spatial language*, or in other word, to develop a "talking" medium. Both methods of language and touch have been utilized in trying to create non-visual media to convey spatial information to the person who is blind.

2.2.4.1 Tactile Maps

A tactile map is "a map which is designed and constructed to be read by the sense of touch, requiring portions be elevated in the third dimension." (Walter and Robinson 1983, p.70). Tactile maps have the potential to contribute to the cognitive maps of people with visual impairments in several ways. They have the potential to provide geographical information about distant places, such as other countries, that could not be experience directly (Ungar *et al*. 1997). For years tactile maps have been used in education to convey ideas with a spatial component (e.g., Dodds 1988; Golledge 1991; Ungar *et al*. 1996). Most of the research has been concerned with the design and production of tactile maps, such as the issue of cartographic communication (Sherman 1955; Sherman and Heath 1958). Braille is commonly used for labeling on tactile maps. This poses some problems, however, since Braille can only be read by 15-25% of the blind population (Gill 1997). Braille cell size is also far larger than any equivalent conventional lettering on a visual map. It must also be oriented horizontally, and be of fixed dimensions and spacing.

The representation of geographic information on a tactile map and the subsequent understanding of that information have been explored both through the use of cartographic communication theory, and later through research on visualization (Jacobson 1999). Early theories borrowed ideas from the electronics industry, applying electronic communication models to maps. The cartographic model of communication incorporates the complex process of selection and interpretation between the source (the cartographer) and the destination (the map user). In visual cartography, the representation of the geographic world is created by the visual sense of the cartographer, and is read visually by the reader. As a result, the cognitive conception of the area being mapped has a greater potential for overlap. With tactile cartography, the matching of these two concepts is more difficult. This discrepancy is due partly to the methods of coding the message, where the cartographer's visual sense has to be matched with the tactile perception of the user. Although maps present an overall view of an area, they have to be explored sequentially by the user who is blind, which places great demands on memory. Information has to be integrated from the hand movements and the fingertips. Differences in the effectiveness of scanning strategies, and how these are taught will influence the usability of the maps (Ungar *et al*. 1996). Throughout the 1980s the increased adoption of computing techniques related to tactile map production has increased the flexibility of the map production process. These include the creation and placement of symbology, the conversion from typed text to Braille, and more control of peripheral devices such as Braille printer and voice synthesis.

2.2.4.2 Novel Methods for Representing Geographic Space

There has been an increase in the number of assistance devices for people with visual impairments or blindness. Most of these have been mobility devices (Table 2.3). These aids only assist mobility within the immediate vicinity of the user, but provide no contextual frame of reference incorporating information from further away. Recently more sophisticated technological aids have been developed to help utilize advances in computing. All of these devices (e.g., NOMAD - an audio-tactile graphics processor, personal guidance systems, Atlas Speaks/Atlas Strider) use GIS databases to underlie their use. Devices within the orientation and mobility category tend to use language interfaces, while those in the learning category use a mixture of both tactile and language media. However, it is pointed out that these technologies are not intended to replace simpler mobility aids but rather to supplement them.

Table 2.3 Listing of the assistive devices for people with visual impairment and blindness (From Golledge and Stimpson 1997, p. 499).

■ Long cane	■ Atlas Strider
■ Joople	■ Talking Signs
■ Guide dog	■ Auditory beacons
■ Human assistant	■ Electronic strips
■ Laser cane	■ Motion detectors
■ Mowat sensor	■ Pressure detectors
■ Sonic guide	■ Bar code readers
■ Nottingham Obstacle Detector	■ Beacons
■ NOMAD	■ Braille/Auditory compass
■ Tactile displays/maps/arrays	■ Vision enhancing devices (monocular)
■ Personal guidance system	■ Infrared detectors
■ MoBIC (Mobility of blind and elderly interacting with computers)	

One approach to presenting geographic space to an individual who is visually impaired is through an audio-tactile, multimedia, map-based approach (Jacobson and Kitchin 1997). Computer audio based systems can augment the line work on a tactile graphic by user friendly interface. When the map is touched, the corresponding sound label is triggered. The labels of the objects within 'real space' such as 'tree', 'path', and 'library' are spoken through a pair of headphones and appear as virtual sounds at their correct locations within the auditory space of the traveler. As such, objects appear to 'announce' themselves with the sound emanating from the geographic location of the landmark. Such systems include NOMAD (Parkes 1988) and talking tactile maps (Blenkhorn and Evans 1994). The touch pad can be connected to any personal computer. Audio is generated through an internal or external speech synthesizer, and additional sounds can be added or created using commonly available sound production software and hardware. These devices are evolving into digital sound map representations of the geographic world.

2.3 Part Three: Perception in Sound

2.3.1 Perceptual and Cognitive Considerations in Sound versus Visualization

Visualization has been employed for centuries as a powerful way to present information. Chart and graphing techniques (Tufte 1998b) and maps and cartography (Tufte 1998) are well-established ways to represent information. To replace sight, which is a rapid and precise way of conveying graphical information about many objects simultaneously, it is essential to investigate the use of many interactive modalities. While voice synthesis and braille can be used for textual information, audio output can also enable the users who are blind to review spatially organized information, and to navigate and explore spatially structured user interfaces. Several studies have explored the use of "earcons" (auditory icons) to complete the graphical metaphor (Blattner *et al*. 1989; Brewster *et al*. 1995; Leinmann and Schulze 1995). Gaver (1989) examined the use of earcons in computer interface to provide information about sources of data. Dufresne *et al*. (1996) proposed facilitating access to graphical information by allowing direct manipulation through the use of tactile and auditory modalities. With the people who were blind, however, they found it difficult to preserve the diversity of the graphical display while transposing it to auditory simulation.

Abstract sound variables have been used successfully in many disciplines aimed at the presentation of complex multivariate and geometric data. Yeung (1980) presented seven chemistry variables through abstract sound reporting a 90% correct classification rate prior to training and 98% correct response after training. Mansur *et al*. (1985) found comparable information communication capabilities between sound graphs and tactile graphs, with the auditory displays having added benefit of being easier to create and quicker to 'read'. These sound variables had the potential to clarify and synthesize complex data, allowing for more efficient visualization. Sound has recently been used to convey information in a geographical context. For example, Golledge *et al*. (1998) used sound in a virtual auditory display for a personal guidance system; NOMAD was used to geocode areas of a tactile map with sound (Parkes 1988); sound has been used to represent classification reliability on remote sensing images (Fisher 1994); and Greene (2000) utilized the sound variable of pitch to represent the elevation data on a topographic map.

Although sound can be effective for representing data in a variety of settings, in order to design an effective sound interface, it is important to consider the perceptual differences between hearing and vision (Table 2.4) (Members of the International Community for Auditory Display 1997). First, auditory perception is particularly sensitive to temporal characteristics, or changes in sound over time. This is the advantage of auditory over visual displays, since human hearing can detect small changes in the frequency of continuous signals that might be missed by a visual display. Dufresne *et al*. (1996) found that long-lasting continuous sounds can be annoying, especially for activities such as writing. Thus, continuous sounds should be used only if objects are small. However, in order to perceive and manipulate small objects, it is important that they be associated with longer sounds. Second, unlike visual perception, perception of sound does not require the listener to be oriented in a particular direction. Therefore, audio display can be used in situations where visual attention is diverted from other tasks. Dufresne *et al*. (1996) found that relative differences, such as increasing or decreasing pitch, are easily perceived.

Table 2.4 Benefits of auditory display (From Kramer 1994, p.6).

Quality	Application / Advantage
■ Eyes free	Monitoring where other variables or tasks must be observed visually; complex or quickly changing visualizations; interface is vision impaired.
■ Rapid detection	Monitoring; high-stress environments.
■ Alerting	Monitoring; high-stress environments; general interfaces.
■ Orienting	Data exploration, indicates areas of interest. In monitoring tells the eyes where to look.
■ Backgrounding	Monitoring or exploring very large data sets.
■ Parallel listening	Exploring high-dimensional systems; monitoring multiple processes; comparing multiple data sets.
■ Acute temporal resolution	Time-sequenced data; broad dynamic range (milliseconds to several thousand milliseconds).
■ Affective response	Ease of learning; engagement; convey subtle qualitative information.
■ Auditory gestalt information	Discerning overall relationships or trends in data; picking out meaningful events or states in a stream of data.

Other aspects of sound perception lie on the promise of sound as a medium for data display. These aspects include affective response (ease of learning and high engagement qualities) and auditory gestalt formation (discerning relationships or trends in data streams) (Kramer 1994). As a result, perception of sound can help illuminate the optimal means of mapping data to specific dimensions of sound. However, sounds are sometimes harder to interpret than visual cues, because they are dependent on the user or on the system's activity (Dufresne *et al*. 1996). Ongoing research in auditory perception that is particularly relevant to sonification includes dynamic sound perception, auditory scene analysis, auditory memory, and the role of attention in extracting information from sound (Members of the International Community for Auditory Display 1997).

2.3.2 Abstract Sound Variables

The combination of visual and sonic displays is one approach to dealing with the increasing complexity of geographic information. Key auditory variables that can be used in the presentation of geographic data were presented by Krygier (1994). These abstract sound elements include location, loudness, pitch, register, timbre, duration, rate of change, and attack/decay. Krygier discusses separately each of the abstract sound elements and their effectiveness for representing nominal and ordinal data (Figure 2.7). These variables have the potential to convey more complex relationships found within geography, such as pattern, relation, or hierarchy.

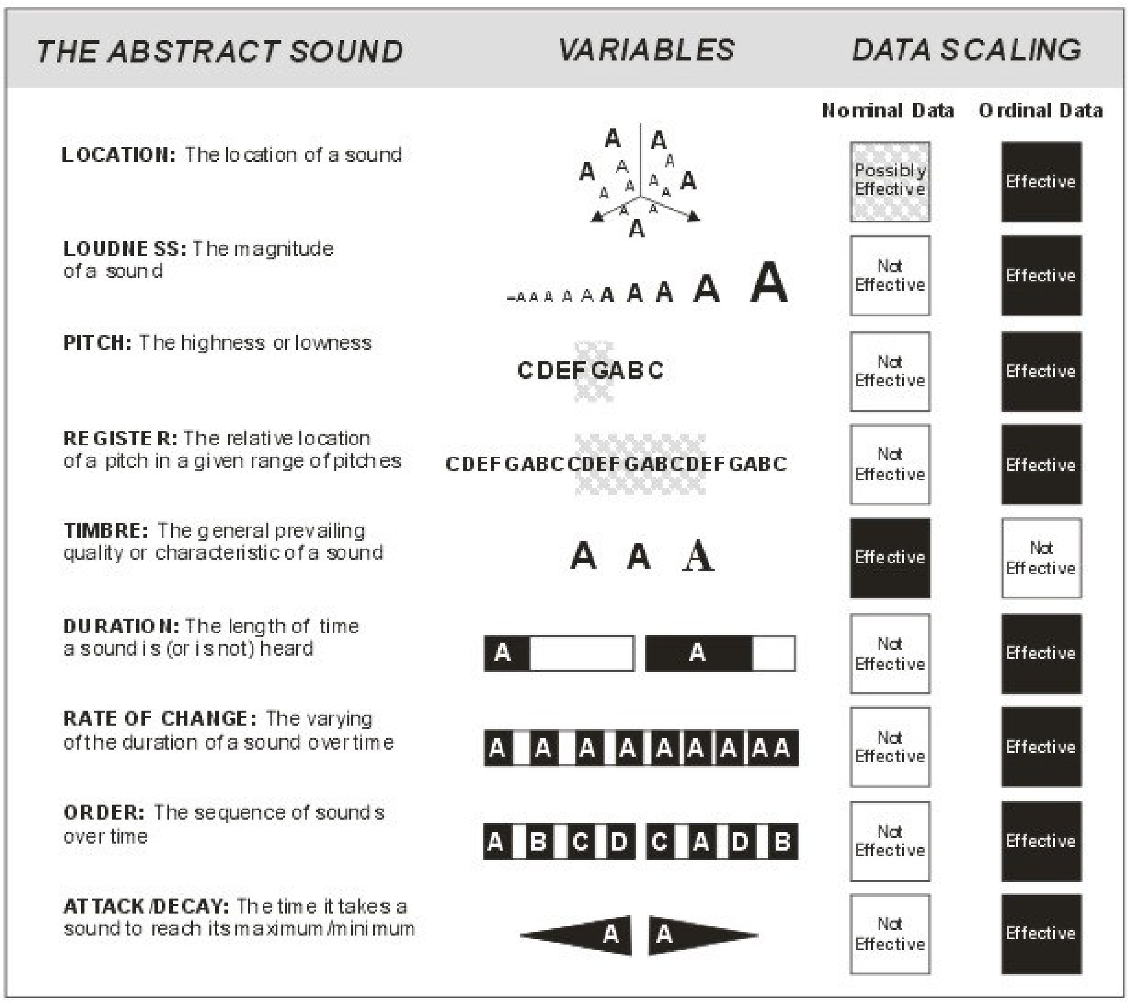


Figure 2.7 Abstract sound variables (After Krygier 1994, p.153).

Location relates directly to the location on a two- or three-dimensional space, such as a spatially referenced verbal landmark on a touch pad. **Loudness** is the magnitude of a sound, measured in decibels. The inherent order of loudness makes it appropriate for representing ordinal data. **Pitch** is the highness or lowness (frequency) of a sound. It is easily distinguishable by most people because of its large but finite options. In Western music pitch is usually divided into eight octaves of twelve pitches each. Thus, there are ninety-six possible unique pitches. **Register** is the relative location of a pitch in a given range of pitches. In other words, register describes where a pitch is within a set of available pitches. **Timbre** is the general prevailing quality or characteristic of a sound. The difference between the same pitch played on different instruments is a difference of timbre. Therefore, the variable of timbre would be suited to represent nominal rather than ordinal data. **Duration** is the length of time a sound is or is not heard. **Rate of change** relates to the varying of duration of sounds and silences over time. **Order** is the sequence of sounds over time. **Attack/decay** could relate to the spread of a phenomenon over time. The attack of a sound is the time it takes that sound to reach its maximum loudness. Decay is the time it takes for a sound to return to its minimum or silence.

All sound variables are not wholly independent of each other, and therefore exhibit behaviors that are correlative to one another and to the degree of change. However, they represent the collection of alternatives when selecting auditory signals and the qualities of sound that listeners can distinguish.

2.3.3 Multimodal Presentation of Geographic Space

The majority of geographic representation aids have been predominantly visual in nature. However, an advance in the field of human computer interaction interface allows designers to expand the functionality of the interface

Table 2.5 The sensory variables used for information representation through a multimodal interface (From Jacobson 1999, p.100).

■ **Sight / Vision**	■ **Touch**
Horizontal position	Position
Vertical position	Size
Depth position	Shape
Shape	Elevation
Size	Intensity / sharpness
Length	Texture / roughness
Area	Frequency
Volume	Outline
Angle	Density
Curvature	Interval
Color	Orientation
Hue	Vibration
Value	Locus
Saturation	Frequency
Orientation	Amplitude
Pattern / texture	Duration
Roughness	Temperature
Transparency	Pain
Focus	Pleasure
Reflectivity	
Time-varying parameters	■ **Kinesthesis / Proprioception**
Blinking	Position
Movement	Movement
Change	Effort, tension/force
■ **Hearing / Audition**	■ **Vestibular Perception**
Location	Direction
Direction	Orientation
Pitch / frequency	Acceleration
Damping	Rotation
Duration / repetition	
Rest	■ **Smell / Olfaction**
Attack rate	Fragrance
Decay rate	Concentration
Phase	Essence
Envelop	
Ewave shape	■ **Taste / Gustation**
Timbre	Sweetness
Intensity	Saltiness
Reverberation	Bitterness
Harmony	Sourness

to incorporate other modalities. *Modality* refers to perception via one of the perception channels, the type of communication channel used to convey or acquire information. In general, a multimodal interface supports communication with the user through many modalities, such as vision, voice, gesture, and typing (Jacobson 1999). In fact, humans engage nearly all of their sensory modalities when traversing space. Table 2.5 illustrates a wide range of sensory variables that are possible to present through a multimodal interface. Multimodal interfaces are often developed for specialist situations where vision is not available, such as a military situation (Cohen and Wenzel 1995). The multimodal presentation of geographic information allows for innovative visualization of large and complex data sets (e.g., Fisher 1994; Flowers *et al*. 1996). It also provides intuitive interaction with geographic information, making it accessible and easy to use (Oviatt 1997).

Brooks (1977) suggests that providing information through more than one sensory modality offers another independent channel to the brain, a channel whose information is assimilated subconsciously. By making use of these additional input channels, the amount of information that reaches the brain is increased. This can reduce the error and time taken to complete a task. With suitable design parameters being addressed, it may be possible to effectively communicate spatial scenes without vision. This implies it is possible to represent geographic space without the need for vision.

2.3.4 Audio Interfaces

A fundamental principle of Auditory Display is that the listener must be capable of detecting sounds and sound changes that represent information in the display system. Further, it is essential that particular configurations of sound parameters convey consistent percepts to the user (Williams 1994). Problems related to parameter overlap and distraction are amongst the pitfalls one encounters in constructing a multivariate auditory display. Even if sound parameters that do not directly interface with each other are used, the fact that our attention is drawn more to certain variables than other makes the design of a balanced auditory display virtually impossible. For example, changes in pitch generally draw a listeners attention more forcefully than the loudness variable (Kramer 1994a). Therefore, a display employing these parameters is influenced by the perceptual impact of the auditory variable, which in turn may skew the observer's perception of the relative importance attributed to other data variables.

2.3.4.1 Design Considerations of Audio GUIs

The graphical user interface (GUI) is the most crucial component in any form of human-computer interaction. It is the medium through which geographic information is presented to the user, and the tool with which the user manipulates and interacts with the data. Each sensory modality has its own perceptual domain, a range of information to which it is particularly well suited. Presenting information of a certain type in a particular modality may be the most efficient and economical way of displaying that information. However, interface designers should remain cautious. Sounds are allocated to perceptual groups depending on their perceived attributes, rather than a direct result of the attributes of the acoustic signal. The resulting percept may depend on attentional factors, previous training, or familiarity with similar sounds (see Bregman 1990). Kramer (1994a) suggests some techniques that can be used to create a balanced, or unbiased, auditory display. These include mapping down the range of the auditory variable, multiple mapping of the data to more than one variable, and employing a range of mapping variables for the data set.

1) Scaling: Scaling the range of auditory variables is accomplished by narrowing the upper and lower limits of that variable in the sound generator. For example, one could limit the highest and lowest pitch that the full range of data may produce (i.e., from seven octaves to one octave), thereby reducing the variability induced by all the intermediary data points. The result may produce lower resolution from the pitch variable, but at the same time, it may serve to help balance the display.

2) Multiple Mapping: Multiple mapping of the data to more than one variable may highlight the contour of the chosen data variable. Some parameters, such as attack time, are difficult to perceive. Therefore, they may be used to incrementally adjust the perceptual impact of the input data.

3) Variety of Mappings: A variety of mappings refers to auditory mapping where each data stream input into the map is sequenced through a selection of auditory variables. This may be considered analogous to re-mapping colors or rotating an object in a three-dimensional visual data display. In this way, the system user may listen to the same data a number of times with different mappings and decide which mapping most satisfactorily displays the meaningful contours he is looking for in the data.

2.3.4.2 Metaphorical Association in Auditory Display

Multimodal interfaces through the use of other modalities and natural tasks, like sketching, afford a natural interaction between the physical space of the interface and the geographic information being represented. In an interface accessed without vision, a metaphorical understanding of the interface is even more crucial in order to aid visualization. A metaphor allows us to understand one thing in terms of another. Metaphors are highly relevant to interactions with representations of the real world, such as maps. As the real world cannot be mapped at one to one, a form of metaphorical translation, transformation and mapping has to occur.

Metaphorical association is the association of a physical world variable with a metaphorically related change in an auditory display. In representing the data with sound, the metaphor of 'more' sound can be used to indicate more of what is being represented by the data. Thus, a change in the quantity of these measures may be represented by a change in loudness (volume) or by changing the magnitude of another sound variable. The metaphor concept to sound variables includes (Kramer 1994a):

- **Louder is more**: Based upon the physical reality that large objects usually make louder sounds than small objects. Also louder sounds move more air and so have greater sensory impact.
- **Brighter (harmony) is more**: Based upon the physical properties of sound, a sound that is perceived to be bright typically has more high harmonics or more energy in the upper partials of the sound.
- **Faster is more**: Based upon the observation that more of a certain event occurs within any given time frame, all else being equal.
- **Higher pitch is more**: Based upon the physical fact that higher pitched sounds have more vibrations per second. It is more likely that the 'higher pitch is up' metaphor combines with the 'up is more' metaphor to produce the net association. The 'up is more' metaphor is grounded in the physical experience of adding more to a pile, and thus making it higher.
- **Higher pitch is up**: This metaphor may be related to the perceptual phenomenon of higher pitched tones being perceived as originating from higher in space (Pratt, 1930). It may be related to the physiology of using the voice to produce a higher pitch often look up or stretch their necks upward when vocalizing high-pitched sounds. It may also be derived

from the cultural imprinting of the graphical representation in which a higher note is higher up on the page.

- **Higher pitch is faster**: Based upon the physical fact that higher pitches are associated with faster vibrations, or more cycles per second. For example, the faster the machine runs, the higher the pitch area of the sound that it emits.

2.3.5 Applications of Sonification

The study of auditory perception is multi-disciplinary, integrating concepts from human perception, physics, psychology, physiology, hearing science, computer science and music (Members of the International Community for Auditory Display 1997; Welch 1997). The progression of hardware and algorithms has provided users with increasingly powerful interactive three-dimensional graphics with corresponding breakthroughs in representation of spatially indexed data. Meanwhile, sophisticated interaction methods have made it possible to efficiently explore dynamic data sets (Tufte 1998a). Software enhancements that encourage exploration of symbolic data representation by sound have also lead to useful creative developments for a variety of applications. Flowers *et al*. (1996) suggested that making data sonification tools more accessible to standard software packages could further aid experimentation in a number of data-related domains.

Sonification is defined as the transformation of data into perceived relations in an acoustic signal for the purposes of facilitation, communication, or interpretation (Scaletti 1994). This would include mapping data to pitch, brightness, loudness, or spatial position. Sonification is highly relevant to auditory cartography (Krygier 1994). Many research areas in sonification focus on the identification of applications for which audition provides advantages over other modalities (i.e. visual modality). These applications are currently being explored for users who are sighted and visually impaired. One of the most straightforward ways of using sound to describe changes in magnitude of a single dependent variable is to code it by pitch. For example, Mansur *et al*. (1985) showed the potential utility of this approach as a display format for users who are blind or visually impaired, and demonstrated that only minimal training was necessary to assess basic function characteristics, such as linearity and relative slope differences. Flowers and Hauer's (1995) sonification efforts have continued to use pitch and timing as the primary information-carrying dimensions. Subjective reports from participants also indicate that pitch coded auditory function graphs were relatively effortless to perceive. Walker and Kramer (1996) examined metaphors employed in the temperature-to-pitch mapping where rising pitch signaled a rise in temperature. The result indicated that the human's mental model of the data space (i.e. temperature) seemed to correlate well with the display space (i.e. pitch).

Regardless of the application area, advances in sonification depend upon the existence of flexible and usable tools for sound production and display. In order to provide an adequate perception of sound-source elevation (i.e. vertical position) and to avoid unreasonable increases in localization errors, individualized HRTFs (head-related transfer functions) must be used in current displays (Wenzel *et al*. 1993). Several laboratories are developing more efficient ways to customize these synthesis techniques to fit individual listeners. Although the use of nonspeech audio to convey information is rapidly maturing, it is still at the technical and conceptual stage.

CHAPTER 3

EXPERIMENTAL DESIGN AND PROCEDURE[1]

This research investigates the application of sound variables of pitch and duration to enhance the interpretability of topographic maps. Subsequent sections detail the steps and techniques utilized in order to perform the statistical and cognitive map analyses.

3.1 Map Selection

The Digital Raster Graphics (DRG), which were scanned images of the USGS standard series topographic maps, using a scale of 1:24,000, was used as a base map in the experiment. These maps were selected according to the following criteria (Greene 2000):

3.1.1 Contour Interval. The contour intervals vary, depending on the complexity of the terrain and the scale of the map. For the sake of simplicity, a map with a 10-foot contour interval was selected for the investigation.

3.1.2 Topographic Variability. In this experiment, maps that had large terrain variability (topography) were selected. This map generally has greater relief, steeper slopes represented by the contour lines that are close to each other on the map, and contains different spatial features, such as hill, valley, and stream.

---

[1] The experimental design for this research has been approved by the Institutional Review Board (IRB). See Appendix A for an approval form.

3.1.3 The General Appearance. Since this research is focused on determining the topography of the environment, large urban areas, complex road networks, and other cultural features (i.e. golf courses, quarries, communication lines and utilities , etc.) were avoided.

The maps that were used in this experiment were subsets of the USGS 7.5 minutes series, specifically topographic maps in rural areas from Thomas and Dade Counties, Georgia (Figures 3.1 and 3.2). The portion of the map used in this experiment was approximately equivalent to 3.5 inches by 3.5 inches on a printed map, covering an area of 4.63 square kilometers. These subsets of maps were on-screen digitized and enlarged by an additional 100 percent to enhance visualization and to facilitate in tagging the contour lines with their corresponding notes. This resulted in all of the features on the maps, symbols, and contour lines appearing two times larger than their paper counterparts to accommodate for the effects of on-screen display.

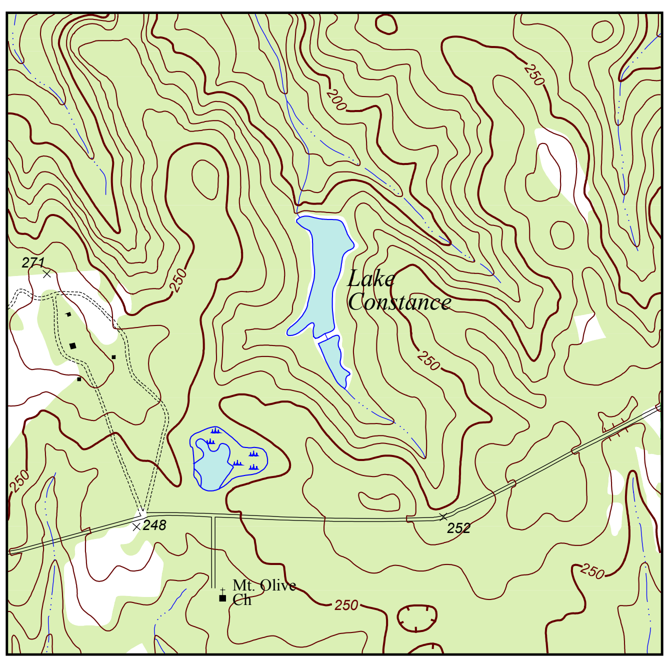


Figure 3.1 A subset of map in Thomas County, Georgia. Scale 1:24,000.

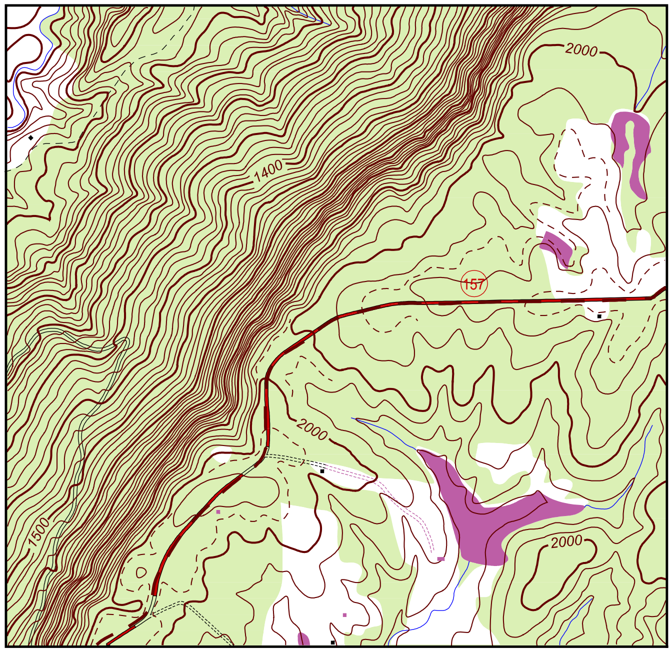


Figure 3.2 A subset of map in Dade County, Georgia. Scale 1:24,000.

3.2 Respondents

The participants in this research were college students at the University of Georgia and other individual volunteers from outside. The sample group consisted of individuals who are sighted and those who are visually impaired or blind.

3.2.1 Individuals who are Sighted

Seventy-three participants, both graduate and undergraduate students participated in this experiment. The sighted participants consisted of 46 males and 27 females, who were between 18 and 56 (mean 22.6; s.d. 5.8 years) years of age. Participants were volunteers from the Cartography and Graphics lab sessions and were given extra credit toward their laboratory class grade for their participation. Other volunteers were colleagues in Geography Department and students enrolled in the Seminar in Climatology and the Weather Analysis and

Forecasting class. The participants were arbitrarily assigned to one of two groups as they entered the testing area so that there were thirty-six people in the first group and thirty-seven people in the second group. Participants in the first group were instructed to view Tutorial 1 which explored the topographic maps without augmentation of the auditory display. The participants in the second group were given sonically enhanced maps in which the sound variables pitch and duration was incorporated to explore (Tutorial 2). The tutorials provided for these two groups were identical except the instruction of how to explore the sonically enhanced maps.

3.2.2 Individuals who are Visually Impaired or Blind

The participants in this group had diverse visual impairments and consisted of individuals who are visually impaired (legally blind but with some residual or peripheral vision) and those who are blind (both congenital and adventitiously blind). These participants were assigned to explore sonically enhanced maps in which the sound variables and voice-over were incorporated (Tutorial 3). Thirty-five participants participated in this experiment while only thirty-one included in the analysis. One participant reported having hearing deficiency and was removed because all map quiz questions were related to sound determination. Three participants were also removed due to incomplete answers during the test.

The recruitment was announced and conducted through the local organization, VISTA (the resource center for the blind and visually impaired in Athens), and other service centers in Georgia. The majority of participants had not been involved in this type of research, but some had experiences in tactile map reading. Two participants were recruited from the Office for Disability Services at the University of Georgia and seven participants were volunteers from VISTA. The Blind and Low Vision Services of North Georgia in Smyrna provided five participants and the American Foundation for the Blind (AFB) in Atlanta provided nine participants for this research. The other eight participants were contacted individually by the researcher. Participants in this group, who had either contacted the researcher directly or whose names had been passed on to the researcher via the above organizations, were contacted. Information was given about the project and contact details were taken. Then, appointments were made at their convenience.

The participants with visual impairments consisted of nine males and ten females, who were between 24 and 75 years old (mean 47.8; s.d. 12 years), and had been partially sighted between one and 54 years (mean 33.3; s.d. 16.6 years). Nine of the participants who are visually impaired were born visually impaired, four of them lost their vision prior to their teens, and six of them lost their vision later in life.

The participants with blindness consisted of four males and eight females, who were between 25 and 64 years of age (mean 47.5; s.d. 12.7 years), and had been blind between two and 64 years (mean 27.4; s.d. 22.6 years). Only one participant was congenitally blind, three of the totally blind participants lost their vision prior to their teens, and the remaining ones became blind later in life (after 21 years of age).

3.3 Methodology

Since the participants in this experiment consisted of individuals with sight and those with visual impairment or blindness, the creation of graphical and audio interfaces were designed to use hypermedia to convey spatial information. Hypermedia is comprised of text, still and animated images, and sound recordings. It allows people with visual impairments a 'virtual' way of exploring the environment (Jacobson and Kitchin 1997). This technique has also been proven extremely useful in cartographic visualization.

3.3.1 Designing the Interface

The development of a tutorial interface was accomplished with the software package *Macromedia Flash MX*. This package has sound and interaction capabilities that enabled the participants to view, hear, and reply in one interface. *Flash MX* has a built-in programming language, "Action Script", that allows the use of a clock to keep track of the time it takes the participant to answer a question. It also has the capability of storing multiple sequences of events so that the user can return to the tutorial section at any time.

Three tutorials were created in this experiment. The tutorial section included descriptions of the basic fundamentals of topographic maps as well as an explanation of how the sonically enhanced map works. The tutorial was designed to flow like an interactive web site in which a series of individual screens of text were seen by the participants. At the bottom of each screen were buttons that linked to the next page or previous page of the tutorial (Figure 3.3). Since the same information was presented to the participants who are sight and those who are visually impaired, the researcher decided not to include any graphics in the tutorial sections. This was to ensure that all participants were given the same amount of knowledge to explore during the testing sequence. The first and the second tutorials were created for the participants who are sighted in groups 1 and 2, and the third tutorial was designed for the individuals with visual impairment or blindness in group 3. The content in the tutorial sections were the same for all groups except for an instruction of sound in Tutorials 2 and 3. The voice over was also integrated in Tutorial 3 in order to help the participants with no sight navigate through every page of the tutorial.

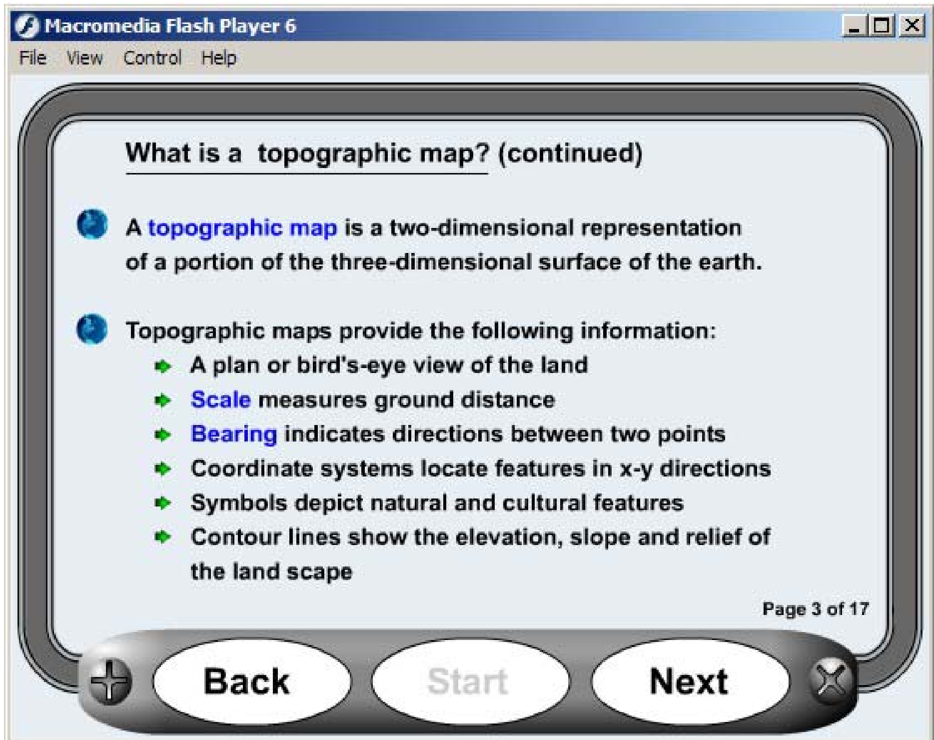


Figure 3.3 An example of tutorial provided for the participants who are sighted.

3.3.2 Sound Generation

The sounds used to sonify the elevation data were generated using a Musical Instrument Digital Interface (MIDI). MIDI is a communication protocol that allows electronic musical instruments to interact with each other. It operates on 16 different channels, numbered 0 through 15. In its most basic mode, MIDI information tells a synthesizer when to start and stop playing a specific note. Other shared information includes the volume and modulation of the note. MIDI information can also tell a synthesizer to change sounds, master volume, adjust modulation devices, and even how to receive information (Lipscomb 2001). The individual piano note was recorded through the sound editor software package *CakeWalk Pro Audio 9.0* (Figure 3.4). These piano sounds were stored in the MID format, and then converted to the WAV format using the *WinGroove* software.

Next, the WAV files were edited and saved as individual files in the MPEG Audio Layer 3 format (MP3). This step was performed in the sound editor software package *CoolEdit 2000*. The MP3 format is a compression system for sounds that helps reduce the number of bytes in the sound while still maintaining the original sound quality (Brain 2001). Finally, these MP3 sounds were imported into *Flash MX* in order to sonify the contour lines.

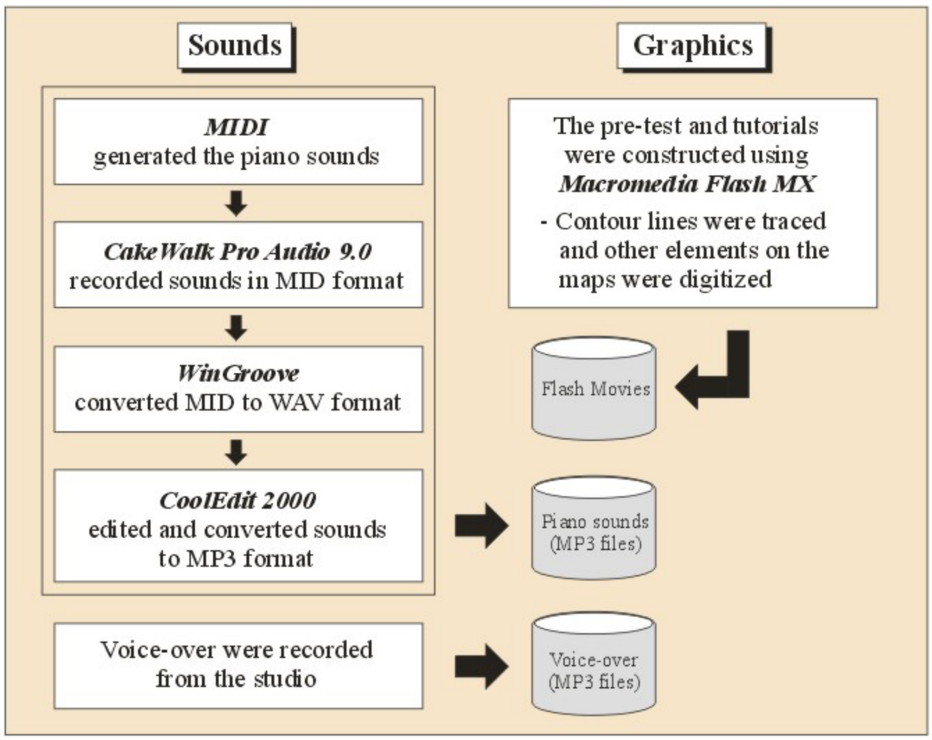


Figure 3.4 Diagram illustrates the procedures of sound generation.

The contour lines were digitized from the base map and then tagged with their corresponding pitch. Musical notes in two octaves were assigned to individual contours (Figure 3.5). These sounds varied in pitches in order to emulate elevations on topographic map from the lowest to the highest. As one traversed the map using the mouse, the pitch varied with equivalent changes in elevation. The sound labels, which are verbal audio messages, and the script provided for the participants with visual impairments were read by two professional announcers: one was from Magic 102.1 FM, a Southern Broadcasting Company radio station and the other one was from WUGA, The University of Georgia public radio station. These sounds were recorded in the studio, edited using *CoolEdit 2000*, then imported as individual files to *Flash MX*. The sound labels were attached to the features shown on the maps, such as school, church, and map legends. These labels were "spoken" when the appropriate region on screen was touched.

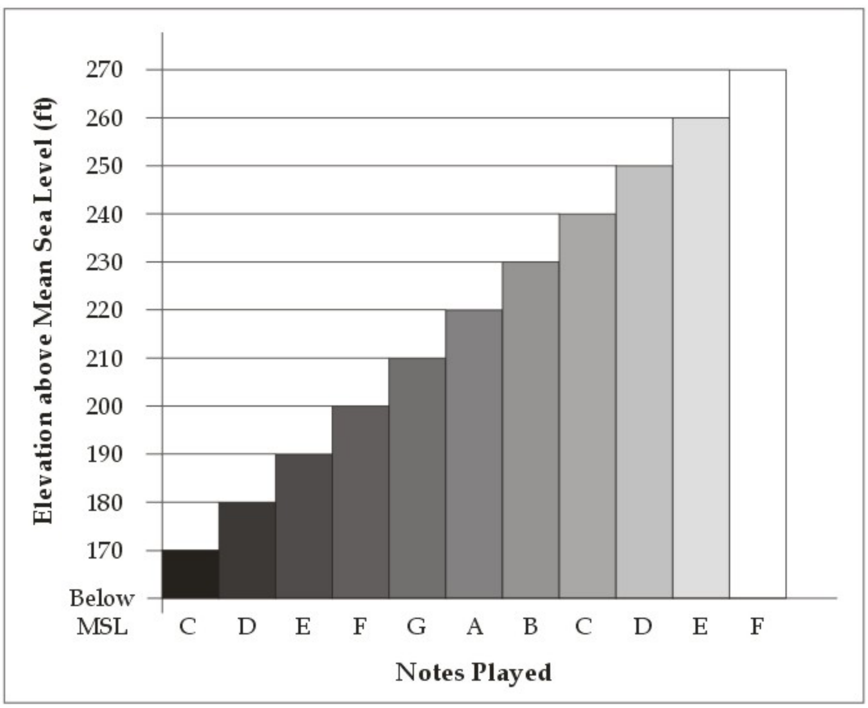


Figure 3.5 Musical notes apply to elevation data.

3.3.3 Applying Sensation

In this research, the sonically enhanced map was designed as a prototype to explore the possibilities for conveying spatial information in a “touch-audio” manner. This means all materials, including the tutorial and map questions, provided for the participants who are visually impaired were incorporated with the voice-over. An additional device, the iFeel mouse, was also used in order to allow the participants with visual impairment and blindness to perform the task on a computer. An iFeel mouse is a product from Logitech Corporation (2000). This optical mouse is well designed and includes two buttons and a scroll wheel. The iFeel mouse works in a manner similar to a conventional mouse with two key differences. First, it is an absolute pointing device rather than a relative one, so a certain mouse position will always correspond to a certain mouse cursor position. Secondly, the device is able to apply sensation, a vibration feedback to the hand, to offer varying degrees of vibration in a two dimensional plane. When the pointer is moved over icons, buttons, and links on screen, the iFeel mouse gives the user the sensation. The vibration level and other properties, such as speed and sensitivity, can also be adjusted to meet the user's capability.

In order to facilitate the participants who are visually impaired to navigate through the tutorial, the tactile effects were applied to all buttons in Tutorial 3. The sensations were customized using the *Immersion Studio* Version 4.1.0. *Immersion Studio* is a fully animated graphical environment for rapid adjusting physical parameters, feeling sensations, and then saving them as "touch resources" that can be easily accessed and played by other applications (e.g. Macromedia Flash, Microsoft Internet Explorer, or Netscape Navigator, etc.). The *Immersion Web Plugin* was also installed on the computer in order to allow codes in *Flash MX* file to cause a touch enabled tactile device to create, modify, play, or stop playing various effects. The steps for designing and adding tactile effects in *Flash MX* were as follows:

1) <u>Create</u>. Tutorial 3 was first created in *Flash MX* and saved as a Flash movie.

2) Conceptualize. In this step, the researcher decided what kinds of tactile effects would best enhance the Flash movie, where each of these effects should be placed, and under what condition it should be played. In this experiment, the researcher decided to create the *position based* and *time based effects* and apply them to the buttons in Flash movie. These effects included the *texture effect*, the *grid effect*, the *periodic effect*, and the *compound effect* (Immersion Corporation 2001).

a) *Texture Effect (Position Based Effect)*. A texture was a condition, similar to friction, which caused the mouse to feel as if it were traveling over a series of bumps. Textures were defined by the magnitude, size (thickness), and center-to-center spacing of a series of bumps (Figure 3.6).

b) *Grid Effect (Position Based Effect)*. A grid was a condition that created a 2-dimensional array of snap points or snap lines. Grid was not geometrically bounded, unless by an enclosure effect (Figure 3.7).

c) *Periodic Effect (Time Based Effect)*. The periodic effect was a force that varied over time, such as a sine wave, square wave, etc. This effect created a feeling like a simple back and forth motion or a high frequency vibration (Figure 3.8).

d) *Compound Effects*. Multiple effects were combined into a single object called a compound effect (Figure 3.9). A compound effect was basically a collection of references to other effects. When the properties (e.g. duration, magnitude, direction, etc.) of the referred effect in one compound effect were changed, those properties of the original effect were also changed and thus affected the behavior of the other compound effect.

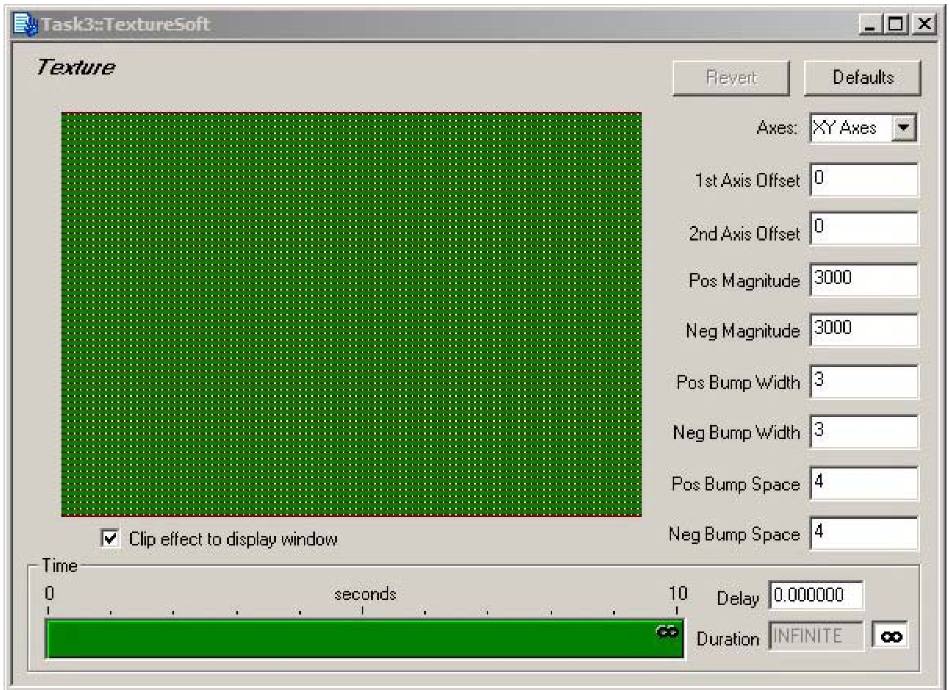


Figure 3.6 A texture effect Editor.

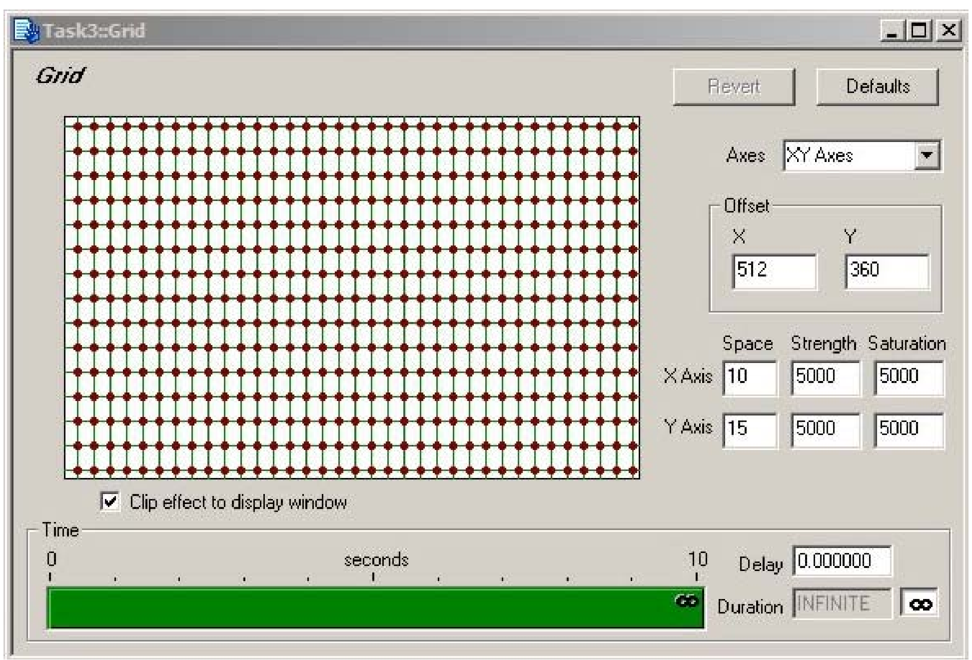


Figure 3.7 A grid effect Editor.

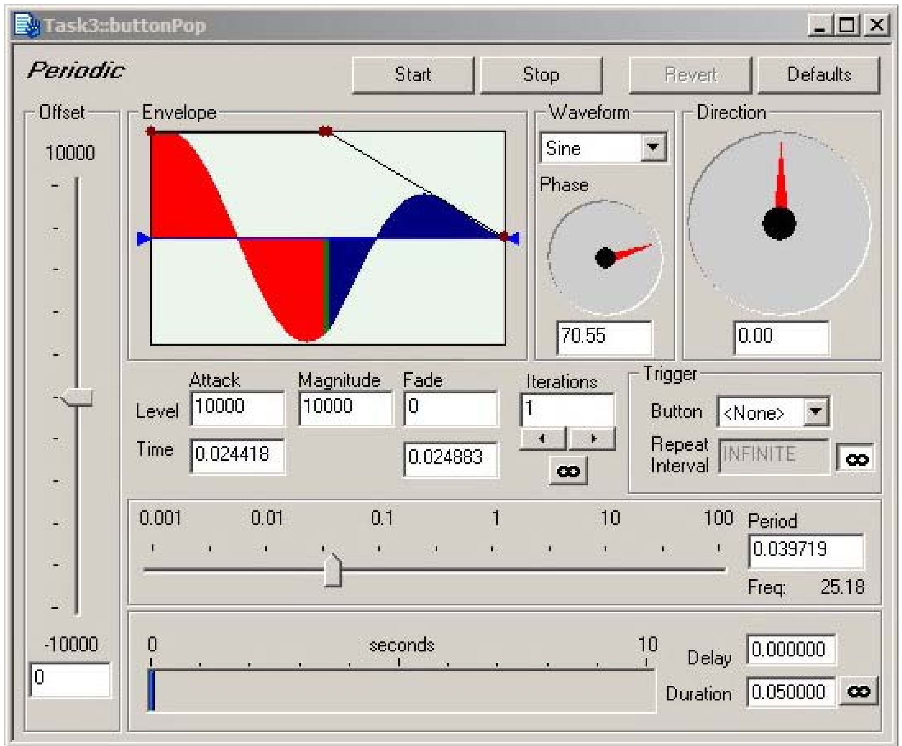


Figure 3.8 Periodic effect Editor.

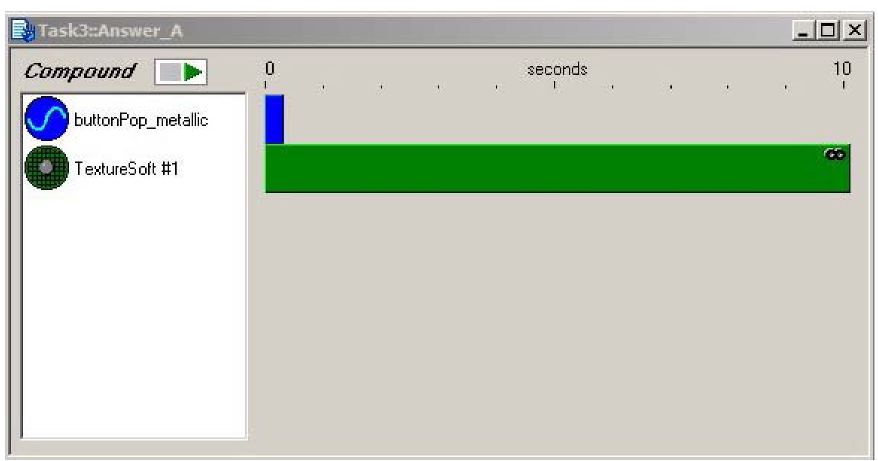


Figure 3.9 A compound effect Editor.

3) Implement. The tactile effects were then created and refined in the *Immersion Studio* application. All the effects were saved into a single .IFR file (the *Immersion Studio* document file format).

4) Command. In the Tutorial 3 Flash movie, an "FS Command Action" was added to each button where a tactile effect should be played or stopped.

5) Publish. Once all the actions triggering all the desired tactile effects had been added and saved in the .FLA file (Flash movie), the .SWF file (Shockwave movie) and the HTML page in which Tutorial 3 was played were published.

The challenge of programming for force feedback or tactile effects is not the act of coding. It is the act of designing touch sensations that appropriately match the environments. Designing touch sensations requires a creative and interactive process where parameters are defined, experienced, and modified until the sensations are just right.

3.4 Testing Procedure

3.4.1 Testing Sequence for the Participants who are Sighted

The test provided for the participants who are sighted was given in the same computer lab over a five-day period of November 12-16, 2002. Participants were brought into the testing room by groups but seated individually at a computer. They were asked to sign the consent form (Appendix B) and fill in the background questionnaire (Appendix C) prior to taking the test. The questionnaire contained several questions such as age, gender, and major subject. They were also asked to rank their map reading experience and the ability to distinguish different pitches according to the qualitative terms of "advanced," "intermediate" or "beginner".

As mentioned earlier, the participants who are sighted were randomly placed into two groups. The participants in the second group, who were assigned to view Tutorial 2, were asked to complete the preliminary hearing test on the computer before they began the tutorial. First, they were asked to identify whether the pitches of two given sounds were different. Second, they had to determine which given sound was higher or lower. Third, the participants had to place three sets of sounds in descending order from highest to lowest pitch. Fourth, they had to determine which of the two given sounds had longer duration. Fifth, they had to put the three sets of sounds in descending order from longest to shortest duration. The testing results were used to exclude the participants who had hearing problems from the study. Only the ones who passed the initial test proceeded to the tutorial section. All instructions and explanations were contained within the tutorial section, so once the participants were seated, they could begin the tutorial and work at their own pace. The researcher was present at all times during the test and assistance was provided if there were problems with the computer hardware or software. However, no questions regarding test content were answered.

3.4.2 Testing Sequence for the Participants who are Visually Impaired or Blind

The data for the group of people who are visually impaired or blind was collected between January 23rd and April 7th, 2003. The participants in this group were instructed to examine Tutorial 3 which is an interpretation of topographic maps with augmentation of sounds. A laptop with an iFeel mouse was provided for participants during the testing sequence. The steps assigned to the participants who are sighted were identical to the sighted group although different approaches were used. First, the consent form was read to the participants by the researcher. Then, they were asked to sign it before they could perform the task on the computer. Next, the researcher read the questionnaire to them and recorded the answers on the questionnaire sheet. The participants in this group were also asked to take a preliminary hearing test before they started the tutorial. This procedure ensured that the participants did not have any hearing deficiencies and that they could proceed to the next step. The researcher guided them through the pre-test section by reading the questions and clicking the buttons to play sounds for them. The participants had to listen to the sounds and answer all five questions. Their scores were then recorded.

After the participants passed the pre-test, they were given Tutorial 3 to explore. This tutorial incorporated voice-over and sensations to supplement visualization. The instructions on how to use the iFeel mouse and how the tutorial was laid out on screen were given to the participants. The majority of participants were familiar with computers and keyboards, therefore they were willing to try the iFeel mouse and explore the tutorial by themselves. Only a few participants felt uncomfortable using the laptop computer and the researcher offered guidance through the tutorial and map quiz section. The researcher was present at all times to help the participants through the tutorial, but no questions regarding test content were answered.

3.5 Tasks Assigned to Participants

In this experiment, two different tasks were assigned to the participants. (Table 3.1) The participants with sight who were placed in the first group were given Tutorial 1 to view. They were instructed to perform Task 1 which is an interpretation of topographic maps without augmentation of sound. The participants with sight who were placed in group 2 were provided Tutorial 2 to explore and those who are visually impaired in group 3 were given Tutorial 3 to navigate. These participants were assigned to perform Task 2 that utilized the sonically enhanced maps to answer questions.

Table 3.1 Tasks assigned to participants in the experiment.

Group	Participant	Tutorial	Task
1	Sighted	1) Viewing traditional topographic maps	1) Map interpretation without augmentation of sound
2	Sighted	2) Exploring sonically enhanced maps	2) Map interpretation with augmentation of sound
3	Non-sighted	3) Exploring sonically enhanced maps	2) Map interpretation with augmentation of sound

3.5.1 Task 1: An Interpretation of Topographic Maps without Augmentation of Sound

This task was assigned to the participants who are sighted only. After they reviewed the materials in the tutorial, they were instructed to perform a series of tasks on the computer. These included:

a) determining the relative elevations at a particular location on the map;
b) determining the slope of a pre-defined area according to its qualitative terms of gentle slope, medium slope, and steep slope;
c) determining the profile of the study area;
d) determining the distance between the two points on the map; and
e) identifying the topographic features on the map such as hill, valley, and depression.

The questions conducted in this experiment were in multiple choice formats. The participants were asked to complete the map quiz on the computer after they viewed the tutorial (Figure 3.10). There were a total of five question types dealing specifically with topographic data. These included questions on relative elevation, slope, profile, distance, and landform identification. The participants in this group were given a total of twenty-seven questions to answer; two of these were dummy questions (questions that are easy to answer) that were left out when performing statistical analysis. The results of the dummy questions were only used to determine whether fatigue had an effect on the participant's performance. Each type of question was asked repeatedly five times while changing the pre-defined location on the map. This yielded the total of twenty-five questions (5 question types times 5). The sequences of questions were randomly assigned in the map quiz section (Table 3.2). The answers were scored and the response time for each question was also recorded by the program. After the participants completed this task, they were told to leave the testing area quietly. The score summaries were printed out and kept for record.

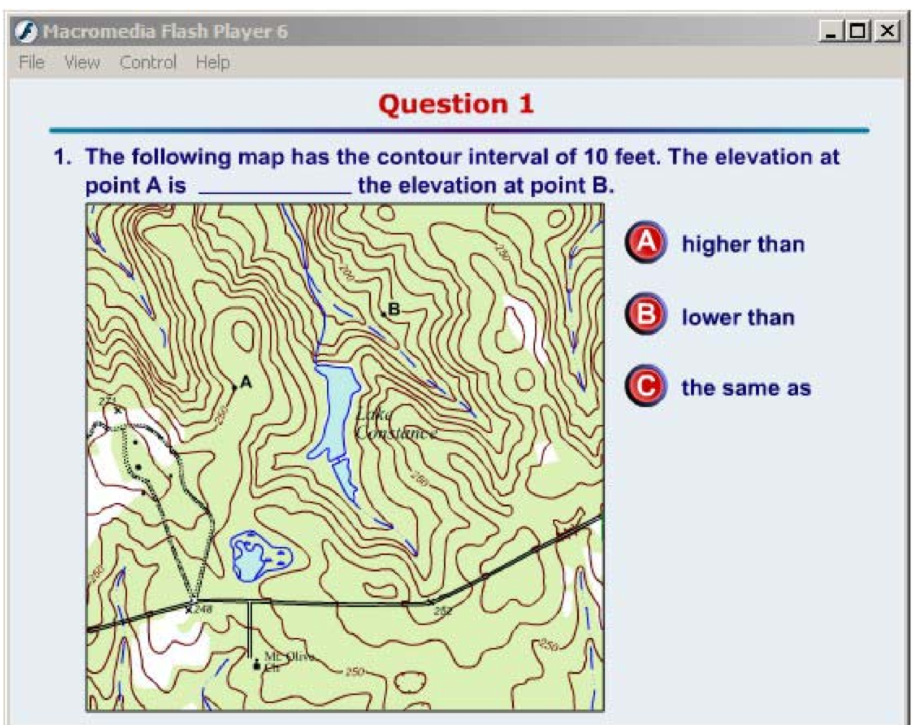


Figure 3.10 An example of map question given to the participants in group 1 who performed Task 1.

Table 3.2 Questions given to the participants who performed Task 1.

Question Type	Question	Question Number
Relative Elevation	The following map has the contour interval of 10 feet. The elevation at point A is ___________ than the elevation at point B.	1, 7, 11, 21, 27
Slope	If you travel from point A to point B, you are going _________________.	2, 6, 16, 20, 26
Profile	What does the cross section from point A to point B look like?	3, 10, 14, 18, 24
Distance	The map you view on screen has a scale of 1:48,000. How far is it from point A to point B.	4, 8, 12, 17, 23
Landform	According to the information you derive from the map, in/on what landform is point A located?	5, 9, 13, 19, 22
Dummy Question	15) Where is Mt. Olive Church located on the map? 25) The 200 and 500 contour lines that are drawn in red on the map are called ____________ contours.	15, 25

3.5.2 Task 2: An Interpretation of Topographic Maps with Augmentation of Sound Variables Pitch and Duration

The second task was assigned to the participants who are sighted (group2) and those who are visually impaired (group 3). The testing sequences for this task were conducted in the same manner as the previous one except for the addition of sound. The map provided for this task covers the same area as the one employed in the previous task. However, the goal of this task was mainly to test the usefulness of sound rather than the visual map interpretation. The participants were asked to answer the questions dealing specifically with topography. These included:

a) determining the relative elevations by listening to different pitches;

b) determining the slope of a pre-defined area by listening to a set of notes played;

c) determining the slope by listening to different pitches and duration;

d) determining the profile of the study area by listening to a set of notes played;

e) determining the profile by listening to different pitches and duration;

f) determining the distance between the two points by listening to the sounds played in different duration;

g) identifying the topographic features on the map such as hill, valley, and depression by listening to a set of notes played; and

h) identifying the topographic features on the map by listening to different pitches and duration.

During the map quiz session, the participants in group 2 were presented a blank screen with only transect lines, the "Speaker" buttons, questions, and multiple choices visible (Figure 3.11). No visual maps were given to participants except for ones in dummy questions. Sound occurred just as if the contour lines were there. Participants were then asked to determine the relative elevation, slope, profile, distance, and landform of the pre-defined area. The same set of questions was given to the participants with visual impairment in group 3. The interface and screen displayed were designed in a manner that allowed the individuals who are visually impaired to navigate through the map quiz session. The questions were read aloud and the sounds were played automatically. The sensation and voice-over were also applied to help participants locate the buttons on screen and to provide a step-by-step instruction for them. When the pointer was moved over the buttons, the voice-over was activated and the sensation was generated. If the participants would like to listen to the questions or the sounds again, they could just click the “Repeat” button that was placed on the left of the screen (Figure 3.12). The “Answer Choice” buttons were placed vertically from A to E on the right half of the screen.

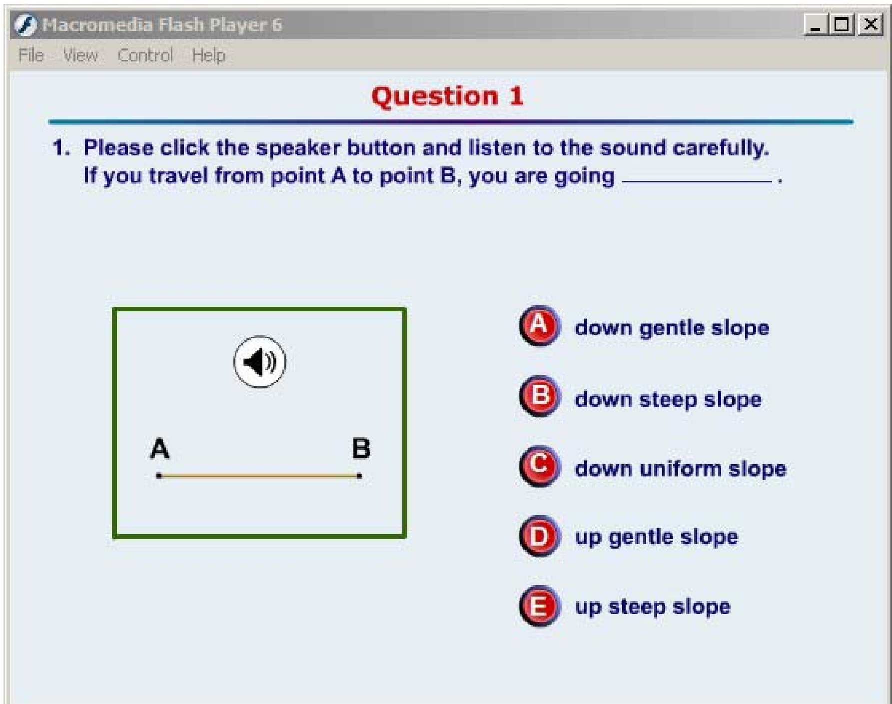


Figure 3.11 An example of map question given to the participants in group 2 who performed Task 2.

A total of forty-two questions were given to the participants in groups 2 and 3 (Table 3.3). Two of these were dummy questions and were excluded from the analysis. There were eight question types randomly asked five times in map quiz section, resulting in a total of forty questions (8 question types times 5). The correct answers were scored and the response time for each question was recorded. After the participants completed their task, they were told to leave the testing area quietly. The researcher then printed out the results and kept them for record.

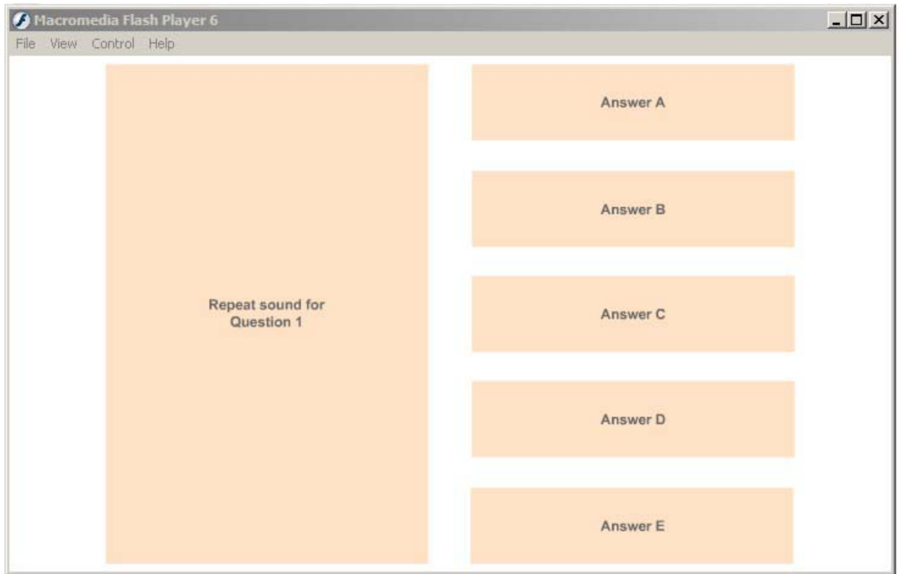


Figure 3.12 An example interface provided for the participants with visual impairment in group 3 who performed Task 2.

3.6 The Pre-test and Initial Results

Before the experiment was implemented, the initial prototype was developed with input from a few students who are sighted and visually impaired at the University of Georgia. This allowed the researcher to review the initial prototype design to ensure it would be effective with the target groups. The purpose of the pre-test was more for discovering problems with interface, especially for the individuals with visual impairment, than to examine possible results. The pre-test also helped the researcher gauge the difficulty and improve the clarity of the questions to be asked during the experiment. Using this approach, the initial results were obtained to refine the designs before the researcher tested with target groups, thus ensuring the researcher provided the best interface designs for them.

Table 3.3 Questions given to the participants who performed Task 2.

Question Type	Sound variable		Question	Question Number
	Pitch	Duration		
Slope	X		If you travel from point A to point B, you are going _______________.	1, 13, 21, 31, 35
Slope	X	X	If you travel from point A to point B, you are going _______________.	5, 16, 25, 32, 39
Landform	X		What type of landform does the profile represent?	7, 14, 23, 31, 37
Landform	X	X	What type of landform does the profile represent?	2, 11, 18, 27, 42
Relative Elevation	X		The elevation at point A is ______ than the elevation at point B.	3, 9, 17, 26, 41
Profile	X		What does the cross section from point A to point B look like?	4, 12, 20, 33, 40
Profile	X	X	What does the cross section from point A to point B look like?	8, 15, 24, 29, 36
Distance		X	The sound played on speaker 1 represents the distance of 1 kilometer. Please determine the distance of the second sound based on the first sound played.	6, 13, 22, 30, 34
Dummy Question	N/A	N/A	What does the dot on the map represent?	19 (integrating voice-over)
Dummy Question	X		What is the elevation of the red contour line shown on the sonified map?	38

The total of ten participants (seven with sight and three without sight) volunteered to perform tasks in the pre-test session. These participants consisted of graduate and undergraduate students from the University of Georgia (UGA). Only one person in the group of people with visual impairment was not affiliated to the UGA. Three participants who are sighted were given Tutorial 1 to view and four participants were given Tutorial 2 to explore (Tables 3.4 and 3.5). Most of the participants who are sighted did not have difficulty going through the tutorial and answering the questions on both traditional and sonically enhanced maps.

Table 3.4 Tasks assigned for participants who viewed Tutorial 1 during the pre-test session. Only five questions were asked in map quiz section.

Tutorial 1	Viewing traditional topographic map
Task	Map interpretation without augmentation of sound
Question Types	1) Relative elevation 2) Slope 3) Profile 4) Distance 5) Landform

Table 3.5 Tasks assigned for participants who explored Tutorial 2 during the pre-test session. Eight questions were asked after they completed the tutorial.

Tutorial 2	Exploring sonically enhanced map
Task	Map interpretation with augmentation of sound
Sound Variables	Pitch and duration
Question Types	1) Slope (using pitch) 2) Landform (using pitch and duration) 3) Relative elevation (using pitch) 4) Profile (using pitch) 5) Slope (using pitch and duration) 6) Distance (using duration) 7) Landform (using pitch) 8) Profile (using pitch and duration)

The same tutorial (Tutorial 2) and map questions were given to the participants who are visually impaired. During the pre-test session, voice-over and sensation were not incorporated to the tutorial yet. Therefore, the researcher read the content in the tutorial and map questions out loud to them. The answer choices provided for the questions pertaining to topographic profiles (questions 4 and 8) were also verbally described (Figures 3.13 and 3.14).

The participants were also asked to draw the cross sections according to the sounds they heard in questions 4 and 8. The drawings shown in Figure 3.15 illustrated that they could associate sounds with the topographic data. Although the vertical and horizontal scales were distorted, the overall shapes were maintained. The participants were able to response to map questions without difficulties as they listened to the sounds. All participants suggested that if the voice-over were included in the tutorial, it would help them navigate through the tutorial on the screen.

It was important to consider the needs of individuals with disabilities during the initial software development phase. The researcher found that it was beneficial to discuss this with the people with visual impairment early in this stage. Some guidelines and design strategies were provided as follows:

1) Use consistent, standard user-interface elements.

Create an interface that was consistent throughout the program and consistent with other applications so individuals could learn to navigate the program quickly with skills they had developed using other applications.

2) Label all graphics and icons.

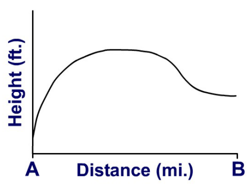
Provide text labels for all iconic elements so they could be rendered by other software. Users who were visually impaired may be able to decipher a text label easier than they could recognize an icon. Similarly, text labels helped users who are sighted learn the function of each icon.

3) Do not rely on color alone to convey information.

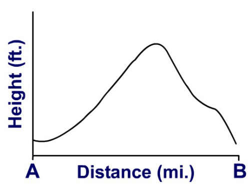
Provide redundant means of conveying information. Color-based distinctions may be invisible to people who are color blind, who are visually impaired and blind, or who use speech or Braille access technology.

Question 4 Profile (using pitch only)

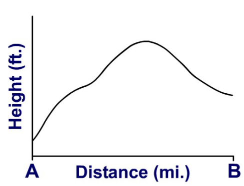
What does the cross section from point A to point B look like?



a) This sound represents a rounded hill that looks like the turtle shell. It has a steep slope on the left side and levels off on the right side.



b) This sound represents a peaked hill that has steep slopes (approximately 50^{o}) on both sides. On the right side, about half way down hill, slope is steeper.

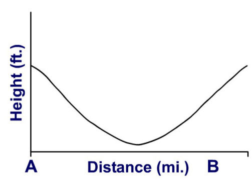


c) This sound represents a peaked hill with a wider top. It begins with a steep slope on the left side and continues to go up. About half way up, there is a break in the slope and levels off. Then it continues to the top of the hill. On the way down hill, the slope is gradual and extending half the altitude of the other side.

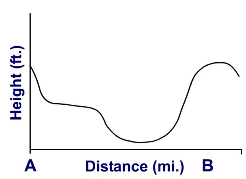
Figure 3.13 The description of profiles in question 4 provided for the participants who are visually impaired.

Question 8 Profile (using pitch and duration)

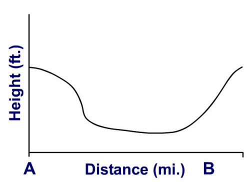
What does the cross section from point A to point B look like?



a) This sound represents a V-shape valley that has uniform slopes on both sides.



b) This sound represents a U-shape valley with the terrain on the left side and rounded hill top on the right side.



c) This sound represents a U-shape glacial valley. It begins with a gradual slope on the left side and continues to go down with a steep slope until it reaches the bottom of the valley. This area has a flat and wide valley. On the right side, on the way up hill, the slope is more gradual.

Figure 3.14 The description of profiles in question 8 provided for the participants who are visually impaired.

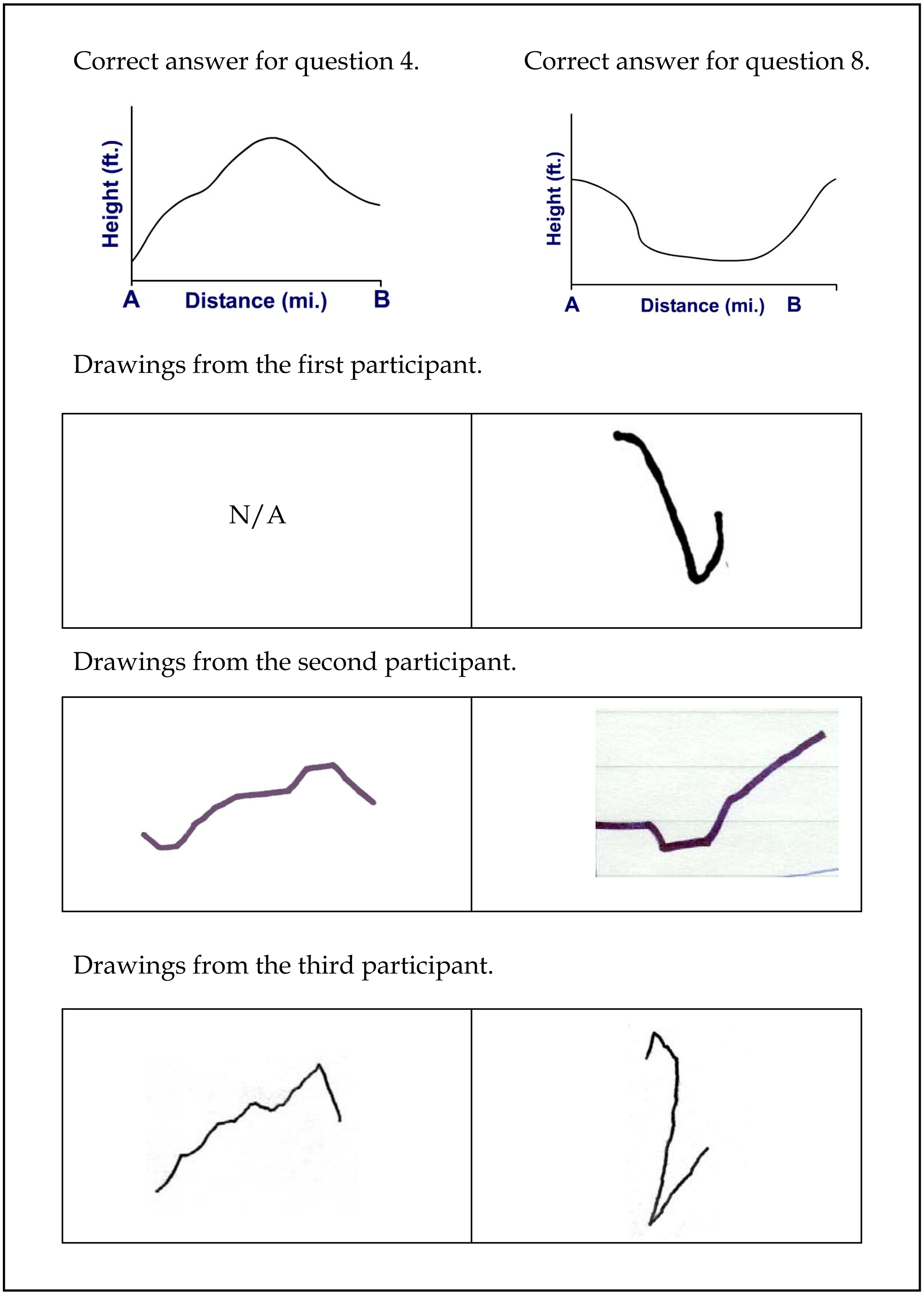


Figure 3.15 Drawings derived from the participants who are visually impaired during the pre-test session.

3.7 Analysis Techniques

Descriptive statistics were computed to obtain the frequencies, means, and standard deviations for the data obtained from the questionnaire sections. The frequency data were used to class numeric variables such as age and number of geography classes taken. Each of the participants responses were converted to either '1' for correct or '0' for incorrect. These parameters provided a general feel for which group performed more accurately during the experiment as a whole. The data were manipulated in *Microsoft®Excel 2000* and the statistical calculations were performed using the *SPSS* program (*SPSS* for Windows Version 10.0.5). An alpha level of *0.05* was required for significance in all comparisons.

The One-Way Analysis of Variance (One-way ANOVA) was conducted in order to determine if there were statistically significant differences in the overall results among groups, and the differences in the number of correct answers for each question type among these three groups. The One-Way ANOVA procedure produced a one-way analysis of variance for a quantitative dependent variable by a single factor variable (Table3.6). Analysis of variance was used to test the null hypotheses (Ho_1, Ho_2, and Ho_3) that several means were equal. This technique was an extension of the two-sample t test. In addition to determining that differences existed among the means of these three groups, the Tukey's post hoc test was used for pairwise multiple comparisons to indicate which means differed.

In order to statistically analyze whether the sound variables pitch and duration enhanced the interpretability of topographic data, two approaches were utilized. The first step involved treating the participants as two groups (groups 2 and 3) for comparison (the number of correct answers obtained from the slope, profile, and landform question types) **between groups** using One-way ANOVA

(Table 3.7). The second step involved analyzing the results **within group** using Paired Samples *t*-test to assess whether there were significantly differences between the results derived from one sound variable (pitch) and two sound variables (pitch and duration combined) on an individual basis for each question type (Table 3.8). Using a *t*-test for paired samples provided a method to evaluate in a very general sense which of these two sound variables facilitated in map interpretation.

Finally the Univariate Analysis of Variance was conducted to analyze if other factors (e.g., age, gender, status, computer skill, etc.) had effects on participants' performances (Table 3.9). This procedure tested about the effects of other variables on the means of various groupings of a single dependent variable. The interaction between factors could be investigated as well as the effects of individual factors. The Tukey's post hoc test was also performed to evaluate differences among specific means if the *F*-test showed significance.

As a follow up to the statistical analysis, the cognitive analysis was performed on the profile data derived from the participants who are visually impaired and blind. These data were first chain coded (see Burrough and McDonnell 1998), and then analyzed using cross chain correlation. The Freeman chain code is a compact way to represent a contour of an object (Freeman 1974). The chain code is an ordered sequence of n links $\{C_i, i = 1, 2, \ldots, n\}$, where C_i is a vector connecting neighboring contour pixels. The directions of C_i are coded with integer values $k = 0, 1, \ldots, K\text{-}1$ in a counterclockwise sense starting from the direction of the positive x-axis (Iivarinen *et al*. 1997). The directions of the eight connected chain code were applied in this experiment (Figure 3.16).

Table 3.6 The variables used to analyze the overall results among participants in three groups.

<u>Statistical Analysis:</u> One-way Analysis of Variance	
Dependent Variables	Standardized total score
	The number of correct answers for relative elevation question type
	The number of correct answers for slope question type
	The number of correct answers for profile question type
	The number of correct answers for distance question type
	The number of correct answers for landform question type
	The speed of response (in seconds) for relative elevation question type
	The speed of response (in seconds) for slope question type
	The speed of response (in seconds) for profile question type
	The speed of response (in seconds) for distance question type
	The speed of response (in seconds) for landform question type
Independent Variables	Groups (1, 2, and 3)

Table 3.7 The variables used to analyze the results of participants in groups 2 and 3 who performed task on sonically enhanced maps.

<u>Statistical Analysis:</u> One-way Analysis of Variance	
Dependent Variables	The number of correct answers for slope question type (using pitch only)
	The number of correct answers for slope question type (using pitch and duration)
	The number of correct answers for profile question type (using pitch only)
	The number of correct answers for profile question type (using pitch and duration)
	The number of correct answers for landform question type (using pitch only)
	The number of correct answers for landform question type (using pitch and duration)
Independent Variables	Groups (2 and 3)

Table 3.8 The variables used to analyze whether sound variables had an effect on the number of correct answers within group.

Statistical Analysis: Paired Samples *t*-test	
Test Variables	The number of correct answers for slope question type from group 2 (using pitch only)
	The number of correct answers for slope question type from group 3 (using pitch only)
	The number of correct answers for slope question type from group 2 (using pitch and duration)
	The number of correct answers for slope question type from group 3 (using pitch and duration)
	The number of correct answers for profile question type from group 2 (using pitch only)
	The number of correct answers for profile question type from group 3 (using pitch only)
	The number of correct answers for profile question type from group 2 (using pitch and duration)
	The number of correct answers for profile question type from group 3 (using pitch and duration)
	The number of correct answers for landform question type from group 2 (using pitch only)
	The number of correct answers for landform question type from group 3 (using pitch only)
	The number of correct answers for landform question type from group 2 (using pitch and duration)
	The number of correct answers for landform question type from group 3 (using pitch and duration)
Group Variables	Groups (2 and 3)

Table 3.9 The variables used in Univariate Analysis of Variance.

Statistical Analysis: Univariate Analysis of Variance	
Dependent Variables	Standardized total score
Factors for all groups	Gender
	Age
	Status (Graduate / Undegraduate students)
	The number of Geography calsses taken
	Computer skill
	Topographic map interpretation skill
	Sound skill
Factors for participants who are visually impaired (group 3)	Condition (Congenitally blind / Blind early in life / Blind later in life)
	Visibility condition (How much do you rely on vision?)
	Time that has been blind (How long ago did you lose your vision?)

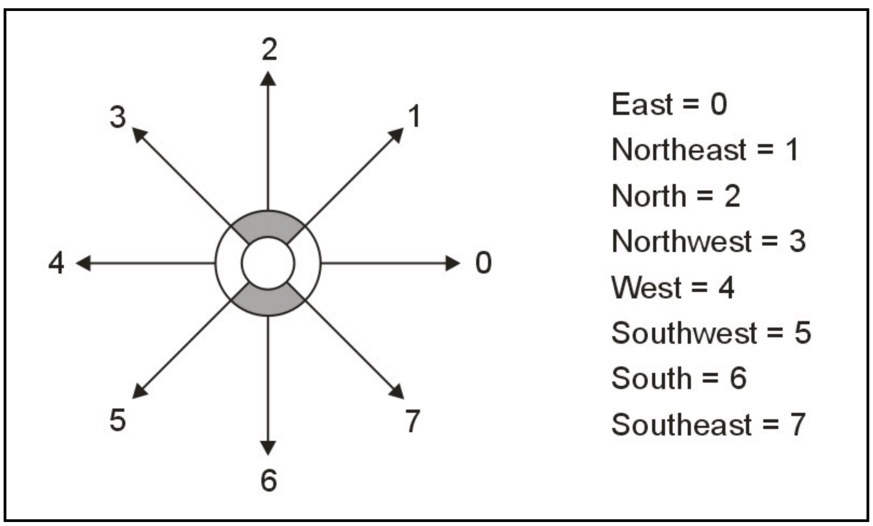


Figure 3.16 The directions of the eight connected chain code ($K = 8$).

When collecting the data, the participants who are visually impaired were presented with a blank piece of paper which they could orientate to suite their purposes. Participants were not told to orientate their drawings or to try and fit the drawing to a set scale. In order to make the drawings comparable for chain code correlation calculation, the data were transformed to the same scale. The drawings were scanned and pasted into CorelDraw. The scanned images were then re-drawn to increase definition and the images were scaled to match the actual profile. Finally, these images were imported to ArcView in order to create a chain code. A 9″ x 9″ grid was generated and overlaid on the profile. The conventional chain code method described above was then utilized. A chain code is a more succinct way of representing a contour than a simple collection of co-ordinate points along the profiles. It describes a profile as a series of one-pixel vector transitions at different orientations (8 different move directions for 8-connected profiles), with only the starting point being defined explicitly. In this experiment, the leftmost pixel in a given profile was chosen as the starting point. The size and shape of a profile could be represented as a set of directional codes, with one code following another like links in a chain (Figure 3.17).

After the cognitive profiles were chain coded, the cross chain correlation was calculated in order to compare the similarities between the actual and the cognitive profiles. Cross chain correlation measured the degree and direction of any association between configurations. The following equation (3-1) was applied to calculate the correlation if the two profiles had the same length:

$$C_{ab} = \frac{1}{n}\left(\sum_{i=1}^{n} \overline{a_i b_i}\right) \tag{3-1}$$

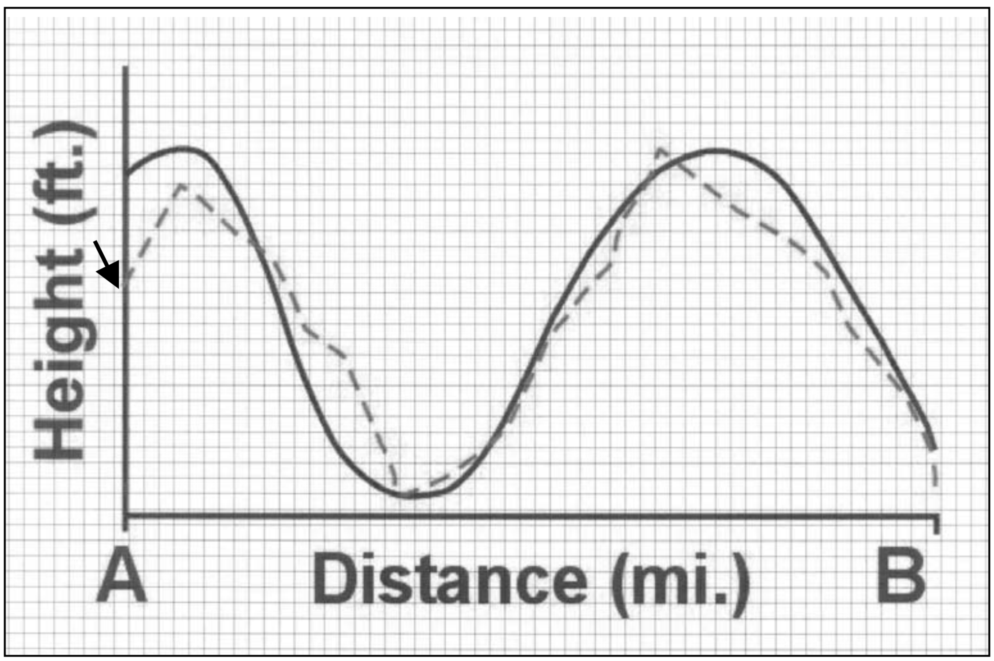
where $\overline{a_i b_i} = COS(\angle a_i - \angle b_i)$

For unequal chain lengths, simply slide the chains over another, then re-compute a correlation coefficient at each step. The portion that resulted in the highest correlation coefficient was used in the analysis. The following equation (3-2) was applied if the two profiles had different lengths:

$$C_{ab(j)} = \frac{1}{n}\left(\sum_{i=1}^{n} \overline{a_i b_{i+j}}\right) \qquad (3\text{-}2)$$

where $\overline{a_i b_{i(j)}} = COS(\angle a_i - \angle b_{i+j})$

The cosine function guarantees the matching measure to be less than one. When C_{ab} = 1, there is a perfect match between the actual and cognitive profiles. C_{ab} = 0 indicates that the two profiles are perpendicular. If C_{ab} = -1, then the profiles are mirror images.



<u>Chain code for the cognitive profile</u>: 0, 2^2, 1, 2, 0, 2^2, 0^2, 7^3, 0, 6, 0, 6, 0, 6^2, 0, 6^2, 0, 7, 0, 6^2, 7, 6, 7, 6, 7, 6^2, 0^3, 1, 0, 2, 0, 2, 0, 2, 0, 2, 1, 2, 1, 2, 1, 2, 0, 2, 0, 2, 1^2, 2^2, 1, 2, 0, 2^2, 0, 2, 7^3, 0, 6, 0, 7, 0, 7, 0, 6, 0, 6, 0, 6^2, 0, 6^2, 0, 6, 0, 6, 7^2, 6, 0, 6^2, 0, 6^3

Figure 3.17 An example of chain code; the reference pixel is marked by an arrow. The actual profile is represented by solid line and the cognitive profile is represented by dash line.

CHAPTER 4

RESULTS AND ANALYSIS

The data from one hundred and four participants were collected and used in the analysis. These included the data obtained from thirty-six participants (24 males and 12 females) who completed Tutorial 1, thirty-seven participants (22 males and 15 females) who completed Tutorial 2, and thirty-one participants with visual impairment (14 males and 17 females) who completed Tutorial 3. The statistical and cognitive map analyses were conducted in order to evaluate the individual's ability to learn and interpret topographic maps. This chapter presents and discusses the results of the analysis. The one-way ANOVA technique was employed to compare the overall results among groups and the pair *t*-test was applied to evaluate the usefulness of sound variables in map interpretation. The questionnaire data were also analyzed using the univariate analysis of variance. The confidence level for the study was set as 95%. Finally, cross chain correlation was performed to assess the accuracy of the cognitive profiles that the participants with visual impairment drew during the experiment.

4.1 Total Correct Responses

4.1.1 Total Correct Responses for All Questions

The total score for each group was first standardized and then tested to determine if viewing the traditional maps or exploring the sonically enhanced maps reflected a difference in the number of correct responses. Figure 4.1 illustrates the average scores for all questions among these three groups. The data were analyzed using one-way ANOVA to compare sample means for significant differences. The results indicate that the participants in groups 2 and 3 who performed tasks on the sonically enhanced maps (Task 2) have higher scores than those in group 1 who viewed the traditional topographic maps (Task 1). On average, the participants who are visually impaired outperformed the participants who are sighted with the highest mean score of 72.82%. The participants in group 1 had the lowest mean score of 60.44% and those in group 2 had an average score of 64.39% (Table 4.1).

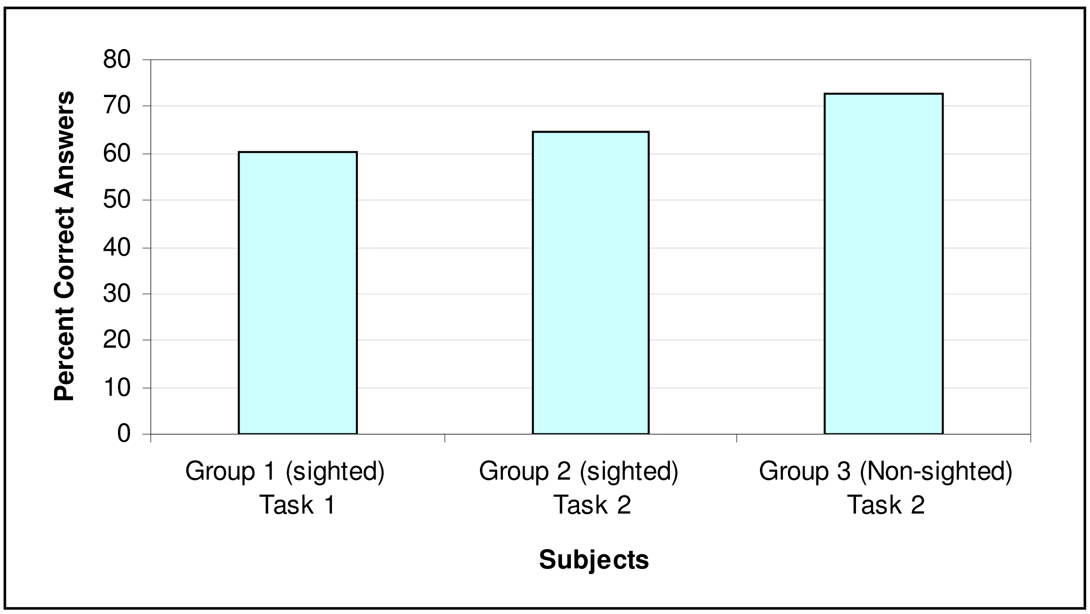


Figure 4.1 Percent of correct answers on all questions.

Table 4.1 Results from one-way ANOVA for the number of correct responses between groups.

Group	*Mean*	*Standard Deviation*	*N*	*F*	*P*
1	60.44	2.32	36	7.708	.001
2	64.39	2.07	37		
3	72.82	2.25	31		

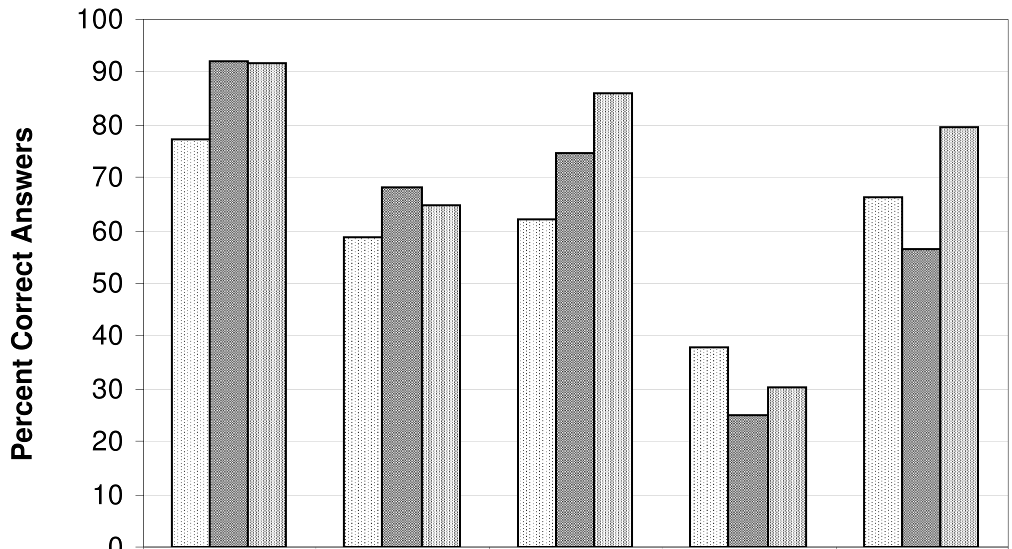
As might be expected, the effect of sound variables upon the ability to interpret topographic maps is highly significant ($F(2,101) = 7.708$, $p < .01$), especially for the group of participants who are visually impaired. However, there are no significant differences in the mean scores between the two conditions (sounds vs. without sounds) in groups 1 and 2 (Table 4.2). From making observations of participants during the experiment, those who are visually impaired paid more attention on sounds when they were doing map quiz.

Table 4.2 Post Hoc test for the number of correct responses between groups.

(I) Group	*(J) Group*	*Mean Difference (I - J)*	*Standard Error*	*Significance*
1	2	-3.95	3.06	.403
1	3	-12.38	3.20	.001
2	3	-8.43	3.18	.025

4.1.2 Total Correct Responses by Question Type

A total of five question types were asked in the map quiz section. These included the questions pertaining to relative elevation, slope, profile, distance, and landform (see Sections 3.5.1 and 3.5.2). The results indicate that the participants in groups 2 and 3 who answered topographic questions by listening to the sounds have higher mean scores than those in group 1 in all question types, except for the distance questions (Figure 4.2). More detail analyses are described in the following sections.



	Elevation	Slope	Profile	Distance	Landform
Group 1	77.22	58.89	62.22	37.78	66.11
Group 2	91.89	68.11	74.59	24.86	56.49
Group 3	91.61	64.84	85.81	30.32	79.68

Figure 4.2 Percent of correct answers by question type.

4.1.2.1 Total Correct Responses for Questions Pertaining to Relative Elevation Determination

Figure 4.2 illustrates that the sound variable, pitch, helps improve the interpretation of the contour lines on topographic maps. When comparing the mean scores for the elevation questions, participants in groups 2 and 3 obtained approximately 15% higher mean scores than those in group 1. On average, participants who performed tasks on the sonically enhanced maps answered the question pertaining to relative elevation correctly 92% of the time (group 2: mean score = 91.89; group 3: mean score = 91.61), while the participants in group 1 answered correctly only 77.22% of the time (Table 4.3). The overall results clearly demonstrate that the use of sound variable pitch has a significant effect (F(2,101)

= 7.595, $p < .01$) on relative elevation determination on topographic maps. It significantly increases the number of correct responses and allows participants to answer questions more accurately. The results also indicate that there is no significant difference in mean score between the participants in groups 2 and 3 who performed tasks on sonically enhanced maps (Table 4.4).

Table 4.3 Results from one-way ANOVA for elevation questions.

Group	Mean	Standard Deviation	N	F	P
1	77.22	21.99	36	7.595	.001
2	91.89	15.96	37		
3	91.61	15.30	31		

Table 4.4 Post Hoc test for the number of correct responses in elevation question type between groups.

(I) Group	(J) Group	Mean Difference (I - J)	Standard Error	Significance
1	2	-14.67	4.24	.002
1	3	-14.39	4.44	.005
2	3	.2790	4.41	.998

4.1.2.2 Total Correct Responses for Questions Pertaining to Slope Determination

The results from Table 4.5 and Figure 4.2 illustrate that the participants in groups 2 and 3 have higher scores than those in group 1. This is evident by their respective means of 68.11% and 64.84%. The participants in group 1 yielded the lowest mean score of 58.89%. The results show an improvement in accuracy when the sounds are incorporated in topographic maps. However, the statistical analysis indicates that there are no significant differences among the mean scores for these three groups (Table 4.6).

Table 4.5 Results from one-way ANOVA for slope questions.

Group	*Mean*	*Standard Deviation*	*N*	*F*	*P*
1	58.89	19.09	36	2.159	.121
2	68.11	19.98	37		
3	64.84	18.23	31		

Table 4.6 Post Hoc test for the number of correct responses in slope question type between groups.

(I) Group	*(J) Group*	*Mean Difference (I - J)*	*Standard Error*	*Significance*
1	2	-9.22	4.49	.105
1	3	-5.95	4.70	.417
2	3	3.27	4.67	.764

4.1.2.3 Total Correct Responses for Questions Pertaining to Profile Determination

The differences in abilities to determine topographic profiles for each group are illustrated in Figure 4.2. In the experiment, group 1 was instructed to view the traditional topographic maps on screen, while groups 2 and 3 were given the sonically enhanced maps to explore. The figure clearly shows that the participants who are visually impaired outperform those who are sighted. The participants in group 1 had the lowest mean score of 62.22% while those in groups 2 and 3 had higher mean scores of 74.59% and 85.81%, respectively (Table 4.7). The results from the Post Hoc test also indicate that there is a statistically significant difference between the mean score in group 3 and that in group 1 (Table 4.8). This confirms an assumption that sound variables help the individuals with visual impairment and blindness understand geographic environment. Although the participants in group 3 outperformed those in group 2, there is not a significant difference of mean score between these two groups.

Table 4.7 Results from one-way ANOVA for profile questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	62.22	26.52	36	8.664	.000
2	74.59	23.05	37		
3	85.81	18.76	31		

Table 4.8 Post Hoc test for the number of correct responses in profile question type between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	-12.37	5.43	.063
1	3	-23.58	5.68	.000
2	3	-11.21	5.65	.121

4.1.2.4 Total Correct Responses for Questions Pertaining to Distance Determination

The comparison of mean scores among groups is graphically displayed in Figure 4.2. The participants in group 1 viewed topographic maps with a graphical scale on screen, while the participants in groups 2 and 3 listened to different duration of sounds to determine the distances. On this type of question, the visual maps allowed the participants with sight (group 1) to answer questions more accurately than the sonically enhanced maps. The graphical scale provided on the screen helped calculate the distance on the map, thus making it easier to determine how close or how far between two points. This was true especially when they had to select answers in two digits (e.g., 2.75, 3.25, 4.75, etc.). The mean scores for the distance questions are illustrated in Table 4.9. None of these three groups achieved mean scores higher than 40%. Group 1 yielded the highest mean score of 37.78%, while the other two had lower mean scores of 24.86% in group 2 and 30.32% in group 3. Overall the mean score is significantly reduced in the sound condition ($F(2, 101) = 3.386$, $p < .05$). The results shown in Table 4.10 indicate that there is a significant difference in mean score between groups 1 and 2. However, there is not a significant difference in mean score for participants with sight (group 2) and those without sight (group 3) who performed tasks on the sonically enhanced maps.

Table 4.9 Results from one-way ANOVA for distance questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	37.78	22.31	36	3.386	.038
2	24.86	19.67	37		
3	30.32	21.83	31		

Table 4.10 Post Hoc test for the number of correct responses in distance question type between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	12.91	4.98	.029
1	3	7.46	5.21	.329
2	3	-5.46	5.18	.545

4.1.2.5 Total Correct Responses for Questions Pertaining to Landform Identification

The average scores for the landform questions are also shown in Figure 4.2. The participants who are visually impaired (group 3) performed very well in this task, resulting in a higher mean score than the participants who are sighted in groups 1 and 2. The mean score of group 3 was 79.68% where as the mean scores of groups 1 and 2 were 66.11% and 56.49%, respectively (Table 4.11). The statistical analysis also indicates that there is a significant difference ($F(2, 101) = 13.917$, $p = .00$) in mean score between the participants who are sighted in group 1 and those who are visually impaired in group 3. Although the participants in group 1, who performed tasks without augmentation of sounds, had higher mean score than those in group 2, the results indicate that this is not statistical significance (Table 4.12).

Table 4.11 Results from one-way ANOVA for landform questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	66.11	20.74	36	13.917	.000
2	56.49	17.03	37		
3	79.68	15.81	31		

Table 4.12 Post Hoc test for the number of correct responses in landform question type between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	9.62	4.23	.064
1	3	-13.57	4.43	.008
2	3	-23.19	4.40	.000

4.2 Response Time

4.2.1 Average Response Time Per Question

The response time for each question was recorded by the program during the experiment. The data were then analyzed using the one-way ANOVA technique to determine if the average response time for each group was significantly different. It was expected that the group with visual impairment would take more time to answer map questions than the groups with sight (Figure 4.3). This was due to the fact that the participants who are visually impaired performed tasks on Tutorial 3 in which the voice-over was incorporated throughout the map quiz section. This process would take more time based on the increased number of steps taken to get the answer. On the other hand, the participants who have sight could read the question-answer on screen, and thus they could work on their own pace.

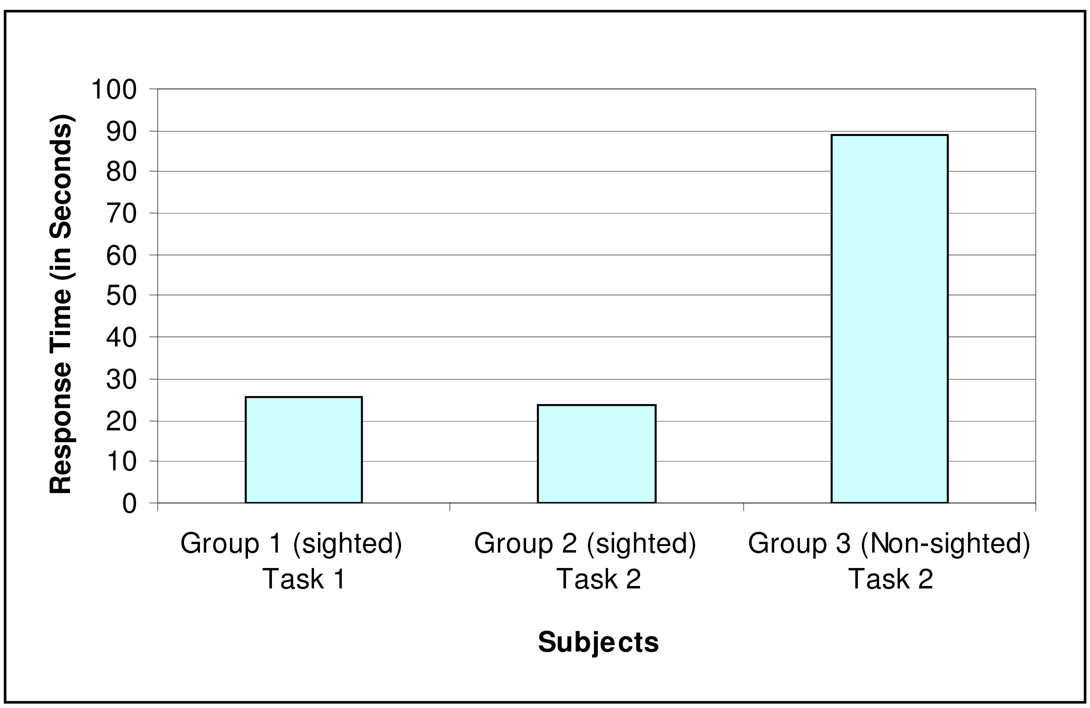


Figure 4.3 Average response time (in seconds) on all questions.

On average, the participants in group 1 took 25.70 seconds and those in group 2 took 23.49 seconds to answer map questions (Table 4.13). This difference is not statistically significant although group 1 spent more time to response to questions than the other group (Table 4.14). The average time that it took the participants in group 3 to answer map questions was 88.79 seconds. The statistical analysis shows a significant difference in the average amount of time to answer the question between the participants with visual impairment (group 3) and those in groups 1 and 2.

Table 4.13 Results from one-way ANOVA for the average response time (in seconds) on all questions.

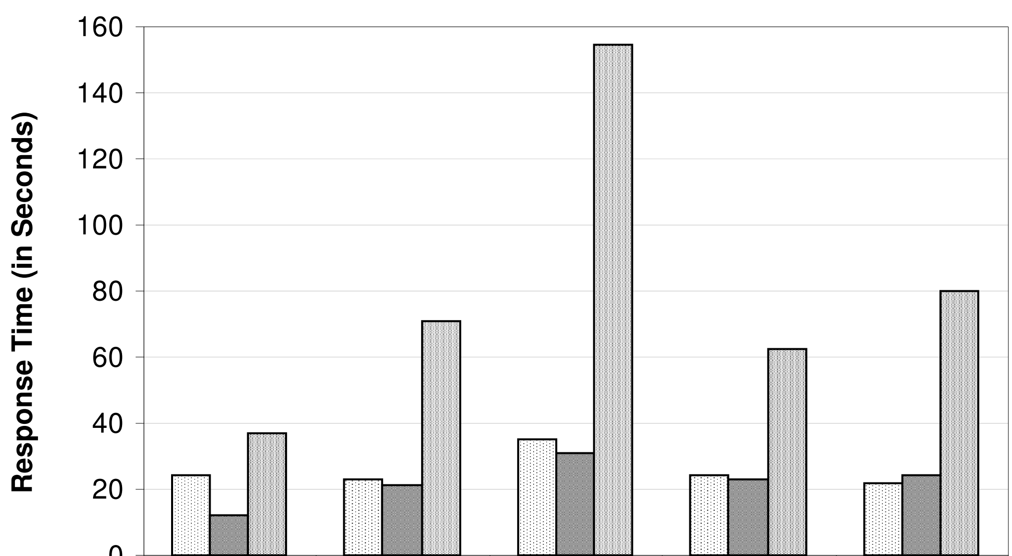
Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	25.7	8.26	36	199.627	.000
2	23.49	7.77	37		
3	88.79	24.60	31		

Table 4.14 Post Hoc test for the average response time (in seconds) on all questions between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	2.21	3.51	.805
1	3	-63.10	3.68	.000
2	3	-65.30	3.65	.000

4.2.2 Average Response Time by Question Type

The following sections present the statistical results of the average response time by question type among groups. The average response time for the questions relevant to elevation is illustrated in Figure 4.4. Generally, the group with visual impairment took more time to answer all types of questions because they had to listen to the integrated voice-over before they could select the answer. However, it was expected that the sound variables pitch and duration would help interpret the topographic maps. Therefore, the participants with sight (group 2) who performed tasks on sonically enhanced maps would take less time to answer all questions than those in group 1 who performed tasks on the topographic map without augmentation of sound would.



	Elevation	Slope	Profile	Distance	Landform
Group 1	24.03	23.07	35.44	24.31	21.63
Group 2	11.82	21.03	31.04	22.99	24.47
Group 3	36.97	71.10	154.25	62.35	80.14

Figure 4.4 Average response time (in seconds) by question type.

4.2.2.1 Average Response Time for Questions Pertaining to Relative Elevation Determination

It is clearly depicted in Figure 4.4 that the group with visual impairment takes more time to answer this type of question than the other two groups. The average time that it took the participants in this group to determine the relative elevation between points on the sonically enhanced map was 36.67 seconds (Table 4.15). The participants in group 1 took an average of 24.03 seconds to answer questions. Among these three groups, the participants in group 2 who were given different pitches to listen took the least time to find the elevation between two points. They responded in an average time of 11.82 seconds. The result from the one-way ANOVA indicates that there are high significantly differences ($F(2, 101) = 34.523$, $p = .00$) of mean scores in this task. The Post Hoc test also indicates that the amount of time requires to complete this task is significantly different for all groups (Table 4.16). Thus, the sound variable pitch helps reduce the amount of time it takes to identify elevation and increase the percent of correct responses in the sighted group (see also Section 4.1.2.1).

Table 4.15 Results from one-way ANOVA for the average response time (in seconds) for elevation questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	24.03	8.04	36	34.523	.000
2	11.82	4.88	37		
3	36.97	20.42	31		

Table 4.16 Post Hoc test for the average response time (in seconds) in elevation question type between groups.

(I) Group	*(J) Group*	*Mean Difference (I - J)*	*Standard Error*	*Significance*
1	2	12.21	2.91	.000
1	3	-12.94	3.05	.000
2	3	-25.15	3.03	.000

4.2.2.2 Average Response Time for Questions Pertaining to Slope Determination

In the experiment, the participants in groups 2 and 3, who performed tasks on the sonically enhanced maps, were given a set of sounds to listen to. Then, they had to determine the type of slope (e.g., up gentle, down steep, etc.) based on the sounds played. As might be expected, the participants with visual impairment took more time to complete this task than the other two groups (Figure 4.4). They took an average of 71.10 seconds to answer the slope questions, while the sighted participants in group 2, who performed the same task, took only 21.03 seconds to answer this type of question (Table 4.17). The participants in group 1 who visually determined the type of slope on topographic maps took an average of 23.07 seconds to answer questions. Although group 2 took slightly less response time than group 1, the results in Table 4.18 indicate that this difference is not statistically significant. Conversely, the analysis shows high significant differences of the average response time between group 3 and the other two groups.

Table 4.17 Results from one-way ANOVA for the average response time (in seconds) for slope questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	23.07	9.24	36	120.730	.000
2	21.03	6.81	37		
3	71.1	24.00	31		

Table 4.18 Post Hoc test for the average response time (in seconds) in slope question type between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	2.04	3.45	.825
1	3	-48.03	3.61	.000
2	3	-50.07	3.59	.000

4.2.2.3 Average Response Time for Questions Pertaining to Profile Determination

As shown in Figure 4.4, the group with visual impairment took the most time to complete this task. This is a result of the fact that the participants in this group were assigned to construct the profiles based on the sounds played while those who are sighted were provided the on-screen graphics to select. This process increased their average response time to 154.25 seconds. The results provided extra information and allowed the researcher to compare their cognitive profiles with the actual ones (see Section 4.5). The average response time that it took the participants in group 1 to complete this task was 35.44 seconds (Table 4.19). The participants in group 2 took less response time (31.04 seconds), but had a higher mean score than those in group 1. The participants with visual impairment who performed the profile determination task by listening to the sounds played yielded the highest mean score on this type of question (see Section 4.1.2.3). Therefore, an assumption that the sound variables pitch and duration help enhance the interpretability of topographic profile, especially for the individuals with visual impairment, can be made. By comparing the average response time among three groups, the statistical analysis shows high significant differences between group 3 and the other two groups (Table 4.20).

Table 4.19 Results from one-way ANOVA for the average response time (in seconds) for profile questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	35.44	17.24	36	247.231	.000
2	31.04	11.34	37		
3	154.25	40.89	31		

Table 4.20 Post Hoc test for the average response time (in seconds) in profile question type between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	4.40	5.95	.740
1	3	-118.81	6.23	.000
2	3	-123.21	6.19	.000

4.2.2.4 Average Response Time for Questions Pertaining to Distance Determination

On the distance questions, the participants in group 1 took slightly more response time than those in group 2 (Figure 4.4). Their mean response time was 24.31 seconds, while the other group that performed task under sound condition took on average 22.99 seconds to answer these questions (Table 4.21). The results shown in Table 4.22 indicate that this difference is not statistically significant. However, as might be expected, the group with visual impairment took more time to answer questions than the groups with sight. On average it took them 62.35 seconds to complete this task. This was approximately 3 times as high as the other two groups, and thus they are statistically significant differences ($F(2, 101) = 103.249$, $p = 0.00$).

Table 4.21 Results from one-way ANOVA for the average response time (in seconds) for distance questions.

Group	*Mean*	*Standard Deviation*	*N*	*F*	*P*
1	24.31	9.64	36	103.249	.000
2	22.99	8.35	37		
3	62.35	18.45	31		

Table 4.22 Post Hoc test for the average response time (in seconds) in distance question type between groups.

(I) Group	*(J) Group*	*Mean Difference (I - J)*	*Standard Error*	*Significance*
1	2	1.32	2.94	.896
1	3	-38.05	3.08	.000
2	3	-39.37	3.06	.000

Although the participants in group 1, who viewed topographic maps on screen, took considerably more time to response to questions pertaining to distance, they yielded 12.90% and 7.46% higher mean score than the those in groups 2 and 3 who performed tasks on sonically enhance maps (see Section

4.1.2.4). The result suggests that the sound variables do not help the user determine the distances on topographic maps.

4.2.2.5 Average Response Time for Questions Pertaining to Landform Identification

The average response time for the landform questions is graphically shown in Figure 4.4. The group with visual impairment took the longest time (80.14 seconds) to answer the landform questions, while the groups with sight took nearly 3.5 – 4 times less to complete the same task. The average response times for groups 1 and 2 were 21.63 seconds and 24.47 seconds, respectively (Table 4.23). The statistical results indicate no significant differences of the average response time between groups 1 and 2, but show highly significant differences between group 3 and the other two groups (Table 4.24).

Table 4.23 Results from one-way ANOVA for the average response time (in seconds) for landform questions.

Group	***Mean***	***Standard Deviation***	***N***	***F***	***P***
1	21.63	7.26	36	79.202	.000
2	24.47	9.12	37		
3	80.14	36.72	31		

Table 4.24 Post Hoc test for the average response time (in seconds) in landform question type between groups.

(I) Group	***(J) Group***	***Mean Difference (I - J)***	***Standard Error***	***Significance***
1	2	-2.83	4.96	.835
1	3	-58.51	5.19	.000
2	3	-55.67	5.16	.000

While group 2, sighted using sonification, took less response time to determine the landform on the specified area on the map, they produced 23.19% lower mean score than those in group 3 who are visually impaired (see Section 4.1.2.5). The participants in group 1 who performed tasks on the topographic maps without augmentation of sounds also yielded significantly lower mean score of 13.57% than those with visual impairment in group 3. Accordingly, the sound variables pitch and duration most likely helped the participants who are visually impaired identify the type of landform on topographic maps.

4.3 Comparing the Results of One Sound Variable (Pitch) and Two Sound Variables (Pitch and Duration Combined)

The statistical analysis of the participant's ability to interpret topographic maps through sound variables pitch and duration was conducted using the one-way ANOVA and paired sample *t*-test. Only the results from the slope, profile, and landform questions were included in the analysis because both sound variable conditions, pitch and duration, were applied to these three types of questions. First, the comparison between groups under 2 conditions: one sound variable (pitch only) and two sound variables (pitch and duration combined) was performed. Second, the results within group were analyzed to determine which of these two sound variables assisted in map interpretation.

4.3.1 Statistical Results between Groups

When the participants were asked to determine the type of slope based on the given sets of sounds, the participants in group 2 yielded slightly higher mean scores than those in group 3 who are visually impaired in both conditions (Figure 4.5). However, the statistical results indicate that whether one sound variable or two sound variables are utilized, there are no significant differences

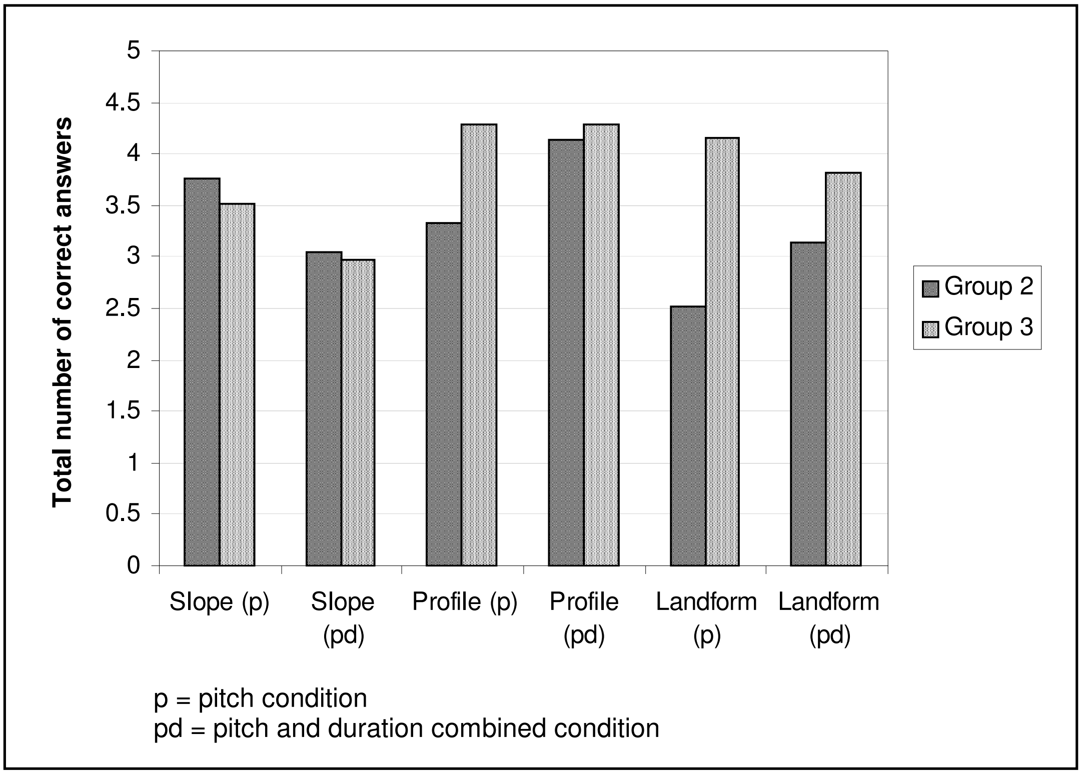


Figure 4.5 The number of correct answers between group 2 (sighted) and group 3 (visually impaired) in the pitch and the combined pitch and duration conditions.

between the mean scores of these two groups (Table 4.25). On the questions pertaining to profile determination, the group with visual impairment produced higher mean scores than the group with sight in both conditions. The statistical analysis indicates a high significant difference ($F(1, 66) = 8.917$, $p < .01$) in the average number of correct answers between groups in the pitch condition, while showing no significant difference in the pitch and duration combined condition. This suggested that the sound variable pitch could be used to facilitate the participants who are visually impaired in constructing topographic profiles. When comparing the mean scores on the landform questions, it is clearly shown in Figure 4.5 that the group with visual impairment outperforms the group who has sight in both conditions. The statistical results also confirm that their mean scores are significantly higher than those of the group with sight ($F(1, 66)$ =

41.161, p = .00). Thus an assumption that sound variables pitch and duration help in identifying the type of landform on topographic maps can be concluded.

Table 4.25 The comparison of mean scores between group 2 (sighted) and group 3 (visually impaired) in the pitch and the combined pitch and duration conditions.

Variables	Mean Scores		F	Significance
Question Type: Slope	Group 2	Group 3		
Pitch	3.76	3.52	.728	.397
Pitch and duration combined	3.05	2.97	.079	.779
Question Type: Profile	Group 2	Group 3		
Pitch	3.32	4.29	8.917	.004
Pitch and duration combined	4.14	4.29	.324	.571
Question Type: Landform	Group 2	Group 3		
Pitch	2.51	4.16	41.161	.000
Pitch and duration combined	3.14	3.81	8.203	.006

4.3.2 Statistical Results within Group

The comparison of the mean scores within group is graphically shown in Figures 4.6 and 4.7. Overall, the participants who are sighted (group 2) tended to perform well when two sound variables were utilized, while those without sight (group 3) performed well when only one sound variable was applied. The results from the paired sample t-test indicate that there are statistically significant differences ($p < .01$) of the mean scores on all types of questions in the group with sight (Table 4.26). This illustrates that the sound variables pitch and duration facilitate the participants who are sighted in visualizing topographic profiles and interpreting the type of landform on topographic maps. Conversely, on the slope questions, their mean score was significantly higher when only one sound variable was used (mean of one sound variable = 3.76; mean of two sound

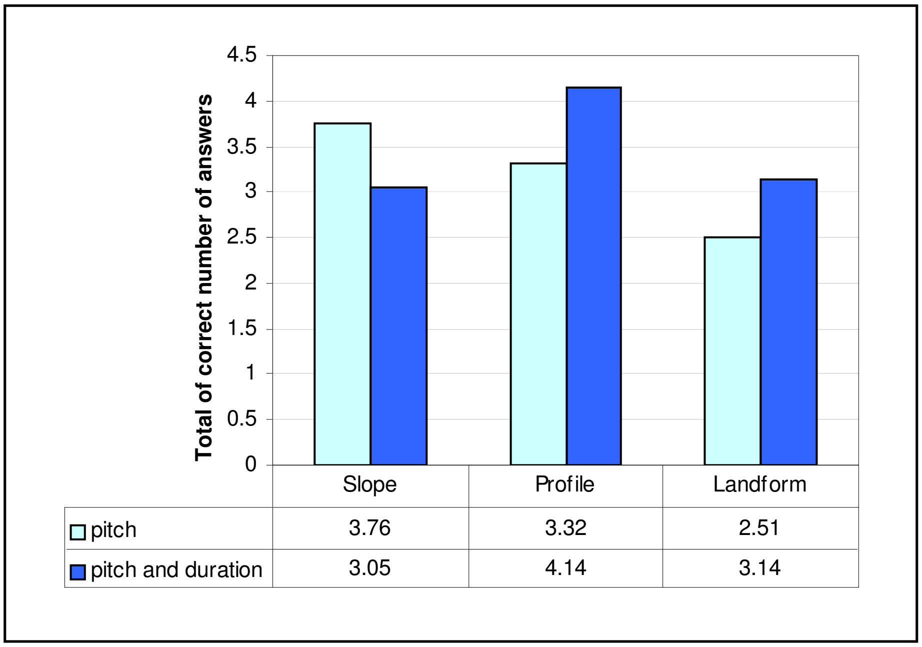


Figure 4.6 The number of correct answers in group 2 (sighted) in the pitch and the combined pitch and duration conditions.

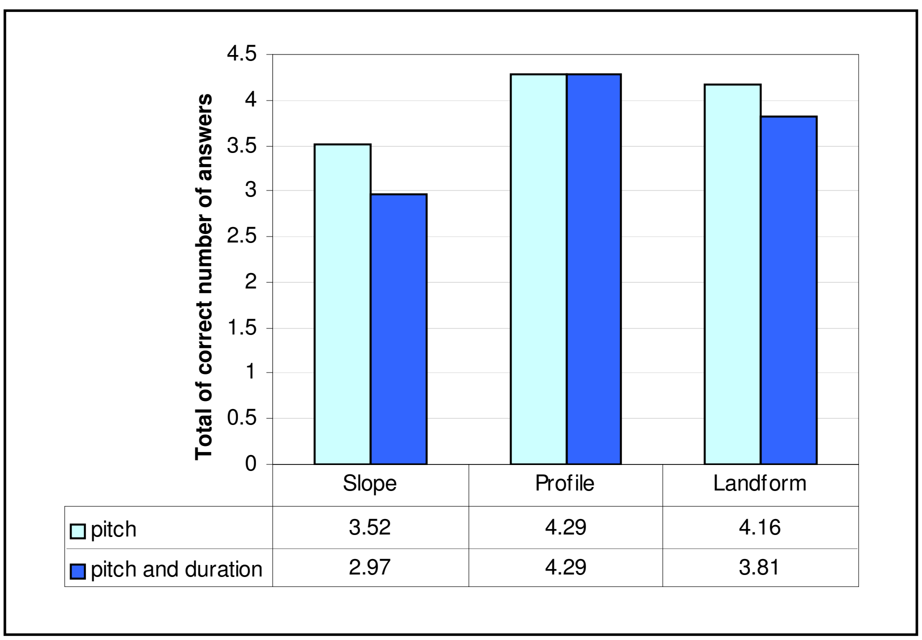


Figure 4.7 The number of correct answers in group 3 (visually impaired) in the pitch and the combined pitch and duration conditions.

Table 4.26 The comparison of mean scores within group in the pitch and the combined pitch and duration conditions.

Variables	Paired Differences			
	Means	df	t	Significance (2-tailed)
Question Type: Slope				
Group 2: p vs. pd	.703	36	2.987	.005
Group 3: p vs. pd	.548	30	2.003	.054
Question Type: Profile				
Group 2: p vs. pd	-.811	36	-3.545	.001
Group 3: p vs. pd	.000	30	.000	1.000
Question Type: Landform				
Group 2: p vs. pd	-.622	36	-3.186	.003
Group 3: p vs. pd	.355	30	1.731	.094

p = pitch condition

pd = pitch and duration combined

variables = 3.05). The statistical analysis for the group of participants who are visually impaired shows that there are no significant differences of the mean scores on all types of questions ($p > .05$). Therefore, it can be assumed that using either one or two sound variables have almost the same effect in map interpretation in the group with visual impairment.

4.4 Statistical Results for Questionnaire

The data from the questionnaire, such as age, gender, status, were analyzed using the Univariate Analysis of Variance technique. If the outcome of the *F*-test indicated that a significant difference existed between those factor's means, the follow-up tests would be conducted.

4.4.1 Effects of Group and Gender on Total Score

A 3 (group – groups 1 and 2 who are sighted and group 3 who is visually impaired) X 2 (gender – male, female) analysis of variance with the percent of correct answers as the dependent variable is presented in Table 4.27. The statistical results show a high significant effect for group ($F(2, 98) = 10.143$, $p = .000$) and a significant main effect for gender ($F(1, 98) = 7.421$, $p < .01$). However, there is no interaction between group and gender, meaning that the difference between the mean scores earned by 60 males and 44 females who performed tasks under sound condition is very similar to the difference between the other males and females who were given the traditional topographic maps to view. In both cases, males yielded, on average, higher mean scores than did females (Figure 4.8).

Table 4.27 Effects of group and gender on standard total score.

Variables	***df***	***SS***	***MS***	***F***	***P***
Group	2	3,284.70	1,642.03	10.143	.000
Gender	1	1,201.37	1,201.37	7.421	.008
Interaction	2	138.18	69.09	.427	.654
Within Groups	98	15,865.52	161.89		
Total	103	19,843.85			

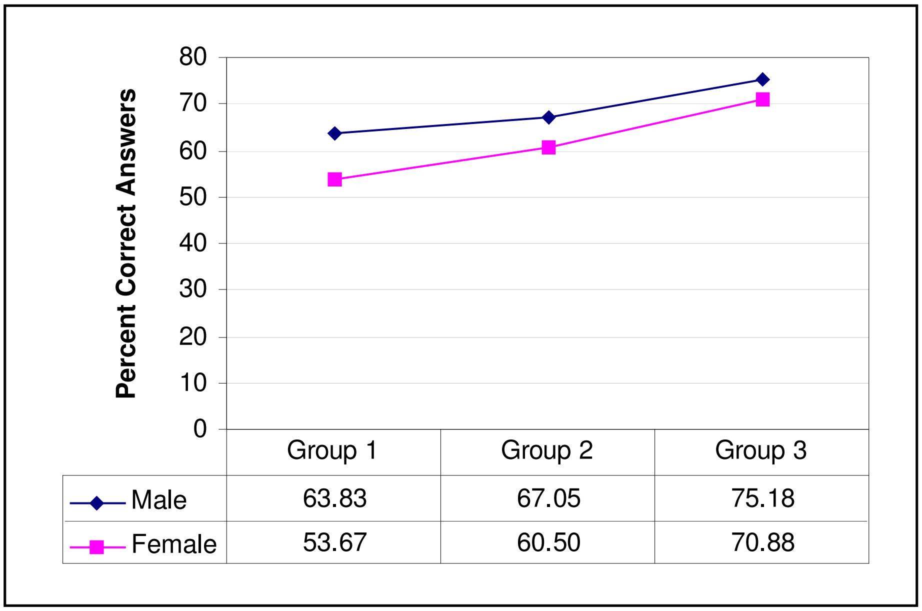


Figure 4.8 The interaction between group and gender.

4.4.2 Effects of Group and Age on Total Score

The participants in this study are in the ages between 18 and 75. Descriptive statistics were computed to obtain frequencies and ranges for these data. They were then combined into 5 groups. Of all one hundred and four participants, sixty participants were in between 18 and 25 years of age and were classed as group 1. Fourteen participants, who fell between the ages of 26 and 35, were placed in group 2. Six participants were placed in group 3. These participants were graduate students from the University of Georgia and the individuals with visual impairment who were in between 36 and 45 years of age. Fourteen participants who were between the ages of 46 and 55 were classed as group 4 and eight participants who were older than 55 years of age were classed as group 5. The results of the univariate ANOVA (Table 4.28) show that there are significant effect for group ($F(2, 93) = 3.205$, $p < .05$), whereas there are no significant main effect for age ($F(4, 93) = .938$, $p > .10$) and no significant interaction ($F(4, 93) = .862$, $p > .10$). Thus, age is not a major factor and does not have significant effect on a participant's ability to interpret topographic maps.

Table 4.28 Effects of group and age on standard total score.

Variables	*df*	*SS*	*MS*	*F*	*P*
Group	2	1,113.11	556.55	3.205	.045
Age	4	651.35	162.84	.938	.446
Interaction	4	598.70	149.68	.862	.490
Within Groups	93	16,151.72	173.67		
Total	103	19,843.85			

Overall, the participants who are visually impaired yielded the highest mean score (71.60%), while the other groups had lower mean scores of 55.90% in group 1 and 64.87% in group 2. When comparing the average number of correct answers based on the age group, the results indicate that the participants who are between 26 and 35 years of age produce the lowest mean score (59.15%), while the participants who are between the ages of 46 and 55 yield the highest mean score (73.57%).

4.4.3 Effects of Group and Status on Total Score

The participants were placed into 3 groups based on their level of education: (1) graduate, (2) undergraduate, and (3) high school or others. Ninety-seven participants who participated in this experiment were undergraduate and graduate students, and seven participants in the group with visual impairment had only a high school education. The results illustrated in Table 4.29 show a significant interaction between group and status ($F(2, 97) = 8.665$, $p < .05$). A Tukey's Post Hoc analysis finds that the mean scores for group 1 (mean = 58.92) and group 2 (mean = 59.93) do not vary significantly from one another, but are both significantly lower than group 3 (mean = 73.92).

Table 4.29 Effects of group and level of education on standard total score.

Variables	*df*	*SS*	*MS*	*F*	*P*
Group	2	2,797.35	1,398.68	8.665	.045
Status	2	91.6	45.80	.284	.446
Interaction	2	1,476.67	738.33	.862	.490
Within Groups	97	15,658.32	161.43		
Total	103	19,843.85			

The graph (Figure 4.9) indicates that the interaction exists. The ordering of these two lines stays the same when we consider the line's left endpoint to the midpoint. However, the ordering of the two lines' endpoints is changed. Considered as a whole, the graph suggests that the differential amount of mean scores derived from the undergraduate, graduate, and high school participants vary among groups. Regardless of the education levels, the participants who are visually impaired (group 3) tended to produce higher mean scores than those who are sighted (groups 1 and 2). The graph is also illustrated that those in group 3, who had higher education (graduate level), outperform every participant in all groups.

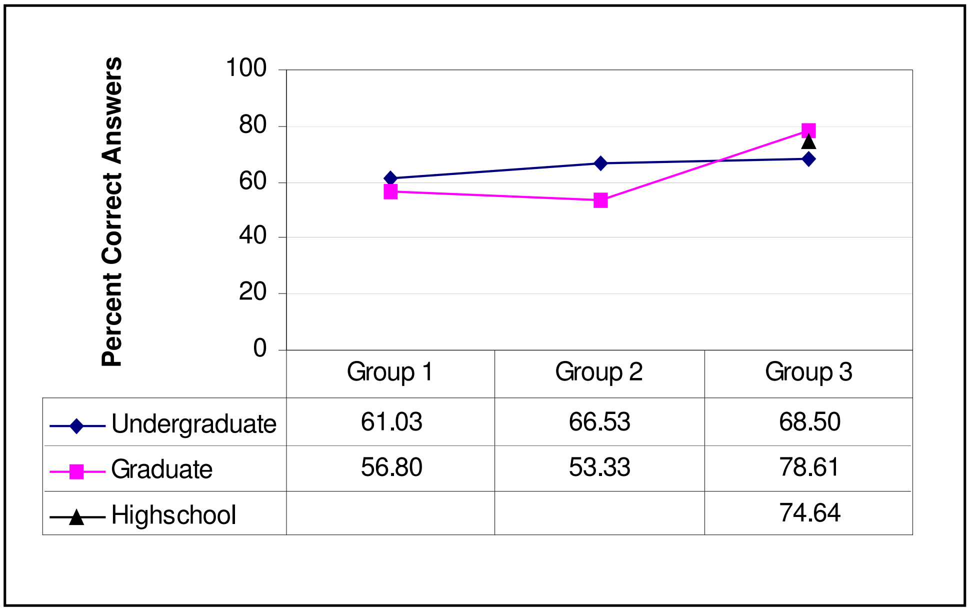


Figure 4.9 The interaction between group and level of education.

4.4.4 Effects of Group and Number of Geography Classes Taken on Total Score

The average number of geography classes taken was 2.66 with a range from 0 to 12. These numbers were grouped into 4 classes: (1) 0 class, (2) 1-4 classes, (3) 5-9 classes, and (4) more than 9 classes. The univariate ANOVA (Table 4.30) on standard total scores produces a significant main effect for group ($F(2, 94) = 6.207$, $p < .01$) and for number of classes ($F(3, 94) = 3.38$, $p < .05$), with the participants who took more geography classes scoring higher than those who took less number of classes. The results indicate that the participants who had no background in geography yield the lowest mean score (60.99%). Conversely, those who took more than nine geography classes produced the highest score of 78.00%. The participants who took 1-4 classes had lower mean score (65.67%) than those who took 5-9 classes (72.15%). A non-significant interaction ($F(4, 94) = .100$, $p > .05$) also indicates that the participants in all groups who attended more geography classes produce higher mean scores than those who took less number of classes.

Table 4.30 Effects of group and number of geography classes taken on standard total score.

Variables	***df***	***SS***	***MS***	***F***	***P***
Group	2	1,975.82	987.91	6.207	.003
Number of Classes	3	1,612.68	537.56	3.38	.022
Interaction	4	63.46	15.86	.100	.982
Within Groups	94	14,962.06	159.71		
Total	103	19,843.85			

4.4.5 Effects of Group and Computer Skill on Total Score

Since all participants performed tasks on the computer, they were asked to rank if they were comfortable working with computers as (1) very uncomfortable, (2) uncomfortable, (3) comfortable, and (4) very comfortable. Overall, 93% of the participants ranked themselves as comfortable or very comfortable. In the group with no sight, only 3% ranked themselves as uncomfortable. These data were then analyzed to determine if the computer skill had an effect on the participants' performance. The results of the univariate ANOVA (Table 4.31) show that there is a significant main effect for group ($F(2, 94) = 4.186$, $p < .05$), but no significant main effect for computer skill ($F(3, 94) = 2.60$, $p > .05$). The interaction between group and computer skill is not statistically significant ($F(4, 94) = .100$, $p > .05$), indicating that the average scores of the participants in all groups vary depending on other factors rather than on the computer skill.

Table 4.31 Effects of group and computer skill on standard total score.

Variables	*df*	*SS*	*MS*	*F*	*P*
Group	2	1,330.90	665.448	4.186	.018
Computer Skill	3	1,238.97	412.99	2.598	.057
Interaction	4	958.95	239.74	1.508	.206
Within Groups	94	14,943.02	158.97		
Total	103	19,843.85			

4.4.6 Effects of Group and Topographic Map Reading Skill on Total Score

The participants were asked to rank their topographic map reading as (1) beginner, (2) intermediate, and (3) advanced. With one hundred and four participants, 50% ranked themselves as beginner, 39.42% as intermediate, and 10.58% as advanced. Both main effects: group and topographic map reading skill, are statistically significant with alpha set as .01 level (Table 4.32). However the interaction is not significant ($F(4, 95) = 1.190$, $p > .05$). The statistical analysis indicates that the participants who ranked themselves as "advanced" in map reading skills have higher mean scores than those who ranked themselves as "intermediate" or "beginner" in all groups.

Table 4.32 Effects of group and topographic map reading skill on standard total score.

Variables	*df*	*SS*	*MS*	*F*	*P*
Group	2	1,870.83	935.41	6.644	.002
Map Reading Skill	2	3,482.09	1,741.05	12.366	.000
Interaction	4	670.36	167.59	1.190	.320
Within Groups	95	13,375.42	140.79		
Total	103	19,843.85			

4.4.7 Effects of Group and Pitch Identification Skill on Total Score

The participants who performed tasks on the sonically enhanced maps were asked to ranked their ability to identify different pitch a note on the musical scale without any reference note as (1) not good at pitch, (2) intermediate, and (3) close to perfect pitch. With sixty-eight participants, 58.82% ranked themselves as intermediate, 27.94% as not good at pitch, and 13.24% as close to perfect pitch. A statistically significant main effect for group is found ($F(1, 62) = 5.484$, $p < .05$), while there is no significant main effect for pitch identification skill ($F(2, 62) = 1.298$, $p > .05$). The results also show no statistically significant in interaction ($F(2, 62) = 1.514$, $p > .05$), indicating that the pitch identification skill is not influence the mean scores differentially among groups.

Table 4.33 Effects of group and pitch identification skill on standard total score.

Variables	*df*	*SS*	*MS*	*F*	*P*
Group	1	839.27	839.27	5.484	.022
Pitch Identification Skill	2	397.30	198.65	1.298	.280
Interaction	2	463.47	231.73	1.514	.228
Within Groups	62	9,488.89	153.05		
Total	67	11,639.24			

4.4.8 Effects of Visually Impaired Condition on Total Score in the Group of Participants with Visual Impairment

In the background questionnaire, the participants with visual impairment were asked if they were (1) congenitally visually impaired or blind, (2) visually impaired or blind early in life before the age of 40, or (3) visually impaired or blind later in life. A one-way ANOVA was then conducted to determine if the mean scores differed significantly among groups. The Post Hoc test was also performed if the differences existed.

The results in Table 4.34 indicate that the participants who are congenitally visually impaired or blind have the highest mean score (77.12%). The participants who were blind early in life yielded lower mean score (69.17%) than those who were blind later in life after the age of 40 (mean = 70.83%). However, the one-way ANOVA analysis indicates that these differences among groups are not statistically significant ($F(2, 28) = 1.384$, $p > .05$). Thus, the conditions in which the participants were congenitally blind or blind later in life do not reflect the mean scores on the test.

Table 4.34 Results from one-way ANOVA for the average mean scores in the group of participants with visual impairment in different conditions.

Group	*Mean*	*Standard Deviation*	*N*	*F*	*P*
(1) Congenitally Blind	77.12	9.06	13	1.384	.267
(2) Blind Early in Life	69.17	14.35	12		
(3) Blind Later in Life	70.83	14.38	6		

4.4.9 Effects of Time that the Participants Have Been Blind on Total Score in the Group of Participants with Visual Impairment

The participants in the group with visual impairment consisted of the persons who lost their vision from 1 to 64 years ago. These numbers were grouped into 5 classes: (1) less than 5 years, (2) from 5 to 10 years, (3), from 11 to 15 years, (4) from 16 to 20 years, and (5) longer than 20 years. The majority of participants in this group had lost their vision longer than 20 years (Table 4.35). As might be expected, the participants in this group yielded the highest mean score of 74.22%, while the participants who were blind less than 5 years produced the lowest mean score of 67.50%. From the observation during the experiment, the researcher found that the persons who were blind longer than 20 years (or some were blind for all of their life) paid more attention on what they heard than other groups did. On the other hand, most of the persons who just lost their sight and had some residual vision still relied on their vision rather than audition. The results of a one-way ANOVA indicate that there are no differences of the mean scores among groups ($F(2, 26) = .224$, $p > .05$).

Table 4.35 Results from one-way ANOVA for the average mean scores in the group of participants with visual impairment based on time that the participants have lost their vision.

Group	*Mean*	*Standard Deviation*	*N*	*F*	*P*
(1) < 5 years	67.50	7.07	2	.224	.922
(2) 5 - 10 years	71.88	10.08	4		
(3) 11 - 15 years	73.75	12.42	6		
(4) 16 -20 years	68.33	16.27	3		
(5) > 20 years	74.22	13.90	16		

4.4.10 Effects of Visibility Condition on Total Score in the Group of Participants with Visual Impairment

The participants were asked how much they relied on their vision. The choices provided for this question were coded as (1) none, (2) rarely, (3) sometimes, and (4) as much as other senses. The results shown in Table 4.36 illustrate that the persons with visual impairment who relied on their vision as much as other senses have the lowest mean score of 62.50%. On average, the participants with visual impairment and blindness who performed tasks on the sonically enhanced maps yielded the total score of approximately 76%. This mean score was higher than that in the group who is sighted. Based on the visibility condition, the results of a one-way ANOVA indicate that the differences of the mean scores in the group with visual impairment are not statistically significant ($F(3, 27) = 2.906$, $p > .05$). Thus, the conclusion that the visibility condition is the major factor that influences the mean scores in the group of participants who are visually impaired cannot be drawn.

Table 4.36 Results from one-way ANOVA for the average mean scores in the group of participants with visual impairment based on the visibility condition.

Group	Mean	Standard Deviation	N	F	P
(1) None	76.32	10.20	17	2.906	.053
(2) Rarely	76.67	11.81	3		
(3) Sometimes	76.67	12.33	3		
(4) As Much As Other Senses	62.50	13.69	8		

4.5 Cross Chain Correlation

The drawings from the participants who are visually impaired were analyzed using cross chain correlation. This process was conducted as a follow up to statistical analysis in order to determine if the cognitive profiles obtained from the participants with visual impairment were similar to the actual ones. The sketching task provided one such source of this corroborating evidence because it tapped a different facet of spatial knowledge. Twenty-nine individual's drawings for each trial at varying scales are displayed in Appendix D. These sketch profiles were subjective upon individual's skill of drawing. Thus, it was clear that some drawings appear better than others. The appearance of better quality was based on a number of factors, such as level of detail, orientation, and shape. For the purpose of this research, the artistic aspect of constructing a sketch profile was removed. These profiles were first chain coded and then analyzed using cross chain correlation to access their accuracies. The correlation values of the cognitive profiles were presented in Appendix E.

The researcher further examined if one sound variable or two sound variables had more effect on the participants ability to interpret topographic profiles. A paired sample *t*-test was performed to compare the means of two sets of data whether they differed from zero. For this test, the data were evaluated as two groups, the first being the mean of the estimated correlation by one sound variable (pitch), and the second being the mean of the estimated correlation by two sound variables (pitch and duration). The results shown in Table 4.37 indicate that there is no statistically significant difference between the two sets of means ($t = -.594$, $p > .05$). This suggests that the participants succeed with their attempt to draw the cognitive profiles whether one sound variable or two sound variables are presented.

Table 4.37 Results from a paired sample *t*-test for the mean of the estimated correlation by one and two sound variables in the group with visual impairment.

	Paired Differences			
Variables	**Mean**	**df**	**t**	**Significance (2-tailed)**
Pair 1: Pitch - Pitch and Duration	-5.62E-03	28	-.594	.557

CHAPTER 5
CONCLUSION AND DISCUSSION

A map is a source of spatial information *par excellence*. No other medium is able to convey spatial information as efficiently as a map. However, people with visual impairments have severely restricted access to maps. This restriction occurs on two levels. First, maps in a suitable format for people who are visually impaired are very scarce. While they do exist, they are likely to be of limited use due to their outdated, too specialized nature (e.g., a map of a particular public building), or too generalized nature (e.g., a map of the world). Second, non-visual reading of relief via a tactile map is difficult and time consuming.

This research examined the utilization of sound variables for cognitive enhancement of topographic maps for the people with visual impairment and blindness. The research was undertaken for a variety of reasons, some applied and others theoretical. The main purposes were to develop a tool to allow access to spatial information without using vision and to provide a thorough investigation on how to improve the spatial learning of geographic environments. The sonically enhanced maps developed in this experiment have the potential to overcome the barriers to map use that people with visual impairment encounter. The problems of access to the information contained within topographic maps are minimized by the use of tactile and auditory senses. This chapter begins by examining the conclusions that can be drawn from this research followed by a discussion of the work conducted throughout the experiment, then addressing how this research contributes to cartography. Finally, the opportunities for future research are discussed.

5.1 Conclusion

5.1.1 Null Hypothesis Ho_1: Using the combination of sound variables pitch and duration will not increase accuracy for participants who are sighted and those who are visually impaired or blind when compared to using on sound variable.

This research hypothesis anticipates a difference in how well an individual who has sight and one without sight performs map interpretation and comprehension tasks on the traditional topographic maps and sonically enhanced maps. The tutorials and map quiz were created to test the null hypothesis Ho_1 which states that using the combination of sound variables pitch and duration will not increase accuracy for participants who are sighted and those who are visually impaired or blind when compared to using one sound variable. Overall, there are differences in the number of correct answers for the slope, profile, and landform questions in the group with sight, but there are no differences in the group with visual impairment (see Section 4.3 and Table 5.1). The participants who are sighted tend to perform well, especially in the profile determination task, when two sound variables were utilized. It appears that an integration of sound variables pitch and duration with contour lines can be used to convey the concept of topographic surface, which is continuous, to the individuals who are sighted. Therefore, the null hypothesis Ho_1 is rejected and the assumption that the combination of these two sound variables enhances the interpretability of topographic maps in the group with sight can be made. However, this null hypothesis cannot be rejected in the group with visual impairment. In this group, this suggests that either one or two sound variables have almost the same effects in map interpretation.

Table 5.1 The overall results between groups in the pitch and the combined pitch and duration conditions.

	Slope Questions	Profile Questions	Landform Questions
Group with Sight	Difference	Difference	Difference
	(p < .01)	(p < .01)	(p < .01)
Group with No sight	No Difference	No Difference	No Difference
	(p > .05)	(p > .05)	(p > .05)

5.1.2 Null Hypothesis Ho_2: An integration of the sound variables pitch and duration with contour lines will not affect the ability of participants who are sighted and those who are visually impaired or blind to correctly answer questions pertaining to topographic maps

The evidence obtained from the statistical analysis leads to the rejection of the null hypothesis Ho_2 (see Section 4.1 and Table 5.2). An integration of sound variables with contour lines provide the participants a multi-sensory (e.g., audition and touch) approach to access information, thus allowing them to correctly answer questions pertaining to topographic maps. Overall, the participants who were given the sonically enhanced maps to explore produce higher mean scores than those who view topographic maps without augmentation of sound. The results clearly indicate that the sound variables pitch and duration significantly help the participants, especially those who are visually impaired, determine the relative elevation and profile, and identify landforms on topographic maps. However, for the distance determination, the visual maps still have advantages over the sonified maps because they provide graphical scales for the viewers to compare and calculate distances on the maps. This approach allows for more accuracy when the participants who are sighted were assigned to select answers in two decimal digits. The participants who are visually impaired also reported having difficulties in determining the length of sounds, counting them in seconds, and correlating them to scale. For the slope questions, the statistical results indicate no significant differences in the number of correct answers among groups. The slope determination task is found to be very subjective, especially when the participants are not given an instruction on how to determine slope characteristics on topographic maps. It is obvious in the group of participants with visual impairment that they identify slope as steep, gentle, or uniform by correlating the aspects of sound variables (e.g., pitch, duration) with the way they traverse through space. For example, if there is a long pause between the first note (e.g., C note on the musical scale that represents the elevation of 170 feet) and the second note (e.g., D note on the musical scale that represents the elevation of 180 feet), they perceive it as "up steep slope" rather than "up gentle slope". In fact, in this experiment, a long pause or a long duration between each note represents widely spaced between adjacent contour lines on the map, meaning that the slope is gradual. However, some participants who are visually impaired reported that a long pause in the pitch condition gave them a feeling that they had to put much effort in order to walk up hill. Also the long duration between each note gave them the same effect as the long pause in the pitch condition did. Additionally, they perceive it as "up steep slope".

Table 5.2 The comparison of total correct responses to map questions in the groups of participants who are sighted and who are visually impaired.

Question Type	**Result**
Average score for all questions	Difference ($p < .01$)
Elevation	Difference ($p < .01$)
Slope	No Difference ($p > .05$)
Profile	Difference ($p = .00$)
Distance	Difference ($p < .05$)
Landform	Difference ($p = .00$)

5.1.3 Null Hypothesis Ho_3: An integration of the sound variables pitch and duration with contour lines will not affect the speed of response to map questions in the group of participants who are sighted.

The null hypothesis Ho_3, which states that an integration of the sound variables pitch and duration with contour lines does **not** affect the **speed of response** to map questions in the group of participants who are sighted, was tested. In the case of participants who are visually impaired, the researcher expects that they would take longer time to answer questions as a result of the additional steps necessary to obtain the same information presented in the tutorial and map quiz section. Therefore, the response time to map questions in this group is not considered. When the average response time on all questions in the groups with sight were compared, the results indicate that the participants in group 2 who performed tasks on sonically enhanced maps take slightly less response time (23.49 seconds) than those in group 1 who performed tasks on topographic maps without augmentation of sound (25.70 seconds). However, this difference is not statistically significant (see Section 4.2 and Table 5.3) and the null hypothesis Ho_3 cannot be rejected. This suggests that an integration of the sound variables pitch and duration with contour lines does not significantly reduce the speed of response to map questions in the group with sight.

Table 5.3 The comparison of average response time to map questions between groups 1 and 2.

Question Type	**Result**
Average response time for all questions	No Difference ($p > .05$)
Elevation	Difference ($p = .00$)
Slope	No Difference ($p > .05$)
Profile	No Difference ($p > .05$)
Distance	No Difference ($p > .05$)
Landform	No Difference ($p > .05$)

5.2 Discussion

There is no denying that sight is the spatial sense *par excellence* and it is commonly understood that the spatial abilities of people with visual impairment are underdeveloped in comparison to individuals who are sighted. However, within the geographic environment, surrounded by other sources of sensory information, and with suitable experimental variables, training, familiarization, and experience, it is possible for people who are visually impaired and blind to acquire an equivalent level of understanding in only a relatively short time frame. Traditionally three theories have been used to explain these differences. The *deficiency theory* postulates that people with severe visual impairment, because of their lack of vision, are unable to cognitively process spatial information. The *inefficiency theory* states that people with severe visual impairment can cognitively process spatial information but they do so in inefficiently because their spatial abilities do not develop fully due to a lack of vision. The *difference theory* contends that people with severe visual impairment under-perform on spatial tasks because they compensate for a lack of vision by using different cognitive processes to individuals with sight. Juurmaa (1973) found that differences between participants who are sighted and those who are blind in the experiment disappeared when the participants dealing with material that was not "optically familiar" (e.g., squares, triangles, and crosses, etc.). Differences between the two groups were thus based on experience of the medium. This led Juurmaa to contend that people who are congenitally blind are able to develop spatial representations based on non-visual inputs from information supplied by other senses.

While for people with visual impairment cognitive map knowledge is generally considered to be somewhat impoverished (e.g., Casey 1978), it is not inevitable that a visual loss leads to an impoverished spatial knowledge of a real world environment. In general the participants who are visually impaired and blind need more time to be familiarized with an environment. In studies where participants with sight and those without sight have been given the (short) time to familiarize themselves with the test, the non-sighted have generally performed worse (Rieser *et al*. 1986). However, in some studies where participants who are blind have been given greater opportunity to familiarize themselves with the data they performed equivalently (Herman *et al*. 1983). The findings from this research reveal that people with visual impairment are able to learn and develop spatial knowledge equivalent to that of people who are sighted if they are provided with subsequent experience, such as training, and most importantly with access to representation of the environment (e.g., topographic maps). The findings of this research support the difference theory initially proposed by Fletcher (1980) and indicate that persons with visual impairment are able to acquire spatial representations and develop their spatial knowledge with alternative coding and designing strategies. We can also assume that the internal spatial representation is not linked to any specific sensory modality.

The sighted have more experience with space and they have more experience with the sorts of tasks that are required in spatial experiment than do the people with visual impairment. However, it does not mean that the people who are visually impaired would be any less capability than those with sight if given the same amount of information of experience, but because they have had less they perform worse than the sighted in spatial tasks (Spencer *et al*. 1989). Individuals with visual impairment do experience a different geographic world than people who have sight since their space is transformed by their loss of vision. This transformation is reinforced by the lack of appropriate communication media to describe and explain the geographic world to people who are visually impaired. Methods for communicating geographic space have undergone the most change in recent years, with the advent of new mapping and computer technologies. New ways of communicating geographic space to people without sight have the potential to build upon the ability of graphic based material (e.g., maps, models, etc.) to promote active learning as demonstrated by the integration of sound variables and spoken audio with topographic maps in the study. Novel media has the greatest potential of all, as it is possible to overcome some of the limitations of blindness for accessing spatial information through sensory substitution and multimodal data presentation. The interaction with data through sound and touch provide other sensory channels to provide information to the brain, which offer the potential for multisensory visualization, data augmentation (rather than replacement), and increased understanding of spatial information.

5.3 Contributions to Cartographic Research

A new approach for learning and communicating spatial information was developed during this research. This has the potential to be of great benefit especially to the population with visual impairment and blindness because it provides information about the world experienced by them. By presenting geographic information in a multimodal manner, it is possible to adopt a "design for all" approach, which has significant practical and theoretical implications for individuals who are visual and non-visual. It is necessary to know how to compensate for lack of sight, to understand different aspects of what each perceptual system contributes, and what information is missing, so that this can be substituted. Some guidelines and design strategies for users with visual impairment (e.g., using consistent user-interface elements, labeling of all graphics and icons with sounds and voice-over, etc.) should be considered to provide these individuals an opportunity of learning. The insights and understanding obtained through cognitive mapping research can also be used to facilitate the designing of maps that are easier to remember and more pleasurable to use. Through the use of sound variables, spoken audio, verbal landmarks, and auditory icons, the users without sight were able to explore the topographic maps and learn geographic environment in a way that they have not experienced before.

This research provides clues as to how to enhance the interpretability of topographic maps via other media rather than traditional paper maps. The findings in this research exceeded the researcher's expectation and should not be underestimated. Participants who are visually impaired and blind performed equally as well as sighted participants and in some cases marginally (if not somewhat) better. The analysis suggests that the reasons why the group with visual impairment outperformed the group with sight is due to the methods of testing spatial abilities and knowledge's. Participants were required to undertake the tests and answer several questions, which forced them to think about map exploration in novel ways. The perceptual variability or multiple representations (the same concepts represented in varying ways) provide participants with the opportunity to build abstractions about the concept of space (Ainsworth and van Labeke 2002). The results also seem to suggest that the future testing of the spatial abilities and knowledge of people with visual impairment might be best undertaken in real-world environments, the locations they actually interact with (e.g., urban environment), rather than through abstract, laboratory tasks.

Although vision is the most effective sense for gaining spatial information, people who are blind are able to use language, audition, haptic, smell, and taste as well as motion to gain a direct or indirect awareness of their geographic environment. Whether blind, visually impaired, or sighted, our quality of life is greatly dependent on our ability to make informed spatial decisions within variety of situations, at differing scales (Golledge 1993). There is no denying that a map is the predominant method for presenting spatial information in cartography. However, the traditional, printed map has its own limitations. The map lacks interaction and it is not possible to link features to other types of media. This research utilized sound and tactile mouse to communicate the representations of geographic world. This approach serves as an enabling technology and allows for accessing to spatial information. This, in turn, is likely to improve education, mobility, and employment opportunities for the individuals who are visually impaired.

5.4 Future Research

The ways of presenting geographic information have to incorporate more multimodal data presentation and manipulation. This multimodal interaction has the potential to provide not only better representation, but also improve understanding, and more intuitive interaction and visualization. The design of multimodal interface aims to provide a more expressive, efficient, and easy to learn manner of interacting with computers. The multimodal presentation of geographic information allows for innovative visualization of large and complex data sets (Fisher 1994; Flowers *et al*. 1996). Oviatt (1997, p.93) stresses that "...future map systems ideally should be designed to be accessible to a broad range of people, irrespective of age, sensory impairment, skill level, or other considerations." Cartographers can embrace the concept of Universal Design and begin applying it to the design of learning materials in geographic space, methods, and assessment. Universal Design for Learning (UDL) assumes that every learner is an individual with individual needs, interests, strengths, and limitations (Center for Applied Special Technology 1999). In addition, UDL achieves the goal of meeting individual needs by providing alternatives, not by seeking a single solution for all. UDL does not imply "one size fits all" but rather acknowledges the need for flexibility to suit the requirements of many different people. This option, in some cases critical for persons with disabilities, also offers new learning opportunities for those with a range of learning interests and abilities. In the case of exploring geographic space, maps presented through modalities other than vision are particularly powerful in that they offer a vehicle for empowerment for individuals who are unable to use their visual sense. In providing information in this manner, additional research avenues are opened. This provides additional opportunities for a wide variety of people.

This research is complicated by the necessity to use different modalities to access information (maps) for the people with visual impairment. The use of audition and touch allows them to access purely visual and spatial concepts of topographic map interpretation. Nonetheless, there is a need to investigate the combinations and interactions of these modalities in order to find the optimal methods for presenting information. For example, is it best to represent certain information through language, sound variables, touch, or a virtual surface? Does this information need to vary between novice and expert knowledge? What are the appropriate fundamental audio-tactile variables (e.g., shape, size, pitch, duration, loudness, etc.) used to communicate spatial information? Do these variables combine, complement, or offer redundancy to spatial information? These questions are left unanswered and are important considerations for future research in this field.

REFERENCES

Ainsworth, S. and van Labeke, N. (2002). "Using a Multi-Representational Design Framework to Develop and Evaluate a Dynamic Simulation Environment." In *On-line Proceedings of the International Workshop on Dynamic Visualizations and Learning. Tubingen: Knowledge Media Research Center*. [web page] http://www.iwm-kmrc.de/workshops/visualization/proceedings.htm [accessed August 5, 2003].

Anderson, J. (1978). "Arguments Concerning Representations for Mental Imagery." *Psychological Review*, Vol.85, pp.249-277.

Anderson, J. and Bower, G. (1973). *Human Associative Memory*. V.H. Winston and Sons, New York.

Baddeley, A. (1986). *Working Memory*. Clarendon Press, Oxford.

Berkeley, G. (1709). "An Essay Towards a New Theory of Vision." In *Berkeley's Philosophical Writings*, D. Armstrong (ed). Macmillan, New York, pp.274-352.

Blattner, M.M., Sumikawa, D.A. and Greenberg, R.M. (1989). "Earcons and Icons: Their Structure and Common Design Principles." *Human-Computer interaction*, Vol.4, pp.11-44.

Blenkhorn, P. and Evans, D.G. (1994). "A System for Reading and Producing Talking Tactile Maps and Diagrams." *Proceedings of the 9th International Conference on Technology and Persons with Disabilities*, at California State University, Northridge.

Brain, M. (2001). "How MP3 Files Work." In *HowStuffWorks*. [web page] http://www.howstuffworks.com/mp3.htm [accessed March 11, 2001].

Bregman, A.S. (1990). *Auditory Scene Analysis*. MIT Press, Cambridge.

Brewster, S.A., Wright, P.C., Dix, A.J. and Edward, A.D.N. (1995). "The Sonic Enhancement of Graphical Buttons." *Proceedings of IFIP International Conference Interactions'95*, at Lillehammer, Norway.

Brooks, F.P. (1977). "The Computer 'Scientist' as Toolsmith - Studies Interactive Computer Graphics." *Proceedings of IFIP 1977*.

Burrough, P.A. and McDonnell, R.A. (1998). "Chapter Three: Geographical Data in the Computer." In *Principles of Geographical Information Systems*. Oxford University Press, New York, pp.35-74.

Buziek, G. (1999). "Dynamic Elements of Multimedia Cartography." In *Multimedia Cartography*, W. Cartwright, M.P. Peterson and G. Gartner (eds). Springer, New York, pp.231-244.

Casey, S.M. (1978). "Cognitive Mapping by the Blind." *Journal of Visual Impairments & Blindness*, Vol.72, No.8, pp.297-301.

Center for Applied Special Technology (1999). "Universal Design for Learning." In *CAST Universal Design for Learning*. [web page] http://www.cast.org/udl/ [accessed August 5, 2003].

Cohen, M. and Wenzel, E.M. (1995). "The Design of Multidimensional Sound Interfaces." In *Virtual Environments and Advanced Interface Design*, T.S. Woodrow Barfield and E. III Furness (eds). Oxford University Press, New York, pp.291-346.

Cook, I. (1996). *Drowning in a Seeing World? Critical Ethnographies of Blindness*. Unpublished Master Thesis, Department of Geography, University of Kentucky.

Dacen Nagel, D. and Coulson, N. (1990). "Tactile Mobility maps - A Comparative Study." *Cartographica*, Vol. 27, pp.47-63.

Descartes, R. (1637). *Discourse on Method, Optics, Geometry and Meteorology*. Bobbs-Merrill, Indianapolis, Indiana.

Dodds, A.G. (1988). *Mobility Training for Visually Handicapped People*. Croom Helm, London.

Downs, R. M. and Stea, D. (1973). *Maps in Minds: Reflections on Cognitive Mapping*, Harper and Row, New York.

Dransch, D. (1999). " Theoretical Issues in Multimedia Cartography." In *Multimedia Cartography*, W. Cartwright, M.P. Peterson and G. Gartner (eds). Springer, New York, pp.41-50.

Dufresne, A., Martial, O., Ramstein, C. and Mabilleau, P. (1996). "Sound, Space, and Metaphor: Multimodal Access to Windows for Blind Users." In *Proceedings of ICAD'96*. [web page] http://www.santafe.edu/~icad/ICAD96/proc96/dufresne1.htm [accessed October 22, 1999].

Fisher, P. (1994). "Hearing the Reliability in Classified Remotely Sensed Images." *Cartography and Geographical Information Systems*, Vol.21, No.1, pp.31-36.

Fletcher, J.F. (1980). "Spatial Representation in Blind Children, 1:Development Compared to Sighted Children." *Journal of Visual Impairment and Blindness*, Vol.74, No.10, pp.381-385.

Flowers, J.H., Dion, C.B. and Turnage, K. (1996). "Data Sonification from the Desktop: Should Sound Be Part of Standard Data-analysis Software?" In *Proceedings of ICAD'96*. [web page] http://www.santafe.edu/~icad /ICAD96/proc96/flowers.htm [accessed October 22, 1999].

Flowers, J.H. and Hauer, T.A. (1995). "Musical versus Visual Graphs: Cross-modal Equivalence in Perception of Time Series Data." *Human Factors*, Vol.37, pp. 553-569.

Foulke, E. (1983). "Spatial Ability and the Limitations of Perceptual Systems." In *Spatial Orientation: Theory, Research, and Application*, H.L. Pick and L. Acredolo (eds). Plenum Press, New York, pp.125-141.

Freeman, H. (1974). "Computer processing of line-drawing images." *Computing Surveys*, Vol.6, No.1, pp.57-97.

Garling, T. and Golledge, R.G. (1993). *Behavior and environment: Psychological and Geographical Approaches*. Elsevier Science Publishers, North-Holland.

Gaver, W. (1989). "The SonicFinder: An Interface that Uses Auditory Icons." *Journal of Human Computer Interaction*, Vol.4, pp.67-93.

Gill, J. (1997). *Access Prohibited? Information for Designers of Public Access Terminals*. Royal National Institute for the Blind, London.

Gold, J. (1980). *An Introduction to Behavioural Geography*. Oxford University Press, Oxford.

Golledge, R.G. (1991). "Tactual Strip Maps as Navigation Aids." *Journal of Visual Impairment and Blindness*, Vol.85, No.7, pp.296-301.

_____, (1993). "Geography and the Disabled: A Survey with Special Reference to Vision Impaired and Blind Populations." *Transactions of the Institute of British Geographers*, Vol.18, pp.63-85.

Golledge, R.G., Klatsky, R.L. and Loomis, J.M. (1996). "Cognitive Mapping and Wayfinding by Adults without Vision." In *The Construction of Cognitive Map*, J. Portugali (ed). Kluwer, Dordrecht, pp.215-245.

Golledge, R.G., Klatsky, R.L., Loomis, J.M., Speigle, J. and Tietz, J. (1998). "A Geographic Information System for a GPS Based Personal Guidance System." *International Journal of Geographical Information Science*, Vol.12, No.7, pp727-749.

Golledge, R.G., Marston, J.R. and Costanzo, C.M. (1998a). "Assistive Device and Services for the Disabled. Final Report. February. University of California achievement Field Station PATH Division Grant #MOU276.

Golledge, R.G. and Stimpson, R. (1997). *Spatial Behaviour: A Geographic Perspective*, The Guilford, New York.

Golledge, R.G.M.J.R. and Costanzo, C.M. (1997). "Attitudes of Visually Impaired Persons toward the Use of Public Transportation." *Journal of Visual Impairment & Blindness*, Vol.91, No.5, pp.446-459.

Gould, P. (1966). *On Mental Maps*, Michigan Inter-University Community of Mathematical Geographers, Discussion Paper#9.

Greene, W.M. (2000). *Using Sound Variables to Expedite Topographic Map Reading*. Unpublished Master Thesis, Department of Geography, The University of Georgia.

Herman, J.F., Chatman, S.P. and Roth, S.F. (1983). “Cognitive Mapping in Blind People: Acquisition of Spatial Relationships in a Large-scale Environment.” *Journal of Visual Impairment & Blindness*, Vol.77, No.4, pp.161-166.

Hill, E.W., Rieser, J.J., Hill, M.-M. and Hill, M. (1993). "How Persons with Visual Impairments Explore Novel Spaces: Strategies of Good and Poor Performers." *Journal of Visual Impairment and Blindness*, Vol.87, No.8, pp.295-301.

Immersion Corporation. (2001). “Immersion TouchSense™ Fundamentals.” [web page] http://www.immersion.com/developer/downloads/ImmFundamentals/HTML/index.htm [accessed December 11, 2001].

Iivarinen, J., Peura, M., Särelä, J. and Visa, A. (1997). “Comparison of Combined Shape Descriptions for Irregular Objects.” [web page] http://www.cis.hut.fi/research/IA/paper/publications/bmvc97/bmvc97.html [accessed May 1, 2003].

Jacobson, R.D. (1998). "Cognitive Mapping without Sight: Four Preliminary Studies of Spatial Learning." *Journal of Environmental Psychology*, Vol.18, pp.289-305.

_____, (1999). *Exploring Geographies of Blindness Learning, Reading and Communicating Geographic Space*. Unpublished Doctoral Dissertation, Queen's University of Belfast.

Jacobson, R.D. and Kitchin, R.M. (1997). "Geographical Information Systems and People with Visual Impairments or Blindness: Exploring the Potential to Education, Orientation and Navigation." *Transactions in Geographical Information Systems*, Vol.2, No.4, pp.315-332.

Johnson-Laird, P. (1983). *Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness*. Cambridge University Press, Cambridge.

Johnson-Laird, P. (1993). *Human and Machine Thinking*. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Juurmaa, J. (1973). "Transportation in Mental Spatial Manipulation: A Theoretical Analysis." *American Foundation for the Blind Research Bulletin*, Vol.26, pp.87-134.

Kahneman, D. and Treisman, A. (1984). "Changing Views of Attention and Automaticity." In *Varieties of Attention*, R. Parasuraman and D. Davies (eds). Academic Press, New York, pp.29-61.

Kennedy, J.M., Gabias, P. and Heller, M.A. (1992). "Space, Haptics and the Blind." *Geoforum*, Vol.23, No.2, pp.175-189.

Kitchin, R.M. (1995). *Issues of Validity and integrity in Cognitive Mapping Research: Investigating Configurational Knowledge*. Unpublished Doctoral Dissertation, University of Wales, Swansea.

_____, (1997). "Understanding Spatial Concepts at the Geographic Scale without the Use of Vision." *Progress in Human Geography*, Vol.21, pp.225-242.

Kitchin, R.M., Blades, M. and Golledge, R.G. (1997). "Understanding Spatial Concepts at the Geographic Scale without the Use of Vision." *Progress in Human Geography*, Vol.21, No.2, pp.225-242.

Kitchin, R.M. and Jacobson, R.D. (1997). "Techniques to Collect and Analyse the Cognitive Map Knowledge of People with Visual Impairments or Blindness." *Journal of Visual Impairment and Blindness*, Vol.91, pp.360-376.

Kitchen, R.M., Jacobson, R.D., Golledge, R.G. and Blades, M. (1998). "Belfast without Sight: Exploring Geographies of Blindness." *Irish Geography*, Vol.31, No.1, pp.34-46.

Klatzky, R.L., Loomis, J.M., Golledge, R.G., Cicinelli, J., Doherty, S. and Pellegrino, J. (1990). "Acquisition of Route and Survey Knowledge in the Absence of Vision." *Journal of Motor Behavior*, Vol.22, No.1, pp.19-43.

Kosslyn, S. and Swartz, S. (1978). "Visual Images as Spatial Representations in Active Memory. " In *Computer Vision Systems*, A. Hanson and E. Riseman (eds). Academic Press, New York, pp.223-241.

Kramer, G. (1994). "An Introduction to Auditory Display." In *Auditory Display: Sonification, Audification, and Auditory Interfaces*. *Proceedings of ICAD'92*, G. Kramer (ed). Reading, Addison-Wesley, Massachusetts, pp.1-77.

_____, (1994a). "Some Organizing Principles for Representing Data with Sound." In *Auditory Display: Sonification, Audification, and Auditory Interfaces*. *Proceedings of ICAD'92*, G. Kramer (ed). Reading, Addison-Wesley, Massachusetts, pp.185-221.

Krygier, J.B. (1994). "Sound and Geographic Visualization." In *Visualizaiton in Modern Cartography*, A.M. MacEachren and D.R. Fraser-Taylor (eds). John Wiley & Sons, Chichester, England, pp.149-166.

Leinmann, E. and Schulze, H.H. (1995). "Earcons and Icons: An Experimental Study." *Proceedings of IFIP International Conference Interactions'95*, at Lillehammer, Norway, pp.49-54.

Levie, W. (1987). "Research on Pictures: A Guide to the Literature." In *The Psychology of Illustration, Volume 1: Instructional*, D. Willows and H. Houghton (eds). Springer-Verlag, New York, pp.1-50.

Lloyd, R. (1997). *Spatial Cognition*. Kluwer Academic Publishers, The Netherlands.

Locke, J. (1689). *An Essay Concerning Human Understanding*. Roteledge and Sons, London.

Logitech Corporation (2000). [web page]
http://www.logitech.com
[accessed January 2, 2000].

Loomis, J., Klatzky, R.L., Golledge, R.G., Cicinelli, J.G., Pellegrino, J.W. and Fry, P.A. (1993). "Non-visual Navigation by Blind and Sighted: Assessment of Path Integration Ability." *Journal of Experiment Psychology: General*, Vol.122, No.1, pp.73-91.

Lowenthal, D. (1961). "Geography, Experience, and Imagination: Toward a Geographical Epistemology. " *Annals of the Association of American Geographers*, Vol.51, pp.241-261.

Lynch, K. (1960). *Image of the City*. MIT Press, Cambridge, Massachusetts.

Mansur, D.L., Blattner, M.M. and Joy, K.I. (1985). "Sound-graphs: A Numerical Data Analysis Method for the Blind." *Journal of Medical Systems*, Vol.9, pp.163-174.

Martin, J., Meltzer, H. and Elliot, D. (1988). *The Prevalence of Disability Among Adults: OPCS Survey of Disability in great Britain, Report 1*. Office of Population censuses and Surveys, HMSO, London.

Members of the International Community for Auditory Display. (1997). "Sonification Report: Status of the field and Research Agenda." Paper prepared for *the National Science Foundation in the Fall of 1997 in Association with the International Conference on Auditory Display (ICAD)*. [web page]
http://www.santafe.edu/~icad/websiteV2.0/References/nsf.html
[accessed October 22, 1999].

Millar, S. (1988). "Models of Sensory Deprivation: The Nature/Nurture Dichotomy and Spatial Representation in the Blind." *International Journal of Behavioral Development*, Vol.11, pp.69-87.

Morgan, M.J. (1977). *Molyneux's Question: Vision, Touch and the Philosophy of Perception*. Cambridge University Press, Cambridge.

Morrongiello, B.A., Timney, B., Humphrey, G.K., Anderson, S. and Skory, C. (1995). "Spatial Knowledge in Blind and Sighted Children." *Journal of Experimental Chile Psychology*, Vol.59, p.221.

Ohio LIONS Eye Research Foundation (2003). "Simulations." [web page] http://ohiolionseyeresearch.com/simulati.htm [accessed March 23, 2003].

Oviatt, S. (1997). "Multimodal Interactive Maps: Designing for Human Performance." *Human-Computer Interaction*, Vol.12, pp.93-129.

Park, D., Radford, J. and Vickers, M. (1998). "Disability studies in human Geography." *Progress in Human Geography*, Vol.22, pp.91-118.

Parkes, D. (1988). "NOMAD-an Audio-tactile Tool for the Acquisition, Use and Management of Spatially Distributed Information by Partially Sighted and Blind People." *Proceedings of the Second International Conference on Maps and Graphics for Visually Disabled People, July 24-29*, at Nottingham, UK.

Passini, R. and Proulx, G. (1988). "Wayfinding without Vision: An Experiment with Congenitally Totally Blind People." *Environment and Behavior*, Vol.20, No.2, pp.227-252.

Passini, R., Proulx, G. and Rainville C. (1990). "The Spatio-cognitive Abilities of the Visually Impaired Population." *Environment and Behavior*, Vol.22, No.1, pp.91-118.

Patterson, R.D. (1982). "Guidelines for auditory Warning Systems on Civil Aircraft." *Paper No.82017*. Civil Aviation Authority, London.

Pick, H.L. (1980). "Perception, Locomotion and Orientation." In *Foundations of Orientation and Mobility*, R.L. Welsch and B.B. Blasch (eds). American Foundation of the Blind, New York, pp.73-88.

Pinker, S. (1984). "Visual Cognition: An Introduction." *Cognition*, Vol.18, pp.1-63.

Pollack, T. and Ficks, L. (1954). "Information of Elementary Multidimensional Auditory Displays. *Journal of the Acoustical Society of America*, Vol.26, pp.155-158.

Pratt, C.C. (1930). "Spatial Character of High and Low Tones." *Journal of Experiment Psychology*, Vol.13, pp.278-285.

Raaijamakers, J. and Shiffrin, R. (1981). "Search of Associative Memory." *Psychological Review*, Vol.88, pp.16-45.

Rieser, J.J., Guth, D.A. and Hill, E.W. (1986). "Sensitivity to Perspective Structure while Walking without Vision." *Perception*, Vol.15, No.2, pp.173-188.

Rumelhart, D., Lindsay, P. and Norman, D. (1972). "A Process Model for Long-Term Memory." In *Organization of Memory*, E. Turving and W. Donaldson (eds). Academic Press, New York, pp.197-246.

Scaletti, C. (1994). "Sound Synthesis Algorithms for Auditory Data Representations." In *Auditory Display: Sonification, Audification, and Auditory Interfaces*. *Proceedings of ICAD'92*, G. Kramer (ed). Reading, Addison-Wesley, Massachusetts, pp.223-251.

Scholl, M.J. (1996). "From Visual Information to Cognitive Maps." In *The Construction of Cognitive Maps*, J. Portugali (ed). Kluwer, Dordrecht, pp.157-186.

Sherman , J.C. (1955). "Maps the Blind can See." *Journal of Geography*, Vol.54, No.6, pp.289-295.

Sherman, J.C. and Heath, H.R. (1958). "Problems in Design and Production of Maps for the Blind." Paper presented at *Rand McNally Second International Cartographic Conference*.

Solso, R. (1979). *Cognitive Psychology*. Harcourt Brace Jovanovich, Inc., New York.

Spencer, C., Blades, M. and Morsley, K. (1989). *The Child in the Physical Environment: The Development of Spatial Knowledge and Cognition*. John Wiley & Sons, New York.

Tuan, Y. (1975). "Images and Mental Maps." *Annals of the Association of American Geographers*, Vol. 65, pp.205-213.

Tufte, E.R. (1998). "Layering and Separation." In *Envisioning Information*. Graphics Press, Cheshire, Connecticut, pp.53-65.

_____, (1998a). "Smallest Effective Difference." In *Visual Explanations*. Graphics Press, Cheshire, Connecticut, pp.73-77.

_____, (1998b). *The Visual Display of Quantitative Information*. Graphics Press, Cheshire, Connecticut.

Tuttle, D. 1984. *Self-Esteem and Adjusting with Blindness. The Process of Responding to Life's Demands*. Charles Thomas Publisher, Springfield, Illinois.

Ungar, S., Blades, M. and Spencer, C. (1996). "The Ability of Visually Impaired Children to Locate Themselves on a Tactile Map." *Journal of Visual Impairment and Blindness*, Vol.90, No.6, pp.526-535.

Ungar, S., Blades, M. and Spencer, C. (1997). "Strategies for Knowledge Acquisition from Cartographic Maps by Blind and Visually Impaired Adults." *The Cartographic Journal*, Vol.34, No.2, pp.93-110.

Ungar, S., Blades, M., Spencer, C. and Morsley, K. (1994). "Can Young Visually Impaired Children Use Maps to Estimate Directions in the Environment?" *Journal of Visual Impairment and Blindness*, Vol.88, pp.221-233.

von Senden, S.M. (1960). *Space and Sight. The Perception of Space and Shape in the Congenitally Blind Before and After Operation*. Free Press, Glencoe, Illinois.

Walker, B.N. and Kramer. G. (1996). "Mapping Metaphors in Auditory Display: An Experimental Assessment." In *Proceedings of ICAD'96*. [web page] http://www.santafe.edu/~icad/ICAD96/proc96/walker5.htm [accessed October 22, 1999].

Walter, H. and Robinson, A. (1983). "Processing of Auditory Information by the Blind in Spatial Localization Tasks." *Perception and Psychophysics*, Vol.38, pp.91-96.

Welch, N. (1997). "Introduction to Auditory Perception." In *Demonstrations in Auditory Perception*. [web page] http://www.music.mcgill.ca/Auditory.html [accessed October 22, 1999].

Wenzel, E.M., Arruda, M., Kistler, D.J. and Wightman, F.L. (1993). "Localizing Using Nonindividualized Head-related Transfer Functions." *Journal of the Acoustical Society of America*, Vol.94, pp.111-123.

West, R. and Morris, C. (1985). "Spatial Cognition on Nonspatial Tasks: Finding Spatial Knowledge when You're not Looking for It. " In *The Development of Spatial Cognition*, R. Cohen (ed). Erlbaum, Hillsdale, New Jersey, pp.13-39.

Wiedel, J.W. and Grooves, P.A. (1970). "Tactual Maps." *International Journal of Cartography*, Vol.10, pp.116-123.

Wieskrantz, L. (1972). "Behavioural Analysis of the Monkey's Visual Nervous System." *Proceedings of the Royal Society of London*, pp.427-455.

Williams, S.M. (1994). "Perceptual Principles in Sound Grouping." In *Auditory Display: Sonification, Audification, and Auditory Interfaces*. *Proceedings of ICAD'92*, G. Kramer (ed). Reading, Addison-Wesley, Massachusetts, pp.95-125.

Yeung, E. (1980). "Pattern Recognition by Audio Representation of Multivariate Analytical Data." *Analytical Chemistry*, Vol. 52, No.7, pp.1120-1123.

Zeevi, Y.Y. and Kronauer, R.E. (1975). "Single Processing in Visual Systems and Its Relevance to Pattern Recognition." In *Signal Analysis and Pattern recognition in Biomedical Engineering*, G.F. Inbar (ed). John Wiley & Sons, New York.

APPENDICES

APPENDIX A: AN APPROVAL FORM

The University of Georgia
Office of The Vice President for Research
DHHS Assurance ID No. : M1047

Institutional Review Board
Human Subjects Office
606A Graduate Studies Research Center
Athens, Georgia 30602-7411
(706) 542-6514; 542-3199
Fax No. (706) 542-5638

APPROVAL FORM

Date Proposal Received: 2002-07-22 **Project Number:** H2003-10040-0

Name	Title	Dept/Phone	Address	Email
Ms. Paporn Thebpanya	MI	Geography GGY Building +2502	549-5980	paporn@arches.uga.edu
THOMAS W HODLER	CO		204 GGS BLDG ATHENS GA 306022502	

Title of Study: An Analysis of the Utilization of Sound for Cognitive Enhancement of Topographic Maps for the Visually Impaired

45 CFR 46 Category: Administrative 2

Modifications Required for Approval and Date Completed: 2002-07-31
Application and consent form changes

Approved : 2002-08-02 **Begin date : 2002-08-02** **Expiration date : 2003-02-02**

NOTE: Any research conducted before the approval date or after the end data collection date shown above is not covered by IRB approval, and cannot be retroactively approved.

Number Assigned by Sponsored Programs: **Funding Agency:**

Form 310 Provided: No

Your human subjects study has been approved as indicated under IRB action above.

Please be aware that it is your responsibility to inform the IRB . . .
. . . of any adverse events or unanticipated risks to the subjects or others within 24 to 72 hours; . .
. . . of any significant changes or additions to your study and obtain approval of them before they are put into effect; . . .
. . . that you need to extend the approval period beyond the expiration date shown above; . . .
. . . that you have completed your data collection as approved, within the approval period shown above, so that your file may be closed.

For additional information regarding your responsibilities as an investigtor refer to the IRB Guidelines.
For your convenience in obtaining approval of changes, extending the approval period, or closing your file, we are providing you with a blue Researcher Request form. Detach this blue form, complete it as appropriate, sign and date it, then return it to the IRB office. Keep this original approval form for your records.

Copy:
Dr. Vernon Meentemeyer
Dr. Chor-Pang Lo

Chris A. Joseph
Christina A. Joseph, Ph.D.
Chairperson, Institutional Review Board

APPENDIX B: A CONSENT FORM

I ___________________________ agree to take part in a research study titled *An Analysis of the Utilization of Sounds for Cognitive Enhancement of Topographic Maps for the Visually Impaired*, which is being conducted by Paporn Thebpanya, Geography Department at the University of Georgia-Athens, 542-2856 under the direction of Dr.Thomas Hodler, Geography Department at the University of Georgia-Athens, 542-4795. I do not have to take part in the study; I can stop taking part at any time without giving any reason, and without penalty. I can ask to have information related to me return to me, remove from the research record, or destroy.

The purpose of the study is to develop a new method of learning and interpreting topographic maps by means of sound instead of vision. I will not directly benefit from this research. However, my participation may lead to information that could benefit the visually impaired community from gaining more knowledge about spatial concept of the geographic environment. If I volunteer to take part in this study, I'll be asked to do the following things:

1. Perform a preliminary hearing test on the computer for qualification;
2. Fill in the background questionnaire;
3. Sit at the computer and view the tutorial section; and
4. Complete the computerized map quiz.

The complete test will take approximately 20-25 minutes. No discomforts or stresses are expected. Neither any risk is expected when I take this test.

I understand that my name or personal contact information will not be collected by the researcher and therefore participation is confidential.

The researcher will answer any further questions about the research, now or during the course of the project, and can be reached by telephone at: 542-2856.

My signature below indicates that the researcher has answered all of my questions to my satisfaction and that I consent to volunteer for this study. I have been given a copy of this form.

____

Signature of Researcher Date

____

Signature of Participants Date

For questions or problems about your rights please call or write: Human Subjects Office, University of Georgia, 606A Boyd Graduate School Research Center, Athens, Georgia 30602-7411; Telephone (706) 542-6514; E-mail Address IRB@uga,edu.

APPENDIX C: A BACKGROUND QUESTIONNAIRE

Date ____/____/____ **Participant # ______**

Please fill in the following questions

1) Sex: ☐ Male ☐ Female

2) Age: ______

3) Major: __________________

4) How many geography classes have you had? (If none, write down a zero) _____

5) How comfortable are you working with computers?

- ☐ Very comfortable
- ☐ Comfortable
- ☐ Uncomfortable
- ☐ Very uncomfortable

6) 'Topographic maps' use contour lines to show elevation (height above mean sea level).

How would you rank your topographic map reading experience?

- ☐ Advanced
- ☐ Intermediate
- ☐ Beginner

7) Absolute pitch or AP (commonly referred to as "perfect pitch") is the ability to identify a note on the musical scale without any reference note. How would you rank your ears according to this criterion?

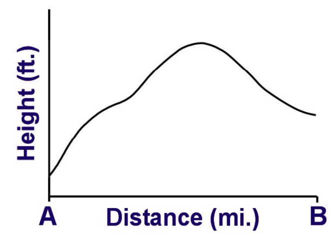
- ☐ Close to perfect pitch
- ☐ Intermediate
- ☐ Not good at pitch

8) Do you have any hearing deficiencies that you are aware of?

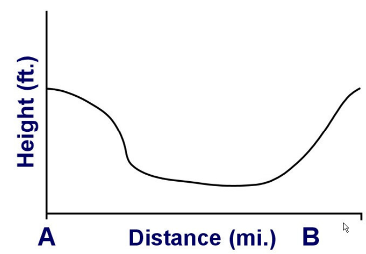
- ☐ Yes (Please explain ____.)
- ☐ No

APPENDIX D: ACTUAL PROFILES AND EXAMPLES OF PROFILE DRAWINGS FROM THE PARTICIPANTS WITH VISUAL IMPAIRMENT

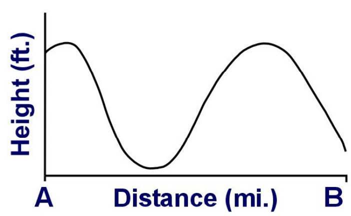
Question 4



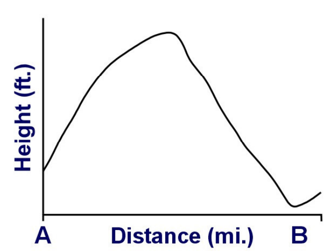
Question 8



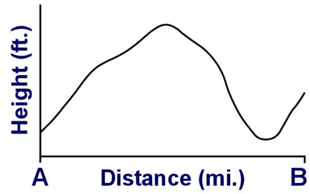
Question 12



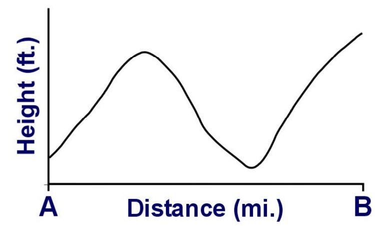
Question 15



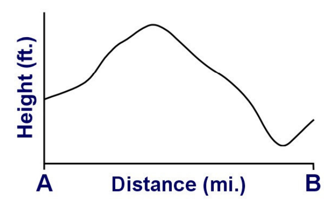
Question 20



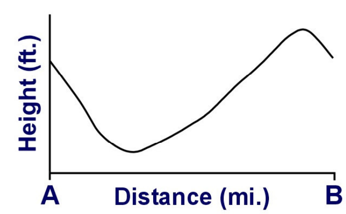
Question 24



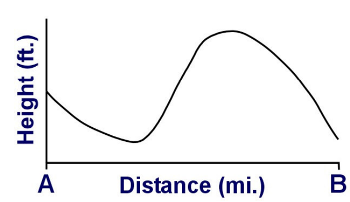
Question 29



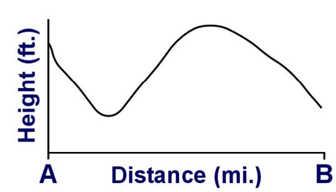
Question 33

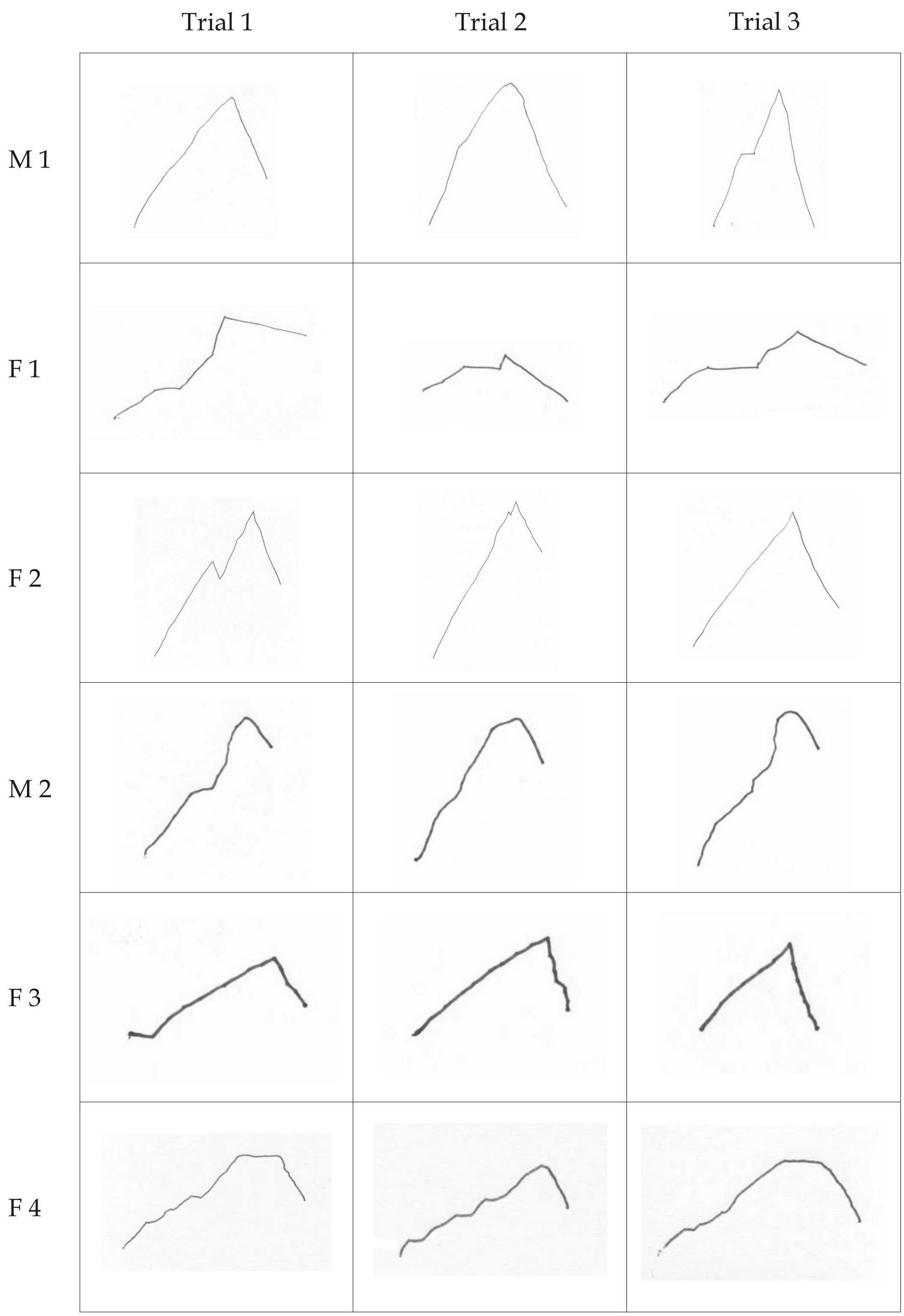


Question 36



Question 40



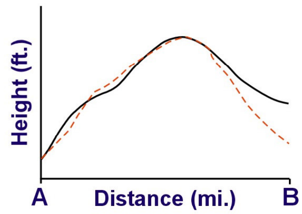


Cognitive profiles for question 4 obtained from participants #1 to #6 who are visually impaired.

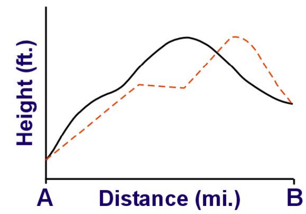
Note: Contact the author for a complete detail of the data set.

APPENDIX E: EXAMPLES OF CROSS CHAIN CORRELATION OF THE COGNITIVE PROFILES

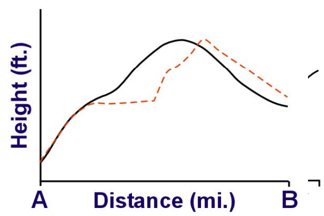
Participant: M 1; Correlation = 0.6558



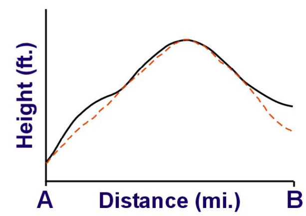
Participant: F 4; Correlation = 0.6063



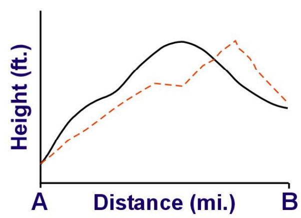
Participant: F 1; Correlation = 0.5561



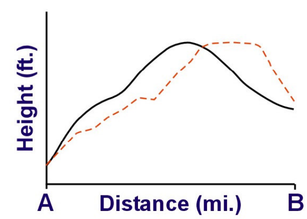
Participant: M 3; Correlation = 0.7472



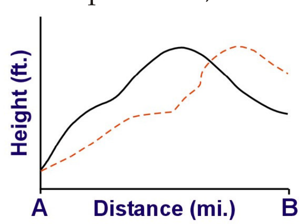
Participant: F 2; Correlation = 0.6045



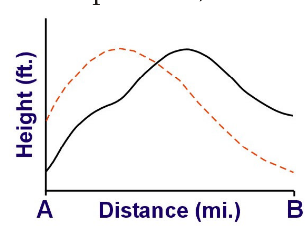
Participant: M 4; Correlation = 0.5699



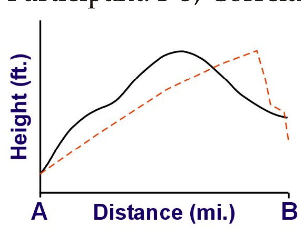
Participant: M 2; Correlation = 0.5289



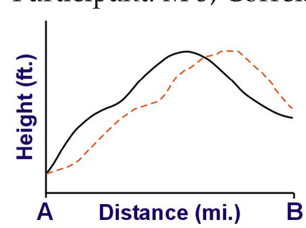
Participant: F 5; Correlation = 0.6484



Participant: F 3; Correlation = 0.6584



Participant: M 5; Correlation = 0.6340



Note: The actual profile is represented by the solid line and the cognitive profile is represented by the dash line. Contact the author for a complete detail of the data set.