WILMOT MCRAE GREENE III
Using Sound Variables to Expedite Topographic Map Reading
(Under the direction of Dr. THOMAS W. HODLER)

This research examined if the sound variable of pitch is a suitable representative for elevation data on a map. The experiment utilized a method in which pitch was used in conjunction with virtual displays of topographic maps. Subjects were evaluated according to how they performed simple map reading tasks where one group was allowed to hear sounds and the other was not. Results indicate that sound enhancement improves map readers' accuracy and speed. The pitches also eliminated an increase in response time due to more visually complex maps. The experiment detailed in this thesis produced dramatic evidence that utilizing this multi-sensory symbolization scheme increases accuracy and decreases response time to topographic map reading questions.

INDEX WORDS: Auditory Display, Cartography, Visualization, Sonification, Multimedia, Topographic Maps

USING SOUND VARIABLES TO EXPEDITE

TOPOGRAPHIC MAP READING

by

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DEDICATION

This thesis is dedicated to two true American heroes, Earl Dean and Mac Greene. These two men had an abundance of “real” education, but they were both envious of my “fancy” education. I would give anything to have been able to learn more from each of them.

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CHAPTER ONE: INTRODUCTION

1.1 Problem Statement

Maps are often produced and displayed virtually, which provides the opportunity for multimedia design options. Use of dynamic, animated, and other non-traditional map types are becoming more common. However, one aspect of multimedia display, sonification, has not been fully explored. There is no evidence of widespread personal or professional use of sound for aiding map readers with their tasks. Our sense of sound is used in spatial terms for everyday maneuvering and environmental awareness, but it is rarely used while deciphering spatial representation on a map. The average human is capable of detecting subtle changes in numerous auditory variables such as pitch, volume, and duration; and modern computers are able to play sounds in combination with complex on-screen graphics. The combination of high-resolution visual displays and sound enhancement could prove to increase the communicative ability of maps to an incredible degree. The representational repertoire of the modern cartographer must be complete with geographic precision, technological adeptness, and psychological understanding to maximize the utility of maps.

As the data sets available for transformation into cartographic display increase in complexity, the need to understand the cognitive processes that affect how map readers ingest that information increases also. “Map reading, like all reading then, is cognitive, and draws as much upon the structures of the mind of the reader as upon the marks on the face of the map" (Head 1984, p.6) Investigations into increasing the harmony between the mind and maps by using non-traditional techniques must then be performed cautiously. The usefulness of using sound as an auxiliary mode of conveying cartographic data has little scientific evidence. However, the natural properties of sound have been shown to be perceived in a consistent manner, and these properties can be manipulated to represent a limitless array of phenomena. Using sound to represent data on a map is possible and demands further investigation.

The purpose of this research is to determine if the sound variable of pitch is a suitable representative for elevation data on a map. The experiment and results described within this thesis utilize a method in which pitch is used in conjunction with virtual displays of traditional maps. Subjects are evaluated according to how they perform simple map reading tasks where one group is allowed to hear sounds and the other is not.

1.2 Background

Sonification is defined as "The use of non-speech audio to convey information" (ICAD 1997, p.4). This definition is further described as being "…the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation." There are several reasons that the field of sonification is an important area of inquiry. The primary reason that sonification is necessary is due to the abundance of data available for inspection. As computational power, speed, and reliability increase, the amount of data that is available for comprehension will continue to outpace our ability to use these data efficiently. The second reason to indicate support for sonification research is the availability of multi media technologies. In other words, we are now able to create and play sounds that relate to complex data sets. The ability to do something with technology is not reason enough to pursue that endeavor, but the field of sonification is an example of a data inspection technique that has been needed and is now feasible.

Visualization is defined as "formation of mental visual images or the act or process of interpreting in visual terms, or of putting into visible form" (Merriam-Webster 1999). Scientific visualization remains a field capable of aiding researchers in comprehending large volumes of data, but these techniques can often produce displays that go beyond humans' ability to visually interpret the information in question. "Audio's natural integrative properties are increasingly being proven suitable for presenting high-dimensional data without creating information overload for users" (ICAD 1997, p.5) The combination of the natural properties of sound, the ability to create and play sound, and the need to investigate complex data all lead to a logical conclusion that the field of sonification combined with visualization techniques will become increasingly important in the future.

1.3 Traditional Elevation Maps

Isolines are a common method for representing continuous spatial data. Topographic data in particular are frequently represented via contour lines. "People are notoriously poor at reasoning in three dimensions and so it is no surprise that many people find relief harder to interpret than most other information on a map" (Phillips *et al.* 1975, p.40). More than a dozen various other methods for displaying elevation have been developed and researched with positive results (depending on the specific map reading tasks at hand). However, contour line maps are still the most common and easily available maps that depict elevation data. The intuitiveness of relating isolines to elevation is questionable, but using the sound variable of pitch is both logical and intuitive due to the fact that pitch flows from high to low or low to high along a continuum, similar to elevation.

Block diagrams provide a three-dimensional view of a landscape on a two-dimensional surface. The utility of block diagrams lie mainly in their ability to provide a pictorial representation of an area. Although these diagrams are not intended for precise measurements of the landscape, they successfully communicate the general flow of elevation across the mapped area. The aesthetic purity of this type of relief portrayal is ideal for general landscape visualization. However, block diagrams rarely include roads, political boundaries, or georeferencing coordinates. The usefulness of aiding in landscape visualization is immeasurable, however that is the extent of the utility of block diagrams.

Shaded relief maps are another common type of display that shows elevation on a two dimensional surface. The USGS publishes shaded-relief editions of certain topographic maps to accentuate physiographic features of special interest. These maps use shaded relief, as well as contour lines, to represent the shape of the terrain. The pictorial effect of such maps is emphasized by relief shading, a halftone overprint that simulates the appearance of sunlight and shadows on the terrain and creates the illusion of three-dimensional topography.

The United States Geologic Survey produces topographic quadrangles that are readily available, excellent for orienteering, and comply with national map accuracy standards. The method these maps use for displaying topography is contour lines spaced at regular intervals with bolder index contours every fifth line. Most USGS topographic maps use brown contours to show the shape and elevation of the terrain. Contour intervals vary, depending mainly on the complexity of terrain and the scale of the map. Such maps include prominent natural and cultural features identified by name. Those at scales of 1:24,000 show an area in detail. Such detail is useful for engineering, local area planning, and recreational purposes. Less detail is shown at the smaller scales of 1:50,000 and 1:100,000. They cover larger areas and are used in land management and planning. Maps at scales of 1:250,000, 1:500,000, and 1:1,000,000 cover large areas on each sheet and are used in regional and statewide planning. Most USGS map series divide the United States into quadrangles bounded by lines of latitude and longitude. For example, a 7.5-minute map bounds an area that spans 7.5 minutes of latitude and longitude, and it is usually named after the most prominent feature in the quadrangle.

1.4 Objectives

This project will ascertain the usefulness of adding the sound variable of pitch to contour lines in virtual topographic map displays. The results will hopefully indicate that the precision of isolines mapping combined with the intuitive sonic variable of pitch create a topographic display that can be read and comprehended in a more efficient manner than traditional contour maps.

The objectives of this research are:

1) to develop a user friendly interface in which topographic maps can be examined visually and sonically

2) to test how subjects interpret the information on the sonically enhanced maps as compared to maps without sound in two areas

a. absolute elevation; and

b. relative elevation

3) to suggest further developments with sound in the mapping sciences, and detail the methods by which the sonic maps were created.

1.5 Hypotheses

Based upon the objectives of this project, the null hypotheses to be examined are:

Ho_1: The ability to hear notes that correspond with elevation will **not** affect the ability of map readers to **correctly answer** questions pertaining to topographic maps

Ho_2: The ability to hear notes that correspond with elevation will **not** affect the **speed** of map readers to answer questions pertaining to topographic maps.

Ho_3: Visual map complexity will **not** affect the **accuracy** or **speed** of responses to map questions on sonified maps.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Visualization techniques have been found to be instrumental in exploring the virtual world created from mathematical models and other computer intensive data gathering techniques (Marshall *et al*. 1990). Sonification has been suggested as a possible method for simplifying complex visual displays. The human-computer interface is not perfect in terms of providing an optimal method for people to ingest information directly from the computer screen. In today's digital world data sets are produced more easily and on a grander scale than they were prior to widespread personal computer use; therefore visualization techniques should improve concomitant to the rapid pace established by researchers who create these data sets. Sonification represents a method by which extremely complex data can be examined, sorted, or organized in a more efficient manner than if the same data are visually inspected.

Although there is a relative paucity in the scientific literature dealing directly with utilizing sonification techniques in cartographic visualization, there are a multitude of articles, chapters, and books on the individual subjects of sonification, cartographic visualization, and the human-computer interface. In this chapter, an attempt will be made to synthesize these separate fields of inquiry into a logical basis for using sound to aid cartographic visualization via the human-computer interface. Due to the fact that all three of the aforementioned subjects are relatively new fields of scientific inquiry, this literature review will probably become outdated quickly. However, as the literature dealing with these subjects grows and expands, this thesis itself will become a part of that literature expansion.

2.2 Sound and Maps

The keystone of the literature dealing specifically with the use of sound in cartographic visualization is John B. Krygier's chapter "Sound And Geographic Visualization" in *Visualization In Modern Cartography* (MacEachren and Taylor 1994). His chapter outlines the general aspects of sound variables and possible uses of sound in cartographic applications.

> *Uses of sound in geographic visualization include sound as vocal narration, a mimetic symbol, a redundant variable, a means of detecting anomalies, a means of reducing visual distraction, a cue to reordered data, an alternative to visual patterns, an alarm or monitor, a means of adding non-visual data dimensions to interactive visual displays, and for representing locations in a sound space* (Krygier 1994, p.175).

Krygier's chapter blazed a trail for future cartographers to expand upon. The theories behind using sound for a tool in cartographic visualization are established, and a multitude of possible research ideas are revealed.

Realistic sounds and abstract sounds represent the two major methods for auditory data representation. Vocal narration is the most obvious example of using realistic sound in a multimedia display, but "earcons" are becoming increasingly common. Earcons are "audio messages used in the human-computer interface to provide information and feedback to the user about computer entities" (Blattner *et al* 1989, p.11) Research has shown that earcons provide an efficient method of conveying information (Blattner *et al* 1989, Gaver, 1986). Most personal computer operating systems now include earcons as part of their design such as the "Microsoft chord" which functions as an attention grabber or the "thunk" of a Macintosh when an item is placed in the trash can. These action confirmations eliminate problems experienced by earlier computer users unsure if a task was complete.

Just as visual elements can be displayed in variable forms such as color, size, and brightness, auditory elements can also be played with abstract variables. The abstract sound variables include; location, loudness, pitch, register, timbre, duration, rate of change, order, and attack/decay. These "variables" are not wholly independent of each other, and therefore exhibit behaviors that are correlative to one another and the degree of change. However, they represent the collection of alternatives when selecting auditory signals and the qualities of sound that are distinguishable to the listener. If we consider the analogy with the visible variables, cartographers realize that the font, size, and color present options that must be considered for map use. Sounds also have characteristics that carry cognitive weight. Krygier discusses each of the abstract sound elements and their effectiveness for representing nominal and ordinal data separately (Figure 2-1).

Location relates directly to location on a two-dimensional map. To incorporate the sound variable of location a stereo or quadraphonic sound system is necessary. The use of this variable can direct map readers to specific locations on a map where the sound is perceived as being heard. **Loudness** is measured in decibels. The inherent order of loudness makes it appropriate for representing ordinal data. **Pitch** is easily distinguishable by most people. In Western music pitch is usually divided into eight

THE ABSTRACT SOUND VARIABLES

	Nominal Data	Ordinal Data
Location The location of a sound in a two or three dimensional space	Possibly Effective	Effective
Loudness The magnitude of a sound	Not Effective	Effective
Pitch The highness or lowness (frequency) of a sound	Not Effective	Effective
Register The relative location of a pitch in a given range of pitches	Not Effective	Effective
Timbre The general prevailing quality or characteristic of a sound	Effective	Not Effective
Duration The length of time a sound is (or isn't) heard	Not Effective	Effective
Rate Of Change The relation between the durations of sound and silence over time	Not Effective	Effective
Order The sequence of sounds over time	Not Effective	Effective
Attack/Decay The time it takes a sound to reach its maximum/minimum	Not Effective	Effective

Figure 2-1. The abstract sound variables. (from Krygier, p.153)

octaves of twelve pitches each. **Register** is similar to pitch in that register describes where a pitch is within a set of available pitches. **Duration** is simply the length of time a note is or is not heard. The alternation of sound and silence is required for duration to be perceived. **Rate of change** relates to the varying of sounds and silences in a series over time. **Order** can be analogous to melody in that when sounds are ordered they create a pattern. A change in that pattern could then represent change in the phenomena being represented. The attack of a sound is the time it takes that sound to reach it's maximum loudness. Decay is the time it takes that note to return to silence. **Attack \ decay** could relate to the spread of a phenomena over time. The preceding variables all have ordinal qualities that enable listeners to perceive minimum and maximum values of sounds which utilize those variables. **Timbre** relates to specific characteristics of 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.

The foundation provided in Krygier's chapter is thorough but theoretical. With the limits to research in sound and cartographic visualization being boundless, it is surprising that the practical applications developed to date are so few. Most of the literature dealing specifically with sound in combination with visual cartographic display remains in the realm of theoretical hypotheses. Some practical or working uses of sonic mapping techniques are present in the realm of maps designed for persons who are visually impaired, but the object of this proposed research focuses on using audio cues as well as visual stimulation.

Weber (1994) examined the use of harmonic intervals to enhance map information. These experiments dealt with maps enhanced by dyads or harmonic intervals; these are basically two unique tones played simultaneously. Musical intervallic distances have properties that carry cognitive weight and perceptual precedence. Weber's tests were designed to ascertain if the sonic intervals would create an association that would override conscious decision making by the test subjects about the visual map information, or if intervallic distance could provide a proper association with information such as map distance. His results indicate that both of these scenarios may occur.

With the above exceptions, scientific literature dealing specifically with the use of sound in maps is practically non-existent. There is however a substantial amount of work done in the fields of sound in computer interfaces, cartographic visualization, and sonification. The exciting aspect of this research is the fusion of cartographic visualization techniques used in conjunction with sonification techniques. The conclusions of research done in these fields provide a logical basis for combining sound in a cartographic computer interface to aid in visualization. The research detailed in this thesis tested the theories in one specific use of sound in maps, the variable of pitch in relation to absolute elevation and relative elevation.

2.3 Sound in Computer Interfaces

The use of sound to attract attention in the context of a graphic display continues to become more commonplace. Research has proven that sound can successfully represent various data types including time-varying, multidimensional, and logarithmic (Bly 1982, Blattner *et al.* 1994). Some concerns in the literature are how listeners "map" data and the means by which those data are presented (Gaver 1986). Examples of the different ways in which we identify data and its representation are symbolic, metaphorical, and nomic. The USGS maps used in this research contain symbols and names to represent data. The metaphorical aspect of topographic maps are the contour lines. Therefore, the concept of metaphorical sounds are most valid because pitch is not a wholly arbitrary way of depicting elevation. Even though higher or lower tones are not caused by elevation changes, it is intuitive that a higher pitch would represent a higher elevation.

Pitch could be considered one of the more straight forward sound variables because of the large but finite options for pitch. Western music generally consists of eight octaves containing twelve pitches each so there are ninety six possible unique pitches. Sometimes a sequence of notes heard in an ascending or descending order can result in musical tension when the beginning and/or ending notes leave the listener waiting for a resolve or a note that makes the listener feel like the progression of notes has ended. This effect of musical tension also relates to the progression of pitch. In music, pitch flows via a scale, and the inclusion of every note is termed the chromatic scale. A chromatic scale includes half steps, which can increase the likelihood of musical tension. However, excluding notes from the chromatic scale creates major and minor modes of scale which have specific cultural connotations. In other words, some modes of scale tend to evoke specific emotions to the listener (Piston 1976). This issue of chromatic versus diatonic or other scales will not be addressed in this research because a scalar progression of notes will not necessarily be heard by the map readers. Rather, pitch will be used as a reference so that one or many notes will be heard in any order that the user needs to help identify elevation.

It is beyond the scope of this research to delve into music theory and its properties. However, it is important to briefly discuss some of the perception issues involved with melody and its components silence and pitch. Melody is created by a linear grouping of pitches and silence in a uniquely ordered time series (Piston 1976). The great majority of pitches contain overtones or sympathetic tones. These overtones are what give musical notes their individual character. “The basic difference between the same pitch played on a clarinet and an oboe, and thus the listener’s ability to identify the instrument being played, is the overtone series produced by each instrument” (Weber 1994, p. 14). The type of pitches that do not contain these overtones are notes created by tone generators. These machine generated tones are simply amplified sound waves in their purest form. It may seem that these simplified tones would be ideal for use in a research project such as this one, but this type of note is generally perceived as sounding harsh, stale, or unnatural because people rarely hear pure tones in everyday life. The aspect of pitch that is important for this research is consistency. In other words, as long as all the notes used in this study sound natural and similar to each other, perception of overtones should not be an issue.

2.4 Cartographic Visualization

The goal in scientific visualization is “to develop mental representations that allow us to identify patterns and to create or impose order” (MacEachren 1994, p.18). Current research and applications in cartographic visualization range tremendously in method and scope. The main issue in the field is the interpretation of phenomena by means of maps (MacEachren 1994, DiBase *et al.* 1992). The term "visualization" may not seem to fit in a study dealing with sound, but sound can actually be a powerful visualization tool. Cartography is becoming an extremely technological field. Computer systems exist that enable map designs that stimulate senses in various ways. Multimedia and three dimensional maps are two examples of techniques being more frequently used by modern cartographers.

Animated maps have been researched and utilized for nearly forty years (Campbell and Egbert 1990). Map animation provides a method to visualize spatio-temporal data as well as non-temporal data. Dynamic multimedia maps are not necessarily animated, however the design principles and software systems used to create both types of maps are identical. The only differences are in the data themselves and the display variables which are chosen to represent these data. Designing a map requires the cartographer to consider the visible variables: position, size, value, texture, hue, orientation, and shape. When the data for a map include temporal data the designer must go an extra step and consider the dynamic variables: duration, rate of change, and order (DiBase *et al.* 1992). Nonetheless, most dynamic maps include some sort of animation even if the movement does not occur within the border of the map area proper. An example could be animated buttons that a map reader would click to open, close, or switch maps in a multimedia display. Animated buttons are a common method for making the human-computer interface more exciting, therefore keeping attention levels high.

An important question one must ask when creating a multimedia map is whether or not the information is being portrayed in a more useful manner or simply a new and different manner. “The primary motivation in new technology is often novelty” (Goodchild 1988, p.317). This type of skepticism creates a need for more research that compares multimedia maps with non-multimedia maps. There is a tendency for cartographers to evaluate dynamic maps with other types of dynamic maps to determine which type of animations or sounds communicate in the most efficient manner. However, this proposed research will discover whether the multimedia aspect is simply an interesting novelty or truly an improvement in display methods.

2.5 Sonification

The field of sonification is interdisciplinary, combining concepts from acoustics, perception, engineering, and the arts into a new area of inquiry that is attempting to establish itself as scientific discipline. Research has shown that properly designed sonifications have the potential to increase the amount of data a human can simultaneously process beyond that achievable with traditional visual methods (Scaletti and Craig 1990). There have been some successful applications of this technology including aviation and medical auditory displays, but the most popular example of a sonification tool is the Geiger counter.

The International Community for Auditory Display (ICAD) was created in an attempt to organize the field of sonification. This group has outlined a research agenda and identified the issues that need to be addressed by scientist involved in audio data representation. A positive note regarding the field is that sonification tools generally do not require as much processing power as do three dimensional displays (Wenzel 1988). This observation could prove to be of great importance in this proposed research due to the fact that sound will be used to represent three dimensional data. In general, the field of sonification is leading the way in utilizing sounds to complement visual data and as an alternative to visual data inspection. Although there are several “success stories”, the bulk of work done in the field is theoretical and immature.

CHAPTER THREE: METHODOLOGY

3.1 Selection of Maps

USGS 7.5 minute series topographic maps are the workhorse of the mapping world. They are available for all of the United States, and they are viewed by millions of people on a regular basis. It seemed logical that a practical example of using sound to facilitate map reading should utilize these maps. The individual maps that were incorporated into this study were chosen according to topographic variability, complexity, and contour interval size rather than location or other factors. The introduction and tutorial parts of the experiment were complete at the time when map selection began. During the tutorial, example contour maps created using Golden Software's *Surfer* were shown and described (Golden Software 1994). These simple example maps were created with a ten foot contour interval because this researcher felt it would be easier for inexperienced map readers to count by tens. Therefore it was deemed appropriate to use maps with the same contour interval for the experimental maps. The final criterion for selecting the maps was simply the general appearance of the maps. It seemed important that the maps should be similar except for the contour lines themselves. Avoiding maps with large urban areas, complex networks of roads, or other manmade features was therefore important. The three maps that were finally chosen were rural areas from Barrow, Thomas, and Hall counties Georgia.

The size of paper at which these maps are traditionally printed is approximately 27 inches by 22 inches, which is much larger than most computer screens. Because this study tested subjects with experience reading these maps as well as novice map readers, portions of the map equal to the area of the screen display were used. That is to say that subsets of the maps were selected at a dimension equivalent to that displayed on a 21 inch monitor. Utilizing these subsets, the size of the symbols and other features of the maps were consistent with what experienced USGS map readers are accustomed. After the process of sizing the maps in order to accomplish said dimensions, this researcher determined the onscreen display was more difficult to see than the printed maps viewed at the same scale. The reasons for this discrepancy are probably a result of screen resolution and other cognitive issues that extend beyond the scope of this study. Therefore, it was decided that the on-screen maps would be enlarged by an additional ten percent. This resulted in all of the map symbols and contour lines appearing slightly larger than their paper counterparts to accommodate for the effects of on-screen display. Although all of the experiment subjects viewed on the on-screen versions of the maps, care was taken by this researcher so that the virtual display would not confuse people with experience reading USGS maps.

These maps are available in digital form in several different formats. Digital raster graphics (DRGs) are scanned images of the printed maps. The DRGs provided suitable base maps for this study. The USGS also provides digital line graphs (DLGs) which are available as coverages for a select portion of the United States. The DLGs are individual layers of the maps which are produced and sold separately. The contour layer provides vector data to which sounds could be tagged and then incorporated into the display. Due to the different interpolation methods used to create elevation data, it was questionable as to how exactly the lines from the DLGs matched up to the contour lines from the DRGs. Therefore, the alternate method of tagging the individual lines with their respective notes, requiring on-screen digitizing of each contour line, was used. This method was certainly more time consuming than the former, but precision was insured by this method. In the future, more streamlined methods of tagging map features for the purpose of sonification will be facilitated by increased map accuracy and superior software packages for converting raster images to vector graphics.

3.2 Creating the Interface

Designing an interface in which a map reader could "hear the topography" required creative use of animation software. Although there are no software packages that are designed specifically for this purpose, there are graphic interface systems that will work. In the recent past, developing this type of interface would have required advanced programming skills. However, developments in web technology and mouse rollover functionality allowed this type of interface to be created and viewed without the benefit of advanced programming knowledge.

The raster base maps were imported into the software package *Macromedia Flash* (Macromedia 1993). This package has sound and interaction capabilities that enabled test subjects to view, hear, and reply in one interface. *Flash* has the capability of storing multiple sequences of events so that the user could return to the tutorial section of the interface at any time. Because of the unusual nature of relating a sound to elevation data, continuous reference to the fundamentals of the relationship should help the map reader (Gaver 1986). The tutorial section of the testing sequence included descriptions of the basic fundamentals of topographic maps as well as an explanation of how the sonically enhanced maps work. Steps were taken to ensure that test subjects were aware of how the sonic map legend related to the map and elevations.

The tutorial was designed to flow like an interactive movie or web site in which a series of individual screens of text and illustrations were seen by the test subjects. At the bottom of each screen was a button that linked to the next page of the tutorial (See Appendix). An attempt was made to make the first few screens relaxing, entertaining, and/or interesting so that the subjects would focus on the remaining sections. Several experimentees remarked that the tutorial was “fun” and “neat”. However, the majority of the section was text describing the basics of contour maps and the experiment. One particularly interesting portion of the tutorial showed a simple contour map that rotated, turned, and morphed into a three dimensional surface plot seen from ground level (Figure 3-1). This animation began with contour lines and ended up showing nothing but horizontal lines. Creating this animation proved difficult, and the final version contained minor glitches due to attempting to morph a two dimensional object into a three dimensional object. But, it was obvious to everyone who helped administer the experiment that this visualization technique was successful at communicating what elevation contours show to subjects who were unfamiliar with isoline displays.

The sounds used to sonify the elevation data were recorded by the researcher using a four channel digital mixing board. Piano notes were recorded from an electric piano plugged directly into the mixing board. These notes were separated into individual files and compressed using a software package called *Cool Edit Pro* (Syntrillium 1996). The software package was run on the Macintosh platform so the individual files were originally collected and saved in a Macintosh format. To convert all of these piano note files into .wav files a software package called *Awave* (Reimold & Schumann 1995) was utilized. *Awave* is shareware software that was simply downloaded from the web at no

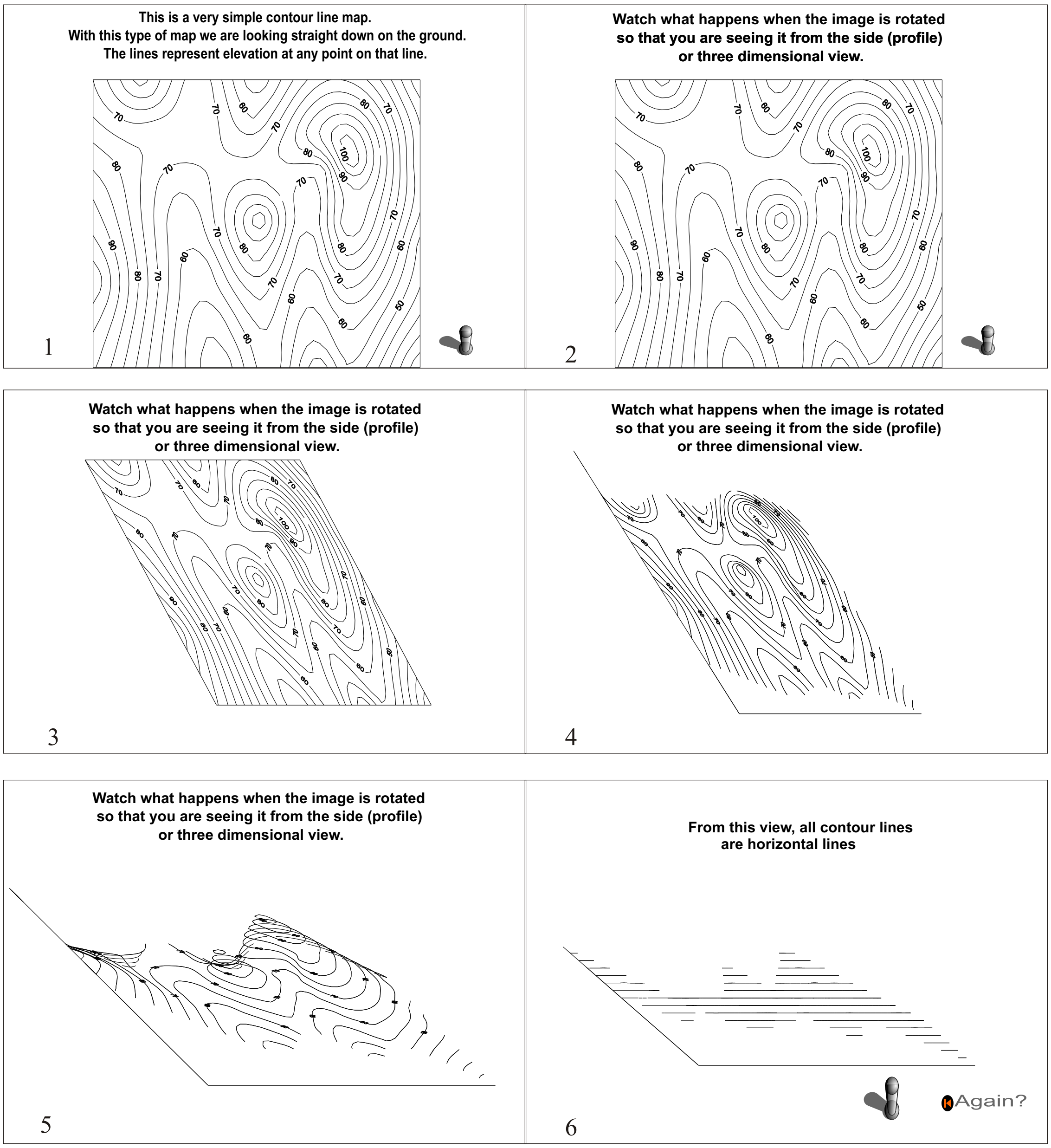

Figure 3-1. Individual frames from tutorial.

cost. After all of the piano notes were stored in the '.wav' format they were imported into *Flash* for use with this experiment.

The steps for importing and sonifying the maps were as follows:

1. The desirable section of the DRG was cropped and converted to a portable network graphic file (PNG).
2. That PNG file was imported into *Flash*.
3. Each elevation value that was to be sonified was assigned a layer.
4. Each line was traced from the base map into its proper layer.
5. Elements of each elevation including all lines and all legend elements (numbers and surrounding boxes) were grouped and made individual buttons.
6. Each button was assigned a sound to play on the 'mouse down' action.

A difficult situation was identified during pre-testing of the sonic maps. The large volume of vector data created from tracing each of the contour lines made the program run slowly. The functionality of the experiment would be jeopardized if the map reader had to wait to hear the pitch associated with the individual contour line on which he was clicking. This 'lag time' problem proved to be most difficult. Discussion on how this problem could be dealt with in the future can be found in the final chapter of this thesis. The solution that was utilized in this experiment for the 'lag time' problem was to activate only a subset of two rectangular areas. Each map had four labeled points, and these points were in groups of two's (Figure 3-2). The points were labeled A,B,C, and D with A and B being near each other and surrounded by a rectangle, and C and D being near each other and also surrounded by a rectangle. The rectangles were created large enough so that there was space on all sides of all points that could be clicked and

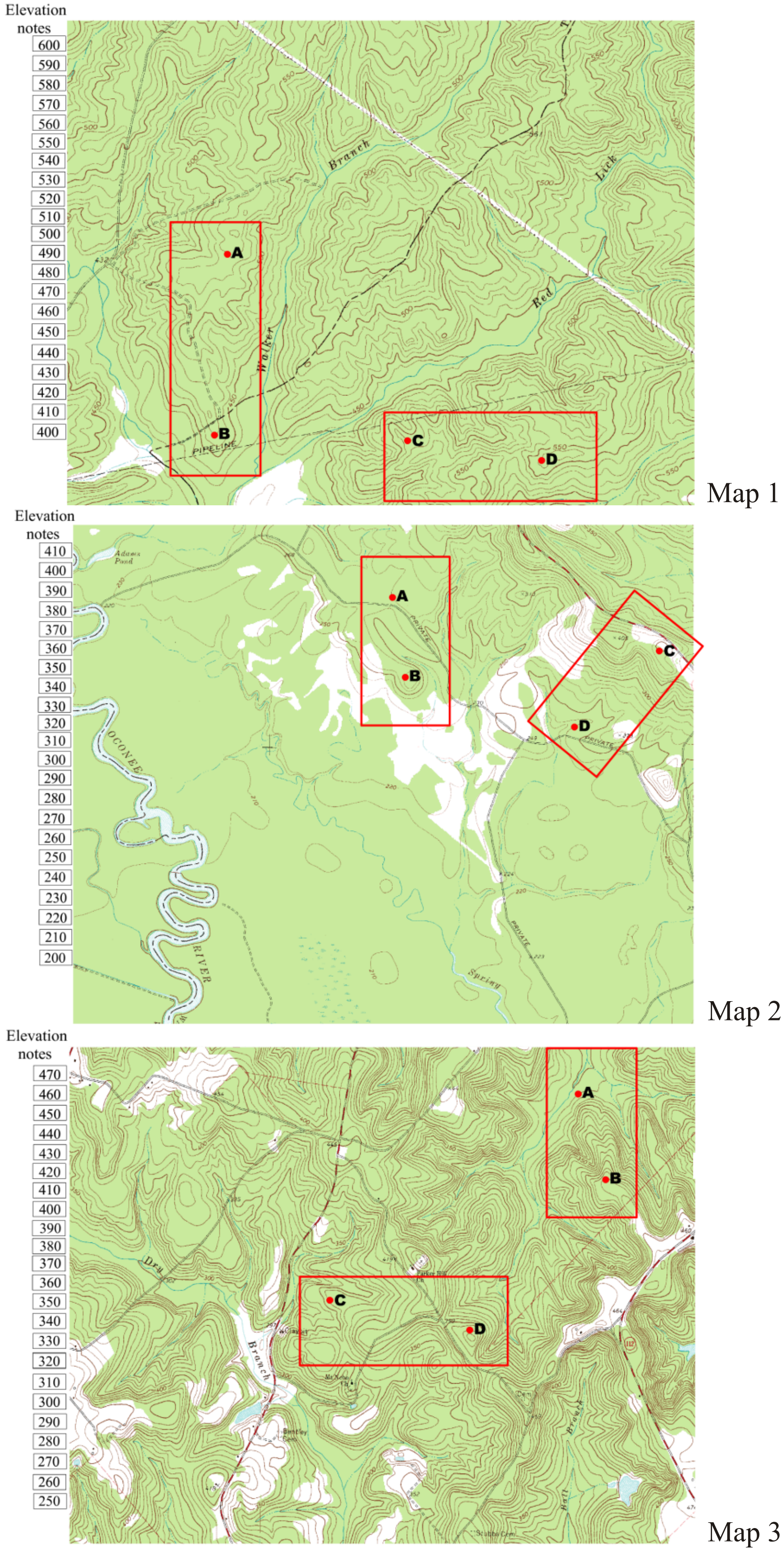

Figure 3-2. Maps as they appeared in the experiment.

heard for sonic reference. Therefore, the entire map was not sonically enhanced, but rather only the area of the two rectangular portions which contained all of the reference points were sonified. This reduction of the portion of the map which contained hidden vector graphics for sonic tagging dramatically decreased the file size of the working maps and therefore increased the speed in which the sounds would play after being clicked by the map reader. The final result was three maps that played sounds practically instantaneously as a contour line was clicked inside one of the guiding rectangles.

3.3 The Pre-Test

Before the experiment was implemented, this researcher performed a limited pre-test. The purpose of the pre-test was more for debugging the interface than to examine possible results. As was previously stated, a major problem was discovered during the pre-test. This problem and it's solution seriously effected this experiment and the way it was designed. The results from the pre-test were not recorded because the 'lag time' problem would have corrupted any potential findings. However, the pre-test was instrumental in discovering problems with the interface, specifically speed related problems.

The pre-test also helped this researcher gauge the difficulty of the questions to be asked during the experiment. The subjects who were available to run through the experiment during the one day of pre-testing were graduate students and a few undergraduates from an advanced cartography class. The pre-test subjects were having a difficult time answering the questions regardless of whether or not they were able to hear the notes. Therefore, the questions that were asked during the experiment were easier than the original questions. The difference between the pre-test questions and the experiment questions was in the location of the labeled points. The result was both experiment groups combined answered correctly 78.5% of the time on the experiment questions.

3.4 The Experiment

All 110 of the subjects that participated in this experiment were underclassmen at the University of Georgia enrolled in Geography 1101, Introduction to Human Geography. Their instructor offered extra credit to each student who signed up for and completed an experiment advertised as dealing with “musical maps”. Each student signed their name on a list that was divided into ten minute sections for the three days of October 20, 21, and 22 of 1999. The students were instructed to meet the experiment proctor outside of a lab room at their scheduled time.

Each student was asked to rank their map reading experience and their ability to distinguish different pitches according to the qualitative terms of advanced intermediate or beginner. The students were then asked to sit at the computer and begin the tutorial. Once the test subjects completed the tutorial section of the testing sequence they were instructed to proceed to the questionnaire section of the test. The students who participated in the experiment were arbitrarily placed into one of two groups as they entered the testing area so that there were fifty-five persons in the control group and fifty-five persons in the test group. The control group did not see the section of the tutorial on how to use the sonic maps nor were they able to use the sound functionality. Except for the tutorial addendum on sound (which was only seen by the test group), the two experiments were identical. Each subject answered nine questions dealing specifically with topography (Figure 3-3). The questions pertained to three different maps depicting

Absolute pitch (commonly referred to as "perfect pitch" or AP) is the ability to identify a note on the musical scale without any reference note.
How would you rank your ears according to this criteria
close to perfect pitch, intermediate, or not good pitch

C T

Topographic maps use contour lines to show elevation (height above sea level).
How would you rank your topographic map reading experience
advanced, intermediate, or beginner

ONE
What is the elevation at point 'A'?
Without using the legend to the left, Is the elevation of point 'C' higher, lower, or the same as point 'D'?
Is there a greater elevational difference between points 'A' and 'B' or points 'C' and 'D'

TWO
What is the elevation at point 'D'?
Without using the legend to the left, Is the elevation of point 'A' higher, lower, or the same as point 'B'?
Is there a greater elevational difference between points 'A' and 'B' or points 'C' and 'D'

THREE
What is the elevation at point 'B'?
Without using the legend to the left, Is the elevation of point 'C' higher, lower, or the same as point 'D'?
Is there a greater elevational difference between points 'A' and 'B' or points 'C' and 'D'

	adv	int	beg	notes
pitch				
map experience				
	answer	time	sound?	make a mark for each sound you hear
Map One				
1				
2				
3				
Map Two				
1				
2				
3				
Map Three				
1				
2				
3				

Figure 3-3. The experiment question sheet.

different levels of topographic complexity and included three questions for each map. Three questions pertaining to absolute elevation and relative elevation were asked for each map. The only personal information collected about the test subjects was one question regarding their previous experience with contour maps and one question relating to their pitch, or how well they could identify notes without reference. The students who were in the test group were also asked to write comments on the back side of their test questionnaire. These comments will be discussed in Chapter Four.

3.4.1 The Questions

As previously stated, each student was asked to rank their map reading experience and their ability to distinguish different pitches according to the qualitative terms of advanced intermediate or beginner. The questions that were answered by the test subjects during the experiment were organized in the following manner. There were three question types which will be referred to as QT1, QT2, and QT3. All of the questions of each type are identically worded except for the variable name. QT1 reads, "what is the elevation at point X?". QT2 reads, "without using the legend to the left, is the elevation at point X higher, lower, or the same as point Y?". QT3 reads, "is there a greater elevational difference between points A and B or X and Y?".

There were also three maps. The issue of map complexity is considered to be a qualitative term in this thesis. Factors that were included in deciding which maps to include were discussed earlier. However the three maps that were chosen to include in the experiment were of different complexities. The spacing between the contour lines and the number of contour lines constitute the majority of the difference between the maps in the experiment. It would be expected that a more complex map, would result in slower and less accurate responses to questions about that map. Map three was the most complex map used in this experiment. Map two was the most simple map, and map one was identified as having middle complexity for this experiment.

3.4.2 The Responses

The students' responses to the test questions were recorded by graduate student volunteers. These proctors were seated behind the students participating in the experiment. The proctors were instructed not to aid the experimentees in answering any questions on the experiment itself. Rather, the proctors performed as answer and time recorders. After each student completed the tutorial section of the interface, the proctor would instruct the student to begin the experiment by proceeding to map one. The test questions were asked out loud by the proctors, and then they started a stopwatch to time the subjects' response. The proctors recorded each response and time before proceeding to the next question. Upon completion of the experiment, students who were in the test group were asked to write comments on the back of their answer sheet. The students who were in the control group were given a brief explanation of how the test group students were able to hear sounds before they left the testing area.

3.5 Statistical Procedures

The data that were gathered during this experiment were analyzed in several ways. The first and primary element to analyze was the question of whether the test or the control group scored a higher percentage of correct answers to the experiment questions. This analysis was done by converting all of the responses into the ordinal variables of either 'correct' or 'incorrect'. The two groups were then compared via the percentage of correct answers by all questions, question type, and question map. Comparisons were done by creating visual graphs and summary statistics in table form.

The second element under investigation was the question of which group answered the questions in the least amount of time. This analysis was accomplished by implementing Tukey's analysis of variance procedures to ascertain if the mean times required to answer questions were significantly different. Once again, this analysis was used to compare the control group with the test group by total time, question type, and map.

The third element under investigation was to identify if either group performed more accurately or more rapidly on one of the three question types. Lastly, analysis was done to see if either group performed differently at the beginning, middle, or end of the experiment. Both of these investigations were done by creating visual graphs and summary statistics in table form.

In order to organize the results of the experiment for analysis, the following scheme was utilized. The groups or treatments were labeled as 'C' or 'T' indicating control group or test group. The question types were labeled as 'QTYPE1', 'QTYPE2', or 'QTYPE3' because the first, second, and third question type pertaining to each map were identical. The three questions pertaining to each map were labeled as 'MAP1', 'MAP2' and 'MAP3'. Once again, the order of the question types and the order of the maps were identical for all 110 subjects.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

In order to evaluate null hypothesis 1, which states that the ability to hear notes that correspond with elevation will not affect the ability of map readers to correctly answer questions pertaining to topographic maps, the results were analyzed in a manner comprised of two groups. The two groups being the test and the control groups. Each of the subjects numeric responses were converted to either '1' for correct or '0' for incorrect. The analysis done within these parameters provided a general feel for which group performed more accurately during the experiment as a whole.

Similarly, null hypothesis 2, which states that the ability to hear notes that correspond with elevation will not affect the speed of map readers to answer questions pertaining to topographic maps, was analyzed according to the number of seconds that elapsed between the time the subject was asked and answered each question. This analysis provides a general feel for which group performed more rapidly during the experiment.

Lastly, null hypothesis 3, which states that visual map complexity will not affect the accuracy or speed of responses to map questions on sonified maps, was analyzed by comparing correctness and time by question type and map. These comparisons were done within groups and between groups in order to ascertain as much information as possible regarding the effect of sound on every aspect of this experiment. In general, the test group outperformed the control group in correctness and time (Table 4-1). However,

Table 4-1

Percent of Correct Responses
and Average Response Times

Percent Correct

Control	M1	M2	M3	average
QT1	60	53	58	57
QT2	51	53	75	60
QT3	78	95	89	87
average	63	67	74	
Test	M1	M2	M3	average
QT1	78	80	85	81
QT2	95	95	95	95
QT3	73	100	98	90
average	82	92	93	

Response Time (In Seconds)

Control	M1	M2	M3	average
QT1	14.7	12.3	16.2	14.4
QT2	9.1	11.6	15.1	11.9
QT3	14.8	9.3	12.2	12.1
average	12.9	11.1	14.5	
Test	M1	M2	M3	average
QT1	15.6	13.7	11.1	13.5
QT2	8.2	6.2	6.8	7.1
QT3	15.9	5.4	7.8	9.7
average	13.2	8.4	8.6	

QT = QUESTION TYPE M = MAP

the test group and the control group performed better as they progressed from map one to map three. The control group's speed varied directly with map complexity while the control group's speed was related to both map complexity and the map of questioning.

The analysis of variance procedures that were executed to analyze the difference of means were all done at the .05 and the .01 alpha level. However, each test that exhibited a significant difference at the .05 level also showed significant difference at the .01 level. There were no comparisons of means that showed a difference in results between the two confidence levels. Therefore, unless otherwise noted, the alpha level for all analysis in this chapter will be .01.

4.2 Total Correct Responses

Comparing the percent of correct responses for all three question types on all three maps using Tukey's analysis of variance procedure, the control group's mean was 67.7% and the test group's mean was 89.3% (Figure 4-1). The minimum significant difference at the .01 alpha level is 5.6%, therefore these means are significantly different.

4.3 Total Time Per Question

The average time in seconds that it took each subject to answer each question was 12.8 seconds for the control group and 10.1 seconds for the test group (Figure 4-2). Again using Tukey's analysis of variance procedure the minimum significant difference at the .01 alpha level was 1.02 seconds. Therefore there was a significant difference in the amount of time it took to answer questions during the experiment between the control and test groups.

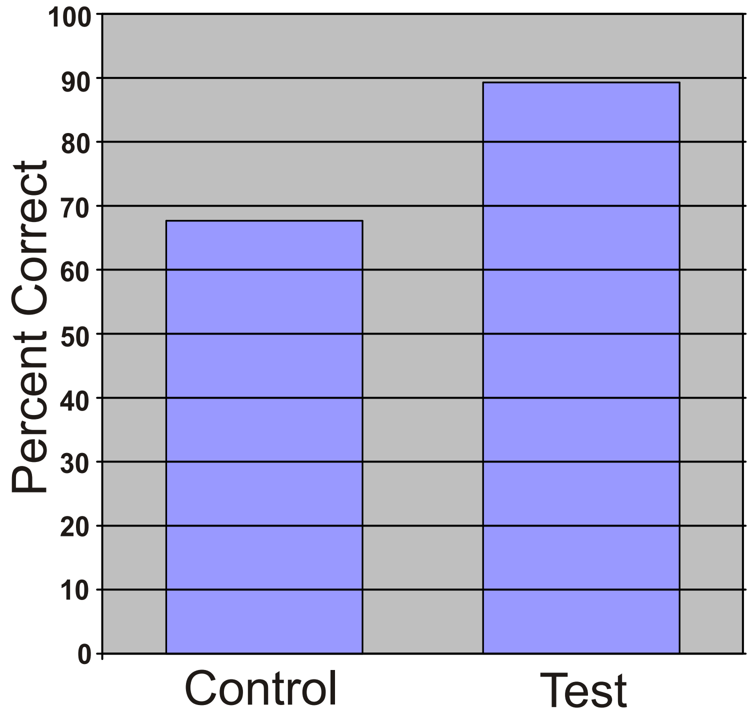

Figure 4-1. Percent of correct answers on all questions for both groups.

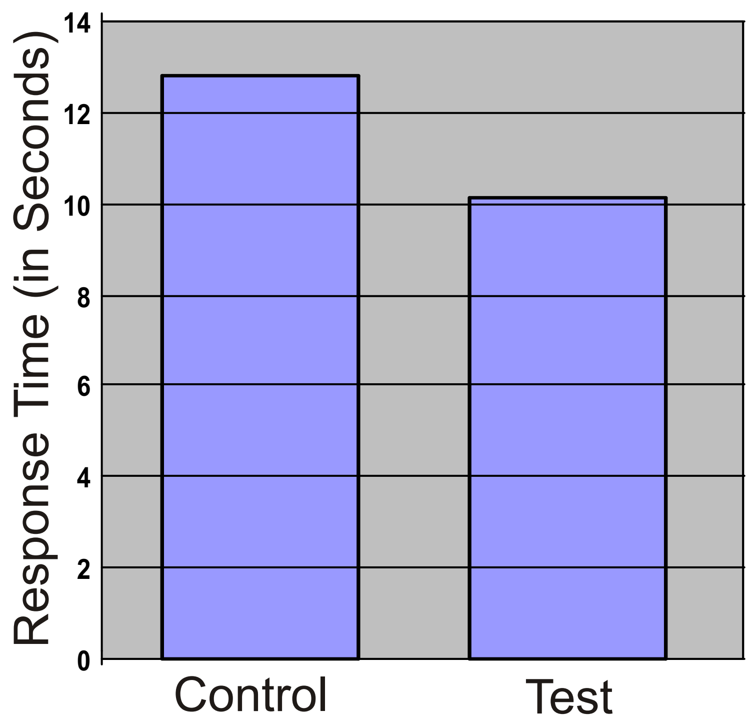

Figure 4-2. Average response time (in seconds) on all questions for both groups.

4.4 Correctness by Question Type

Question type one asked “What is the elevation at point X?”. The test group easily outperformed the control group on this type of question which is evident by their respective means of 83.6% and 57.0% (Figure 4-3). Question type two asked “Without using the legend to the left, is the elevation of point X higher, lower, or the same as point Y?” This type of question produced the greatest difference of means between the two groups. The control group’s mean was 59.4% while the test group answered correctly 94.5% of the time. Question type three read “Is there a greater elevational difference between points X and Y or points X’ and Y’?” This question type failed to produce a significant difference of means between the two groups responses.

4.5 Time by Question Type

There was not a significant difference of mean time between groups for responding to question type one (Figure 4-4). However, on question type two, the control group responded in an average time of 11.9 seconds. The test group’s mean time was significantly faster at 7.1 seconds. There was also a significant difference in mean response time for question type three on which the control group exhibited a mean of 12.1 seconds and the test group’s mean was 9.7.

4.6 Correctness by Map

Both groups showed improved accuracy as the experiment progressed from map one to map three. Although the improvement is clearly visible from graphs (Figure 4-5), the statistical analysis indicates that there is no significant difference between the

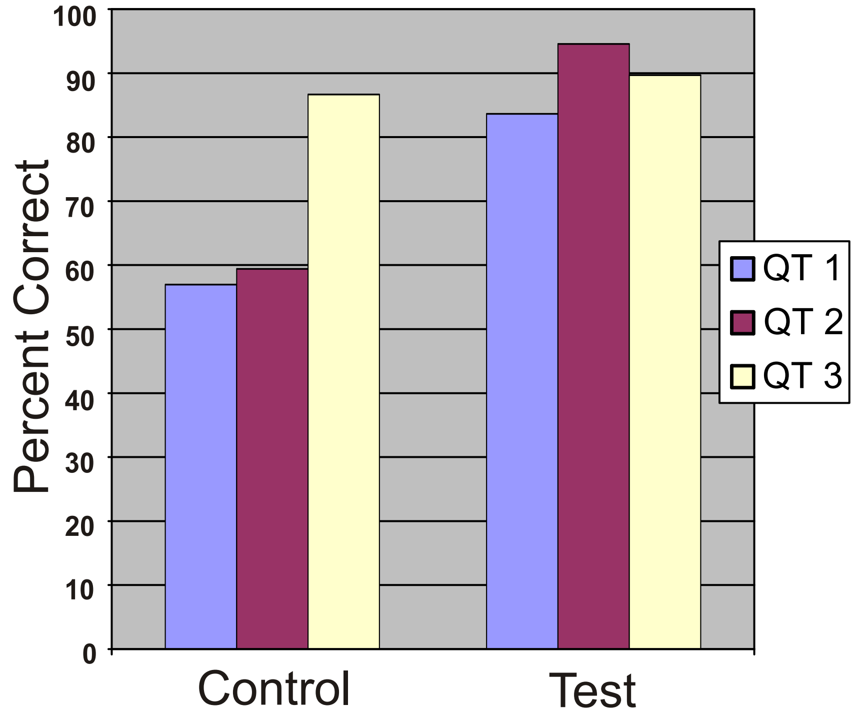

Figure 4-3. Percentage of correct responses by question type.

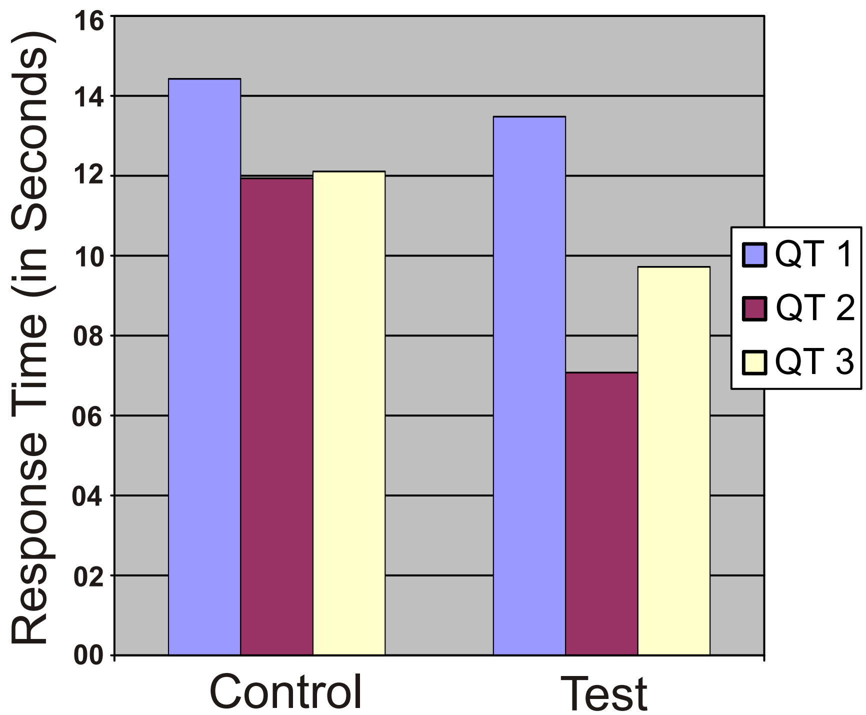

Figure 4-4. Average response time (in seconds) by question type.

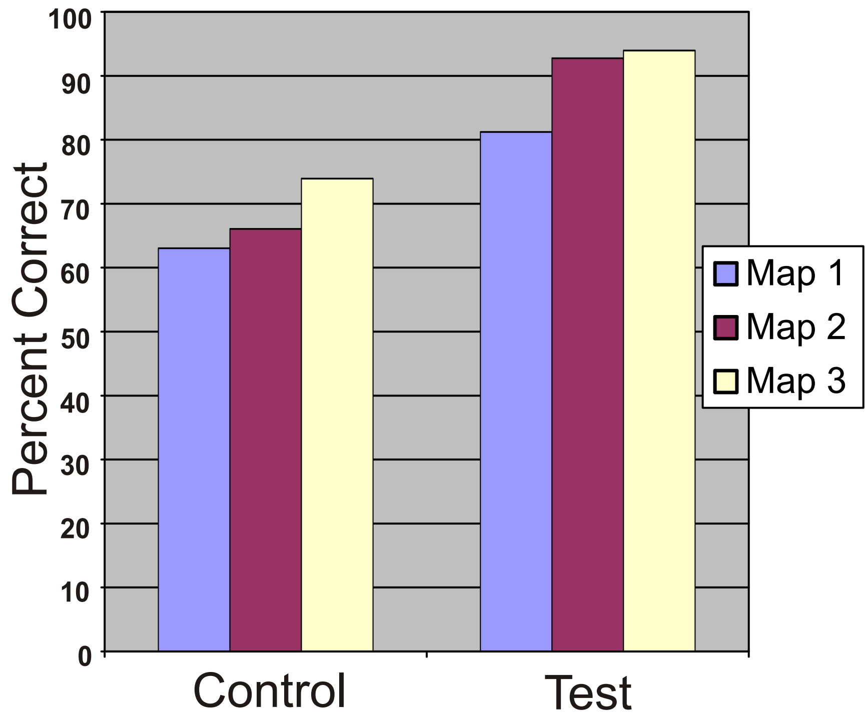

Figure 4-5. Percentage of correct responses by map.

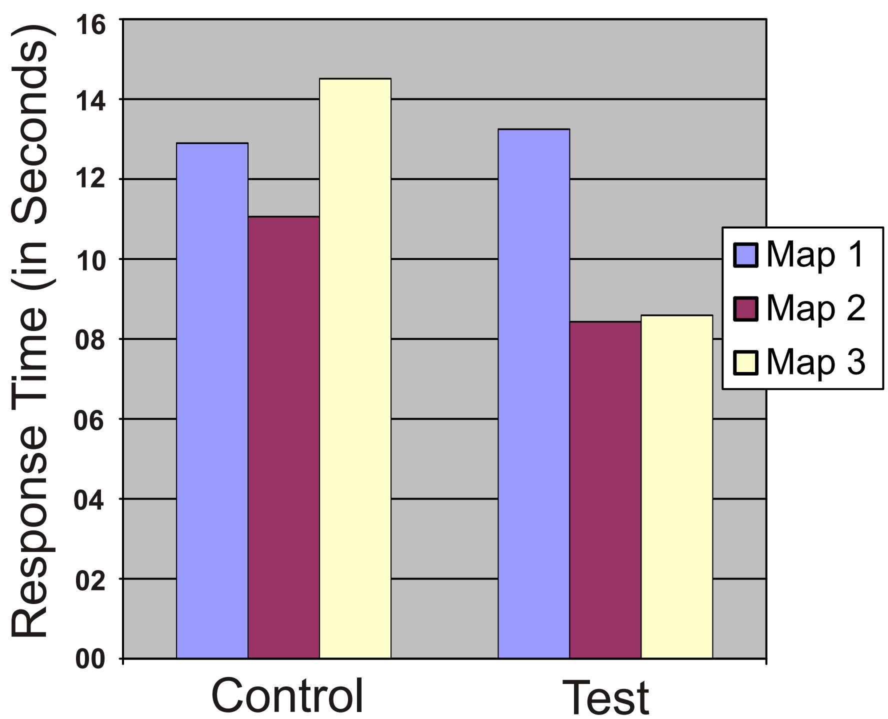

Figure 4-6. Average response time (in seconds) by map.

mean response correctness from map one to map two for either group. However, there is a significant difference in mean response correctness from map one to maps two and three in the test group. Of these students who had the benefit of hearing the notes associated with the contour lines, the average amount of correct responses in the first map was 81.2%. On the following two maps, the test group's mean increased to 92.7% and 93.9% respectively. The control group's scores increased from map to map also. They averaged 63.0% on map one, 66.1% on map two, and 73.9% on map three. Although both groups exhibited improved accuracy as the experiment progressed, these means take on a new significance when compared with average response time and map complexity.

4.7 Time by Map

As previously stated, map three was the most visually complex of the three maps. Map one was the second most complex, and map two was the least visually complex. Using standard map reading techniques (like the control group) it would be safe to assume that the amount of time needed to answer questions would directly correlate with map complexity. In the case of the control group, this assumption was correct. The average times it took subjects in the control group to answer questions in maps one, two, and three respectively were 12.9, 11.1, and 14.5 (Figure 4-6). However, the test group's correlation between time and map complexity was not as clear cut. The average response time for students who could hear the notes was 13.3 seconds in map one. Their average response time for the second map decreased dramatically to 8.4 seconds which would be expected due to the lack of complexity on the second map. However, the map questions relating to map 3, the most complex visual display, were answered with a mean response time of 8.6 seconds. The analysis of variance procedure indicates that this is not a significant difference between map two and three. This lack of difference in response time between the most simple and most complex map in visual terms may indicate that visual complexity does not affect the amount of time necessary to answer map question while using sonification techniques. Alternatively, these results could indicate that the subjects were learning how to use the sonic maps and even though the third map was much more visually complex than the previous, the time required to answer questions pertaining to map three only slightly increased due to a learning curve. Further experimentation would be required to ascertain which or both of the aforementioned scenarios is correct.

4.8 Absolute Elevation

An element of inquiry that is not accounted for in the previous analysis is the question of deviation. Because the experiment questions dealing with absolute elevation (question type one) were recorded using whole numbers, we can investigate the degree to which students who missed those questions were in error (Table 4-2). The ability to ascertain the elevation of a given place on a topographic map is arguably the most important map reading task associated with those maps. Every student in the test group answered question number one correctly within two contour lines in either direction. Using those same criteria, there were only two incorrect answers on all three of the questions pertaining to absolute elevation. In other words, using the sonification technique, all but two subjects in the test group of 55 students or 96.4% answered correctly to within forty feet all the questions of question type one.

Table 4-2
Percentage of Correct Responses
Within Two Contours

	correct	plus/minus one contour	plus/minus two contours	
Control	60.0%	65.5%	67.3%	QT 1 Map 1
Test	78.2%	92.7%	100.0%	
Control	52.7%	56.4%	83.6%	QT 1 Map 2
Test	80.0%	87.3%	98.2%	
Control	58.2%	72.7%	74.5%	QT 1 Map 3
Test	85.5%	94.5%	98.2%	

4.9 Student Reactions

Perhaps the most rewarding aspect of this research was being able to see and hear students reactions to this experiment. The students in the test group seemed to have fun during the experiment. In fact, according to the experiment proctors, some of the students took longer to answer questions than necessary in order to 'play' with the maps. The students in the control group were usually disappointed after they received an explanation of how the other group was able to answer the experiment questions. They seemed to recognize that the questions would have been easier to answer correctly and rapidly with the aid of sound. What follows are some of the comments written on the back of answer sheets by students in the test group.

> *"The pitches made the maps much less confusing because of all the lines everywhere."*

> *"I've never considered that a visual map could be used interactively with a musical scale. It definitely helps you quickly identify elevations instead of searching for numbers on lines"*

> *"I liked the fact that you use more than one sense to find the answers. Sounds make testing easier, and it's a great idea that was fun too."*

> *"This is a good way to find the right elevation. Sometimes I just guess, but with the sounds I can be sure."*

"…you can use vision and hearing to interpret the map so you have a better understanding."

"This experiment was very helpful. I was able to determine elevations more accurately with the pitches rather than just looking at the map. It also helped me to make those decisions much faster. I enjoyed being a part of this experiment."

CHAPTER FIVE: SUMMARY AND CONCLUSIONS

The purpose of this chapter is to assess the validity of the two null hypotheses based upon the test results presented in the previous chapter. These findings will be discussed in respect to the on-screen versions of traditional topographic maps and how they are interpreted in comparison with the sonic versions of those same maps that were created for this research. An attempt will be made to relate what these findings mean for the future of map readers and map reading teachers. Finally this chapter will include suggestions for future research in the combined fields of sonification and cartography.

5.1 The Hypotheses

Again, the null hypotheses tested were:

Ho_1: The ability to hear notes that correspond with elevation will **not** affect the ability of map readers to **correctly answer** questions pertaining to topographic maps

Ho_2: The ability to hear notes that correspond with elevation will **not** affect the **speed** of map readers to answer questions pertaining to topographic maps.

Ho_3: Visual map complexity will **not** affect the accuracy or **speed** of responses to map questions on sonified maps.

The evidence provided by the research reported in this thesis leads to rejection of the first null hypothesis. The ability to hear notes that correspond with elevation can significantly affect the speed of map readers to answer questions pertaining to topographic maps (see Figure 4-2; also Figures 4-4 and 4-6).

As previously discussed, the question of response speed proved more complicated than the question of correctness. However, as the experimentees gained familiarity with the sonic maps and how they functioned, the issue of visual map complexity became obsolete. In other words, once the students figured out how to use the sounds to aid in their map reading tasks, they were able to answer map questions quickly and accurately. Therefore, null hypothesis three is also rejected by the research in this thesis.

This research also proved that students who incorrectly answered questions relating to absolute elevation (*i.e.* question type one) did so by a less severe margin than their peers who were not allowed the benefit of using sound (see Table 4-2). In fact when evaluating the percentage of correct responses plus or minus two contours, the entire test group made a total of two errors on those three questions. These findings indicate that a particular student's ability to distinguish between different notes of the chromatic scale play a limiting role in how accurately he can answer questions on a sonified map. In other words, students with good ears will perform better on sonified maps just as students with good eyes will perform better on standard maps. In order to further evaluate this phenomena a quantitative measure of relative pitch (*i.e.* a hearing test) would need to be implemented in conjunction with an experiment dealing in sonified maps.

5.2 Discussion

The fact that the null hypotheses in this research were rejected should be no surprise. It makes sense that utilizing a multi-sensory approach to a task that is normally accomplished with only one sense would have positive results. The more interesting aspects of this experiment are the qualitative issues concerning how this type of multi-media functionality could be further utilized in cartographic displays. This study will provide a practical framework for the theory that sound enhancement can aid in map reading. Because sections of standard USGS 7.5 minute maps were used for this study, it could prove to be a valuable teaching tool for topographic map users. The base of knowledge in the field of sound in cartographic visualization is extremely limited, and this research will provide a working base on which the field can build. Because the software that was used to construct the test is designed for web applications, the test could be modified to be more of a pedagogic application which could be accessible by anyone on the web.

Using maps similar to those created for this research has promise for the purpose of teaching. This researcher was consistently impressed by the comments made by the students in the test group as they departed the testing area. Many students remarked that they seemed to finally understand topographic maps that had confused them in the past. Students also expressed a desire to have more time to investigate the sonic maps. The students were genuinely interested in the test maps, and this interest is particularly exciting to this researcher as a cartographer. Any time a student becomes interested in a subject a positive result will follow. As topographic maps are often used in the outdoors, the practicality of carrying a laptop computer into the woods for the purpose of having sonic versions of topographic maps is questionable in many circumstances. However, if sonic versions of maps were available, students could spend time exploring those map to become more familiar with topographic displays in general or a specific map before venturing outdoors. In short, sonic topographic maps could be an efficient manner in which to train people to read standard isoline maps.

Although the pedagogic application of sonically enhanced topographic maps is exciting, sonic versions of more complex isoline displays should prove to be useful for research and data inspection purposes. Spatial data are often simplified or generalized to decrease visual complexity. The results of this research indicate that visual complexity has little effect on map readers comprehension of sonically enhanced maps. Therefore, the complex data often encountered by researchers could be efficiently inspected via a combination of visual and sonic techniques much like the maps used in this research.

5.3 Future Research

It has been the intent of this thesis to provide a foundation for future research concerning using sound variables in combination with cartographic displays. This thesis leaves many questions unanswered. For example, would using sounds of different timbres (guitar notes, violin notes, *etc*.) effect the results of a study similar to this one? Could different maps or specific questions significantly alter the trends seen in the analysis of the experiment data? The issue of being able to create maps that are completely sonified rather than having specific areas that are enhanced with sound should become less of an issue with improved processing speed and software. This fact leads to the question of how beneficial would it be to have a topographic map that was completely sonified. That same map could include earcons for the different map symbols and other sonic elements that are beyond the scope of this researcher's current imagination.

The fields of sonification and visualization will continue to strive for ways to create data models that communicate quickly, easily, and thoroughly. Multi-sensory designs represent one of the most exciting developments in data inspection techniques. Cartographic displays in particular should utilize a multi-sensory approach because of the many senses that we use to sense space in everyday maneuvering. Research in the areas of sonification of geographic data and sonic variables in combination with maps certainly holds opportunities and promise for the future.

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