# Classifying Speakers Using Voice Biometrics In a Multimodal World

Except where reference is made to the work of others, the work described in this dissertation is my own or was done in collaboration with my advisory committee. This dissertation does not include proprietary or classified information.

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# Classifying Speakers Using Voice Biometrics In a Multimodal World

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## Dissertation Abstract

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The following dissertation document is a research study conducted to determine whether a classification for a person is obtainable by using the person's voice. The intent of this work was to investigate a collection of voice samples for trends that potentially lead to parameters to be used in the classification of an individual. No classification area was sought specifically; for instance gender or ethnicity, as it was preferred to allow the results to dictate the characteristics that point to a particular classification group. In the data collection stage, each participant was given the same task and then analysis was done on the voice sample given. Analysis was conducted in phases, with the first phase focusing on the time domain which resulted with parameters approximating speed of speech and the amount of pauses in the sample. Next the frequency domain was investigated focusing on the complexity of speech and voice tone attributes. The results of the inquiries into this domain concluded with the peaks, in the frequency of the voice, being tracked by frequency threads and represented numerically by a third order polynomial. It is the coefficients of this polynomial that give a representation of an individual's voice, making it possible to classify them to a particular group. To verify this, the coefficients from these polynomials

were used with a clustering application to validate the hypotheses of this study, substantiating an objective to provide empirical user data to contribute to the design of future phone system communications.

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PRAISE TO JESUS... THIS DISSERTATION WORK IS DONE!

Style manual or journal used Journal of Approximation Theory (together with the style known as "aums"). Bibliography follows van Leunen's *A Handbook for Scholars*.

Computer software used :the document preparation package TEX (specifically LATEX) together with the departmental style-file `aums.sty`.

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# Chapter 1

# Introduction

## 1.1 Motivation

Professionals in the field of Human Computer Interaction (HCI) are continuously searching for ways to improve the communication between humans and computers, especially when using voice interfaces [45]. HCI research has become paramount to the development of computer applications that require user authentication, such as e-commerce [1]. Biometrics is one area in which HCI research is being conducted to examine the potential of strengthening the authentication and security processes. The process of biometrics is the use of an automated method to recognize an individual based on physiological, behavioral characteristic, or a combination of the two [17]. While there are many sub-areas that pertain to biometrics, some of the more recognized areas are: voice, iris, fingerprints, hand, face, retina, signature, keystroke, and gait. Biometrics is founded on the idea that any or all of the aforementioned physical and or behavioral aspects are unique to a person and can be used to identify that person [27]. The focus of this research is the sub-area of voice biometrics, its ideals and its characteristics. Specifically this research is involved in using voice biometrics to classify an individual and thus make the communication process between them and a computer application more successful. This avenue of thought came about while compiling the post survey responses from a usability study conducted for a electronic voting system, Prime III [48]. One of the most frequent comments made was about the voice used for the system to communicate with the user. Some said it talked to fast, some said it talked to slow, and some said they were not able to understand it. The topic of this dissertation came about after reading these comments and thinking of probable solutions to improve this aspect of communication between an individual and machine.

## 1.2 Problem Description

Using voice biometrics in speech technology has evolved greatly over the last decade resulting in many commercial applications. In addition to this evolution, the field of HCI has taken on an important role in the development of applications by getting awareness on the way humans and machines interact to be a part of the development process [16, 45]. With the advancement of speech technology in phone applications, there also must be more consideration given to making the communication between the diverse group of users and the voice applications more compatible [11]. This is not a trivial task that can be solely fixed using technology. It will also require the involvement of social science to help better address the issues that arise. How a system responds to a user can have an immense effect on the interaction between the system and the user [45]. Currently, speech applications do not give any consideration to potential characteristics of the user that can be used to help the communication between the person and the machine. In the past most research concerning voice biometrics has been conducted in the areas of speaker identification or speaker verification and very little has been done in the area of speaker classification. Thus more focus is being given to speaker classification because speech interfaces are becoming widely implemented in today's phone and web applications [45]. Given the increased interest and the perceived usefulness of voice classification in today's applications, the hypothesis of this research arose. By analyzing the human voice one can conclude the following:

- H1) The pitch range of the human voice can be used to create a tone classification set, such as a low, medium, and high tones.
- H2) The human tone classification can be refined into human classifications that pertain to gender, ethnicity and geographical area where their accent was most effected.

## 1.3 Background

Voice biometrics is a method of biometric authentication that uses voice recognition techniques based on characteristics of the human voice. According to Dr. Judith Markowitz, voice biometrics can be broken up into speaker verification, identification, and classification [32]. Research in the area of voice biometrics has mainly been associated with two areas: 1) speaker verification and 2) speaker identification. While equally important, a third area of voice biometrics, referred to as speaker classification is not as widely focused on as the other two but is just as important [34].

Speaker verification requires a user to create a voice template that can be stored in a database associated with that specific user to be used with the system. When the user submits a voice sample for verification to the application and declares to be a certain individual, the system will then perform a one-to-one comparison with the voice template that is stored in the database for that particular individual. Next a calculation will be made to see how close the two templates are, and a confidence value will be generated. If this confidence value is above a given threshold then the application will verify the authenticity of the speaker [26, 32, 30].

Speaker identification is a similar process to speaker verification in that it also collects a voice sample. However, the application performs a one-to-many matching process against an already existing database that holds voice templates of known individuals. The matching process consists of the application comparing the voice sample that is given by the user with each voice template that is in the database. Consequently, this time it is searching for the closest match and then it determines if the calculated confidence value falls within a given threshold. In cases like these, the user's identity is determined by the search and match. In speaker verification, the user identifies him/herself and the system verifies their claim to be that individual using the voice template associated with that user.

Speaker classification is the area of voice biometrics which is used to determine a specific group that the user may or may not belong to. It does not require a preset database as the previous two types of voice biometrics because it is neither looking to verify or identify a certain individual. Speaker classification is the type of voice biometrics that this research is investigating. This research proposes that an algorithm can be developed that will determine a value for the user which can be used to classify the user into a specific group(s). This classifier will be created using the individual's speaking range as it pertains to the pitch and the speed of speech of the individual. This algorithm will be discussed further in chapter three.

### 1.4 Organization

In the chapters that follow a research agenda will be examined. In Chapter 2 a literature review will be given that discusses the areas of biometrics, the three types of voice biometrics, and some mathematical concepts that pertain to representing voices graphically and digitally. The specific mathematical areas covered in the literature review will be the Fast Fourier Transform and windowing processing concepts that will be used to represent the pitch of a person. An overview of the application MATLAB by Mathworks will be discussed as this application and its extensive signal processing libraries will be used in this research. Also the subject area of voice pitch will be discussed as well as what determines the pitch of a person's voice. A detailed plan of research will be outlined in Chapter 3. Chapters 4 - 7 will present the procedure by which the data was analyzed and preliminary results. Concluding with Chapter 8 were the findings, significant contributions to the field of voice enabled technology and future work will be discussed. Finally, Chapter 9 will list preliminary work and publications.

# Chapter 2

# Literature Review

This Chapter describes some of the work done in the field of biometrics and the mathematics involved in this technology. It focuses on biometrics, voice biometric systems, voice pitch, MATLAB programming language and libraries, Discrete and Fast Fourier Transforms, and windowing functions used with data obtained from Fast Fourier Transforms.

## 2.1 Biometrics

The word "biometric" can be broken up in to two words, bio meaning "life" and metric meaning "measurement" [39]. A very basic definition is be "life measurement" which needs to be expanded to give clarity for today's uses. The term biometrics has now become a present day word that many have used or at least heard of, but do not fully comprehend its meaning. The definition of biometrics can vary depending on the specific context it is being used. The following is a definition of biometrics as it relates to this research:

> "Biometrics is the automated use of physiological or behavioral characteristics to determine or verify identity" [44].

As previously mentioned the area of biometrics can be broken into several sub-areas. A broader list of sub-areas are voice, iris, fingerprints, hand, face, retina, DNA, signature, computer keystroke, gait, odor, earlobes, sweat pores, lips, etc. This research will not discuss whether each of these sub-areas is unique in themselves, but will operate under assumption that there are attributes that are unique to each person [44]. In addition to the underlying assumption of this research is that the voice is a unique trait of an individual and thus can be used in identifying the person. Therefore this research will focus on the sub-area of biometrics, referred to as voice biometrics. To understand the topic of biometrics it is beneficial to know that biometrics has been around for hundreds of years. The use of biometrics can be seen throughout history in many different forms. In China, in the 14th century, the explorer Joao de Barros found the use of biometrics as merchants recorded the palm prints and footprints of children on paper with ink, for identification purposes [6]. In Eastern Asia, potters placed their fingerprints on objects for identification of the maker [66]. The use of fingerprints for identification has continued to this day and is extensively used by law enforcement to identify criminals. An anthropologist by the name of Alphonse Bertillon who lived in Paris in the late 1890s and his efforts to make the identification of criminals easier is credited with bringing biometrics to the point where it was considered an actual field of study [6]. This brief look at some of the historical usage of biometrics shows that biometrics has evolved over the years and now with advancing technology, will be evolving even further [44]. Voice biometrics is one such growing area of biometrics and will be discussed in Section 2.2.

## 2.2 Voice biometrics

Voice biometrics has mainly been associated with two areas: speaker verification and speaker identification. The third area of voice biometrics, speaker classification, has not received as much attention as the other two [8, 34]. The first two areas of voice biometrics: speaker verification and speaker identification, at first may appear decidedly similar, but each has a distinct purpose [30]. The third area of voice biometrics, speaker classification, is considerably different from the first two. The next few sections discuss the similarities and the differences in these three aforementioned areas of voice biometrics to distinguish the area of speaker classification from speaker verification and speaker identification.

### 2.2.1 Speaker verification

Speaker verification (SV) aims to validate a person's identity much like having your driver's license picture checked at the airport when you check-in for your flight. SV is becoming widely visible in today's economy due to the added security issues faced by industry

[32]. SV is used to verify that the person speaking is truly the person they are claiming to be [61]. SV is a one-to-one comparison and in general, there are five steps to SV [8]. First is the enrollment of the user to generate a voice template that will be stored in a database. In a second step, the user speaks for a set amount of time so that a voice sample can be obtained for enrollment or for the verification process. This collection phase can be either text dependent or text independent, which will be explained later in Section 2.3. Once the voice sample is obtained, the third step of extracting certain features from this voice sample takes place and a template is made. This template will either be immediately used for comparison or will be stored in a database to be used later. The fourth step is a pattern matching phase, where a confidence value is calculated. This value is used in the fifth step to accept or reject the claims of the authenticity of a person [8, 36]. To make this decision, a confidence threshold is set according to the sensitivity needed for the system, which is based on the security required [36]. It is common to use this process in conjunction with some form of ID number or password known by the user. Upon entering their unique ID in the system, the user is required to speak so that the application can verify they are whom they claim to be.

### 2.2.2 Speaker Identification

Unlike speaker verification where a voice sample is compared to a single stored template in the database, speaker identification (SI) uses an individual's voice to identify them [32]. SI is a one-to-many process, where a sample is obtained from the user and then a comparison is made with all the voice templates in the database to determine if a match can be found [27, 36, 32, 30]. The aforementioned general steps for SV also pertain to SI with a few differences. In the decision making step, SI does not give a decision to accept or reject as in a SV system. The SI decision process is determining if there is a stored template that matches the collected voice sample within a certain predetermined threshold [8]. As stated earlier, SI is a one-to-many matching process, making this process a much more difficult task. The application will need to go through the pattern matching step for each voice template that is stored in the database. For each voice template, it must be determined whether the confidence value for that particular item is within the preset threshold. Finally, an output is given as it pertains to the identity of the person speaking. The output of this process can be [36]:

- No matches - indicating that no stored template had a confidence value above the given threshold
- A single match - where one certain template was the only one to have a confidence value above the threshold for the given sample
- Multiple matches - since all stored templates are checked and more than one can be a close match, where all are within the given threshold; it is not uncommon to get more than one close match

### 2.2.3 Speaker Classification

Speaker classification (SC) is different from speaker verification and speaker identification in that it is used to determine if a speaker can be associated to a particular characteristic group rather than associating it to a particular individual [35]. SC is done by extracting information from a voice sample that is obtained from a given speaker. It is an idea of this research and others that different characteristics can be determined about the speaker once their voice sample is processed. Characteristics such as gender, age, emotion (i.e. fear or anger) and ethnic origin are a few of the characteristics that may be determined [30, 34, 45]. SC has been around for decades, but attention has mainly been on the other two areas. SC for the most part has only been considered for how it can help with developing these two areas. In the development of either SV or SI systems, there is usually a form of classification performed. To facilitate this, the use of Gaussian Mixture Models (GMM) has been and is still being heavily used with speaker classification aspect of systems. However, other models and methods are now being researched such as Hidden Markov Model (HMM), Support Vector Machines (SVM's), and use of voice pitch [41, 68, 51]. Using the pitch of a human voice as a speaker classifier has not yet been researched to a great extent and thus is of interest to this research.

Speaker classification research now is being conducted to help in many areas. One of these is the monitoring of phone conversations [42]. Dr. Judith Markowitz gives an example of this in the book Speaker Classification I, the Loquendo Voice Investigation System. This system is used to monitor cell phone calls where speakers of special interest are determined and this information is then passed on to law-enforcement or intelligence agency clients [34].

The following sections discuss text dependent and text independent methods. An understanding of the difference between these two is needed to add clarity to voice sample collection from the user of a speaker recognition system no matter if it is for verification, identification or classification.

## 2.3 Voice Sampling Methods

In the previous sections, the terms *text dependent* and *text independent* were mentioned as it relates to the collection step and will now be explained. Along with a basic explanation, some of the advantages and disadvantages of each will also be discussed. This overview is important to this research as it dictates which method is most appropriate. This is an important distinction that needs to be determined prior to any study that will be done.

### 2.3.1 Text Dependent

A text dependent system is one that is trained by the user speaking a predetermined phrase or word that has already been established in the system. The phrase that is selected can be determined by the administrator of the application or the user and usually is something that the user will be able to remember easily along with something that will give a broad phonic range. This is an advantage of a text dependent system in that the user will be speaking a phrase, where the voice sample obtained will be a better representation of the person's voice [55, 8]. It is also customary with a text dependent approach for the same phrase to be used to establish a voice template and for the user to repeat when using the application [17]. This improves the matching step of the application by reducing the chances of having a false reject or false acceptance of a given user [8]. An additional advantage of the text dependent method is that the user selects the word or phrase to be used, which is unique to them [36].

The disadvantages of the text dependent method are mostly connected with the area of security. Because the user will use a predetermined word or phrase, there is always the possibility that the word or phrase was compromised (i.e. obtained by another individual). When the word or phrase is known by another individual, a voice sample can be manufactured to circumvent the system or an actual recording can be obtained of the user saying the phrase and this is used to circumvent the system. Both scenarios are possible because of the dependency on a set word or phrase. Along with the risk of someone obtaining the word or phrase, there is a problem that the user of the system must remember the word or phrase that was used to set up their voice sample. When the user does not use the correct word or phrase and the system attempts to match the voice template of the user, then a false reject is given. This puts a burden on the user to always remember the exact word or phrase [67]. The text independent method can be the solution to this problem and will be discussed next.

### 2.3.2 Text Independent

A text independent system in contrast to a text dependent system obtains the voice template by the user reading or speaking anything they prefer. This method allows the user to speak freely and does not tie the user to a predetermined phrase. In the past, this type of system has been used primarily when a person, whose voice sample is being obtained, is not fully cooperative or they are not willing to participate in the process at all. Speaker recognition technology trends for text independent applications are advancing; for example, being able to identify a person without them having to speak any predetermined word or phrase [64]. This is one of the main advantages for this method that the user does not have to remember a phrase. Another advantage is that speaker verification can be utilized in a manner that runs in the background of the application. For example when a user calls a bank to transfer money and as the user is making their request, the application simultaneously verifies the speaker [36]. Unlike the text dependent system that requires the same word or phrase be spoken for the collection step, the user of text independent system can record a voice sample for a template with one phrase and use another phrase when using the system. This can also lead to an immense disadvantage with this type of system. With the user freely speaking, it is not guaranteed that the user will speak or read something that spans a broad range of their voice giving the speech features that identifies them. Due to this fact, in some cases, a longer sample may be necessary which may be difficult to obtain from a user that is not fully cooperative [26].

### 2.4 Voice Pitch

The sound of a human voice is comprised of several components. One of these is the pitch of the voice. In his book, Dr. H. Newell Martin describes the process that a body goes through in order to produce the pitch of a person's voice. He describes that the larynx is the primary body part that determines the sound of a person's voice. The larynx holds the vocal cords and it is the vibration of these cords that produces the pitch. He further states that it is the size or the length of these vocal cords that will give a certain pitch to the voice. The longer they are, the lower the person's voice. Consequently, the shorter the vocal cords are, the higher the pitch of a person's voice [37]. This can be substantiated by listening to the voice of a woman or child in comparison to the voice of an adult male. The woman or child speaks in a higher pitch due to the fact that they are usually smaller in stature [18]. Another fact Dr. Martin concludes, is that the vocal cords of a certain length will always give a set range to the voice. The range is dependent on a set of muscles in the larynx which determine the tension of the vocal cords. This leads to the fact that a person can only speak as high or as low as their vocal cords permit. This description as to how pitch is formed is still used today. The pitch range of a man's voice, has been determined to be approximately 80 - 200 Hz with an average pitch of 120 Hz. Whereas the pitch range for a woman's voice is 150 - 350 Hz with an average pitch of 225 Hz [58]. Upon analyzing this data, one can conclude that a man's pitch can be closer to the woman's average than to a man's average and vice-a-versa. One explanation is the individual's age, which determines their vocal cords' length, in that a young boy does not have vocal cords the length of a man [62]. Their pitch range is generally determined by the length of their vocal cords. The average length of a male's vocal cord is about 18 mm and that of a female is about 16 mm [50]. Along with the length, the thickness of the vocal cords also determines the pitch of one's voice [37]. Based on the research and literature it is quite clear that the physical attributes of a person's vocal cords give him/her a set pitch range that cannot be easily altered. Exceptions are caused by surgery, accident, sickness, smoking or extreme training (as in opera singer) altered the makeup of the vocal cords [37]. All but the latter most likely is a permanent change and still gives a person a set pitch range.

## 2.5 Discrete and Fast Fourier Transform

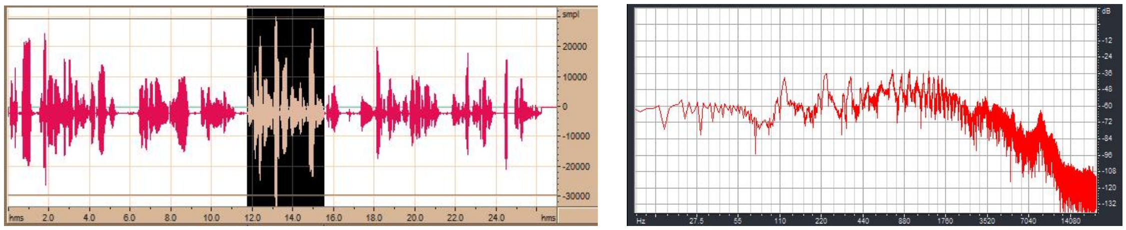
The Discrete Fourier Transform (DFT) is a generalization of the Fourier Transform (FT). In general, the FT takes a function and converts it into another function that may be more useful. The FT processes a continuous-time signal using calculus, making it highly complex. Added to this is the fact that in signal processing, the data is processed only in samples that will not be continuous. Therefore, it can be said that a DFT is used to compute a discrete-frequency spectrum from a discrete-time signal of finite length [56]. This research will be using signal processing to analyze voice samples. Most voice samples are in the time domain and DFT will transform it from the time domain to the frequency domain [28]. Considering that the data of a voice sample is both discrete and finite, it is not difficult to see where this approach of analyzing the sample can give some very useful results, as shown in figure 2.1. Where sub-figure (a) represents a voice in the time domain and sub-figure (b) illustrates a sample of the voice in the frequency domain using DFT. The DFT conversion of a signal x may be defined by the following formula and the table 2.1 contains a description of the symbols utilized by the formula.

$$X(\omega_k) \rightarrow \sum_{n=0}^{N-1} Ce^{-j\omega_k t_n} \quad where \quad k = 0, 1, 2, ...N\text{-}1$$

Calculating the DFT can be computationally expensive, even when using a computer. This requires a faster algorithm to be developed and many have been developed that address this need. The most widely used algorithm was developed by James W. Cooley and John W. Tukey in 1965 [14], also known as the Fast Fourier Transforms (FFT) [56]. As the name implies, it is a faster version of DFT and is widely used today in computer applications [15]. The main advantage of the FFT is that it reduces the computational complexity for N points from $2N^2$ to $Nlog_2N$ [14, 65]. To illustrate the difference, consider that N = 256 points for a given voice sample. With a DFT, there is, worst case, 65536 computations required to make the transform. However, with a FFT, resulting in, worst case, 2048 computations needed. This example shows that it does involve 32 times the number of computations needed to use DFT instead of FFT. Given that a voice sample can have hundreds of thousands of data points, it is clear that the FFT is the best option. It is common that when using Fast Fourier Transform (FFT), a windowing function is also used and is explained next.

Table 2.1: Formula Description Of Symbols

| | |
|---|---|
| $\sum_{n=0}^{N-1} f(n)$ | *f(0)+f(1)+...+f(n-1)* |
| $x(t_n)$ | input signal amplitude (real or complex) at time $t_n$ (sec) |
| $t_n$ | nT = nth sample instant (sec), n an integer $\geq 0$ (sec) |
| T | sampling interval (sec) also called the sampling period |
| $X(\omega_k)$ | spectrum of x (complex valued), at frequency $\omega_k$ |
| $\omega_k$ | k$\Omega$ = kth frequency sample (radians per second) |
| $\Omega$ | $\frac{2\pi}{NT}$ = radian-frequency sample interval (rad/sec) |
| $f_s$ | $\frac{1}{T}$ = sampling rate (samples/sec, or Hertz (Hz)) |
| N | number of time samples = no. frequency samples (integers) |




(a) Approximately 4 seconds of a voice sample

(b) After using DFT to transform from time domain to frequency domain

Figure 2.1: Example of Voice Sample

### 2.6 Window Functions and Spectral Leakage

A windowing function acts as a filter to smooth out the sinusoid (sine curve) that represents the voice sample taken [23]. Since the voice sample being finite, it is most likely the sinusoid representation will be in a truncated waveform [46]. In performing spectrum analysis using a FFT, there can occur a condition identified as spectral leakage. This occurs when, using an FFT function, one whole period is used to represent a periodic form for the sample. When a finite sample has been obtained, there is no assurance that one full period of the waveform has been captured which makes it possible for discontinuity. An example of discontinuity and the spectral leakage connected with it, can be seen in figure 2.2. One solution for avoiding discontinuity in the sample waveform is to apply a windowing function that will minimize the discontinuity of the created periodic waveform. The windowing function is a weighted function and will be applied to the data for the waveform to smooth out the connections at the end points minimizing the discontinuity for these end points. This is done by using as many orders of derivatives as possible of the weighted data at the end points, which will lessen the effect of spectral leakage on the waveform [25].

There are many windowing functions that can be used. Some of the most common window functions are the rectangular, triangular, Rectangle, Hanning, Kaiser, and Hamming [22]. One can determine the choice of a windowing function by resolving the tradeoff between comparable strength signals with similar frequencies [23]. For this research, the Hanning window function shown below:

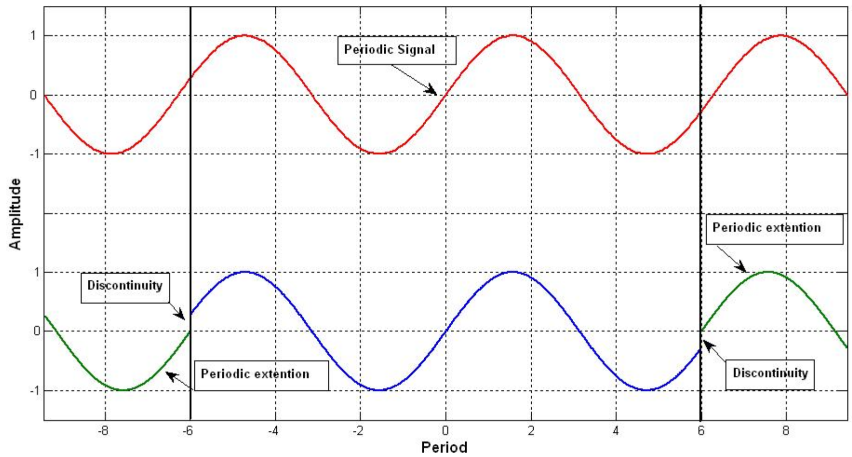



Figure 2.2: Upper graph is a standard periodic signal where as the lower graph is not periodic and has discontinuity

$$w(n) = 0.5\left(1 - cos\left(\frac{2\pi n}{N-1}\right)\right)$$

was used as it is computationally less expensive as compared to the other functions shown in table 2.2. The programming language used in this research is MATLAB[1] . One of the reasons for choosing this language is that it has very efficient algorithms for windowing functions as well as for the FFT function, based on the one developed by Cooley and Tukey[38, 59].

Table 2.2: Windowing Functions

| | |
|---|---|
| Triangular window (non-zero valued end-points) | $w(n) = \frac{2}{N} \cdot \left(\frac{2}{N} - \mid n - \frac{n-1}{2} \mid\right)$ |
| Bartlett window (non-zero valued end-points) | $w(n) = \frac{2}{N-1} \cdot \left(\frac{N-1}{2} - \mid n - \frac{n-1}{2} \mid\right)$ |
| Bartlett-Hann window (non-zero valued end-points) | $w(n) = a_0 - a_1 \mid \frac{n}{N-1} - \frac{1}{2} \mid - a_2 cos\left(\frac{2\pi n}{N-1}\right)$ <br> $a_0$=0.62; $a_1$=0.48; $a_2$=0.38 |
| Blackman window (non-zero valued end-points) | $w(n) = a_0 - a_1 cos\left(\frac{2\pi n}{N-1}\right) + a_2 cos\left(\frac{4\pi n}{N-1}\right)$ <br> $a_0$=0.42; $a_1$=0.5; $a_2$=0.08 |

[1]MATLAB is a registered trademark of The Mathworks Inc.

## 2.7 MATLAB

According to the developers of MATLAB, "MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation.", making it a very powerful tool [59]. It is the dual aspect of MATLAB (programming language and development environment) that makes it a good choice for this research. Another advantage of using MATLAB is that it was originally developed with signal processing in mind [59].

The name MATLAB stands for MATrix LABoratory as the MATLAB language stores all data values in a matrix form [19, 49]. This means that if the program stores one value or one thousand values, each value goes into a cell of a matrix. Another feature of this language is that variables do not have to be declared ahead of time or their data types specified. Also, one does not have to allocate memory as MATLAB has built-in dynamic memory allocation [59]. For this research, a major benefit of this type of storage method is that in processing a voice sample, the size of the sample will not be known ahead of time. In MATLAB, the size of the matrix will provide a representation for the number of elements, as each cell in the matrix will have some value in it. The large built-in function library (over 8000 commands) in MATLAB provides three commands, "size", "length", and "numel" (see Table 2.3) which can be used to easily determine the number of elements in a given matrix that may have been brought in from an outside data file [59].

Efficient accessing of data from an outside source is another strong point of this programming language. There are multiple commands available to access data from different file types, databases, or even other applications that are written in another language such as C or C++ [59]. Some of the commands that were beneficial to this research are "wavread", "xlsread", "textread" and "find", see table 2.3 for a description. These commands were used to read in demographic information pertinent to the voice sample that was stored in other file types or a database. Likewise, writing data to an output file was made more efficient with the commands such as, "fprintf" when a text file was required or "xlswrite" if data was better suited to a spreadsheet.

Having the tools to collect, process and store data efficiently was a necessity for this research. Also, being able to visualize the data was especially important when doing the voice samples. The graphics ability of MATLAB is another area that made this language a good choice for this research. Within MATLAB, there are functions that will plot 2D and 3D graphs to give a clear visual of the data that this study worked with. Along with this list of functions, included are many labeling and formatting functions that will add to the output of this research. All these built-in functions in MATLAB enabled the analysis process to be more dynamic, making it a powerful development tool for this research [59].

Table 2.3: Description of some MATLAB commands used

| COMMAND | DESCRIPTION OF FUNCTION |
| --- | --- |
| find | searches a given matrix for a specified condition and returns a matrix with the index values of the found values |
| numel | Returns the total number of elements in a given matrix |
| length | Returns the larger value between the number of rows and the number of columns for a given matrix |
| numel | Returns the total number of elements in a given matrix |
| size | Returns the number of rows and the number of columns for a given matrix |
| waveread | Reads Microsoft sound files |
| xlsread | Reads Microsoft Excel spreadsheet files |
| xlswrite | Writes data to a Microsoft Excel spreadsheet file |
| fprintf | Writes data to the command window or to a text file |

# Chapter 3

# Research Plan

## 3.1 Subjects

A goal of this research project was to acquire approximately 100 to 200 subjects to participate in this research to achieve a diverse population set. This goal possible to reach due to the large population of undergraduate and graduate students at this institution. Collecting all samples from this population, due to the fact the sample population was not very diverse in age or area of the United States that most affected the way they talk. It was found that of the participants that came from the local area and institute, 89% were of the age of 19 to 21 and from either Alabama or Georgia. To remove this limitation and gain as varied group of participants, a request was sent out to friends and family from different communities around the United States. As will be discussed in Section 3.4 the "snowball" method was used to gain as many participants as possible without having to have direct contact with each potential participant. This method worked well in that there were over 170 voice samples collected along with the particular demographic information associated with each sample. With the request for involvement going out to presumably any part of the United States or the world, participants from diverse groups were collected. All voice samples and data were collected from a remote location of the participants choosing, (i.e. where they had access to the Internet and a telephone). There were 10 participants that did not complete the study because they did not leave a voice sample as required. Since all data collection was obtained in a private manner, it is not known whether the participant chose to not finish the study or did not understand the directions given. They had the option to contact the study organizers via phone or email if they had any questions or encountered any difficulties with the data collection process. Yet only two such contacts were received from participants, one indicating that the web pages for the study did not load, which was due to the server being off line as an unrelated application had caused the server to crash. The other correspondence described an error message that was given when the participant attempted to navigate from the demographic page to the phone instruction page. In this case the reason for the acquired error message was due to an inadvertent double entry in the table that stored the IDs that were given to the users, this was promptly rectified. Excluding these two cases, data collection transpired efficiently for all participants. The demographic data gathered from participants that did not leave a voice sample was deleted from the database due to the fact that without a voice sample the demographic data was not usable.

### 3.2 Equipment and Material Used

There was very little equipment required to participate in the research study. A participant accessed the application via the Internet connection and a telephone. The participants needed no specific computer knowledge or experience to participate in this research. They did however need basic knowledge of the Internet to facilitate them with navigation to the initial web page of the study and to answer the demographic questions. All individuals that were contacted about participating in the research were given the option of either coming to the Shelby Center for Engineering Technology at Auburn University to complete the data entry task or choose to complete the study at a remote location of their preference. Individuals that participated in the study remotely were required to obtain access to the aforementioned equipment as no equipment was provided for any remote involvement in the study. Design of the web pages were such that they loaded on most all universally used web browsers. The content of the pages was kept to a minimum to allow a participant with a dial up connection to still participate with the least amount of waiting for the web pages to load. Had an individual chosen to come to the Shelby Center for Engineering Technology, all equipment was provided for their use.

### 3.3 Software Used

The algorithm development process utilized several different technologies. The primary development environment was the MATLAB programming environment from The MathWorks [60]. MATLAB has literally hundreds of built in functions that vary from the basic functions to specialty functions that are grouped together into what The MathWorks calls toolboxes. For this research several of these functions were utilized in the data processing and analyzing phases. The database used was MySQL by Sun Microsystems [43] and server version: 5.0.51a SUSE MySQL RPM and the operating system for this server was Linux operating system. The basic web pages created were written with HTML and JavaScript. Using JavaScript guaranteed that all fields on the demographic page were filled-in as it does not allow advancement to the next webpage until all fields had been filled. Pages that need to connect to the database were written using PHP along with MySQL commands. For the phone application programs the VoiceXML programming language was used along with PHP and MySQL for situations that needed database access. Clustering analysis was executed by the software Applications Quest™[20] with the output being copied to a Microsoft Excel spreadsheet. Microsoft Excel was also used to do some of the storage of calculated results along with preliminary sorting of data for examination.

### 3.4 Data Collection Methods

To conduct this study voice samples were needed along with the demographic information for each participant. It was determined that to add diversity to the population set, participants needed to be from locations around the United States. Additionally, it was preferred that there be dissimilar ethnic groups be enlisted and that the percentage of male and female participants be balanced. The method chosen for accumulating data was the “snowball” data collection method [57]. This method was conducted in a manner where requests were sent to acquaintances and once they participated they then solicited their friends and family to participate. Originally twenty-five requests were sent out and at the conclusion of the analysis 170 participants had been acquired, making this method a practical way to collect data. During this process each participant was asked to respond to the following demographic request/questions:

- Please select your Gender
- Please enter your Age
- Please select the following that best describes your ethnicity
- Please select what your primary language is
- Please select the country you consider your primary nationality
- Please select the country for your parents primary nationality
- Please select the state of the United States that you would say has affected the accent of your voice the most
- Please select the one that best represents the highest level of education completed
- Please select the one that best describes the area that you live in
- Please select the one that best describes how you feel today
- Have you had a physical injury or a disease that would affect your voice?
- Would you consider yourself to have a speech impediment?
- Please select the category for your height

Upon completion of the data collection it was found that approximately 55% of the participants were female and 45% male. Nine ethnic groups were represented with Caucasian being the largest group at 67%. English made up the largest representative language at approximately 96%, but five other languages were also declared. Ten countries were given as primary nationality with United States being the highest percentage at 92%. In regard to education the top three categories were as follows: Bachelors Degree at 32%, Masters

Degree at 26%, and some college at 21%. Full details of the breakdown of the collected demographics can be viewed in Appendix A.

The collection of all demographic information was completed via a website that is hosted on a server under the supervision of Dr. Juan E. Gilbert. The server is located in a locked room that is only accessible by authorized personnel so that all data collected is secure. The official URL address for this site was "`http://www.voicestudy.com/`". A screen shot of all pages can be seen in Appendix B. The first page of this site gave the person an opportunity to view the information letter about this study (which can be viewed by looking at Figure B.1) and to either agree to continue or not. If the participant chose to continue they were then taken to the demographic page where they responded to thirteen requests for the above information (see Figure B.2). No data was collected to identify any participant. The participant was not able to navigate from this page until they responded to all thirteen requests. Once they completed this and clicked to continue, their information was stored in the database, which was located on the same server previously mentioned, by using a PHP program to interface with the database. The next page that the participant saw was an instruction page that informed them on how to complete the calling procedure for the phone application, that was used to collect a voice sample from them (see Figure B.3). The phone application was accessed using a free developer service under the umbrella of Nuance Communications, Inc by the name of "NUANCE café" formally known as "BeVocal café" [47]. Since this development platform was free for the participant they had to call a toll free number (1-877-338-6225) and they were prompted to enter a user ID and PIN number. The user ID was 8446348 and the PIN was 1234; both of these were provided to the participant on the phone instruction page. An example can be seen in Figure B.4. Once log-in was accomplished the user continued directly to the phone application which proceeded in the following manner.

1. A welcome message was played.

2. Then the application requested the participant to enter the four (4) digit number given to them on the phone instruction webpage, see Figure B.5.

3. The application then verified that a valid number was entered by querying the data base and making sure that number was a primary key for a row in the database.

4. Upon validation of the ID the application gave instructions to the participant on what would take place next. After that they heard a phone ringing and a message played as if they had received a friend's voice mail.

5. When prompted, the participant would then leave the exact message given to them on the instruction page; to see the message view Figure B.6.

6. Next they had an opportunity to hear the message they recorded and either except it or try again.

7. Once they accepted their message they were thanked for their participation and after that the application disconnected.

Nuance café saves all voice recordings as WAV files which are Microsoft's audio file type. Nuance's default file type (audio/wav–WAV (RIFF header) 8 KHz 8-bit mono mu-law [PCM] single channel) worked well and was in a form that MATLAB can open and extract the data from directly. A file name was created by concatenating the word "participant", the four (4) digit number that was given to the participant along with the file extension WAV. This filename was also stored in the database under a field name "fileName". The actual sample file was stored on the secure server that all files associated with this study are stored on. There was a specific folder setup for these files (WAV files) which helped to keep them separate from the program files.

### 3.5 Experimental Overview

This section gives an overview of the approach that was used to validate the hypotheses presented in Section 1.3. The main objective of this research was to develop an algorithm that analyzes a voice sample from an individual and obtain numeric data that represents that person's speech. The sample was analyzed in both the time and frequency domains. Then an evaluation was made using Applications Quest$^{TM}$(AQ) [2, 20] for the determination of the clusters that were formed using the numeric data. SQL queries were made of a database that had been created to store the demographic and result data. In addition result data was written to Microsoft Excel spreadsheets for sorting and examination of the data. To utilize these applications, the following were needed to gather and analyze the data from the participant:

- A uniform method for the collection of the demographic information and voice samples from individuals.
- A database containing all demographic information and values calculated.
- An algorithm that calculates data from the sample as it pertains to time.
- An algorithm that uses a FFT and a windowing function to convert a voice sample from the time domain to the frequency domain.
- An algorithm that calculates different parameter values to be used to observe clusters that may occur.

With guidance from these principles, the architecture for the proposed voice system consisted of three phases: data collection, voice sample processing, and database setup. In the data collection phase the user interacted with a web interface that collected demographic information. That was used to determine classification groups which may be formed after the voice sample was ran through the voice processing algorithms. To prevent bias and to protect anonymity, an arbitrary number was randomly assigned to each submission. Upon completion of the demographic survey a voice sample was collected via a phone application where the user called in and left a voice sample to be analyzed. The voice sample was saved as a WAV file with the given identification number as part of the file name. All the participants' data was stored in a table of the database which corresponded to an Excel spread sheet that held a copy of this data. This allowed it to be more efficient when uploading the records into the clustering algorithm for modeling of the results.

# Chapter 4

## Time Domain Experimentation and Results

This chapter details the experimentation that was conducted on the voice samples before they were converted to the frequency domain. This was the first of four experimental phases for this research intended to investigate parameters to utilize the classification of an individual.

It is not uncommon to hear individuals talking at various rates and/or having differing amounts of pause between their words. Given that the voice samples were in the time domain, a numerical value was calculated for these two occurrences.

### 4.1 Experimental Design

#### 4.1.1 Experiment Goals

The goals of this experimental phase were the following:

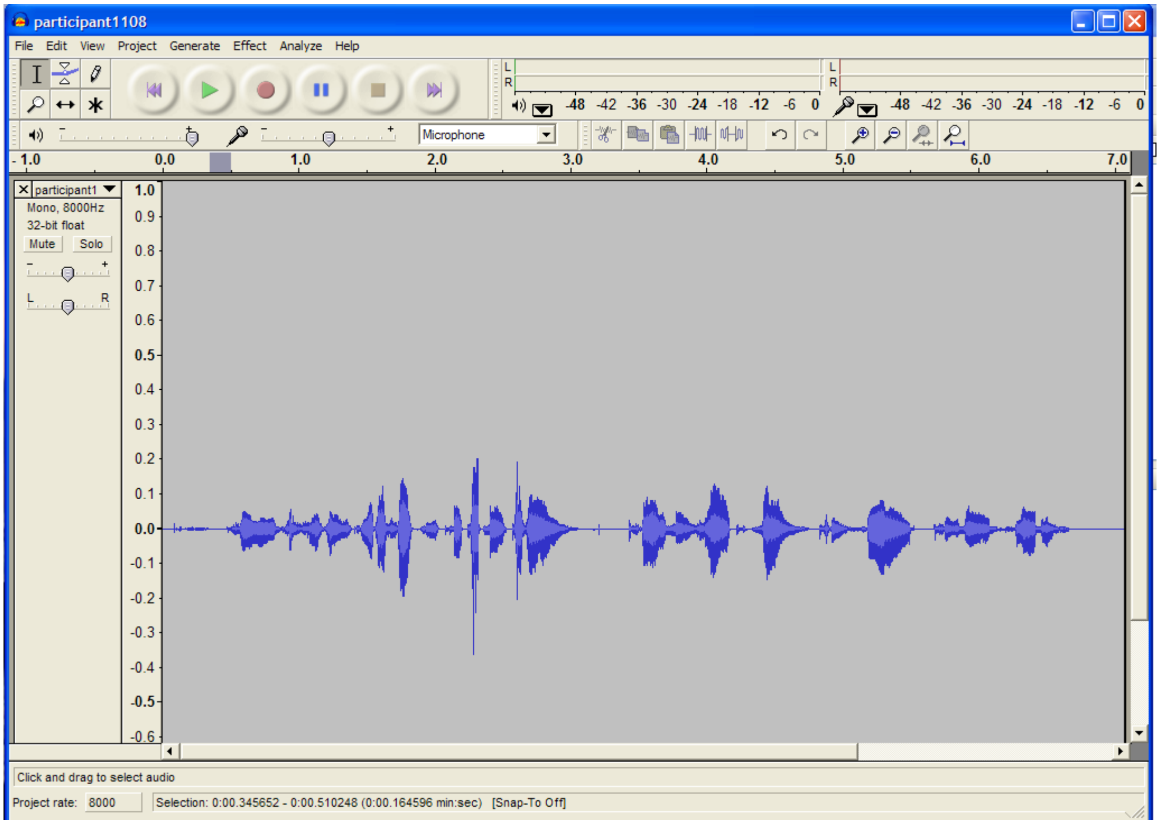
- Create an algorithm to eliminate beginning and ending white noise from the sample.
- Calculate the length of the sample in seconds.
- Create an algorithm to determine where pause areas are in the sample.
- Calculate the total amount of pause in seconds of a sample.

#### 4.1.2 Procedure

The original sample received from each participant was stored at the time of their participation in a WAV file and saved on the same server where the voice application was hosted. All samples were made at a sample rate of 8000 KHz and each participant said the exact same thing "George, I want you to help me fix my tire. Call me at 924-2949.".

The free digital audio editor, Audacity [3], was used initially to view a graph of the voice samples see Figure 4.1. Audacity gave easy access for playing any part of the sample and

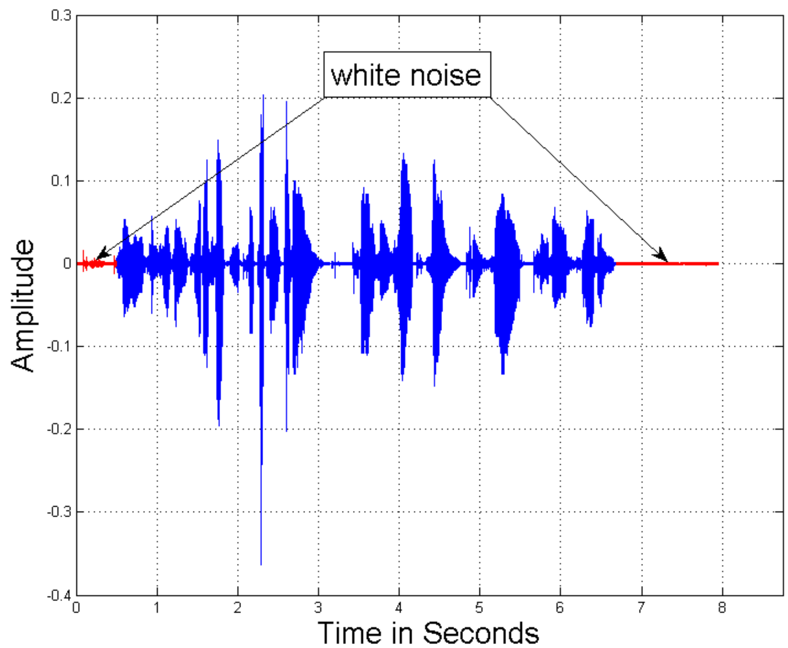
Figure 4.1: Original voice sample opened in digital audio editor, Audacity



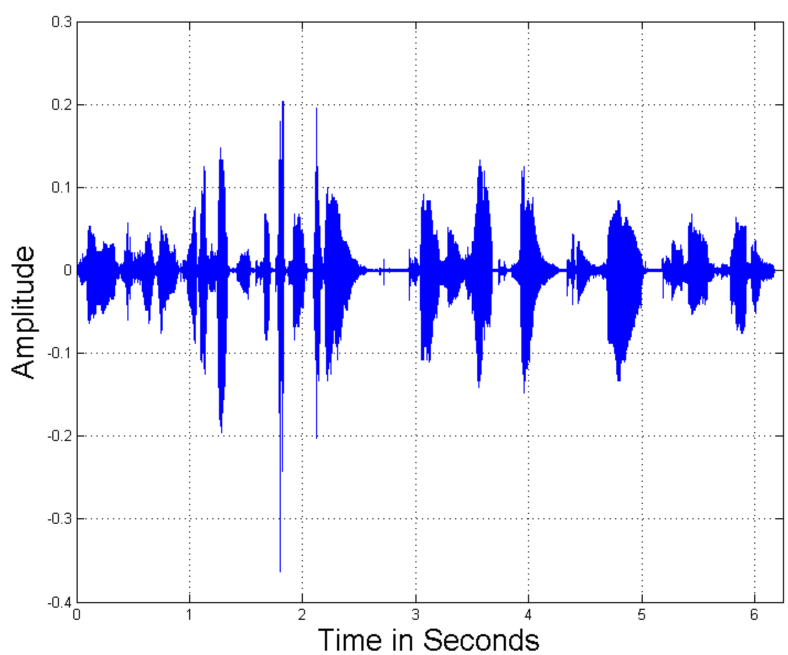

also a quick view of elapsed time. The process that the BeVocal café [47] application records the participant's response, each file has a leading and ending segment that is either silence or nominal white noise, see Figure 4.2a. This proved to be beneficial when developing the algorithm for time domain analysis. A maximum and minimum value for white noise was calculated by using these two sections. With the ability to set these boundaries specific to each sample, an algorithm was developed to crop the beginning and ending noise from each sample see Figure 4.2b. When the data from a WAV file is read into MATLAB it is put into a vector which makes it very efficient to obtain the starting and ending points of the voice sample. Starting at the beginning of the vector the index number is recorded for

Figure 4.2: Example Graph of Voice Sample In Time Domain

(a) Original voice sample in the time domain

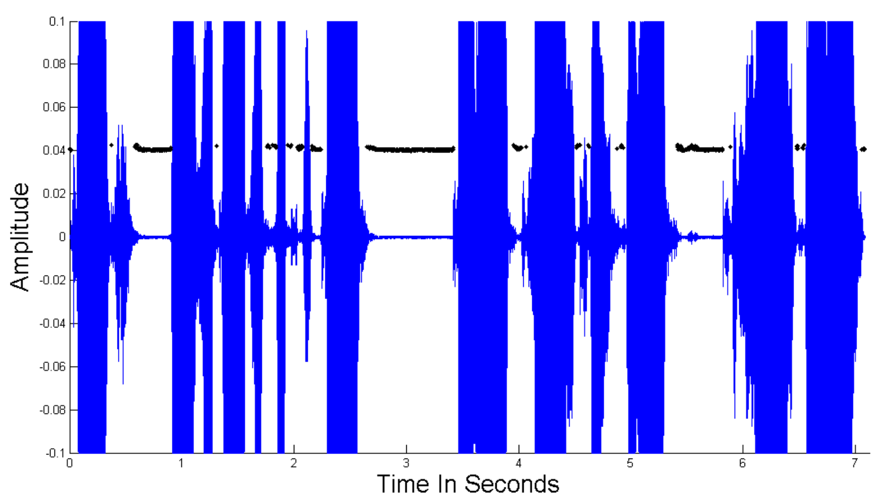



(b) Cropped voice sample in the time domain



the first value that goes above or below the threshold that has been calculated from the white noise. Next, starting at the end of the vector the algorithm begins with the last cell in the vector and decreases the index value by one, until a value that goes above or below the threshold is found and the index number was recorded. Now taking the first index found and the last index found a cropped sample can be obtained by using the "wavwrite" function which takes the vector values and creates a new WAV file. This new WAV file will be the sample left by the participant without the leading and ending white noise. Once the sample had been cropped the first parameter and total message time is calculated. This algorithm also uses the threshold that were calculated during the cropping process using them in an alternative method. The algorithm starts at the beginning of the vector and searches for the first value that falls within the given threshold. The index for this value is then recorded in another vector and the program begins looking for the next value that is above the threshold. This process continues until it has worked its way through the entire vector. The total number of data values found is divided by 8000 (number of bytes per second) giving the total time of pause or no talk in the sample; see Figure 4.3. Deciding

Figure 4.3: Voice sample showing where the calculated pause of sample is located at.




to consider this calculation came about when two cropped samples were observed that had precisely the same talk time. However when the files were viewed in Audacity it revealed that one file had considerably more pause spaces than the other. This can be attributed to the fact that some people may talk at the same speed with one always making sound (i.e. saying something like "uhuhuh" between words and the other not making any sound but yet still having the same amount of time between words, see the graphs in Figures 4.4 and 4.5). All cropped voice samples where run through an algorithm that calculated the three time values, total lapse time of original voice sample (no cropping), total time lapse for the cropped voice sample, and the total time lapse pertaining to pause in the cropped sample. After these calculations were made the values were then written to a text file in the form of MySQL update statements so they can be added to the database. In addition the values were also stored in a Excel spreadsheet that contained all demographic data, along with all calculations that were made for each voice sample. This file was then used to load all pertinent data into Applications Quest$^{TM}$for clustering evaluation.

Figure 4.4: A sample with speaking time of approximately 7 seconds and pause time of 0.44 seconds

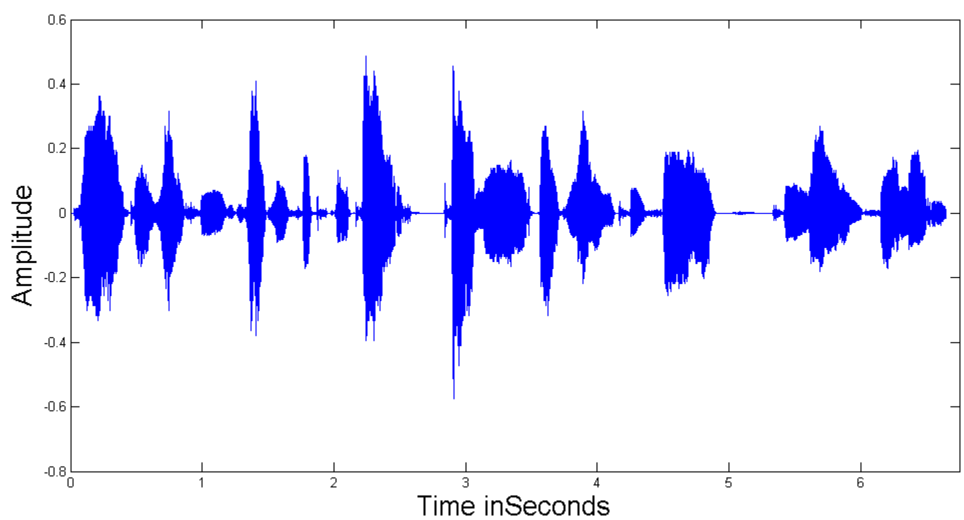
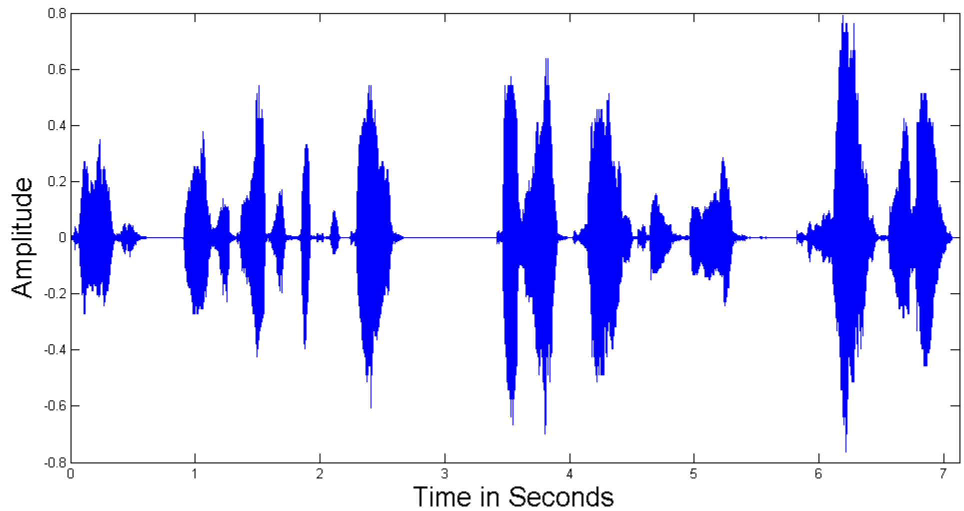


Figure 4.5: A sample with speaking time of approximately 7 seconds and pause time of 1.78 seconds




## 4.2 Results

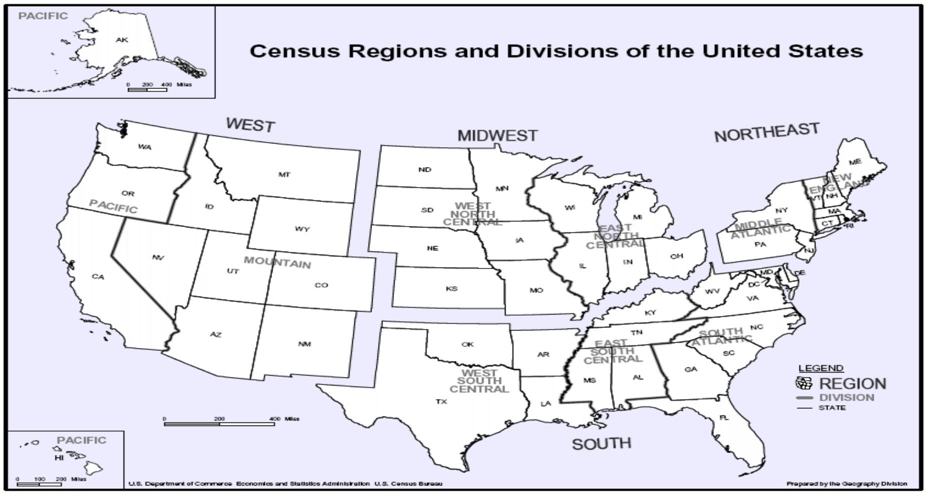
The initial analysis was conducted to see if the time information made any classification as a standalone parameter. The results of this preliminary analysis proved to be very informative when analyzed. The data was sorted, using Excel, by pause time and total talk time of the cropped files and the average for male and female was calculated, see Table 4.1. It was observed that the average time to say the phrase was the same for both male and

Table 4.1: Comparison of total time to say message (cropped sample) and the amount of pause in the sample with the percentage of pause in the sample as it pertains to Gender

| Gender | Number of Samples | Avg Talking Time | Avg Amount Pause | Average Percent Pause |
|---|---|---|---|---|
| **Female** | 93 | 6.28 | 1.64 | 25.7% |
| **Male** | 65 | 6.28 | 1.81 | 28.4% |

female. Comparing the pause time seen in Table 4.1, it shows that males do have a greater percentage of pauses in their speech than females. In addition to gender, the area where the person was from was also examined. To accomplish this the states were separated into regions according to the U.S. census [63]. They are West, Midwest, Northeast, and the South see the map in Figure 4.6. The sample set of participants contained individuals from

Figure 4.6: U.S. Census Regions




all the regions, with the largest group from the South. In Table 4.2 there is a complete list of the states that the participants were from. Table 4.3 shows the same result fields with the focus on the regions. The results are noteworthy in that there is a difference in the total talk time as well as the pause time. As with gender, analysis of the time data in general showed

Table 4.2: Regions in the United States and states represented from these regions

| **West** | **Midwest** | **Northeast** | **South** |
|---|---|---|---|
| California | Illinois | Connecticut | Alabama |
| Colorado | Indiana | Dist. of Columbia | Florida |
| Idaho | Iowa | Maryland | Georgia |
| Montana | Michigan | Massachusetts | Kentucky |
| Oregon | Minnesota | New York | Louisiana |
| Washington | Missouri | Pennsylvania | Mississippi |
| | Nebraska | | North Carolina |
| | Ohio | | Oklahoma |
| | South Dakota | | South Carolina |
| | Wisconsin | | Tennessee |
| | | | Texas |
| | | | Virginia |

Table 4.3: Regions in the United States and states represented from these regions

| Region | Number of Samples | Avg Talking Time | Avg Amount Pause | Average Percent Pause |
|---|---|---|---|---|
| **West** | 13 | 6.48 | 1.99 | 30.7% |
| **Midwest** | 30 | 6.33 | 1.72 | 27.2% |
| **Northeast** | 7 | 6.59 | 1.64 | 24.9% |
| **South** | 103 | 6.22 | 1.68 | 27.0% |

some interesting results such as, which region had the larger average for total time of talking or which region had the highest amount of pause. Still there was not enough of a difference to make any definite classifications at this time.

The data was entered into Applications Quest™and 6 clusters were made. The overall Difference Index (DI) was 29.34%, where this value states as a whole how much similar or dissimilarthe samples are. Therefore the lower DI value indicates the greater similarity of the samples. The recommended DI value for this inquiry was 24.47% giving a target value for the clusters. All the cluster's DI value were below this mark giving validity to the results in that the members of the clusters were close in characteristics. For analysis, gender was the only attribute that was closely distributed within a reasonable ratio, so the focus was put on this attribute when the clusters were evaluated. Clusters 0, 2, had only women participants and 3 had all women participants except one male, where as clusters 1, 4, and 5 only had men, with the following results observed and compared to the total averages shown in Table 4.1.

- Cluster 0 had 15 females, all from small towns and DI at 14.79% which indicates very little difference between the participants. The talk time was 5% above the total average and the pause time was 9.75% above the total average, for all females. Indicating that this group talks slower then the average female in the study.

- Cluster 2 had 65 females, mainly from the suburb/urban area with the DI at 20.81% which indicates a small difference between the participants. For this group the talk time was 3.6% under the average and the pause time was 7.2% under the average, for all females. Indicating that this group talks faster then the average female in the study.

- Cluster 3 had 13 females, all from the suburb area with the DI at 20.42% which indicates a small difference between the participants. For this group the talk time was 13.2% above the average and the pause time was 32.9% under the average, for all females. Indicating that this group talks slower and with considerable more pause then the average female in the study.

- Cluster 1 had 26 males, with no dominant area with the DI at 23.25% which indicates a nominal difference between the participants. For this group the talk time was at the average and the pause time at the average, for all males. Indicating that this group is a good representation of the average male in the study.

- Cluster 4 had 16 males, with all but 1 from a suburban area with the DI at 17.14% which indicates a small difference between the participants. For this group the talk time was 7% under the average and the pause time at the average, for all males. Indicating that this group does talk faster than the average male in the study.

- Cluster 5 had 23 males, with all from a small town with the DI at 16.04% which indicates a small difference between the participants. For this group the talk time was at the average and but the pause time was 8.3% below the average, for all males. Indicating that this group talks at the average speed but with less pause compared to the average male in the study.

### 4.3 Conclusion

This phase of the study yielded good results in that it indicated that the amount of time for an individual to speak a phrase can possibly give an indication of the area they live in and possibly the state where they lived the most. The results did seem to give a clear separation between male and female. When gender is added to the area that they live in this may give characterizing factors for the individual. The findings from the clustering were interesting and worth noting, but with this not being the primary area of investigation all data was recorded and saved to be used in future work.

## Chapter 5

## Frequency Domain Experimentation and Results: Initial Phase

Even though humans do consider the speed and pause of another's voice it is the frequency domain that can give the greatest amount of data for analysis. This chapter details the experimentation that was conducted on the voice samples that were converted to the frequency domain. This was the second of four experimental phases for this research intended to investigate parameters to classify an individual. Once the voice sample had been converted from the time domain to the frequency domain, analysis was done to find results to support the hypothesis of this research.

### 5.1 Experimental Design

#### 5.1.1 Experiment Goals

The goals of this experimental phase were the following:

- Create an algorithm to convert the sample from the time domain to the frequency domain.
- Determine all peaks for the frequency sample between the boundaries 250 - 1250 Hz.
- Determine the most prominent peaks of the sample.
- Calculate and average the slope between the prominent peaks.
- Calculate and average the distance between the prominent peaks.
- Determine the maximum and minimum frequency values for the prominent peaks.
- Determine the total distance between the first and last prominent peak.
- Determine the total number of prominent peaks.

### 5.1.2 Procedure 1 (Converting Data)

Originally the voice sample was saved as it pertains to time domain; for any analysis of the frequency sample the signal must be converted from the time domain to the frequency domain. As mentioned in Section 2.5 the Fast Fourier Transform (FFT) is the most common formula used to accomplish the change from one domain to the other. The MATLAB programming environment has a very efficient FFT function “fft”. This function will receive the time data and process it into frequency data. Since it is not guaranteed that the data sample begins at the start of a cycle, spectral leakage can take place (as explained in Section 2.6) and a windowing function must be applied first before the data is sent to the “fft” function. The Hanning window function shown below:

$$w(n) = .5\left(1 - cos\left(\frac{2\pi n}{N-1}\right)\right)$$

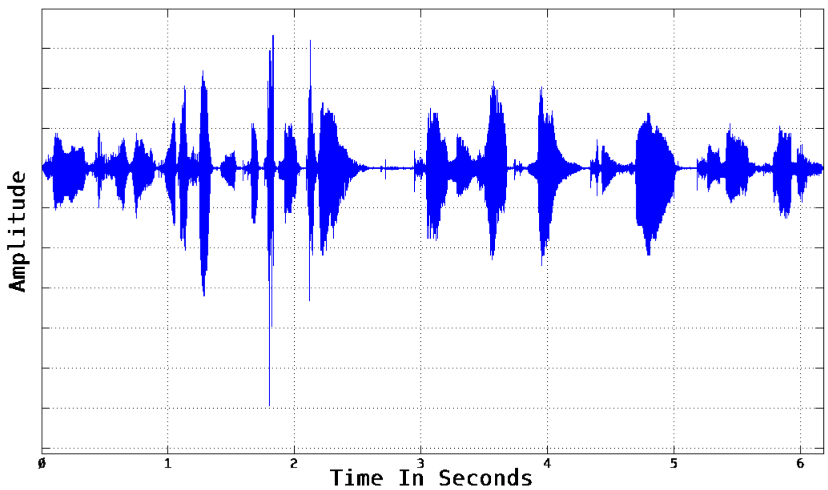
was used because it is a straight forward function and is simple enough that it does not add computational complexity to the algorithm. Once the windowing function was applied the data values were sent to the “fft” function. Each voice sample in this study ranged from 4.5 seconds to 8 seconds of speech which when read into MATLAB using the “wavread” function numbered in the tens of thousands of “time” data points. After sending this time data to the “fft” function, 2048 data values were returned as it is a representation of the frequency for that sample. The graphs in Figure 5.1 show the difference of data representation of the two domains. The frequency analysis was executed only on data from 250 to 1250 Hz as this is the range that will have the most information for the way a person speaks according to an expert in the signal processing industry, Dan Ginzel owner and lead developer of signal/voice applications for Coach Comm [21].

### 5.1.3 Procedure 2 (Locate Primary Peaks)

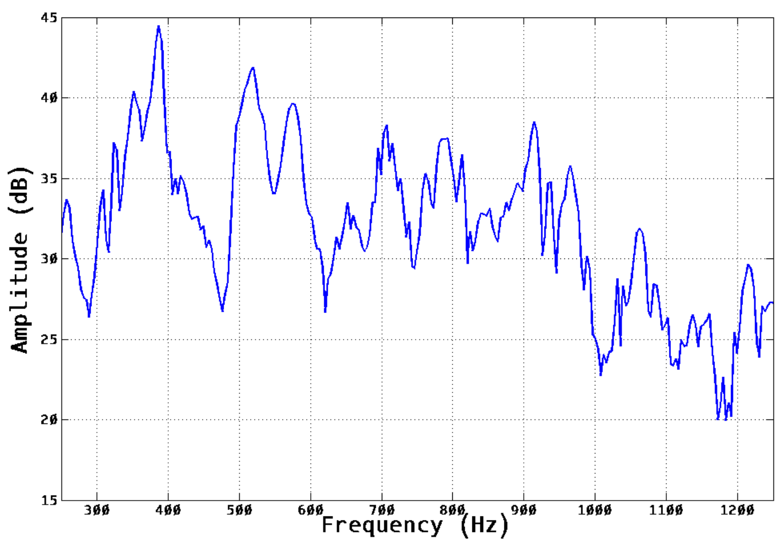
The next task was to take the frequency data from the full sample and crop it to the set boundaries (250-1250 Hz)to get a visual representation of a person’s voice sample. In Figure 5.2 it shows the full view of the frequency graph where as Figure 5.3 shows the

Figure 5.1: Graphs of Cropped Voice Sample Saying Full Message

(a) Sample in the TIME domain




(b) Sample in the FREQUENCY domain (250 - 1250 Hz)



sample after the boundaries were set. To begin with, both the peaks and the valleys were considered but after closer analysis the peak information was determined to be adequate. Initially the algorithm found all the peaks for the entire frequency graph. As illustrated in Figure 5.4 the large amount of peaks made it hard to get a clear view of the peaks in relationship to the graph. The graph was then modified to be within the boundaries (250-1250 Hz) which made it much easier to see where the peaks were located; see Figure 5.5 for an example. At this time the complete message was used and with the sample limited within the boundaries stated, it was clear that analysis can continue forward concerning the tone of the sample.

Figure 5.2: Full frequency graph showing the boundaries for the area that will give the most information for a voice sample.

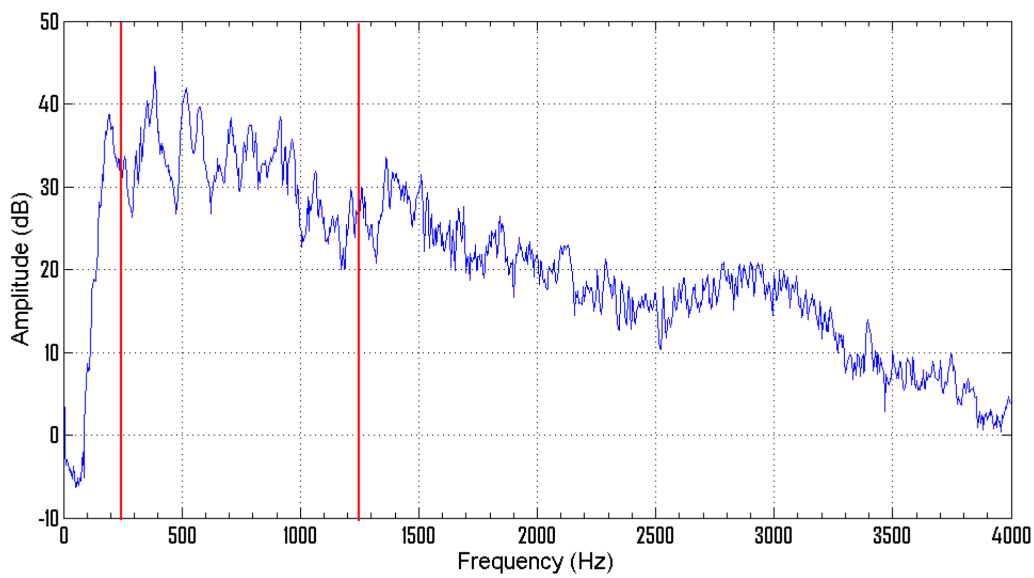


Figure 5.3: Selected frequency sample (250 - 1250 Hz) graph of the bounded area in the graph above.

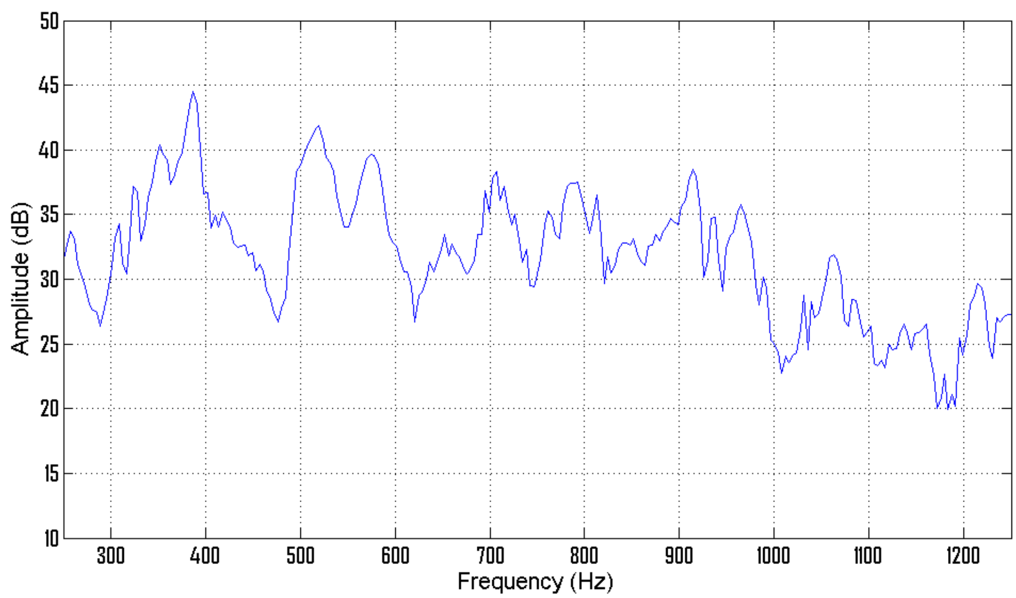



Figure 5.4: Graph showing a view of peak locations of a full frequency sample

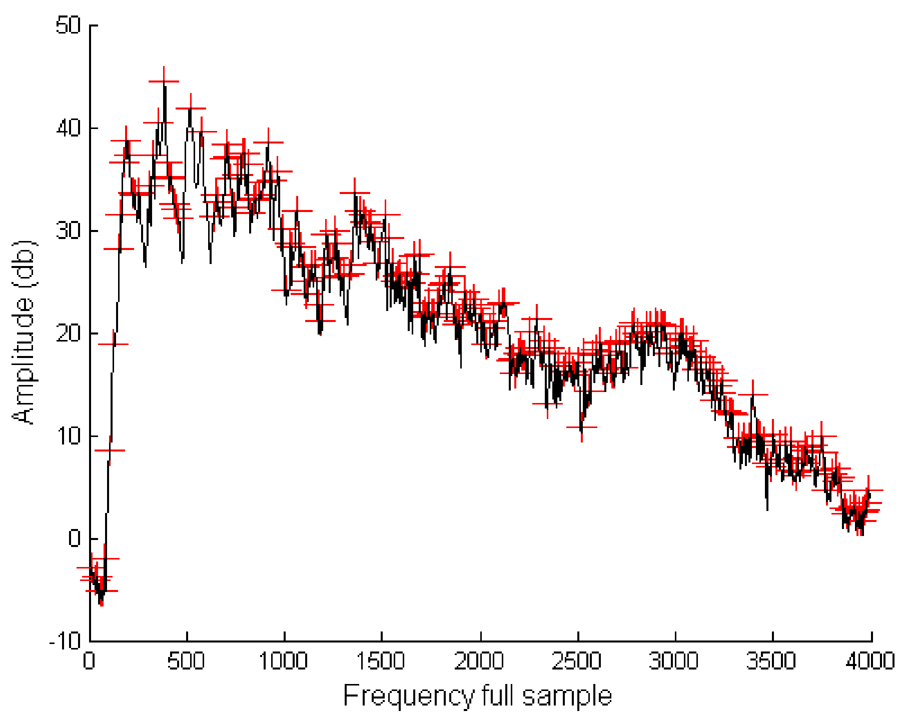
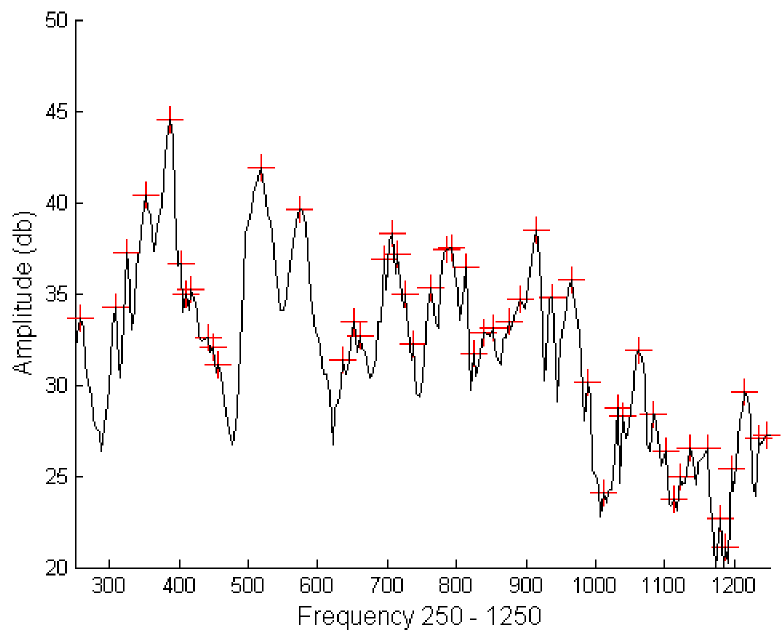
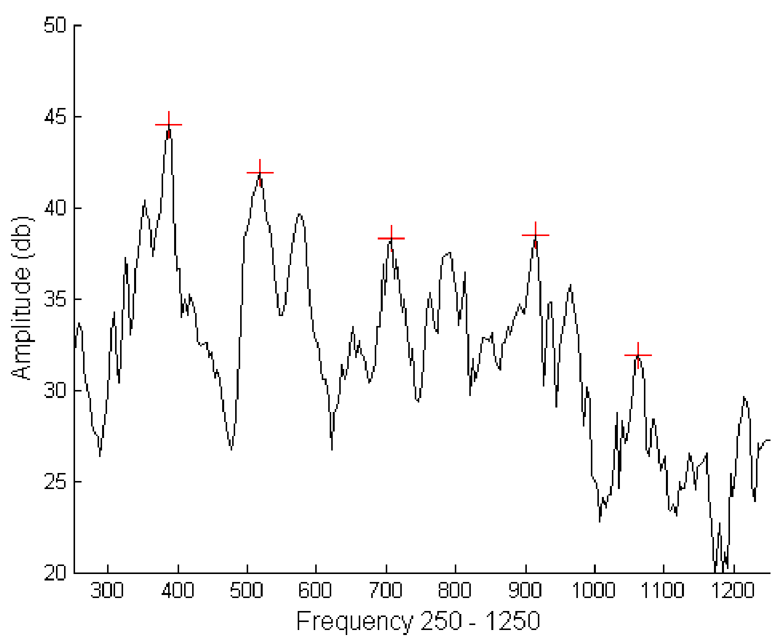


Figure 5.5: Graphs showing different views of peak locations of sample within the frequency boundaries (250 - 1250 Hz)

(a) Shortened Frequency Sample Showing All Peaks




(b) Shortened Frequency Sample Showing Primary Peaks

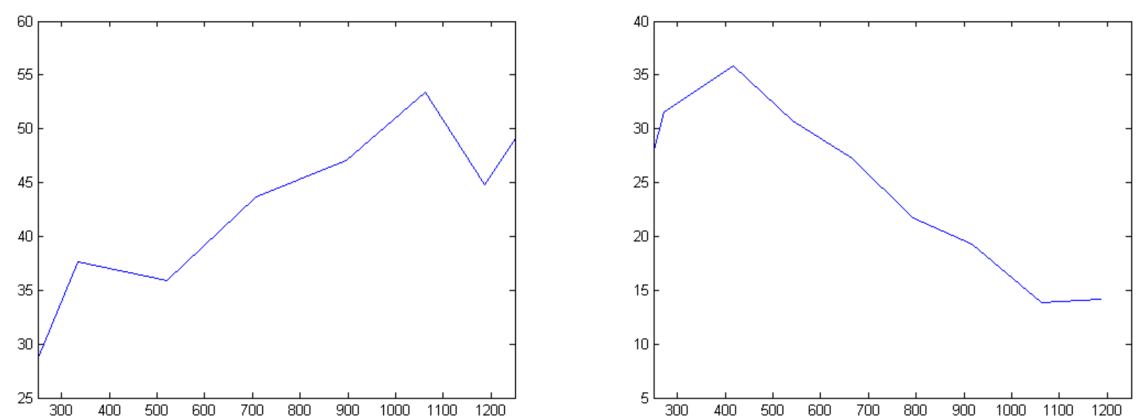


### 5.1.4 Procedure 3 (Calculate Averages)

The initial thought behind calculating the goal values listed was that by seeing this data on the dominant peaks illuminates information about the tone of the sample. If the peaks were more spaced out it indicates a more consistent tone for the sample. If the slope average was positive, then going from left to right the peaks progress up in height, see Figure 5.6a. Likewise if the slope average was negative going from left to right the peaks diminish in the height value, see Figure 5.6b. Giving each of these individuals a totally different sounding voice, where one is lower sounding(decreasing peaks) and the other is a higher sounding (increasing peaks) voice as it pertains to pitch. Another fact that can be ascertained from the slope average is an idea of the closeness of the peaks. The closer the peaks are to each other causes the slope average to advance towards positive or negative infinity. Whereas, if the slope was approaching 0 this indicates that the peaks were farther away from each other. The last three goals, were accomplished, but when analyzed, did

Figure 5.6: Graphs showing one that has a positive slope average and one with a negative slope average

(a) Peaks heights increasing (b) Peaks heights decreasing




not offer any revealing information towards one classification or another. The data was stored for possible further analysis of other variables at a later date. The data tables (30 pages) containing all the averages and number of peaks for the aforementioned goals can be found in the Appendix.

### 5.2 Results

The average slope and average distance between the peaks showed the most promise for determining a classification for a person. It was the results obtained for these two averages that this phase focused on. The results for the average slope were considered first. For visualization, the slope values were put into tables showing the ranges for the positive average slope values and ranges for the negative average slope values according to the demographic data. In the first table gender was considered and it revealed that there was no real difference between the male and female when it came to the negative slope ranges, when graphed the two lines were the

Table 5.1: The average slope between peaks with the focal point on Gender

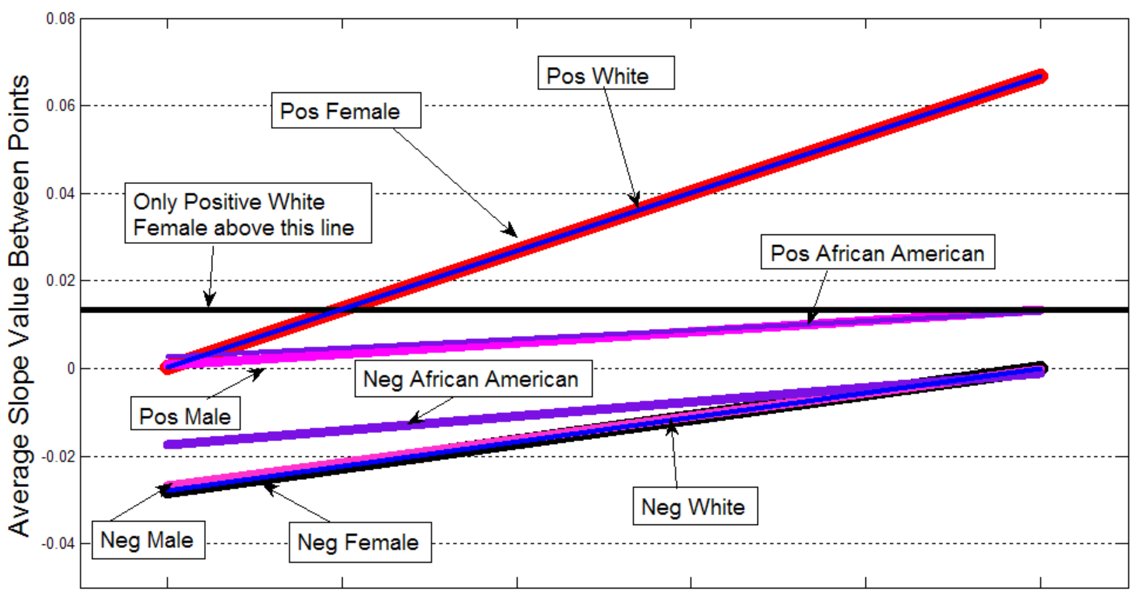
| **Gender** | | | |
|---|---|---|---|
| Negative Boundaries | | | |
| Female | -0.027925 | to | -0.000141 |
| Male | -0.026729 | to | -0.000343 |
| Positive Boundaries | | | |
| Female | 0.000187 | to | 0.066688 |
| Male | 0.000795 | to | 0.013462 |

Table 5.2: The average slope between peaks with the focal point on Ethnicity

| **Ethnicity** | | | |
|---|---|---|---|
| Negative Boundaries | | | |
| African American | -0.017488 | to | -0.000981 |
| White | -0.027925 | to | -0.000141 |
| Positive Boundaries | | | |
| African American | 0.002743 | to | 0.012799 |
| White | 0.000187 | to | 0.066688 |

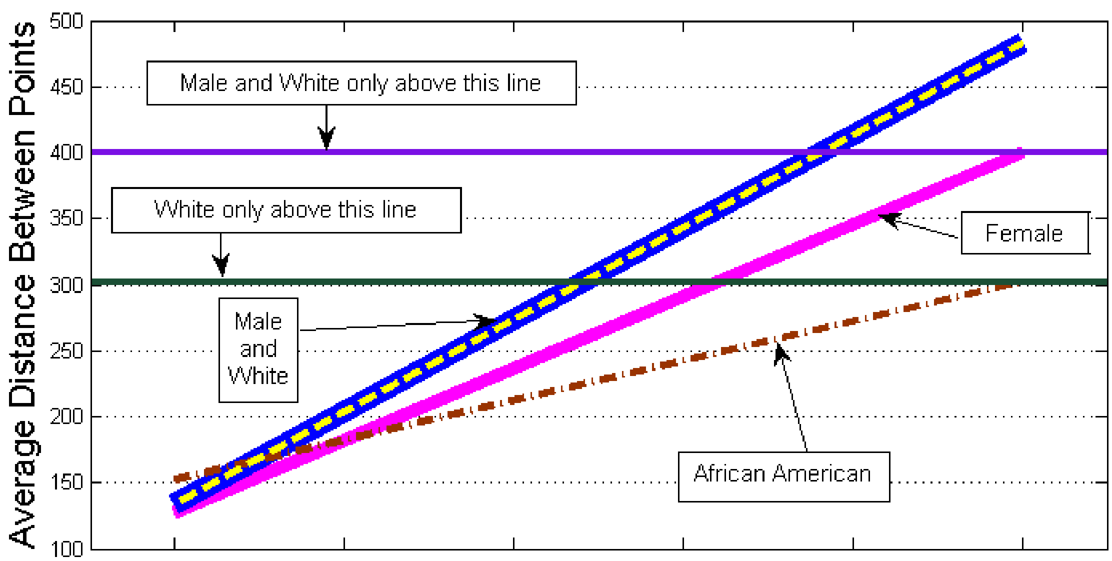
same. However when looking at the table for the positive slope ranges the data visualization indicated a very noticeable difference between the two ranges, see Table 5.1. The next table shows the results for ranges as it pertains to ethnicity, see Table 5.2, where the two most prominent groups are "White" participants and "African American" participants. In comparing data in both tables it was interesting to note that the positive slope range for females was indistinguishable to that of white participants. Therefore a graph was constructed, see graph 5.7, with data for females, males, white and African American participants. In viewing this graph it is apparent that at a distinct positive slope value greater than 0.013462 there is a very high probability that the participant is a female, white or both. Dur-

Figure 5.7: Graph showing the ranges for the positive and negative average slope of lines between peaks




ing this preliminary analysis, data was also considered according to the distance between the peaks. Even though the average slope gave equivalent information, closer analysis was warranted given that the actual distances between peaks aids in the analysis of the tone of a participant's voice. Higher averages indicated a greater distance between each peak. Whereas a smaller average indicates that the peaks were not separated very much. This was investigated for the prospect that it better indicate a characteristic about the participant then the slope average. For this observation, four groups were considered (male, female, White, African American) as some natural breaks were observed when these ranges were graphed. For this data there were two natural separations, one at the average distance value of 301.8281 and one at value 399.7623. When the graph is viewed it is inductive that the probability is high that a person with a value above 301.8281 is either a white female or a white male. This is due to the fact that all African American averages were below this value. When the value gets over 399.7623 the probability of being a female drops out and the probability that the person is a white male is prominent, see Graph 5.8. Along

Figure 5.8: Graph showing the ranges for the average distance between the primary peaks




with storing the calculations in the database, a tab delimited text file was created that had these calculations and the demographic information associated with it. This file was then uploaded to Applications Quest$^{TM}$(AQ) to find clusters in the data [2, 20]. Clustering was done as it pertains to gender, ethnicity and slope average which when the clusters were investigated verified the previous tables. However it reveled that the maximum value was more of an outlier then a representation of the group as a whole. It was the distance average that gave the most validation in that the 11 individuals that had an average above 301.8281 were indeed white female and even more so were members of the same cluster.

# Chapter 6

## Frequency Domain Experimentation and Results: Graphical Phase

All analysis specified to this point was very promising, but did not give a clear separation in any of the demographic areas. At this time a program was written that allowed the viewing of all the graphs of the voice samples as they related to the frequency domain to obtain direction for the next phase in the analysis process. A different digital audio editor, Cool Edit Pro (now Adobe Audition) [12, 13] was used to visualize the frequency graphs. When graphed using Cool Edit the graph changes as the application progresses through the sample. It was then observed that the prominent peaks changed location depending on the section of the sample the application was analyzing. By using the loop function this progression was viewed over and over again. The Cool Edit application showed that inflection was feasible to determine the movement of the peaks that were displayed on the screen. From the examination of the graphs and the visual that Cool Edit presented, it was observed that the first half and the second half of a sample were different.

### 6.1 Experimental Design

It was decided to split the each sample into two parts and do some analysis on both halves to determine if they were similar or dissimilar enough to give some indication of a certain demographic characteristic. The inclination of this analysis was that a parameter is obtained that is connected to voice inflection.

#### 6.1.1 Experiment Goals

The goals of this experimental phase were the following:

- Separate the entire sample into two halves.

- Isolate a single word.
- Separate the word into two halves.
- Get graphical representation for visual analysis.

### 6.1.2 Procedure

Once this decision was made it was straight forward to implement by using the previously mentioned ability of the MATLAB application to store all data in arrays. With all the data points stored as single elements in an array one need only use the command “numel” (number of elements) and then split the array into two separate arrays. Five participant samples were selected for testing to determine whether the smaller samples can be processed using the algorithms that were all ready written or if modifications were needed. At first it appeared to work as well as using the full sample, therefore all samples were processed. As before the results were written to an Excel file and upon observation not all participant half files were processed correctly. It was found that by splitting the sample in two parts there was not sufficient data when a certain calculation was done. A set parameter of 2048 needed to be set to 1024 for the following calculation to work properly. Following this correction the data from the two separate halves were graphed and observations were made to see what useful information was obtained. The graphs of the two halves were plotted in the same window and each sample was viewed using a simple MATLAB script program that allowed straightforward progression through the graphs. To view an instance of this graphical comparison of the two halves of a sample, see Figure 6.1. Though some graphs did illustrate that a useful difference between the two halves was observable, less than 20% of the samples displayed this characteristic. It became clear that using the full sample was going to furnish too much information to obtain a consistent and realistic numeric representation of the voice. The next logical step was to separate a single word from the sample. Because of the work completed earlier, where the pause in the participant sample was determined along with the cropping of the white noise from the beginning and end of the sample, it was possible to isolate words in the sample. The initial preference was to get the first word in the phrase spoken, that being the word “George”. Once this word was isolated, analysis was done with the word separated into two halves. As with the samples that contained the entire phrase, there were several that showed some good interpretation of the voice, but were not robust throughout the entire sample set. After some consultation with Dan Ginzel [21] two situations for this outcome were considered. The first rationale was that in saying the word “George” being the initial word in the phrase the person may take a deep breath before speaking. Some of this white noise may not be eliminated during the cropping process having an influence on the first half of the sample. The second possible explanation for result from analysis, is that some words have what is commonly called “attack” or “variable stress”. Attack is the unambiguous beginning of speaking a word [10] and variable stress is the speaking of a syllable in a word louder and longer [54]. Just as taking that deep breath can create white noise; these two speech methods have the potential to add noise to a word. The situation that arises with these two speech areas is that not everyone may have this mannerism and thus proves to adversely affect the analysis between the two halves of the given sample as it relates to the general population. Displayed in Figure 6.2 is an example of the effect of variable stress. The graph of the first half starts out with an elevated value and then declines continually from there. Where the graph of the second half shows a more osculating sound and the peaks of the two when compared do not give a usable pattern.

Given the aforementioned issues, a close assessment of each word in the spoken phrase was made. It was determined that the word “nine” is the best choice as it did not appear to have the possible pitfalls that the word “George” had and this word was used three separate times. The word nine is to be found in the following locations in the phrase: seventh to the last word (start of saying telephone number), third to the last word, and the last word in the spoken response. The last word was not used as it can have similar issues of acquiring white noise. The second instance of the word was the most logical choice as it was spoken in the flow of speaking other numbers. The location of this word for some samples did present

Figure 6.1: Comparison of participant sample split in two halves

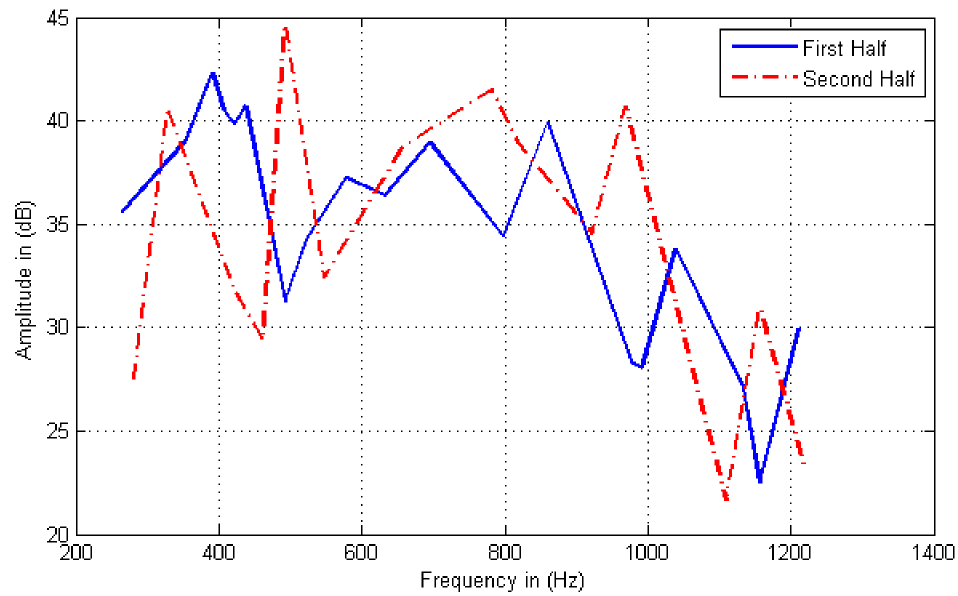
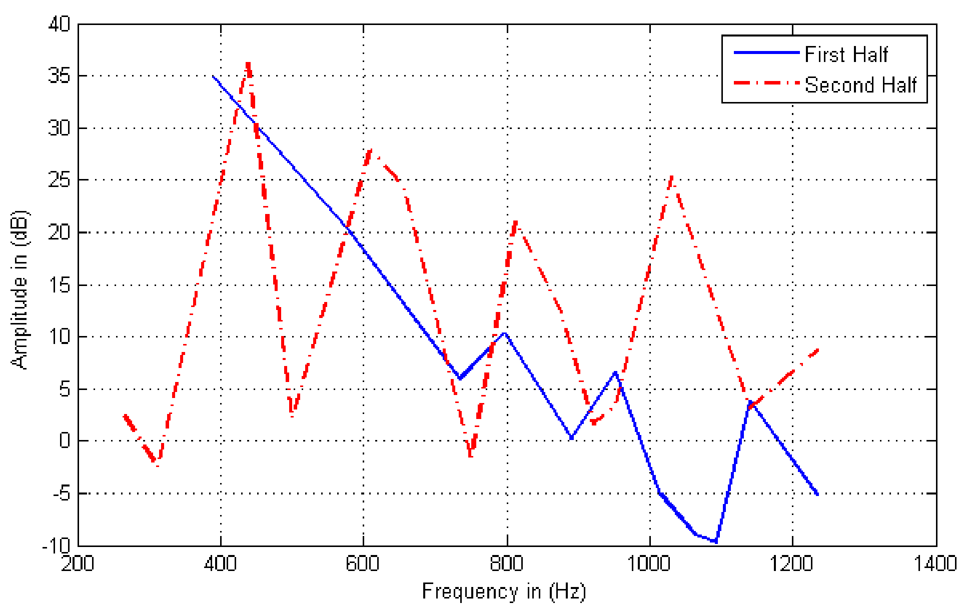



Figure 6.2: Comparison of participant saying the word “George” split in two halves

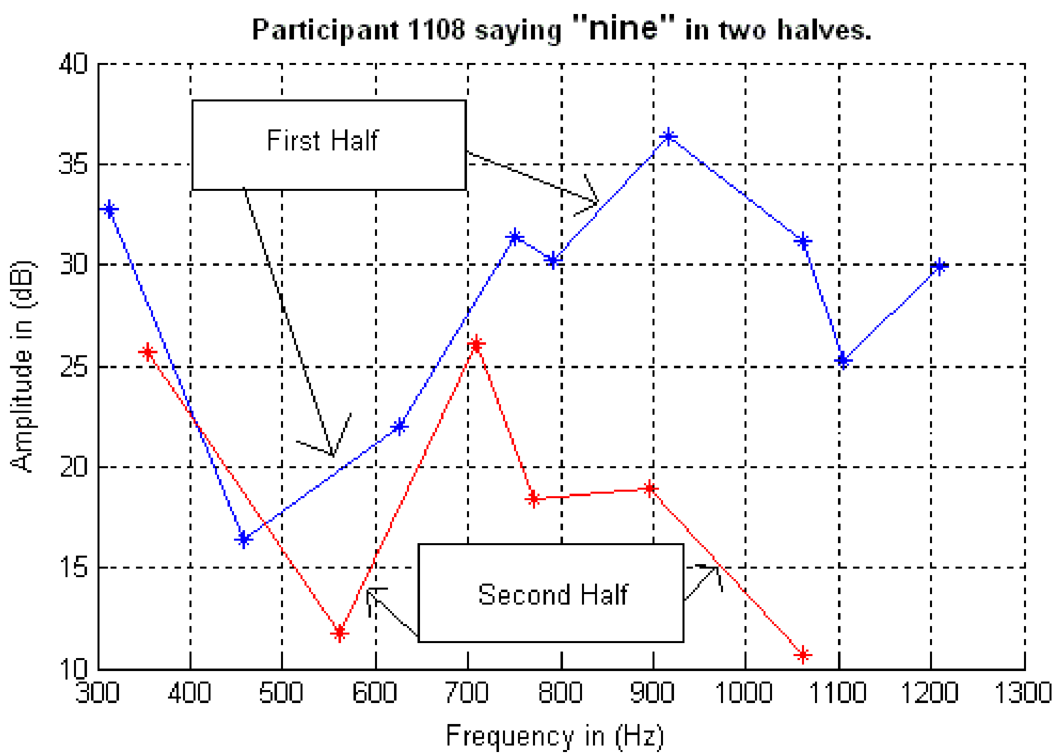


more of a challenge to separate from the phrase as some participants do not have a clear pause in their speech. With the focus of this research not to create an application to retrieve words from a spoken phrase, the second instance of the word nine was manually extracted using the audio application Audacity mentioned previously. As a result of collecting the sample in this manner, it gave assurance that the new samples were an accurate sample of the participant saying the word "nine". Audacity gives the user the ability to see a visual of the WAV file as well as to listen to the section that was selected. All selected instances of the file were listened to and then saved as separate WAV files for analysis. These new samples were then processed into MATLAB and separated into halves as previous samples. Each half was then graphed to determine the new results acquired from the word using the word "George". It can be seen that there is a more usable set of data that comes from these samples, see Figure 6.3, in that there is a higher amount of consistency in the samples. The peaks have a more uniform appearance between them and the amplitude is as one expects. This being that the first part of the word is spoken with more volume then the second half, but not a recognizable amount when listened to.

### 6.2 Results

For this phase all goals were accomplished and extended into involving more than one word for analysis. The results from this phase gave clarity and direction in that by splitting the entire phrase it showed that there were to many frequency changes for good analysis. This lead to choosing a single word which was the word "George". Resulting from graphically analyzing the two halves of this word the issue of variable stress became evident. Another word that was not effected by the variable stress, i.e. the word nine, was then chosen. The graphs for this word showed that nine did give good patterns to analyze. This gave the prominent result from this phase to be; finding and using a word that did not have variable stress. This started the research into the final phase of experimentation.

Figure 6.3: Graphs showing the two halves of the word "Nine"

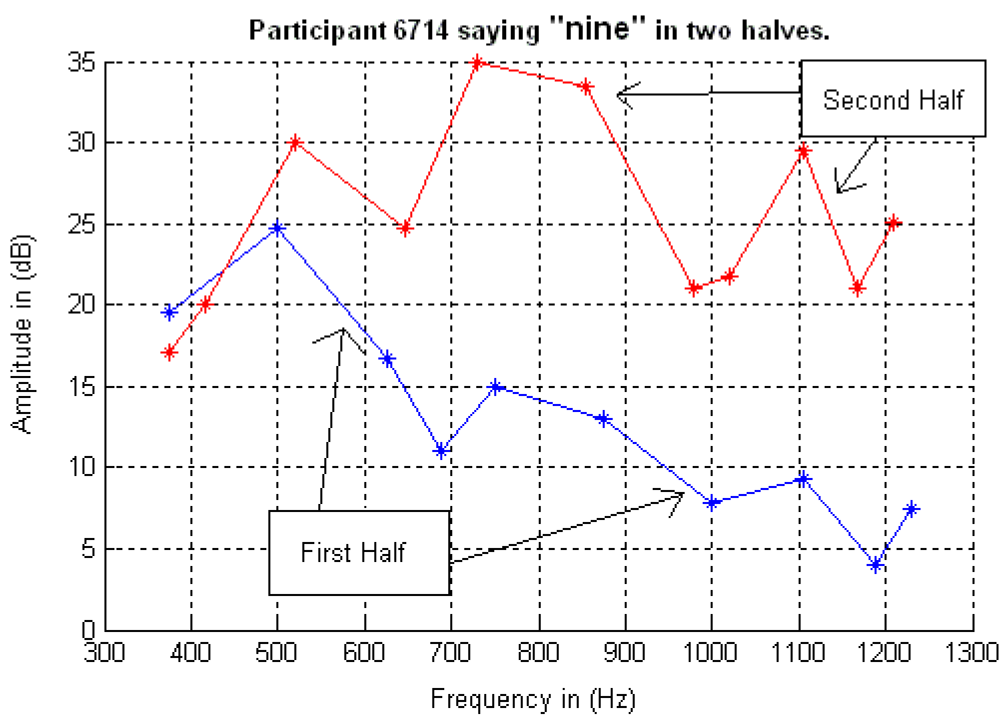


Chapter 7

# Frequency Domain Results: Final Phase

The evolution of this research has been very intriguing, as it relates to the qualifying of the two hypothesizes being pursued. At the completion of analyzing the samples of the participants saying the word "nine" it is the opinion of this research that some important discoveries have been made. One of the most successful is the uniformity that was ascertained by comparing the first and second halves of this word. Graphically it was illustrated that the peak patterns were relatively consistent in their progression, see Figure 7.1 for an example. One can see that even though the value of the amplitude is different the pattern

Figure 7.1: Graphs showing the two halves of the word "nine" and the consistent progression of the two samples



that the peaks make is predominantly analogous. Results such as this were the stimulus for the final phase of experimentation. The final phase commenced by asking the question, "If dividing the word into two equal components displayed a pattern, what would splitting it into multiple samples reveal?".

## 7.1 Experimental Design

### 7.1.1 Experiment Goals

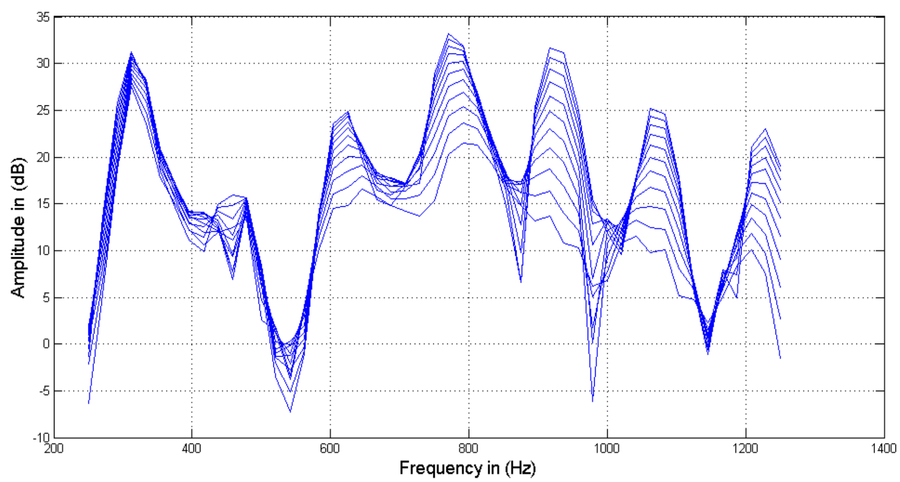
The goals of this experimental phase were the following:

- Create an algorithm that will divide the sample of the word nine into multiple files.
- Determine the most prominent peaks for all sub-samples.
- Store all peak location for prominent peaks for all sub-samples.
- Calculate the number of peaks for each sub-sample.
- Complete graphical analysis of peak location.
- Determine mathematical representation for peak activity.

### 7.1.2 Procedure

At this time a program was written that separates the data values that had been read into MATLAB into multiple WAV files that had 800 bytes each of the original file. A previous observation was recalled when using the audio application "CoolEditPro" [13]. One of the functions of Cool Edit is that it can give analysis in a visual form by illustrating the sample graphically, were the image will change as the application plays the audio sample. Cool Edit also has the function to play a continuous loop of the audio sample which is depicted on the analysis screen as an animated graph. What this confirmed is that as the sample is played the peaks will change position slightly, but because of the overlapping of data there is not a major divergence of location as it ascertains to the peaks. The challenge was to be able to represent what was obvious visually, can be analyzed with tangible results. Therefore the final phase consisted of taking the sample of the word “nine” and taking 800 bytes of data in small increments. Using MATLAB all data was stored into an array with a simple script program that looped through the array. At the start of each iteration of this loop, the program advanced by 26 bytes and created another 800 byte file. In Figure 7.2 graphs of the first eleven files are illustrated, showing the slight change in position mentioned before. It is this shifting that this research proposes will give a clear picture of the fluctuation of a person’s voice numerically and will thus give parameters that will

Figure 7.2: Multiple graphs showing the change of the frequency and amplitude for the word “nine” spoken by a single participant.




facilitate that person to be classified. In viewing Figure 7.2 the main peaks change position as it pertains to frequency i.e. the location of the second peak changed. The phrase “location” will for this section stand for the relationship of the frequency value and the peak order number for a given sample. Location will give insight into what is transpiring with the number of peaks for the files. If it is determined that the peak count increased or decreased, the location value will indicate at where a new peak was formed or a previous peak no longer occurs. The added details this gives is much more informative than when only the number of peaks were known at the initial phase of this analysis. To visualize this data, the first four files were graphed and viewed upon which it was clear as to what had transpired. When the number of peaks increased a minor peak emerged. Likewise if the peak count went down then a minor peak had been eliminated. The two graphs in Figures 7.3 and 7.4 illustrates this by going from one cross-section to the next where a new minor peak is formed and at the

Figure 7.3: View of peak location of the file 1 from the breakdown of the file where the participant said the word “nine”.

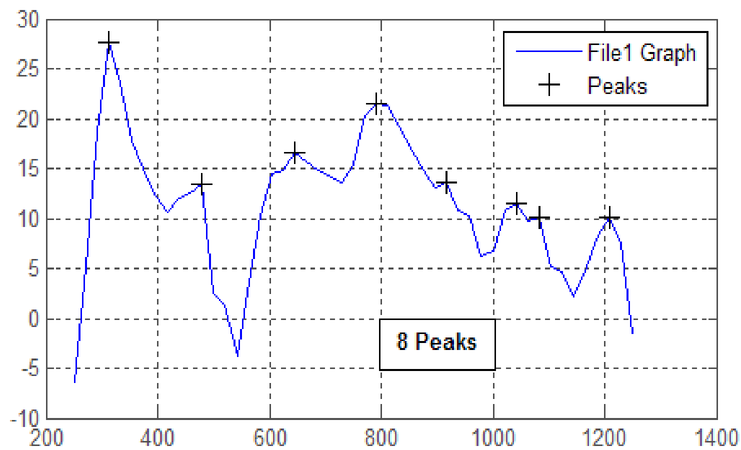
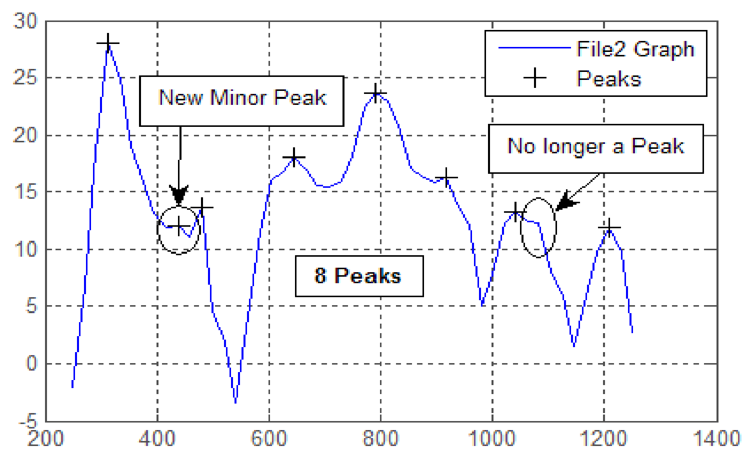



Figure 7.4: View of peak location of the file 2 from the breakdown of the file where the participant said the word “nine”.



same time a previous minor peak is eliminated. If the peak count was only considered it indicated that no change had taken place, when in reality two events had occurred. The next two graphs show, Figures 7.5 and 7.6, the event of going between two different cross-sections where no minor peaks were formed or eliminated, retaining the same peak

Figure 7.5: View of peak location of the file 3 from the breakdown of the file where the participant said the word “nine”.

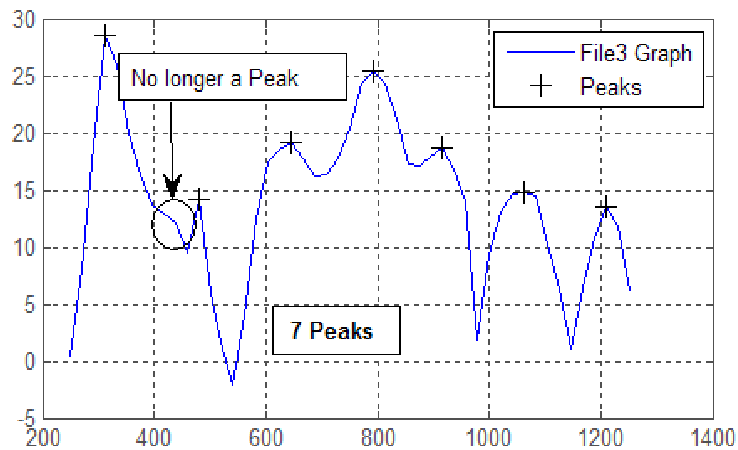
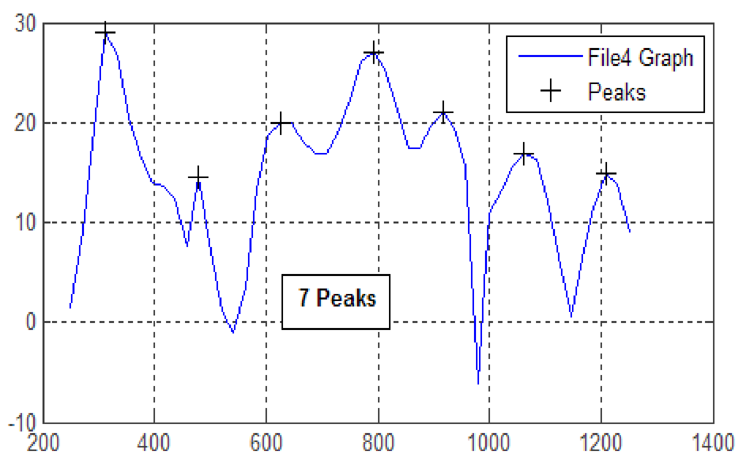



Figure 7.6: View of peak location of the file 4 from the breakdown of the file where the participant said the word “nine”.



count and the graphs are very similar. This indicates, that just counting the number of peaks is not sufficient as with the first set. The count is the same but the location of the second and seventh peak are different. In contrast, the second set of graphs show that the peak count can remain the same, as well as the location of the peaks. The only deviation between the two is that the amplitude is slightly higher in one over the other. It was the assessment of the changing of the locations of the first peak, second peak, third peak and so forth, along with the need to have a numeric representation that inspired the final area of exploration for this research.

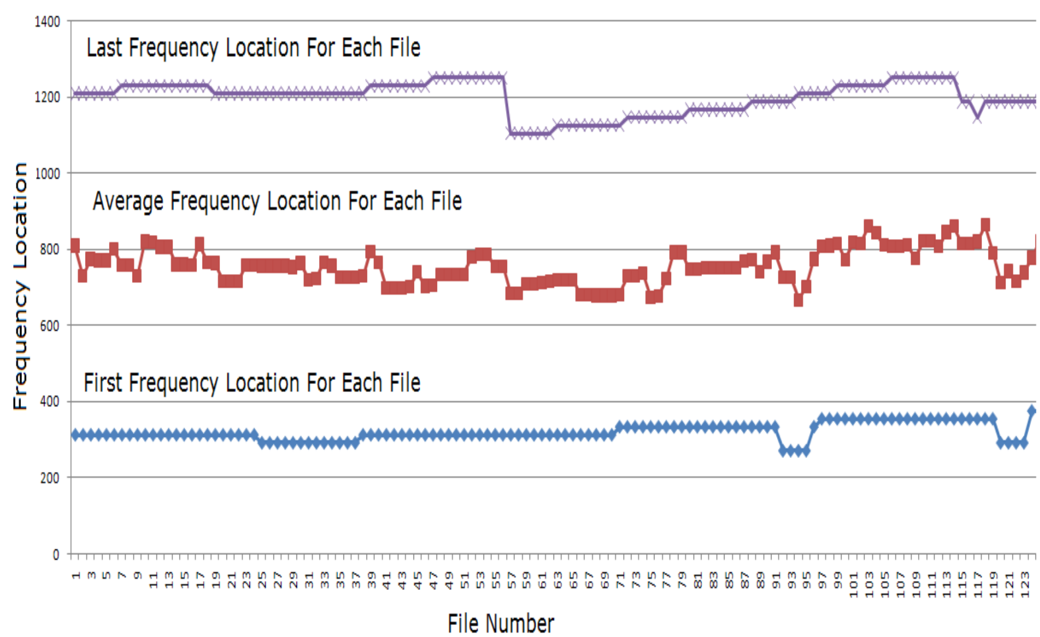
To make the comparison of the numeric data as it relates to the graphs more straight forward, all peak data was stored into an Excel spreadsheet for evaluation. Table 7.1 is an example of what this data might look like in the spreadsheet. Looking at this table it can be seen numerically when the location of the first peak, second peak and so on, either remains at the previous location or changes locations due to a minor peak being found or eliminated. Tracking this activity was vitally important to the completion of this analysis. This is best conveyed by numerically following in the table the previous example the graphs displayed. To accomplish this, two events needed to be monitored, at what location did peaks materialize or dematerialize and the location of each peak as it pertains to all the files. Starting with the location of the first peak in file 1, it is located at 312.5 and remains this value until file 25 where the first peak is found at 291.7. Again this location is continuous until file 38, when it shifts back to 312.5. The shifting from one location to another gave an observable pattern that was of great interest. Also this tracking of the peaks within the spreadsheet gave valued information as to when materialization and exodus of minor peaks transpired. Looking at files 1 and 2 (rows 2 and 3) in the spreadsheet, it reveals the same peak activity as the graph in Figure 7.4 shows. The graph shows peak 1 in the same location for both files and the spreadsheet reveals the same event. It can be seen in the spreadsheet that under the “P2” column it has a location of 479.2 for file 1 and 437.5 for file 2 indicating that some change has taken place . For file 2, “P3” is now at location 479.2, clearly indicating that another peak materialized that was not in the file 1. Likewise,

Table 7.1: This table shows the data on peak location for the first 40 smaller files that were created from the full sample of a person saying the word "nine". It numerically represents the shifting of the peaks as well as the appearance and disappearance of minor peaks.

| **File** | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **P9** | **P10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 312.5 | 479.2 | 645.8 | 791.7 | 916.7 | 1041.7 | 1083.3 | 1208.3 | | |
| **2** | 312.5 | 437.5 | 479.2 | 645.8 | 791.7 | 916.7 | 1041.7 | 1208.3 | | |
| **3** | 312.5 | 479.2 | 645.8 | 791.7 | 916.7 | 1062.5 | 1208.3 | | | |
| **4** | 312.5 | 479.2 | 625.0 | 791.7 | 916.7 | 1062.5 | 1208.3 | | | |
| **5** | 312.5 | 479.2 | 625.0 | 791.7 | 916.7 | 1062.5 | 1208.3 | | | |
| **6** | 312.5 | 479.2 | 625.0 | 791.7 | 916.7 | 1000.0 | 1062.5 | 1208.3 | | |
| **7** | 312.5 | 416.7 | 479.2 | 625.0 | 791.7 | 916.7 | 1000.0 | 1062.5 | 1229.2 | |
| **8** | 312.5 | 437.5 | 479.2 | 625.0 | 770.8 | 916.7 | 1000.0 | 1062.5 | 1229.2 | |
| **9** | 312.5 | 437.5 | 479.2 | 625.0 | 770.8 | 916.7 | 1062.5 | 1229.2 | | |
| **10** | 312.5 | 479.2 | 625.0 | 770.8 | 916.7 | 1062.5 | 1166.7 | 1229.2 | | |
| **11** | 312.5 | 458.3 | 625.0 | 770.8 | 916.7 | 1062.5 | 1166.7 | 1229.2 | | |
| **12** | 312.5 | 458.3 | 625.0 | 708.3 | 770.8 | 916.7 | 1062.5 | 1166.7 | 1229.2 | |
| **13** | 312.5 | 458.3 | 625.0 | 708.3 | 770.8 | 916.7 | 1062.5 | 1166.7 | 1229.2 | |
| **14** | 312.5 | 458.3 | 625.0 | 708.3 | 770.8 | 916.7 | 1062.5 | 1229.2 | | |
| **15** | 312.5 | 458.3 | 625.0 | 708.3 | 770.8 | 916.7 | 1062.5 | 1229.2 | | |
| **16** | 312.5 | 458.3 | 604.2 | 708.3 | 770.8 | 916.7 | 1062.5 | 1229.2 | | |
| **17** | 312.5 | 458.3 | 604.2 | 770.8 | 916.7 | 1062.5 | 1145.8 | 1229.2 | | |
| **18** | 312.5 | 395.8 | 458.3 | 604.2 | 770.8 | 916.7 | 1062.5 | 1145.8 | 1229.2 | |
| **19** | 312.5 | 395.8 | 458.3 | 604.2 | 770.8 | 916.7 | 1062.5 | 1145.8 | 1208.3 | |
| **20** | 312.5 | 395.8 | 458.3 | 604.2 | 770.8 | 916.7 | 1062.5 | 1208.3 | | |
| **21** | 312.5 | 395.8 | 458.3 | 604.2 | 770.8 | 916.7 | 1062.5 | 1208.3 | | |
| **22** | 312.5 | 395.8 | 458.3 | 604.2 | 770.8 | 916.7 | 1062.5 | 1208.3 | | |
| **23** | 312.5 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **24** | 312.5 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **25** | 291.7 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **26** | 291.7 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **27** | 291.7 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **28** | 291.7 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **29** | 291.7 | 437.5 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **30** | 291.7 | 437.5 | 604.2 | 750.0 | 833.3 | 916.7 | 1062.5 | 1208.3 | | |
| **31** | 291.7 | 375.0 | 437.5 | 604.2 | 750.0 | 833.3 | 916.7 | 1062.5 | 1208.3 | |
| **32** | 291.7 | 375.0 | 458.3 | 604.2 | 750.0 | 833.3 | 916.7 | 1062.5 | 1208.3 | |
| **33** | 291.7 | 458.3 | 604.2 | 750.0 | 833.3 | 916.7 | 1062.5 | 1208.3 | | |
| **34** | 291.7 | 458.3 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | | |
| **35** | 291.7 | 458.3 | 520.8 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | |
| **36** | 291.7 | 458.3 | 520.8 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | |
| **37** | 291.7 | 458.3 | 520.8 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | |
| **38** | 312.5 | 458.3 | 520.8 | 604.2 | 750.0 | 916.7 | 1062.5 | 1208.3 | | |
| **39** | 312.5 | 458.3 | 604.2 | 770.8 | 916.7 | 1000.0 | 1062.5 | 1229.2 | | |
| **40** | 312.5 | 458.3 | 541.7 | 604.2 | 770.8 | 916.7 | 1000.0 | 1062.5 | 1229.2 | |

"P7" in file 1 is at position 1083.3, although in file 2 "P7" is at 1041.7 which is where "P6" is located for file 1. This indicates that a minor peak that was previously in file 1 is not in file 2. Now that these events were tracked numerically instead of only observing a graph automation, this process began to materilize. One last visual observation was made, when the entire peak locations for all files were stored in the spreadsheet, a visual of the data as it pertained to the number of peaks increasing and decreasing was noticed. By using the "zoom" feature in Excel, a pattern can be seen as it concerns the number of peaks, giving a very unique blend of the numeric and visual environments. Examination of this new data led to the consideration that for a given participant's multiple samples of the word "nine", there was a pattern pertaining to the frequency values. It became apparent that this pattern of the locations values can be tracked as a thread which is universal to geometric analysis. For this research, the tracking of the location values as it relates to the peaks of that sample will be called a "Frequency Location Thread" (FLT). It is this research's certainty that tracking numerically the FLT, will provide a pattern for each participant's voice. In Figure 7.7 it shows the pattern that is formed by where the first peak is located, where the last peak is located and the average location of all peaks, are represented for all files.

Figure 7.7: Graph of numerical data indicating the FLT stored in an Excel spreadsheet

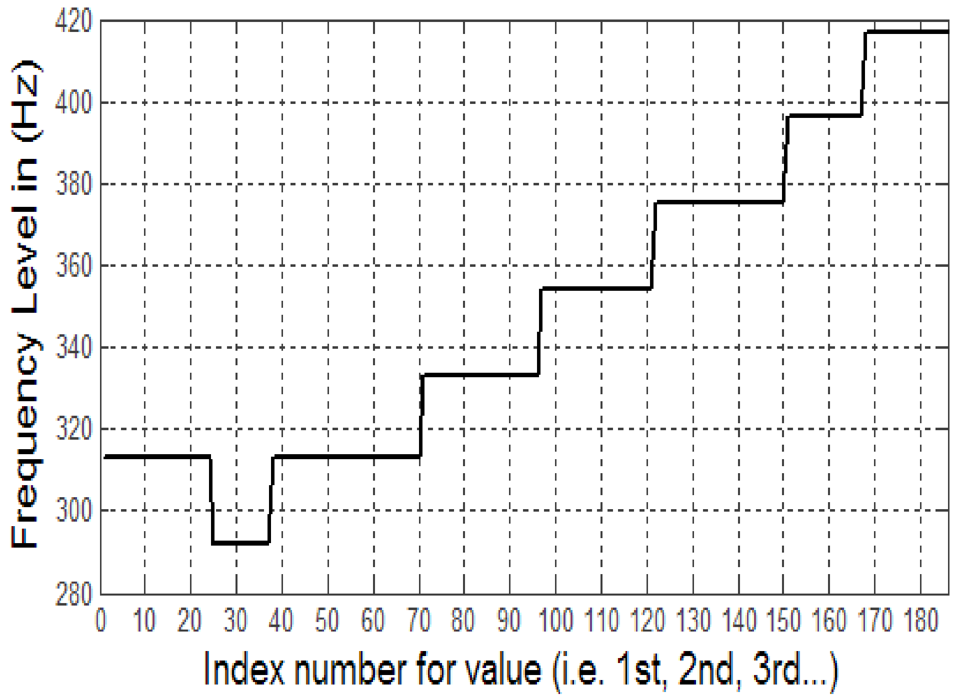


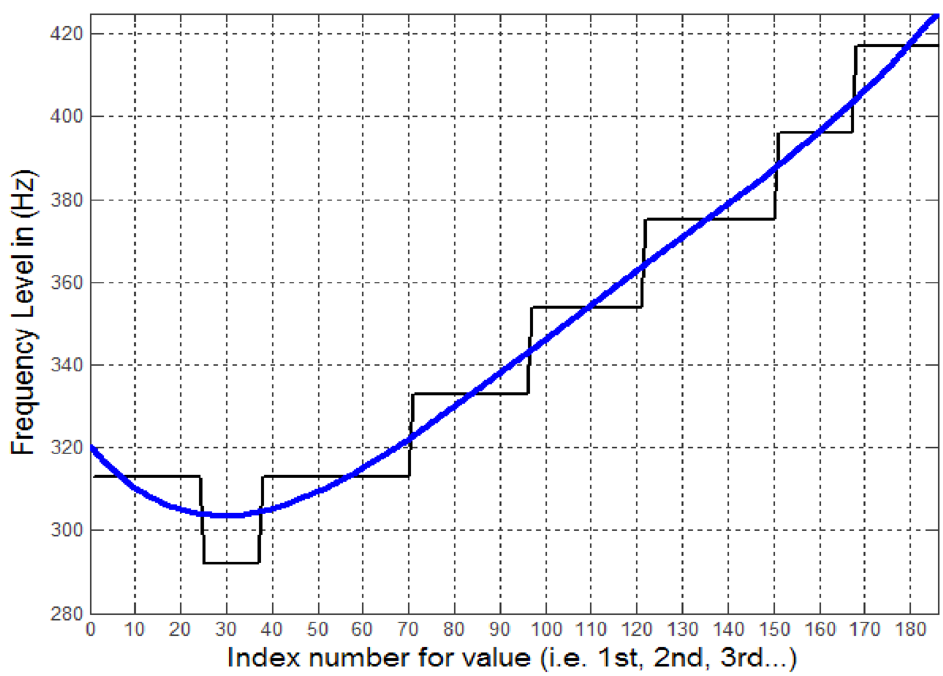
At this point in the experimentation process the following steps had been accomplished for each of the samples:

- The word “nine” was isolated from each full sample and stored in a new WAV file
- The new file then was split in to multiple files of 800 bytes each (150 - 200 files)
- The peak locations for each 800 byte file were established
- All locations for all files were stored in a separate text file
- The threads for the respective files were established

Upon completion of these steps graphical analysis of the threads was initiated. This analysis consisted of selecting one of the samples for a test case and graphically viewing each thread to determine a pattern that can be used to represent the participant’s voice. As described earlier the formation of the threads are directly connected to where peaks materialize or dematerialize as it pertains to previous peak locations. Given the structure of the peak data a thread can have one peak location or any number up to the number of files associated with that sample. Continuing on the same thought process started by looking at the steps that were formulated in just looking at the location values for the individual peaks, it was considered that similar steps occured for this process too. For an illustration of this a graph was created in MATLAB using the “plot” function where the location values for a particular thread were stored as the “y” values and the “x” values corresponded to the number of location values i.e. 1 - (the number of values in that thread). The first thread’s graph for a test participant had 186 values in it and when graphed gave a stair step graphic, see Figure 7.8. Given the pattern of this graphic it was apparent that this type of graph can be represented by a polynomial that is a mathematical representation of the thread data. This polynomial was found by using the function in MATLAB “polyfit” which yields the coefficients for a polynomial of a given order. After some experimentation to find the order for the polynomial it was determined for this research the third and forth order polynomials

Figure 7.8: Graph 1 is of the frequency values of the first thread of a test sample and graph 2 show the polynomial that fits that step graph



was calculated. An example of a forth order polynomial calculated by MATLAB using the test case is displayed below:

$$0.0000003894\mathbf{X}^4 - 0.0001753\mathbf{X}^3 + 0.029085\mathbf{X}^2 - 1.2867\mathbf{X} + 320.46$$

The higher order coefficient (0.0000003894) is representative of the complexity of the sample, whereas the last value (320.46) is representative of the frequency. With this polynomial each participant's voice can be modeled as it pertains to the frequency domain. After further evaluation the third order polynomial was calculated for each sample as creating a forth order polynomial did not add much to the model but did add to the calculation process.

Two tools were used to verify that these polynomial models did give viable information about characteristics of a person and thus allow them to be categorized. The first was an analysis tool created by Dan Ginzel, an independent software developer. This tool uploads a file where the leading coefficient (in the example 0.0000003894) is multiplied by an integer (20 for this example) giving the result (0.000007788). This value is rounded to the nearest integer towards negative infinity (0.000007788 gives the integer 0) and this value is stored. This integer value (coefficient score) was then used to determine groups as they pertained to the total population. This process is done for the ten longest threads for a sample. These threads were selected as they provide a good representation of the voice and any threads beyond contained to few values to give good quality information. The advantage of this tool is that it gives a percentage break down of the analyzed data as it pertains to the, category group (i.e. gender), individual group (i.e male), as well as the entire sample group (all participants). This gives a insight into how the coefficients represent the groups mentioned.

For an example, a file was uploaded and the parameters were selected from a table that was dynamically created. For this experiment the ten longest threads were selected and treated individually. From the table created the coefficient score was selected along with gender and the results can be seen in Table 7.2. In viewing the results it is clear that there are two groups that stand out. One group (0 coefficient score) had a strong showing of females with 68.28% of all females in this group. Another group (-1 coefficient score) had a strong showing of males in it. The information that can come from this is twofold; first it gives a breakdown of where the strongest percentages of the category types are i.e. male or female and second it gives a method for evaluating the clusters that will be given by the second tool.

Table 7.2: The results from the analysis tool showing the percentages as they pertain to male and female in each coefficient score group

| **Total In Category Group** | **Coefficient Score** | **Gender** | **Percentage Category Group** | **Percentage Individual Group** | **Percentage of total Group** |
|---|---|---|---|---|---|
| 1 | -6 | Male | 100.00% | 0.15% | 0.06% |
| 1 | -4 | Male | 100.00% | 0.15% | 0.06% |
| 2 | -3 | Female | 100.00% | 0.22% | 0.13% |
| 17 | -2 | Female | 81.00% | 1.83% | 1.08% |
| 4 | -2 | Male | 19.00% | 0.62% | 0.25% |
| 265 | -1 | Female | 45.70% | 28.49% | 16.77% |
| 315 | -1 | Male | 54.30% | 48.46% | 19.94% |
| 635 | 0 | Female | 65.90% | 68.28% | 40.19% |
| 328 | 0 | Male | 34.10% | 50.46% | 20.76% |
| 9 | 1 | Female | 100.00% | 0.97% | 0.57% |
| 1 | 2 | Male | 100.00% | 0.15% | 0.06% |
| 2 | 3 | Female | 100.00% | 0.22% | 0.13% |

The second tool used that gave the most significant results as it relates to validating the second hypothesis (that a person can be categorized by their voice), is the Applications Quest$^{TM}$software developed by Dr. Juan E. Gilbert. This software is a clustering application that takes a tab delimited file with demographic data along with analysis calculations forming clusters using this data to determine which participants are most alike. After initial experimentation with the settings that a user enters i.e. number of clusters preferred or attributes to be used, it was decided that six (6) clusters gave excellent results for this research. The coefficient data mentioned earlier, was part of the data uploaded to Applications Quest$^{TM}$with some changes. The average for each set of coefficients of the ten threads that had been selected was calculated. This updated data then was stored along with the demographic data for each sample and stored in a tab delimited file. The following are the attributes that were uploaded into Applications Quest$^{TM}$; ID, Gender, Ethnicity, State that has effected voice most, Education, Area they live in, Height, and the three coefficients for the calculated polynomial. Once the file has been uploaded, the next step is to select the attributes that the application will use for clustering. The following shows the results where the attributes gender, ethnicity, and the three coefficient values were used for the final analysis. The AverageDifference as talked about in (PUT Section ref) is an indication of how different the samples are from each other. Cluster 0 members are more different then cluster 4's members which can be seen in Table 7.3 that shows male and

Table 7.3: Clustering results from Applications Quest$^{TM}$reset to look for samples that are alike rather than different.

| | |
|---|---|
| **Cluster 0** | Ethnicity: White (4), African American (2), Native American (1)<br>Gender: Male (6), Female (1) |
| **Cluster 1** | Ethnicity: White (34)<br>Gender: Male (17), Female (17) |
| **Cluster 2** | Ethnicity: White (63)<br>Gender: Female (63) |
| **Cluster 3** | Ethnicity: White (12), Asian (9), African American (8)<br>Gender: Male (29) |
| **Cluster 4** | Ethnicity: White (15), Asian (1)<br>Gender: Male (16) |
| **Cluster 5** | Ethnicity: Native American (9)<br>Gender: Female (9) |

one female in Cluster 0, but all males in cluster 4. It needs to be stated that the primary use of this software is to form groups that are diverse; however the developer was able to set the program to cluster the samples that are most alike. This was represented by the difference index which is the average difference between members of a cluster. So the lower the difference index the better the cluster representation is [20]. The difference index for the complete sample set was 28.60% standard deviation 16. It should be noted that all of the cluster's difference index are under this value which was an anticipated out come and shows the process is valid. The cluster's information can be seen in Table 7.3. One can

- Cluster 0, AverageDifference = 25.21%
- Cluster 1, AverageDifference = 20.87%
- Cluster 2, AverageDifference = 9.30%
- Cluster 3, AverageDifference = 23.84%
- Cluster 4, AverageDifference = 8.76%
- Cluster 5, AverageDifference = 13.22%

observe that the clusters with the higher difference index (0, 1, 3) are not as uniform as the lower difference index clusters (2, 4, 5) which are very distinct. These distinct clustering results and others like them give validity to the approach of establishing threads and calculating the polynomial coefficient to represent the thread pattern for the given voice sample.

### 7.2 Results

A major result from this section was the thread mapping of the frequency peaks. Being able to distinguish when a new peak was formed or an old peak no longer appeared was very important to track the threads as they were created. From these findings evolved the idea of graphically representing these threads yet using a venue that is purely numerical. This resulted in the calculation of polynomials to represent these threads. Taking the 10 most prominent threads and averaging the coefficients then gave way to having a general representation of the voice and allowed for clustering. The clustering validated that the polynomials did represent the voice and given the coefficient values for an individual, they can be put into a certain group, i.e. gender.

### 7.3 Conclusion

It was in this final phase of experimentation that the strongest results occurred. First the splitting of a single word into multiple 800 byte parts was paramount to getting a numeric representation for the voice. From splitting of the word to the thread representation to the creation of polynomials corresponding to the voice, all gave validation to the hypothesis set. Upon completion this phase the results from the clustering application showed that hypothesis 2, “The human tone classification can be refined into human classifications that can pertain to gender, ethnicity and geographical area where their accent was most effected.”, can be accomplished by modeling a person’s voice as a polynomial.

# Chapter 8

## Findings and future work

The goal of this research was to confirm the following two hypotheses as they relate to speaker classification.

- H1) The pitch range of the human voice could be used to create a tone classification set, such as a low, medium, and high tones.
- H2) The human tone classification could be refined into human classifications that could pertain to gender, ethnicity and area where their accent was most effected.

The literature review proved to be the first obstacle, as there was very little published on the subject matter of speaker classification. The two areas of speaker verification and speaker identification had dominated most efforts in research of this kind. When literature was obtained it was either of the theoretical nature or did not divulge the inner workings of the study attempted. Therefore the primary motivation was the thought that if humans could listen to someone speak and be able to tell certain characteristics about them i.e. that they were male or female; it stood to reason that in some way this could be mathematically computer-generated. Given that machines most likely would do this to a lesser degree, the benefits are still numerous [40]. The results from chapters 4 - 7 document the exact progression and calculations this research has undertaken to obtain a mathematical representation of what a human does naturally. The following summarizes the validation of the fore mentioned hypotheses.

The first hypotheses was quickly validated when the voice sample was converted from the time domain to the frequency domain. In Section 5.1.4 it showed that when the frequency data was bounded (250 - 1250 Hz) it could be determined where in that sample the frequency was the strongest. By using the average slope between the prominent peaks of the sample, it could be confirmed when the frequency was stronger at the beginning (negative slope), in the middle (slope approaching 0) or the end (positive slope) of the selected frequency range, review graphs in Figure 5.6. This value clearly indicated that the tone for the sample could be categorized either; high, medium, or low, thus validating the first hypothesis. With the first hypothesis substantiated, the research progressed to the validation of the second hypothesis.

Refining the development associated with hypothesis one as it pertains to frequency was no inconsequential task. With no previous work to act as a guide experimentation was done in phases. Each phase added to the validation process; however it was the final phase (Chapter 7) that gave the key to classifying a person. By a series of experiments the frequency of an individual was represented by a polynomial of the third order, refer to Figure 7.8. This polynomial was created by first establishing a thread that tracked the prominent peaks of a frequency sample. The top ten threads were then selected and a set of polynomial coefficients were calculated for each thread. These ten sets of coefficient values were then averaged and the polynomial that was formed was used for the representation of a person's voice. Confirmation of this was ascertained by taking these values along with the demographic information for the participants and uploading them to Applications Quest$^{TM}$, a clustering application. The results obtained gave a clear indication that the polynomial coefficients gave appropriate representation of a person such that they could be put into cluster groups that would indicate gender and ethnicity. With this conclusion hypothesis two was validated in that it was shown that it is possible to refine the analysis of the voice to give predilection towards a classification of an individual.

## 8.1 Contributions

The use of biometrics and voice biometrics in particular are increasing every day [36]. It is the goal of this research to provide, to the area of voice biometrics, validation that, an application can take a voice sample and glean from it information that can be used to enhance the interaction between humans and machines. This could be done by finding characteristics of a person that can be used to classify that person so that more information is available so the application can better serve the user and the community. This research will not only aid current applications, but could also be expanded into determining other attributes of an individual that will be beneficial to the continuing research of voice applications as they pertain to HCI [40].

## 8.2 Future Work

There is a great deal of future work planned for this research. The following is a list of planned work.

- Target data collection such that a more evenly distributed group is available as it pertains to the target attributes. One idea to accomplish this would be to set up in certain areas where a particular participant group can be found, i.e. collecting samples from a senior group at a monthly meeting.
- Utilize the other parameters established when in the time domain (i.e. amount of pause) into other voice applications
- Conduct the study under a controlled environment where all participants use the same phone and back ground noise is controlled.
- Incorporate speech recognition to listen for particular words that may be used by the participant. i.e. "ya'll"
- Collect numerous samples from the same participant where they are healthy, sick, have throat problems.
- To create an application that is fully automated for the processing of the voice samples.
- Investigate use of classification as it pertains to security.

# Chapter 9

## Scholarly Contributions

Gilbert, J.E., Cross, E.V., McMillian, Y., Rouse, K., Mkpong-Ruffin, I., Gupta, P., & Williams, P. (2007) **A Usable Security Approach to Electronic Voting.** *IEEE Computer.*

Gilbert, J.E., McMillian, Y., Cross, E.V., Rouse, K., Williams, P., Gupta, P., Rogers, G., McClendon, J., Mkpong-Ruffin, I., & Nobles, K. (2007) **Multimodal E-Voting with Older Citizens.** *International Journal of Human-Computer Studies.*

Williams, A., Rouse, K., Seals, C.D., & Gilbert, J.E. (2007) **Enhancing Reading Literacy in Elementary Children using Programming for Scientific Simulations.** *International Journal on E-Learning.*

Cross, E.V., Rogers, G., McClendon, J., Mitchell, W., Rouse, K., Gupta, P., Williams, P., Mkpong-Ruffin, I., McMillian, Y., Neely, E., Lane, J., Blunt, H. & Gilbert, J.E. (2007) **Prime III: One Machine, One Vote for Everyone.** *VoComp 2007, Portland, OR, July 16, 2007.*

Williams, A., Seals, C., Rouse, K., & Gilbert, J. (2006) **Visual Programming with Squeak SimBuilder: Techniques for E-Learning in the Creation of Science Frameworks.** *In Proceedings of E-Learn 2006 World Conference on E-Learning in Corporate, Government, Healthcare, & Higher Education, CD-ROM.*

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Appendix A

Breakdown of demographics

## Number Of Peaks First Half

| **Gender** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|
| Female | | 2 | 14 | 22 | 20 | 15 | 8 | 8 | 1 | |
| Male | | | 1 | 2 | 16 | 13 | 6 | 11 | 6 | 6 |

| **Ethnicity** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|
| African Am | | | 2 | 7 | 1 | 6 | 5 | 4 | 1 | 1 |
| Asian | | | | 1 | 4 | | | | | |
| Hispanic | | | 1 | 1 | 1 | 2 | | | | 1 |
| White | | 2 | 10 | 14 | 26 | 20 | 8 | 14 | 6 | 4 |

| **State** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|
| AL | | 2 | 5 | 8 | 17 | 9 | 6 | 6 | 2 | 2 |
| CA | | | 1 | | 3 | 2 | | 1 | 1 | |
| CO | | | 1 | | | | | | | |
| DC | | | | | | 1 | | 1 | | |
| FL | | | 1 | 1 | 1 | 1 | | | 3 | 1 |
| GA | | | 2 | 1 | 1 | 2 | 1 | 1 | | |
| IA | | | 1 | | 3 | 1 | | 1 | | 1 |
| ID | | | | | | | | 1 | | |
| IL | | | | | 1 | 1 | | | | |
| KY | | | 1 | | | | 1 | | | |
| LA | | | | | | 1 | | 1 | | |
| MA | | | | 1 | | | | | | |

| State | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| MD | | | | 2 | | | | | | |
| MI | | | 1 | | | 1 | | 1 | | 1 |
| MN | | | | 2 | | 2 | 1 | 3 | | |
| MO | | | | 1 | 1 | | | 1 | | |
| MS | | | | | 1 | | | | | |
| NC | | | | 2 | | 1 | 1 | | | |
| NE | | | | | | 1 | | | | |
| NY | | | | | | 1 | | | | |
| OH | | | | | | 1 | 2 | | 1 | |
| OR | | | | | | | | | | 1 |
| PA | | | | | 1 | | | | | |
| SC | | | 1 | | | | | | | |
| TN | | | | 1 | | 1 | | | | |
| TX | | | 1 | 3 | 3 | | 1 | 1 | | |
| VA | | | | 2 | 1 | 2 | | | | |
| WA | | | | | 1 | | 1 | | | |

## Number Of Peaks First Half Continued...

| **Education** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|
| Bachelor | | | 7 | 7 | 9 | 10 | 7 | 8 | 1 | 1 |
| Grammar | | | 1 | | | | | 1 | | |
| High School | | | | 2 | 3 | 4 | | | | |
| Master | | | 2 | 9 | 11 | 4 | 4 | 6 | 3 | 1 |
| MD | | | | | 1 | 1 | | | | |
| PHD | | | 2 | 1 | 3 | 3 | 2 | 1 | 2 | 2 |
| Some college | | 2 | 3 | 5 | 9 | 6 | | 3 | 1 | 2 |
| Vocational | | | | | | | 1 | | | |

| **Area** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|
| Rural | | | 1 | 2 | 2 | 2 | | 2 | | |
| Small Town | | 1 | 4 | 11 | 13 | 9 | 5 | 3 | 4 | 4 |
| Suburb | | 1 | 9 | 7 | 15 | 11 | 6 | 10 | 2 | 2 |
| Urban | | | 1 | 4 | 6 | 6 | 3 | 4 | 1 | |

| **Height** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 to 5 | | | | 1 | 2 | | 1 | 1 | | |
| 5.1 to 5.3 | | | 2 | 6 | 5 | 4 | 1 | 2 | | |
| 5.4 to 5.6 | | 2 | 7 | 8 | 4 | 11 | 5 | 4 | 2 | 1 |
| 5.7 to 5.9 | | | 6 | 6 | 14 | 9 | 3 | 1 | | 1 |
| 5.10 to 6.0 | | | | 2 | 5 | 3 | 1 | 7 | 4 | 3 |
| 6.1 to 6.3 | | | | | 5 | 1 | 3 | 3 | 1 | 1 |
| 6.4 to 6.6 | | | | | 1 | | | | | |
| 6.7 to 6.9 | | | | 1 | | | | | | |
| 6.10 to 7.0 | | | | | | | | 1 | | |

## Number Of Points For The Second Half

| Gender | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| Female | 3 | 4 | 11 | 19 | 19 | 13 | 15 | 2 | 5 | 1 |
| Male | | | 3 | 6 | 11 | 15 | 20 | 5 | | 2 |

| Ethnicity | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| African Am | | 1 | 1 | 6 | 3 | 7 | 5 | 2 | | 2 |
| Asian | | | | | 2 | | 3 | | | |
| Hispanic | | | 1 | | | 1 | 3 | | 1 | |
| White | 3 | 2 | 11 | 16 | 23 | 20 | 21 | 4 | 4 | 1 |

| State | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| AL | 3 | 1 | 5 | 12 | 13 | 9 | 10 | | 3 | 11 |
| CA | | | | 1 | 3 | | 3 | 1 | | |
| CO | | | | | | 1 | | | | |
| DC | | | | | 1 | 1 | | | | |
| FL | | | | 2 | 3 | | 2 | 1 | | |
| GA | | 1 | | 2 | 2 | 1 | 1 | 1 | | |
| IA | | | | 1 | 2 | 3 | 1 | | | |
| ID | | | | | | 1 | | | | |
| IL | | | 1 | | 1 | | | | | |
| KY | | | 1 | | | | | | 1 | |

| State | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| LA | | | | | 1 | | 1 | | | |
| MA | | | 1 | | | | | | | |
| MD | | 1 | 1 | | | | | | | |
| MI | | | | | | | 3 | | | 1 |
| MN | | | 2 | | | 2 | 3 | 1 | | |
| MO | | | | 1 | | | 2 | | | |
| MS | | | | | 1 | | | | | |
| NC | | | | 7 | | 9 | | 1 | | |
| NE | | | | | | 1 | | | | |
| NY | | | | | 1 | | | | | |
| OH | | | | | | 2 | 2 | | | |
| OR | | | 1 | | | | | | | |
| PA | | | | | 1 | | | | | |
| SC | | | | 1 | | | | | | |
| TN | | | 1 | 1 | | | | | | |
| TX | | 1 | 1 | | | | 3 | 2 | 1 | 1 |
| VA | | | | 1 | 1 | 2 | 1 | | | |
| WA | | | | 1 | | | 1 | | | |

**Number Of Points For The Second Half Continued...**

| Education | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| Bachelor | 1 | 1 | 4 | 8 | 8 | 8 | 13 | 3 | 4 | |
| Grammar | | | | | | 1 | 1 | | | |
| High School | | | 1 | 1 | 5 | 1 | 1 | | | |
| Master | 1 | 1 | 2 | 12 | 12 | 7 | 8 | 1 | 1 | 1 |
| MD | | | 1 | | 1 | | | | | |
| PHD | | | 2 | 1 | 3 | 5 | 3 | 2 | | |
| Some college | 1 | 2 | 4 | 3 | 7 | 5 | 6 | 1 | | 2 |
| Vocational | | | | | | | 1 | | | |

| Area | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| Rural | | | | 3 | 3 | | 3 | | | |
| Small Town | 1 | 2 | 6 | 11 | 10 | 10 | 6 | 4 | 3 | 1 |
| Suburb | 1 | 2 | 5 | 6 | 14 | 13 | 17 | 2 | 1 | 1 |
| Urban | 1 | | 2 | 5 | 3 | 4 | 7 | 1 | 1 | 1 |

| Height | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 to 5 | | | 1 | | 1 | 1 | 1 | | 1 | |
| 5.1 to 5.3 | | | 1 | 10 | 2 | 2 | 2 | 1 | 2 | |
| 5.4 to 5.6 | 2 | 2 | 6 | 6 | 8 | 5 | 12 | 1 | 2 | |
| 5.7 to 5.9 | | 2 | 4 | 7 | 11 | 10 | 3 | 2 | | 1 |
| 5.10 to 6.0 | 1 | | 2 | 1 | 3 | 5 | 9 | 3 | | 1 |
| 6.1 to 6.3 | | | | 1 | 5 | 3 | 4 | | | 1 |
| 6.4 to 6.6 | | | | | | 1 | | | | |
| 6.7 to 6.9 | | | | | | | 1 | | | |
| 6.10 to 7.0 | | | | | | | 1 | | | |

## Slope Distance Line

| Gender | | | |
|---|---|---|---|
| Female | -0.99365 | to | -0.00651 |
| Female | 0.00085 | to | 0.61721 |
| Male | -0.49033 | to | -0.00286 |
| Male | 0.00308 | to | 0.66138 |

| Ethnicity | | | |
|---|---|---|---|
| African Am Neg | -0.59546 | to | -0.00651 |
| African Am Pos | 0.00308 | to | 0.66138 |
| Asian Neg | -0.26139 | to | -0.15716 |
| Asian Pos | 0.0885 | to | 0.19448 |
| Hispanic Neg | -0.20888 | to | -0.03503 |
| Hispanic Pos | 0.00433 | to | 0.13985 |
| White Neg | -0.99365 | to | -0.00286 |
| White Pos | 0.00085 | to | 0.61721 |

**Slope Distance Line Continued...**

| State | | | |
|---|---|---|---|
| AL | -0.74824 | to | -0.00286 |
| AL | 0.00085 | to | 0.42001 |
| CA | -0.40647 | to | -0.0089 |
| CA | 0.05684 | | |
| CO | 0.16646 | | |
| DC | -0.23638 | and | 0.38993 |
| FL | -0.49033 | to | -0.00651 |
| FL | 0.10738 | to | 0.66138 |
| GA | -0.09982 | to | -0.02608 |
| GA | 0.03778 | to | 0.58616 |
| IA | -0.29616 | to | -0.03173 |
| IA | 0.00935 | to | 0.61721 |
| ID | -0.46797 | | |
| IL | -0.40137 | and | 0.56757 |
| KY | -0.12478 | to | -0.0204 |
| LA | -0.28038 | and | 0.01232 |
| MA | 0.04451 | | |
| MD | -0.19547 | and | 0.00411 |
| MI | -0.19405 | to | -0.04471 |
| MI | 0.133425 | | |
| MN | -0.41642 | to | -0.04392 |
| MN | 0.0197 | to | 0.25693 |
| MO | -0.05815 | | |
| MO | 0.10037 | to | 0.26848 |
| MS | -0.16467 | | |
| NC | -0.59546 | to | -0.10757 |
| NC | 0.13985 | to | 0.16893 |
| NE | 0.12225 | | |

| | | | |
|---|---|---|---|
| NY | -0.08948 | | |
| OH | -0.19234 | to | -0.03795 |
| OH | 0.00308 | | |
| OR | -0.20888 | | |
| PA | -0.79311 | | |
| SC | 0.06591 | | |
| TN | -0.09841 | to | -0.04037 |
| TX | -0.99365 | to | -0.0147 |
| TX | 0.00798 | to | 0.31808 |
| VA | -0.11912 | to | -0.01772 |
| VA | 0.01027 | to | 0.19143 |
| WA | -0.32368 | and | 0.01558 |

**Slope Distance Line Continued...**

| Education | | | |
|---|---|---|---|
| Bachelor | -0.89478 | to | -0.00366 |
| Bachelor | 0.00433 | to | 0.66138 |
| Grammar | 0.00935 | to | 0.02014 |
| High School | -0.22005 | to | -0.00651 |
| High School | 0.00085 | to | 0.32173 |
| Master | -0.79311 | to | -0.0094 |
| Master | 0.00411 | to | 0.58616 |
| MD | -0.40137 | and | 0.56757 |
| PHD | -0.49033 | to | -0.0204 |
| PHD | 0.00308 | to | 0.40287 |
| Some college | -0.99365 | to | -0.00286 |
| Some college | 0.01027 | to | 0.25693 |
| Vocational | 0.06534 | | |

| Area | | | |
|---|---|---|---|
| Rural | -0.40137 | to | -0.00286 |
| Rural | 0.01667 | to | 0.32173 |
| Small Town | -0.74824 | to | -0.00366 |
| Small Town | 0.00308 | to | 0.66138 |
| Suburb | -0.99365 | to | -0.00663 |
| Suburb | 0.00411 | to | 0.38993 |
| Urban | -0.46797 | to | -0.01772 |
| Urban | 0.00085 | to | 0.61721 |

| **Height** | | | |
|---|---|---|---|
| 4.0-5.0 | -0.99365 | to | -0.02578 |
| 4.0-5.0 | 0.04451 | | |
| 5.1 to 5.3 | -0.59546 | to | -0.04471 |
| 5.1 to 5.3 | 0.00433 | to | 0.56757 |
| 5.4 to 5.6 | -0.89478 | to | -0.00663 |
| 5.4 to 5.6 | 0.00085 | to | 0.66138 |
| 5.7 to 5.9 | -0.79311 | to | -0.00651 |
| 5.7 to 5.9 | 0.00308 | to | 0.61721 |
| 5.10 to 6.0 | -0.44787 | to | -0.00286 |
| 5.10 to 6.0 | 0.00935 | to | 0.31808 |
| 6.1 to 6.3 | -0.46797 | to | -0.04863 |
| 6.1 to 6.3 | 0.01558 | to | 0.26175 |
| 6.4 to 6.6 | -0.00366 | | |
| 6.7 to 6.9 | -0.2121 | | |
| 6.10 to 7.0 | -0.06889 | | |

## Second Half Peak

| Gender | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Female | 13 | 20 | 13 | 16 | 14 | 7 | 3 | 6 | 3 | 1 | | | 1 |
| Male | 3 | 12 | 11 | 4 | 7 | 9 | 5 | 7 | 3 | | | | |
| | | | | | | | | | | | | | |

| Ethnicity | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| African Am | 3 | 3 | 6 | 6 | 1 | | 1 | 6 | 1 | | | | |
| Asian | | 1 | | | 1 | 1 | | | 2 | | | | |
| Hispanic | | 2 | 1 | | 1 | | 1 | | 1 | | | | |
| White | 11 | 24 | 14 | 13 | 10 | 15 | 6 | 7 | 2 | 1 | | | 1 |

| State | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AL | 4 | 13 | 7 | 13 | 5 | 6 | 2 | 5 | 2 | | | | |
| CA | 1 | 3 | 3 | | | 1 | | | | | | | |
| CO | | | | 1 | | | | | | | | | |
| DC | | 1 | | | | | | 1 | | | | | |
| FL | 2 | | 1 | | 2 | | 1 | 1 | 1 | | | | |
| GA | 2 | 1 | 2 | | | 1 | 1 | 1 | | | | | |
| IA | | 2 | 2 | 1 | 1 | | | 1 | | | | | |
| ID | | | | | | | 1 | | | | | | |
| IL | | | | 1 | | | | 1 | | | | | |
| KY | | | 1 | | 1 | | | | | | | | |
| LA | | 1 | | | | 1 | | | | | | | |
| MA | 1 | | | | | | | | | | | | |
| MD | 1 | 1 | | | | | | | | | | | |
| MI | | 1 | 1 | | 1 | | | | 1 | | | | |
| MN | 1 | 2 | 2 | 1 | | 1 | 1 | | | | | | |
| MO | | | | | 1 | | | 1 | 1 | | | | |
| MS | | | | | | 1 | | | | | | | |
| NC | 1 | 2 | | 1 | | | | | | | | | |
| NE | | 1 | | | | | | | | | | | |
| NY | | | | | | 1 | | | | | | | |
| OH | | 1 | | | 1 | 1 | | 1 | | | | | |
| OR | | 1 | | | | | | | | | | | |
| PA | | | | | | 1 | | | | | | | |
| SC | | | | 1 | | | | | | | | | |
| TN | 1 | | 1 | | | | | | | | | | |
| TX | | 1 | 1 | | 2 | | 1 | 1 | 1 | 1 | | | 1 |
| VA | 2 | | 1 | | | 1 | 1 | | | | | | |
| WA | | 1 | 1 | | | | | | | | | | |

## Second Half Peak Continued...

| **Education** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
| Bachelor | 1 | 12 | 7 | 8 | 6 | 5 | 2 | 4 | 4 | 1 | | | |
| Grammar | | 1 | | | 1 | | | | | | | | |
| High School | 1 | 2 | 5 | 1 | | | | | | | | | |
| Master | 8 | 11 | 3 | 5 | 1 | 4 | 2 | 5 | 1 | | | | |
| MD | | | | 1 | | | | 1 | | | | | |
| PHD | 1 | 3 | 4 | | 3 | 2 | 1 | 2 | | | | | |
| Some college | 5 | 3 | 5 | 5 | 3 | 5 | 3 | | 1 | | | | 1 |
| Vocational | | | | | | | | 1 | | | | | |

| **Area** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
| Rural | | 1 | 3 | 2 | | 1 | 1 | 1 | | | | | |
| Small Town | 5 | 12 | 13 | 7 | 4 | 7 | 3 | 5 | 2 | | | | |
| Suburb | 5 | 16 | 9 | 8 | 8 | 6 | 1 | 5 | 4 | | | | 1 |
| Urban | 6 | 3 | 3 | 3 | 2 | 2 | 3 | 2 | | 1 | | | |

| **Height** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** |
|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|---:|
| 4.0-5.0 | 1 | | 1 | | 1 | 1 | | 1 | | | | | |
| 5.1-5.3 | | 4 | 4 | 6 | 2 | | 2 | 1 | | 1 | | | |
| 5.4 to 5.6 | 13 | 9 | 8 | 7 | 2 | 4 | | 4 | 1 | | | | |
| 5.7 to 5.9 | 4 | 11 | 6 | 4 | 4 | 5 | 3 | 2 | | | | | 1 |
| 5.10 to 6.0 | | 4 | 5 | 2 | 2 | 5 | 2 | 2 | 3 | | | | |
| 6.1 to 6.3 | 2 | 4 | | | 3 | 1 | 1 | 3 | | | | | |
| 6.4 to 6.6 | | | | 1 | | | | | | | | | |
| 6.7 to 6.9 | | | | | | | | | 1 | | | | |
| 6.10 to 7.0 | | | | | | | | | 1 | | | | |

## First Half Peak

| **Gender** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Female | 14 | 16 | 17 | 12 | 10 | 5 | 9 | 2 | 3 | 2 | |
| Male | 4 | 10 | 9 | 5 | 7 | 8 | 5 | 6 | 3 | 1 | 3 |

| **Ethnicity** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| African Am | 3 | 2 | 4 | 4 | 5 | | 4 | 2 | 3 | | |
| Asian | 1 | | | | 2 | 1 | | 1 | | | |
| Hispanic | 1 | 1 | 1 | 1 | | 1 | 1 | | | | |
| White | 11 | 20 | 18 | 12 | 9 | 11 | 9 | 5 | 3 | 3 | 3 |

| **State** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AL | 6 | 9 | 7 | 10 | 7 | 6 | 4 | 3 | 2 | 1 | 2 |
| CA | | 3 | 4 | | | 1 | | | | | |
| CO | | | 1 | | | | | | | | |
| DC | | | 1 | | | | | | 1 | | |
| FL | 1 | | 2 | | 1 | 1 | 2 | 1 | | | |
| GA | 3 | 1 | | | 1 | 2 | 1 | | | | |
| IA | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| ID | | | | | | | | | 1 | | |
| IL | | | | | 1 | | | 1 | | | |
| KY | | | 1 | | | 1 | | | | | |
| LA | 1 | | | | | | 1 | | | | |
| MA | | 1 | | | | | | | | | |
| MD | 1 | 1 | | | | | | | | | |
| MI | | | 1 | 2 | | | | | 1 | | |
| MN | 1 | 3 | 2 | | | | 2 | | | | |
| MO | | | | 1 | | | 1 | | | 1 | |
| MS | | | | | | 1 | | | | | |
| NC | | 2 | 1 | | 1 | | | | | | |
| NE | | 1 | | | | | | | | | |
| NY | | | | | | | 1 | | | | |
| OH | | 1 | | | 1 | | | 1 | 1 | | |
| OR | | 1 | | | | | | | | | |
| PA | | | | | | | 1 | | | | |
| SC | | | | 1 | | | | | | | |
| TN | | 1 | 1 | | | | | | | | |
| TX | | 1 | 2 | | 4 | | 1 | | | 1 | |
| VA | 2 | | 1 | 1 | | | 1 | | | | |
| WA | | 1 | 1 | | | | | | | | |

First Half Peak Continued...

| **Education** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bachelor | 4 | 8 | 9 | 5 | 8 | 5 | 5 | 2 | 2 | 2 | |
| Grammar | 1 | | | | 1 | | | | | | |
| High School | 1 | 3 | 2 | 3 | | | | | | | |
| Master | 10 | 5 | 4 | 4 | 4 | 4 | 4 | 1 | 2 | 1 | 1 |
| MD | | | | | 1 | | | 1 | | | |
| PHD | | 3 | 5 | | 3 | 2 | | 1 | 1 | | 1 |
| Some college | 2 | 7 | 6 | 7 | | 2 | 5 | 2 | 1 | | 1 |
| Vocational | | | | | | | | 1 | | | |

| **Area** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rural | 1 | | 1 | 3 | 1 | 2 | | 1 | | | |
| Small Town | 7 | 9 | 12 | 3 | 5 | 5 | 4 | 4 | 3 | | 2 |
| Suburb | 5 | 13 | 11 | 9 | 8 | 5 | 5 | 2 | 2 | 2 | 1 |
| Urban | 5 | 6 | 2 | 2 | 3 | 1 | 5 | 1 | 1 | 1 | |

| **Height** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.0-5.0 | | 1 | 2 | | 1 | | | 1 | | | |
| 5.1-5.3 | 2 | 2 | 3 | 3 | 4 | 3 | 2 | | | 1 | |
| 5.4-5.6 | 9 | 6 | 12 | 6 | 3 | | 6 | | 2 | | |
| 5.7-5.9 | 3 | 12 | 5 | 5 | 3 | 5 | 4 | 1 | 2 | | |
| 5.10-6.0 | 1 | 2 | 4 | 2 | 3 | 4 | 1 | 4 | 1 | 1 | 2 |
| 6.1-6.3 | 3 | 3 | | | 2 | 1 | 1 | 2 | 1 | | 1 |
| 6.4-6.6 | | | | 1 | | | | | | | |
| 6.7-6.9 | | | | | 1 | | | | | | |
| 6.10-7.0 | | | | | | | | | | 1 | |

## Shortest Distance Between Two Peaks

| Gender | | | |
|---|---|---|---|
| Female Range | 20.83334 | to | 29.36933 |
| Male Range | 20.83342 | to | 24.97766 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 20.83343 | to | 24.97766 |
| Asian | 20.91476 | to | 21.5333 |
| Hispanic | 20.83353 | to | 21.28297 |
| White | 20.83334 | to | 29.36933 |

| State | | | |
|---|---|---|---|
| AL | 20.83334 | to | 26.0197 |
| CA | 20.83416 | to | 22.48856 |
| CO | number too high | | |
| DC | 21.33177 | to | 22.36116 |
| FL | 20.83479 | to | 24.97766 |
| GA | 20.84042 | to | 24.14853 |
| IA | 20.83424 | to | 24.48203 |
| ID | 23.00167 | | |
| IL | 22.44879 | to | 23.95501 |
| KY | 20.83767 | to | 20.99489 |
| LA | 20.83491 | to | 21.6367 |
| MA | 20.85396 | | |
| MD | 20.83351 | to | 21.22761 |
| MI | 20.85415 | to | 21.22195 |
| MN | 20.83737 | to | 22.56749 |
| MO | 20.86852 | to | 21.5711 |
| MS | 21.1139 | | |
| NC | 20.95352 | to | 24.24713 |
| NE | 20.98844 | | |
| NY | 27.95571 | | |
| OH | 20.83343 | to | 21.21518 |
| OR | 21.28297 | | |
| PA | 26.59026 | | |
| SC | 20.87853 | | |
| TN | 20.8503 | to | 20.93396 |
| TX | 20.834 | to | 29.36933 |
| VA | 20.83443 | to | 21.21162 |
| WA | 20.83586 | to | 21.8975 |

Shorest Distance Between Two Peaks Continued...

| **Education** | | | |
|---|---|---|---|
| Bachelor | 20.83347 | to | 27.95571 |
| Grammar | 20.83424 | to | 20.83756 |
| High School | 20.83334 | to | 21.885 |
| Master | 20.83351 | to | 26.59026 |
| MD | 22.44879 | to | 23.95501 |
| PHD | 20.83343 | to | 23.20301 |
| Some college | 20.83342 | to | 29.36933 |
| Vocational | 20.87776 | | |

| **Area** | | | |
|---|---|---|---|
| Rural | 20.83342 | to | 22.44879 |
| Small Town | 20.83343 | to | 26.0197 |
| Suburb | 20.83351 | to | 29.36933 |
| Urban | 20.83334 | to | 24.48203 |

| **Height** | | | |
|---|---|---|---|
| 4.0-5.0 | 20.84026 | to | 29.36933 |
| 5.1-5.3 | 20.83353 | to | 24.24713 |
| 5.4 to 5.6 | 20.83334 | to | 27.95571 |
| 5.7 to 5.9 | 20.83343 | to | 26.59026 |
| 5.10 to 6.0 | 20.83342 | to | 22.82738 |
| 6.1 to 6.3 | 20.83586 | to | 23.00167 |
| 6.4 to 6.6 | 20.83347 | | |
| 6.7 to 6.9 | 21.2968 | | |
| 6.10 to 7.0 | 20.8827 | | |

## Another Second Half Peak

| Gender | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Female | 11 | 14 | 11 | 14 | 14 | 6 | 8 | 4 | 3 | 1 | 2 |
| Male | 10 | 7 | 11 | 3 | 6 | 5 | 10 | 7 | 1 | 1 | |

| Ethnicity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| African Am | 3 | | 5 | 3 | 2 | 3 | 5 | 2 | 2 | 1 | |
| Asian | | 1 | | | | | 3 | | 1 | | |
| Hispanic | | | 1 | 1 | 2 | | | | 1 | | 1 |
| White | 17 | 18 | 13 | 10 | 15 | 8 | 10 | 9 | | 1 | 1 |

| State | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AL | 5 | 7 | 10 | 9 | 10 | 3 | 5 | 3 | 2 | | 2 |
| CA | 1 | 2 | 2 | | 1 | 2 | | | | | |
| CO | 1 | | | | | | | | | | |
| DC | | | | | 1 | | | | 1 | | |
| FL | 1 | 1 | 1 | 1 | 1 | | 2 | | | 1 | |
| GA | 2 | 1 | 2 | | 1 | | 2 | | | | |
| IA | 1 | 2 | 1 | | 1 | | | 2 | | | |
| ID | | | | | | | 1 | | | | |
| IL | | | | 1 | | | | 1 | | | |
| KY | 1 | 1 | | | | | | | | | |
| LA | | | | | 1 | 1 | | | | | |
| MA | | | | | 1 | | | | | | |
| MD | 1 | | | 1 | | | | | | | |
| MI | 1 | | | 1 | 1 | | 1 | | | | |
| MN | 2 | 2 | | 3 | | | 1 | | | | |
| MO | | | | | 1 | 1 | 1 | | | | |
| MS | 1 | | | | | | | | | | |
| NC | | 1 | | 1 | | | | 1 | 1 | | |
| NE | | | | | | | 1 | | | | |
| NY | | | 1 | | | | | | | | |
| OH | | 1 | | | | 1 | | 2 | | | |
| OR | | | 1 | | | | | | | | |
| PA | | | | | | | | 1 | | | |
| SC | | | | 1 | | | | | | | |
| TN | | | 1 | | 1 | | | | | | |
| TX | | 2 | 1 | 1 | | 1 | 2 | 1 | | 1 | |
| VA | 3 | 1 | | | | | 1 | | | | |
| WA | | | 1 | | | 1 | | | | | |

Another Second Half Continued...

| **Education** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bachelor | 8 | 8 | 8 | 7 | 9 | 4 | 1 | 1 | 2 | 1 | 1 |
| Grammar | | 1 | | | 1 | | | | | | |
| High School | 2 | 1 | 4 | | 1 | | | 1 | | | |
| Master | 6 | 3 | 5 | 6 | 2 | 4 | 9 | 3 | 1 | | 1 |
| MD | | | | 1 | | | | 1 | | | |
| PHD | 3 | 2 | 1 | | 1 | 2 | 4 | 3 | | | |
| Some college | 2 | 6 | 4 | 4 | 5 | 1 | 3 | 2 | 1 | 1 | |
| Vocational | | | | | | | 1 | | | | |

| **Area** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rural | 2 | 3 | 1 | 1 | 1 | | | 1 | | | |
| Small Town | 8 | 5 | 8 | 5 | 7 | 4 | 8 | 7 | 2 | 1 | 1 |
| Suburb | 18 | 11 | 9 | 10 | 9 | 6 | 5 | 2 | 2 | 1 | |
| Urban | 3 | 2 | 4 | 3 | 2 | 1 | 5 | 3 | | | 1 |

| **Height** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.0-5.0 | | 1 | | | 1 | 1 | | 1 | | 1 | |
| 5.1-5.3 | 2 | 3 | 2 | 6 | 2 | 3 | | | 1 | | 1 |
| 5.4-5.6 | 7 | 4 | 8 | 8 | 7 | 1 | 4 | 1 | 2 | 1 | 1 |
| 5.7-5.9 | 5 | 9 | 7 | 4 | 3 | 3 | 6 | 3 | | | |
| 5.10-6.0 | 4 | 3 | 2 | 1 | 6 | 1 | 5 | 2 | 1 | | |
| 6.1-6.3 | 2 | 1 | 3 | | 1 | 1 | 2 | 4 | | | |
| 6.4-6.6 | 1 | | | | | | | | | | |
| 6.7-6.9 | | | | | | | 1 | | | | |
| 6.10-7.0 | | | | | | 1 | | | | | |

## Another First Half Peak

| **Gender** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Female | 10 | 14 | 16 | 13 | 10 | 9 | 7 | 6 | 3 | 2 | |
| Male | 12 | 7 | 7 | 2 | 6 | 4 | 9 | 7 | 2 | | 3 |

| **Ethnicity** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| African Am | 3 | | 3 | 4 | 2 | 4 | 4 | 3 | 3 | 1 | |
| Asian | 1 | | | 1 | | | 2 | 1 | | | |
| Hispanic | | 1 | 1 | 1 | 1 | | 1 | | 1 | | |
| White | 17 | 16 | 18 | 8 | 13 | 8 | 9 | 9 | 1 | 1 | 3 |

| State | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AL | 6 | 5 | 12 | 5 | 8 | 4 | 8 | 4 | 2 | | 2 |
| CA | | 3 | 2 | | 1 | | 1 | 1 | | | |
| CO | 1 | | | | | | | | | | |
| DC | | | | | | 1 | | | 1 | | |
| FL | | 2 | 2 | | | 1 | | 1 | 1 | 1 | |
| GA | 3 | 1 | | 2 | | | 1 | 1 | | | |
| IA | 1 | 2 | 1 | | 1 | | | 1 | | | 1 |
| ID | | | | | | | | 1 | | | |
| IL | | | | 1 | | | | 1 | | | |
| KY | 1 | 1 | | | | | | | | | |
| LA | | | 1 | | | 1 | | | | | |
| MA | | | | | | 1 | | | | | |
| MD | 1 | | | 1 | | | | | | | |
| MI | | 1 | | 1 | | 1 | 1 | | | | |
| MN | 2 | 3 | | 1 | 1 | | 1 | | | | |
| MO | | | | | 1 | 2 | | | | | |
| MS | 1 | | | | | | | | | | |
| NC | | 1 | | | 1 | | 1 | | | 1 | |
| NE | | | | | | | | 1 | | | |
| NY | | | 1 | | | | | | | | |
| OH | 1 | | | | | 1 | 1 | | 1 | | |
| OR | | | 1 | | | | | | | | |
| PA | | | | | | | | 1 | | | |
| SC | | | | 1 | | | | | | | |
| TN | | | | 1 | 1 | | | | | | |
| TX | | 2 | 1 | 2 | 3 | | 1 | | | | |
| VA | 4 | | | | | | 1 | | | | |
| WA | | | 1 | | | 1 | | | | | |

Another First Half Peak Continued..

| **Education** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bachelor | 8 | 9 | 10 | 6 | 8 | 3 | 1 | 2 | 3 | | |
| Grammar | 1 | | | | 1 | | | | | | |
| High School | 1 | 3 | 3 | | 1 | | | 1 | | | |
| Master | 7 | 1 | 5 | 4 | 2 | 6 | 5 | 6 | | 2 | 2 |
| MD | | | | 1 | | | | 1 | | | |
| PHD | 3 | 1 | 2 | | 1 | 2 | 4 | 1 | 1 | | 1 |
| Some college | 2 | 7 | 3 | 4 | 4 | 2 | 5 | 2 | 1 | | |
| Vocational | | | | | | | 1 | | | | |

| **Area** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rural | 2 | 2 | 3 | | 1 | | | 1 | | | |
| Small Town | 7 | 7 | 9 | 2 | 7 | 4 | 6 | 4 | 4 | 1 | 2 |
| Suburb | 10 | 10 | 8 | 10 | 4 | 7 | 6 | 5 | 1 | | 1 |
| Urban | 3 | 2 | 3 | 3 | 5 | 1 | 4 | 3 | | 1 | |

| **Height** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.0-5.0 | | 1 | | | 1 | 1 | 1 | 1 | | | |
| 5.1-5.3 | 1 | 3 | 6 | 2 | 3 | 1 | 3 | | 1 | | |
| 5.4-5.6 | 8 | 4 | 8 | 6 | 4 | 5 | 2 | 3 | 2 | 2 | |
| 5.7-5.9 | 4 | 10 | 6 | 6 | 2 | 2 | 5 | 3 | 2 | | |
| 5.10-6.0 | 6 | 1 | 1 | | 6 | 3 | 3 | 3 | | | 2 |
| 6.1-6.3 | 2 | 2 | 2 | | 1 | 1 | 1 | 3 | | | 1 |
| 6.4-6.6 | 1 | | | | | | | | | | |
| 6.7-6.9 | | | | 1 | | | | | | | |
| 6.10-7.0 | | | | | | | 1 | | | | |

**Second Half Number Of Direction Changes**

| Gender | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Female | 2 | 4 | 12 | 15 | 20 | 18 | 6 | 8 | 2 | 3 |
| Male | 4 | 6 | 16 | 16 | 11 | 13 | 8 | 2 | | 1 |

| Ethnicity | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| African Am | | | 5 | 6 | 6 | 4 | 4 | 1 | | 1 |
| Asian | | 1 | | 1 | | 1 | | 1 | 1 | |
| Hispanic | | | | 2 | | 1 | | 2 | | 1 |
| White | 1 | 7 | 11 | 20 | 24 | 24 | 8 | 6 | 1 | 2 |

| **State** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|---|
| AL | 1 | 5 | 9 | 12 | 9 | 11 | 4 | 2 | 1 | 3 |
| CA | | | | 4 | 1 | 2 | 1 | | | |
| CO | | | | | | 1 | | | | |
| DC | | | | 1 | 1 | | | | | |
| FL | | | 1 | 1 | 2 | 1 | 2 | 1 | | |
| GA | 1 | | 2 | | 2 | 1 | 1 | 1 | | |
| IA | | | | | 2 | 2 | 1 | 2 | | |
| ID | | | | 1 | | | | | | |
| IL | | | | 1 | 1 | | | | | |
| KY | | | 1 | | | | | | | 1 |
| LA | | | | | 2 | | | | | |
| MA | | | | 1 | | | | | | |
| MD | | | 1 | 1 | | | | | | |
| MI | | | | | 1 | 1 | 1 | 1 | | |
| MN | | 2 | | 2 | 2 | 1 | | 1 | | |
| MO | | | | 1 | 2 | | | | | |
| MS | | | | | 1 | | | | | |
| NC | | | | 1 | | 3 | | | | |
| NE | | | | 1 | | | | | | |
| NY | | | | 1 | | | | | | |
| OH | | | | 1 | 1 | | 2 | | | |
| OR | | | | 1 | | | | | | |
| PA | | | | | 1 | | | | | |
| SC | | | | | 1 | | | | | |
| TN | | | 1 | | 1 | | | | | |
| TX | | 1 | 1 | | | 3 | 1 | 2 | 1 | |
| VA | | | 1 | | | 4 | | | | |
| WA | | | 1 | 1 | | | | | | |

Second Half Number Of Direction Changes Continued...

| **Education** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|---|
| Bachelor | | 4 | 3 | 12 | 9 | 8 | 5 | 5 | 2 | 2 |
| Grammar | | | | | | 1 | | 1 | | |
| High School | | | 1 | 2 | 2 | 3 | | 1 | | |
| Master | | 2 | 10 | 7 | 7 | 6 | 4 | 2 | | 2 |
| MD | | | | 1 | 1 | | | | | |
| PHD | | 1 | 2 | 4 | 2 | 4 | 3 | | | |
| Some college | 2 | 1 | 1 | 5 | 10 | 9 | 2 | 1 | | |
| Vocational | | | 1 | | | | | | | |

| **Area** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|---|
| Rural | | 1 | | 3 | 2 | 3 | | | | |
| Small Town | 1 | 3 | 9 | 13 | 11 | 9 | 6 | 1 | | 1 |
| Suburb | 1 | 2 | 7 | 12 | 10 | 14 | 7 | 7 | 2 | 1 |
| Urban | | 2 | 2 | 3 | 8 | 5 | 1 | 2 | | 2 |

| **Height** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|---|
| 4.0-5.0 | | | | 1 | 1 | 2 | 1 | | | |
| 5.1-5.3 | | | 2 | 4 | 7 | 3 | | 2 | | 2 |
| 5.4-5.6 | 1 | 2 | 7 | 10 | 6 | 8 | 6 | 3 | | 1 |
| 5.7-5.9 | 1 | 3 | 4 | 8 | 7 | 10 | 3 | 3 | 1 | |
| 5.10-6.0 | | 1 | 3 | 5 | 6 | 6 | 2 | 1 | | |
| 6.1-6.3 | | 2 | 2 | 3 | 3 | 1 | 1 | 1 | | 1 |
| 6.4-6.6 | | | | | | | 1 | | | |
| 6.7-6.9 | | | | | | | | | 1 | |
| 6.10-7.0 | | | | | | 1 | | | | |

## First Number Of Direction Changes

| Gender | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Female | 2 | 12 | 19 | 17 | 23 | 7 | 8 | 1 | 1 |
| Male | 2 | 10 | 5 | 12 | 16 | 12 | 4 | | |

| Ethnicity | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| African Am | | 7 | 2 | 7 | 8 | 3 | 1 | | |
| Asian | | 2 | 1 | 1 | | 1 | | | |
| Hispanic | | 1 | 1 | 1 | 1 | 2 | | | |
| White | 3 | 11 | 18 | 21 | 28 | 11 | 10 | 1 | 1 |

| State | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| AL | 3 | 11 | 7 | 13 | 11 | 8 | 4 | | |
| CA | | 2 | 2 | 1 | 1 | 1 | 1 | | |
| CO | | | | 1 | | | | | |
| DC | | | 1 | | 1 | | | | |
| FL | 1 | 1 | 1 | 1 | 2 | 1 | 1 | | |
| GA | | 1 | 2 | 2 | 2 | 1 | | | |
| IA | | | 2 | | 3 | 2 | | | |
| ID | | | | | | 1 | | | |
| IL | | | | 1 | 1 | | | | |
| KY | | | 1 | | 1 | | | | |
| LA | | | | | 1 | | | | 1 |
| MA | | | 1 | | | | | | |
| MD | | | | 1 | 1 | | | | |
| MI | | | | 1 | 1 | | 2 | | |
| MN | | 2 | 3 | | 2 | | 1 | | |
| MO | | | | 1 | 1 | | 1 | | |
| MS | | | | | 1 | | | | |
| NC | | 1 | | 1 | 2 | | | | |
| NE | | | | 1 | | | | | |
| NY | | | | | | | 1 | | |
| OH | | 1 | | 2 | | 1 | | | |
| OR | | | | | 1 | | | | |
| PA | | | | | 1 | | | | |
| SC | | | | 1 | | | | | |
| TN | | | | | 1 | 1 | | | |
| TX | | 1 | 2 | 1 | 2 | 2 | 1 | | |
| VA | | 1 | 1 | | 2 | 1 | | | |
| WA | | | | 1 | 1 | | | | |

First Half Number Of Direction Changes Continued...

| **Education** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| Bachelor | 1 | 4 | 12 | 9 | 11 | 7 | 6 | | 1 |
| Grammar | | | 1 | | 1 | | | | |
| High School | 1 | 1 | 1 | 1 | 3 | 2 | | | |
| Master | | 8 | 4 | 10 | 10 | 5 | 3 | | |
| MD | | | | 1 | 1 | | | | |
| PHD | 1 | 3 | 2 | 5 | 3 | 2 | | | |
| Some college | 1 | 4 | 6 | 3 | 10 | 3 | 3 | 1 | |
| Vocational | | 1 | | | | | | | |

| **Area** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| Rural | | 1 | 2 | 2 | 2 | 2 | | | |
| Small Town | 2 | 8 | 10 | 10 | 9 | 7 | 6 | | 1 |
| Suburb | 2 | 8 | 9 | 13 | 19 | 5 | 5 | 1 | |
| Urban | | 3 | 3 | 3 | 9 | 5 | 1 | | |

| **Height** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|---|---|---|---|
| 4.0-5.0 | | | 1 | | 1 | 2 | | 1 | |
| 5.1-5.3 | | 3 | 3 | 6 | 4 | 2 | 1 | | 1 |
| 5.4-5.6 | 2 | 5 | 7 | 6 | 9 | 4 | 6 | | |
| 5.7-5.9 | 1 | 6 | 9 | 8 | 10 | 5 | 1 | | |
| 5.10-6.0 | 1 | 4 | 3 | 3 | 6 | 4 | 4 | | |
| 6.1-6.3 | | 2 | | 6 | 4 | 2 | | | |
| 6.4-6.6 | | 1 | | | | | | | |
| 6.7-6.9 | | | 1 | | | | | | |
| 6.10-7.0 | | | | | 1 | | | | |

## Total Second X Distance

| Gender | | | |
|---|---|---|---|
| Female | 625 | to | 979.16667 |
| Male | 687.5 | to | 979.16667 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 645.83333 | to | 958.33333 |
| Asian | 875 | to | 937.5 |
| Hispanic | 875 | to | 937.5 |
| White | 625 | to | 979.16667 |

| **State** | | | |
|---|---|---|---|
| AL | 625 | to | 979.16667 |
| CA | 729.16667 | to | 937.5 |
| CO | 812.5 | | |
| DC | 645.83333 | to | 937.5 |
| FL | 791.66667 | to | 937.5 |
| GA | 687.5 | to | 895.83333 |
| IA | 729.16667 | to | 895.83333 |
| ID | 958.33333 | | |
| IL | 708.33333 | to | 916.66667 |
| KY | 812.5 | to | 958.33333 |
| LA | 833.33333 | to | 916.66667 |
| MA | 833.33333 | | |
| MD | 708.33333 | to | 770.83333 |
| MI | 895.83333 | to | 937.5 |
| MN | 770.83333 | to | 958.33333 |
| MO | 812.5 | to | 937.5 |
| MS | 750 | | |
| NC | 812.5 | to | 895.83333 |
| NE | 833.33333 | | |
| NY | 895.83333 | | |
| OH | 854.16667 | to | 895.83333 |
| OR | too low | | |
| PA | 812.5 | | |
| SC | 812.5 | | |
| TN | 729.16667 | to | 854.16667 |
| TX | 708.33333 | to | 958.33333 |
| VA | 833.33333 | to | 979.16667 |
| WA | 770.83333 | to | 916.66667 |

Total Second X Distance Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | 625 | to | 979.16667 |
| Grammar | 875 | to | 895.83333 |
| High School | 625 | to | 937.5 |
| Master | 708.33333 | to | 979.16667 |
| MD | 708.33333 | to | 916.66667 |
| PHD | 791.66667 | to | 937.5 |
| Some college | 645.83333 | to | 979.16667 |
| Vocational | 895.83333 | | |

| Area | | | |
|---|---|---|---|
| Rural | 687.5 | to | 937.5 |
| Small Town | 625 | to | 937.5 |
| Suburb | 645.83333 | to | 979.16667 |
| Urban | 625 | to | 979.16667 |

| Height | | | |
|---|---|---|---|
| 4.0-5.0 | 812.5 | to | 937.5 |
| 5.1-5.3 | 687.5 | to | 958.33333 |
| 5.4-5.6 | 625 | to | 979.16667 |
| 5.7-5.9 | 708.33333 | to | 979.16667 |
| 5.10-6.0 | 625 | to | 937.5 |
| 6.1-6.3 | 750 | to | 979.16667 |
| 6.4-6.6 | 854.16667 | | |
| 6.7-6.9 | 875 | | |
| 6.10-7.0 | 916.66667 | | |

## Average Second Slope

| Gender | | | |
|---|---|---|---|
| Female | -0.09203 | to | -0.00038 |
| Female | 0.00075 | to | 0.06744 |
| Male | -0.04657 | to | -0.00139 |
| Male | 0.00142 | to | 0.02074 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | -0.04718 | to | -0.00252 |
| African Am | 0.00142 | to | 0.01328 |
| Asian | -0.03222 | to | -0.01302 |
| Hispanic | -0.03626 | to | -0.01104 |
| Hispanic | 0.00496 | | |
| White | -0.09203 | to | -0.00038 |
| White | 0.00075 | to | 0.06744 |

| State | | | |
|---|---|---|---|
| AL | -0.0599 | to | -0.00247 |
| AL | 0.00077 | to | 0.03527 |
| CA | -0.03874 | to | -0.02068 |
| CA | 0.00637 | to | 0.03682 |
| CO | -0.00361 | | |
| DC | -0.04232 | to | -0.02347 |
| FL | -0.04211 | to | -0.00038 |
| FL | 0.00933 | | |
| GA | -0.03888 | to | -0.00724 |
| GA | 0.00222 | to | 0.02074 |
| IA | -0.03711 | to | -0.01016 |
| IA | 0.02933 | to | 0.06744 |
| ID | -0.01791 | | |
| IL | -0.0273 | to | -0.00265 |
| KY | -0.03072 | and | 0.01225 |
| LA | -0.02314 | to | -0.00319 |
| MA | -0.01701 | | |
| MD | -0.02163 | to | -0.00692 |
| MI | -0.03305 | to | -0.00253 |
| MN | -0.04381 | to | -0.01107 |
| MN | 0.00238 | | |
| MO | -0.04718 | | |
| MO | 0.00075 | to | 0.03882 |
| MS | -0.01732 | | |
| NC | -0.02475 | to | -0.00139 |
| NC | 0.00496 | | |
| NE | -0.01892 | | |
| NY | -0.0396 | | |
| OH | -0.03398 | to | -0.0037 |
| OR | -0.01355 | | |
| PA | -0.04362 | | |
| SC | 0.01177 | | |
| TN | -0.01908 | to | -0.00572 |
| TX | -0.0845 | to | -0.01101 |
| TX | 0.01218 | to | 0.01369 |
| VA | -0.09203 | to | -0.01039 |
| VA | 0.00855 | | |
| WA | -0.02758 | to | -0.01922 |

Average Second Slope Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | -0.09203 | to | -0.00263 |
| Bachelor | 0.00075 | to | 0.03682 |
| Grammar | -0.01016 | and | 0.06744 |
| High School | -0.03305 | to | -0.00572 |
| High School | 0.00933 | to | 0.02933 |
| Master | -0.04718 | to | -0.00038 |
| Master | 0.00295 | to | 0.03882 |
| MD | -0.0273 | to | -0.00265 |
| PHD | -0.04163 | to | -0.0037 |
| Some college | -0.0845 | to | -0.00139 |
| Some college | 0.00077 | to | 0.01218 |
| Vocational | -0.02185 | | |

| Area | | | |
|---|---|---|---|
| Rural | -0.04657 | to | -0.00265 |
| Rural | 0.00077 | | |
| Small Town | -0.09203 | to | -0.00038 |
| Small Town | 0.00142 | to | 0.03682 |
| Suburb | -0.0845 | to | -0.00139 |
| Suburb | 0.00075 | to | 0.06744 |
| Urban | -0.04718 | to | -0.00247 |
| Urban | 0.00738 | to | 0.02933 |

| **Height** | | | |
|---|---|---|---|
| 4.0-5.0 | -0.0845 | to | -0.01101 |
| 4.0-5.0 | 0.01113 | | |
| 5.1-5.3 | -0.04649 | to | -0.0149 |
| 5.1-5.3 | 0.00077 | to | 0.03682 |
| 5.4-5.6 | -0.09203 | to | -0.00038 |
| 5.4-5.6 | 0.00238 | to | 0.03513 |
| 5.7-5.9 | -0.0599 | to | -0.00139 |
| 5.7-5.9 | 0.00222 | to | 0.06744 |
| 5.10-6.0 | -0.03745 | to | -0.00253 |
| 5.10-6.0 | 0.00075 | to | 0.03527 |
| 6.1-6.3 | -0.03548 | to | -0.00265 |
| 6.4-6.6 | -0.00263 | | |
| 6.7-6.9 | -0.01488 | | |
| 6.10-7.0 | -0.00816 | | |

## Average Second Y Distance

| Gender | | | |
|---|---|---|---|
| Female | 0.76482 | to | 20.11604 |
| Male | 1.06771 | to | 9.62666 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 1.53423 | to | 9.16597 |
| Asian | 1.81319 | to | 8.46621 |
| Hispanic | 1.88871 | to | 6.26574 |
| White | 0.76482 | to | 20.11604 |

| State | | | |
|---|---|---|---|
| AL | 0.76482 | to | 18.98124 |
| CA | 2.19067 | to | 10.75513 |
| CO | 4.46694 | | |
| DC | 1.70472 | to | 6.59579 |
| FL | 3.20572 | to | 9.62666 |
| GA | 3.85139 | to | 7.79519 |
| IA | 1.06771 | to | 7.37868 |
| ID | 2.83795 | | |
| IL | 3.09743 | to | 6.44515 |
| KY | 4.94241 | to | 7.51344 |
| LA | 1.68953 | to | 2.76435 |
| MA | 3.27227 | | |
| MD | 5.3831 | to | 9.16597 |
| MI | 2.11142 | to | 6.26574 |
| MN | 1.76756 | to | 7.2374 |
| MO | 5.13771 | to | 8.50846 |
| MS | 6.75352 | | |
| NC | 5.08627 | to | 8.36667 |
| NE | 2.02068 | | |
| NY | 9.16335 | | |
| OH | 1.53423 | to | 5.33724 |
| OR | 1.88871 | | |
| PA | 6.88837 | | |
| SC | 7.37903 | | |
| TN | 3.22839 | | |
| TX | 2.63324 | to | 11.10742 |
| VA | 1.76285 | to | 5.2077 |
| WA | 3.10199 | to | 6.96012 |

## Average Second Y Distance Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | 1.68953 | to | 18.98124 |
| Grammar | 1.06771 | | |
| High School | 3.22839 | to | 11.40787 |
| Master | 0.76482 | to | 15.10384 |
| MD | 3.09743 | to | 6.44515 |
| PHD | 1.53423 | to | 5.33724 |
| Some college | 1.30732 | to | 16.67643 |
| Vocational | 3.93314 | | |

| Area | | | |
|---|---|---|---|
| Rural | 2.48434 | to | 12.7076 |
| Small Town | 1.09057 | to | 17.44381 |
| Suburb | 1.30732 | to | 18.98124 |
| Urban | 0.76482 | to | 11.10742 |

| Height | | | |
|---|---|---|---|
| 4.0-5.0 | 3.27227 | to | 5.97455 |
| 5.1-5.3 | 2.48434 | to | 16.67643 |
| 5.4-5.6 | 1.30732 | to | 16.62409 |
| 5.7-5.9 | 1.53423 | to | 20.11604 |
| 5.10-6.0 | 1.06771 | to | 8.46621 |
| 6.1-6.3 | 0.76482 | to | 7.2374 |
| 6.4-6.6 | 5.65771 | | |
| 6.7-6.9 | 8.42994 | | |
| 6.10-7.0 | 2.82452 | | |

**Total Second Y Distance**

| Gender | | | |
|---|---|---|---|
| Female | 9.22929 | to | 125.33082 |
| Male | 14.6623 | to | 102.74155 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 31.21441 | to | 73.10173 |
| Asian | 21.76651 | to | 26.58681 |
| Hispanic | 36.28649 | to | 39.22791 |
| White | 9.22929 | to | 84.39188 |

| State | | | |
|---|---|---|---|
| AL | 15.0501 | to | 83.69464 |
| CA | 21.27234 | to | 36.28649 |
| CO | 21.51626 | | |
| DC | 40.44849 | | |
| FL | 64.77386 | to | 73.10173 |
| GA | 58.55602 | to | 63.5027 |
| IA | 32.68834 | to | 38.24517 |
| ID | 21.63775 | | |
| IL | 9.22929 | | |
| KY | 27.36293 | | |
| LA | 20.66605 | | |
| MA | 74.36435 | | |
| MD | 31.21441 | to | 31.91552 |
| MN | 58.65523 | to | 61.37713 |
| MO | 75.72876 | to | 81.3068 |
| MS | 25.6336 | | |
| NE | 14.6623 | | |
| NY | 14.52795 | | |
| OH | 41.07338 | to | 42.37182 |
| OR | 58.74272 | | |
| PA | 58.8329 | | |
| TN | 35.76295 | | |
| TX | 40.51476 | to | 43.82436 |
| WA | 32.10158 | | |

## Total Second Y Distance Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | 20.66605 | to | 83.69464 |
| Grammar | 63.10697 | and | 125.33082 |
| High School | 35.76295 | to | 38.24517 |
| Master | 15.0501 | to | 82.374 |
| MD | 9.22929 | and | 42.43057 |
| PHD | 32.68834 | to | 48.42309 |
| Some college | 20.67707 | to | 74.3866 |
| Vocational | 161.03839 | | |

| Area | | | |
|---|---|---|---|
| Rural | 22.50552 | to | 24.90808 |
| Small Town | 18.81512 | to | 62.91221 |
| Suburb | 14.52795 | to | 84.39188 |
| Urban | 9.22929 | to | 58.65074 |

| Height | | | |
|---|---|---|---|
| 4.0-5.0 | 72.65738 | to | 74.36435 |
| 5.1-5.3 | 9.22929 | to | 63.5027 |
| 5.4-5.6 | 20.66605 | to | 84.30005 |
| 5.7-5.9 | 20.67707 | to | 75.72876 |
| 5.10-6.0 | 24.90808 | to | 59.23719 |
| 6.1-6.3 | 21.63775 | to | 32.68834 |
| 6.4-6.6 | 59.91936 | | |
| 6.7-6.9 | 140.9927 | | |
| 6.10-7.0 | 27.18616 | | |

## Average Second X Distance

| Gender | | | |
|---|---|---|---|
| Female | 78.18906 | to | 182.41839 |
| Male | 76.49549 | to | 142.53808 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 76.49549 | to | 142.83182 |
| Asian | 97.96869 | to | 102.7372 |
| Hispanic | 101.67403 | to | 104.70597 |
| White | 84.47018 | to | 180.62882 |

| State | | | |
|---|---|---|---|
| AL | 83.52587 | to | 180.62882 |
| CA | 93.86788 | to | 97.54918 |
| CO | 101.84681 | | |
| DC | 92.63231 | and | 117.7726 |
| FL | 101.67403 | to | 135.86438 |
| GA | 98.65994 | to | 102.18956 |
| IA | 104.38275 | to | 112.15444 |
| ID | 119.96576 | | |
| IL | 131.11741 | and | 142.0346 |
| KY | 87.8971 | and | 162.67324 |
| LA | 92.7988 | and | 131.01533 |
| MA | 166.78481 | | |
| MD | 142.83182 | and | 192.91273 |
| MI | 101.20673 | to | 105.40881 |
| MN | 99.06263 | to | 100.07749 |
| MO | 95.36461 | and | 104.98533 |
| MS | 108.14805 | and | 137.36484 |
| NC | 112.75407 | to | 113.76038 |
| NE | 104.2441 | | |
| NY | 129.1797 | | |
| OH | 95.10007 | to | 97.40779 |
| OR | 108.4114 | | |
| PA | 116.5901 | | |
| SC | 136.18319 | | |
| TN | 122.46823 | and | 170.94108 |
| TX | 87.69269 | to | 91.1281 |
| VA | 122.15614 | to | 123.55207 |
| WA | 101.9961 | and | 128.97889 |

## Second X Distance Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | 83.52587 | to | 179.62909 |
| Grammar | 99.57493 | and | 112.15444 |
| High School | 104.38275 | to | 125.98373 |
| Master | 94.0926 | to | 156.35884 |
| MD | 131.11741 | and | 142.0346 |
| PHD | 87.69269 | to | 134.07075 |
| Some college | 93.06539 | to | 128.6602 |
| Vocational | 99.70921 | | |

| Area | | | |
|---|---|---|---|
| Rural | 99.68339 | to | 132.10784 |
| Small Town | 76.49549 | to | 171.02154 |
| Suburb | 85.73891 | to | 142.83182 |
| Urban | 89.31884 | to | 123.55207 |

| Height | | | |
|---|---|---|---|
| 4.0-5.0 | 106.30586 | to | 108.39525 |
| 5.1-5.3 | 91.1281 | to | 143.74624 |
| 5.4-5.6 | 84.47018 | to | 142.83182 |
| 5.7-5.9 | 87.88233 | to | 137.36484 |
| 5.10-6.0 | 93.06539 | to | 125.15975 |
| 6.1-6.3 | 100.07749 | to | 131.11741 |
| 6.4-6.6 | 107.47803 | | |
| 6.7-6.9 | 97.96869 | | |
| 6.10-7.0 | 102.01642 | | |

## Average First Slope

| Gender | | | |
|---|---|---|---|
| Female | -0.06508 | to | -0.00009 |
| Female | 0.00085 | to | 0.06542 |
| Male | -0.03581 | to | -0.00002 |
| Male | 0.00069 | to | 0.03931 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | -0.03077 | to | -0.00002 |
| African Am | 0.00172 | to | 0.02396 |
| Asian | -0.02027 | to | -0.00341 |
| Asian | 0.02443 | | |
| Hispanic | -0.01544 | to | -0.0013 |
| Hispanic | 0.00456 | to | 0.02385 |
| White | -0.06508 | to | -0.00009 |
| White | 0.00069 | to | 0.06542 |

## Average First Slope Continued...

| State | | | |
|---|---|---|---|
| AL | -0.06508 | to | -0.00064 |
| AL | 0.00069 | to | 0.05792 |
| CA | -0.03278 | to | -0.00017 |
| CA | 0.01528 | to | 0.03931 |
| CO | -0.0201 | | |
| DC | -0.01278 | to | -0.00919 |
| FL | -0.01494 | to | -0.00165 |
| FL | 0.00098 | to | 0.00172 |
| GA | -0.02813 | to | -0.00821 |
| GA | 0.00271 | | |
| IA | -0.02583 | to | -0.00276 |
| IA | 0.00086 | to | 0.03344 |
| ID | -0.00708 | | |
| IL | -0.01453 | to | -0.0063 |
| KY | -0.01113 | to | -0.00061 |
| LA | -0.01003 | to | -0.00009 |
| MA | 0.0454 | | |

| | | | |
|---|---|---|---|
| MD | 0.00816 | to | 0.01769 |
| MI | -0.00002 | | |
| MI | 0.01623 | to | 0.03491 |
| MN | -0.01046 | to | -0.00175 |
| MN | 0.0096 | to | 0.01316 |
| MO | 0.00184 | to | 0.01882 |
| MS | 0.00305 | | |
| NC | -0.03077 | to | -0.00488 |
| NC | 0.00456 | to | 0.00705 |
| NE | 0.02295 | | |
| NY | -0.03553 | | |
| OH | -0.02016 | to | -0.00147 |
| OH | 0.0067 | | |
| OR | -0.0013 | | |
| PA | -0.01717 | | |
| SC | -0.01212 | | |
| TN | 0.00085 | to | 0.01455 |
| TX | -0.05697 | to | -0.00385 |
| TX | 0.01909 | to | 0.02585 |
| VA | -0.03581 | to | -0.00131 |
| VA | 0.02055 | | |
| WA | -0.02093 | and | 0.06542 |

## Average First Slope Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | -0.05697 | to | -0.00009 |
| Bachelor | 0.00069 | to | 0.06542 |
| Grammar | -0.0243 | to | -0.00525 |
| High School | -0.02119 | to | -0.00276 |
| High School | 0.00085 | to | 0.03491 |
| Master | -0.02417 | to | -0.00064 |
| Master | 0.00184 | to | 0.05792 |
| MD | -0.01453 | to | -0.0063 |
| PHD | -0.03581 | to | -0.00147 |
| PHD | 0.00098 | to | 0.02443 |
| Some college | -0.06508 | to | -0.00002 |
| Some college | 0.0027 | to | 0.05175 |
| Vocational | -0.02403 | | |

| Area | | | |
|---|---|---|---|
| Rural | -0.03097 | to | -0.00341 |
| Rural | 0.01476 | to | 0.03491 |
| Small Town | -0.06508 | to | -0.00002 |
| Small Town | 0.00085 | to | 0.06542 |
| Suburb | -0.05697 | to | -0.00017 |
| Suburb | 0.00069 | to | 0.04558 |
| Urban | -0.02583 | to | -0.00147 |
| Urban | 0.00086 | to | 0.03344 |

| Height | | | |
|---|---|---|---|
| 4.0-5.0 | -0.02583 | | |
| 4.0-5.0 | 0.02501 | to | 0.0454 |
| 5.1-5.3 | -0.03278 | to | -0.00009 |
| 5.1-5.3 | 0.00271 | to | 0.06542 |
| 5.4-5.6 | -0.06508 | to | -0.00017 |
| 5.4-5.6 | 0.00085 | to | 0.02385 |
| 5.7-5.9 | -0.05697 | to | -0.00276 |
| 5.7-5.9 | 0.00086 | to | 0.05792 |
| 5.10-6.0 | -0.03581 | to | -0.00002 |
| 5.10-6.0 | 0.00098 | to | 0.0194 |
| 6.1-6.3 | -0.02093 | to | -0.00536 |
| 6.1-6.3 | 0.00069 | to | 0.01094 |
| 6.4-6.6 | -0.00443 | | |
| 6.7-6.9 | -0.01882 | | |
| 6.10-7.0 | -0.00476 | | |

## Average Slope Between Points

| Gender | | | |
|---|---|---|---|
| Female | -0.027925 | to | -0.000141 |
| Female | 0.000187 | to | 0.066688 |
| Male | -0.026729 | to | -0.000343 |
| Male | 0.000795 | to | 0.013462 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | -0.017488 | to | -0.000981 |
| African Am | 0.002743 | to | 0.012799 |
| Asian | -0.017617 | to | -0.002208 |
| Hispanic | -0.020726 | to | -0.002527 |
| Hispanic | 0.008018 | to | |
| White | -0.027925 | to | -0.000141 |
| White | 0.000187 | to | 0.066688 |

**Average Slope Between Points Continued...**

| State | | | |
|---|---|---|---|
| AL | -0.026729 | to | -0.000141 |
| AL | 0.000215 | to | 0.008716 |
| CA | -0.020726 | to | -0.006276 |
| CA | 0.000187 | to | 0.013462 |
| CO | -0.013631 | | |
| DC | -0.012747 | to | -0.012487 |
| FL | -0.01753 | to | -0.002527 |
| GA | -0.027925 | to | -0.003762 |
| GA | 0.007189 | | |
| IA | -0.021166 | to | -0.003804 |
| ID | -0.007681 | | |
| IL | -0.015346 | and | 0.002814 |
| KY | -0.015761 | to | -0.015108 |
| LA | -0.005995 | to | -0.003574 |
| MA | -0.010597 | | |
| MD | -0.009174 | and | 0.012799 |
| MI | -0.022877 | to | -0.003417 |
| MI | 0.008018 | | |
| MN | -0.019799 | to | -0.001587 |

| | | | |
|---|---|---|---|
| MO | -0.005814 | to | -0.001373 |
| MS | -0.010884 | | |
| NC | -0.009676 | to | -0.005234 |
| NC | 0.002364 | | |
| NE | 0.000795 | | |
| NY | -0.00867 | | |
| OH | -0.012849 | to | -0.002632 |
| OR | -0.013285 | | |
| PA | -0.0158 | | |
| SC | -0.000981 | | |
| TN | -0.002764 | and | 0.003036 |
| TX | -0.018391 | to | -0.000344 |
| TX | 0.001582 | to | 0.002319 |
| VA | -0.010248 | to | -0.00246 |
| VA | 0.066688 | | |
| WA | -0.008811 | and | 0.002016 |

## Average Slope Between Points Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | -0.027925 | to | -0.000141 |
| Bachelor | 0.002319 | to | 0.066688 |
| Grammar | -0.010519 | to | -0.003804 |
| High School | -0.022877 | to | -0.006276 |
| High School | 0.003036 | | |
| Master | -0.026246 | to | -0.001089 |
| Master | 0.000215 | to | 0.012799 |
| MD | -0.015346 | and | 0.002814 |
| PHD | -0.018391 | to | -0.000343 |
| PHD | 0.000795 | | |
| Some college | -0.02123 | to | -0.00184 |
| Some college | 0.000187 | to | 0.002513 |
| Vocational | 0.002743 | | |

| Area | | | |
|---|---|---|---|
| Rural | -0.022877 | to | -0.005032 |
| Rural | 0.002814 | | |
| Small Town | -0.026246 | to | -0.000343 |
| Small Town | 0.000795 | to | 0.066688 |
| Suburb | -0.027925 | to | -0.000141 |
| Suburb | 0.000187 | to | 0.013462 |
| Urban | -0.021166 | to | -0.001587 |
| Urban | 0.000215 | to | 0.002319 |

| Height | | | |
|---|---|---|---|
| 4.0-5.0 | -0.020907 | to | -0.010597 |
| 4.0-5.0 | 0.001582 | | |
| 5.1-5.3 | -0.027925 | to | -0.000981 |
| 5.1-5.3 | 0.002319 | | |
| 5.4-5.6 | -0.026729 | to | -0.000344 |
| 5.4-5.6 | 0.000215 | to | 0.066688 |
| 5.7-5.9 | -0.025951 | to | -0.000343 |
| 5.7-5.9 | 0.000187 | to | 0.002513 |
| 5.10-6.0 | -0.026246 | to | -0.000141 |
| 5.10-6.0 | 0.002743 | to | 0.008716 |
| 6.1-6.3 | -0.019756 | to | -0.004101 |
| 6.1-6.3 | 0.002016 | to | 0.002814 |
| 6.4-6.6 | -0.002208 | | |
| 6.7-6.9 | -0.00753 | | |
| 6.10-7.0 | -0.012586 | | |

## Average Difference Between Points

| Gender | | | |
|---|---|---|---|
| Female | 127.2556 | to | 399.7623 |
| Male | 133.392 | to | 482.5931 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 152.3675 | to | 301.8281 |
| Asian | 183.6524 | to | 371.154 |
| Hispanic | 159.1971 | to | 265.7289 |
| White | 133.392 | to | 482.5931 |

| State | | | |
|---|---|---|---|
| AL | 133.392 | to | 482.5931 |
| CA | 181.1088 | to | 327.0401 |
| CO | 201.214 | | |
| DC | 199.3032 | to | 277.4044 |
| FL | 152.3675 | to | 259.496 |
| GA | 127.2556 | to | 326.1891 |
| IA | 168.036 | to | 388.1414 |
| ID | 198.5997 | | |
| IL | 195.3549 | to | 265.8221 |
| KY | 205.1516 | to | 278.3755 |
| LA | 207.8237 | to | 224.2535 |
| MA | 186.3697 | | |
| MD | 243.7944 | to | 256.8543 |
| MI | 159.1971 | to | 254.0115 |
| MN | 173.2406 | to | 278.3502 |
| MO | 225.3363 | to | 356.8013 |
| MS | 156.3135 | | |
| NC | 142.1766 | to | 237.0423 |
| NE | 232.1382 | | |
| NY | 286.2156 | | |
| OH | 170.7894 | to | 246.116 |
| OR | 256.2844 | | |
| PA | 227.4499 | | |
| SC | 159.1133 | | |
| TN | 250.8339 | to | 399.7623 |
| TX | 159.6963 | to | 265.6611 |
| VA | 161.8613 | to | 316.4243 |
| WA | 219.7375 | to | 248.5473 |

## Average Difference Between Points Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | 159.1133 | to | 371.154 |
| Grammar | 168.036 | to | 242.9888 |
| High School | 193.7717 | to | 388.1414 |
| Master | 133.392 | to | 482.5931 |
| MD | 195.3549 | to | 265.8221 |
| PHD | 159.6963 | to | 306.7029 |
| Some college | 127.2556 | to | 349.0001 |
| Vocational | 247.1431 | | |

| Area | | | |
|---|---|---|---|
| Rural | 171.9593 | to | 349.0001 |
| Small Town | 127.2556 | to | 482.5931 |
| Suburb | 133.392 | to | 356.8013 |
| Urban | 168.036 | to | 399.7623 |

| Height | | | |
|---|---|---|---|
| 4 to 5 | 186.3697 | to | 308.6529 |
| 5.1 to 5.3 | 159.1133 | to | 346.3599 |
| 5.4 to 5.6 | 159.1971 | to | 399.7623 |
| 5.7 to 5.9 | 127.2556 | to | 388.1414 |
| 5.10 to 6.0 | 145.1255 | to | 482.5931 |
| 6.1 to 6.3 | 156.3135 | to | 367.2222 |
| 6.4 to 6.6 | 221.1146 | | |
| 6.7 to 6.9 | 184.2821 | | |
| 6.10 to 7.0 | 133.392 | | |

## Difference For Y

| Gender | | | |
|---|---|---|---|
| Female | 3.1695 | to | 24.202 |
| Male | 4.6963 | to | 25.4026 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 3.1695 | to | 24.5502 |
| Asian | 9.9157 | to | 18.0594 |
| Hispanic | 4.3011 | to | 17.2095 |
| White | 3.5783 | to | 25.4026 |

| State | | | |
|---|---|---|---|
| AL | 3.1695 | to | 25.4026 |
| CA | 9.8764 | to | 21.414 |
| CO | 12.6157 | | |
| DC | 12.6416 | to | 16.149 |
| FL | 9.217 | to | 21.5992 |
| GA | 5.8614 | to | 16.7694 |
| IA | 8.2849 | to | 24.1218 |
| ID | 14.29 | | |
| IL | 12.6083 | to | 21.7575 |
| KY | 16.3881 | to | 18.3383 |
| LA | 7.6347 | to | 7.8482 |
| MA | 15.7179 | | |
| MD | 16.7983 | | |
| MI | 4.3011 | to | 23.099 |
| MN | 3.8212 | to | 19.9132 |
| MO | 9.1064 | to | 11.3593 |
| MS | 16.5769 | | |
| NC | 6.1231 | to | 17.9883 |
| NE | 19.4994 | | |
| NY | 19.5033 | | |
| OH | 6.7098 | to | 24.5502 |
| OR | 17.2095 | | |
| PA | 15.2904 | to | |
| SC | 16.2137 | to | |
| TN | 8.195 | to | 11.8413 |
| TX | 6.0749 | to | 21.0472 |
| VA | 6.5411 | to | 18.2006 |
| WA | 7.2793 | to | 15.9411 |

## Difference For Y Continued...

| Education | | | |
|---|---|---|---|
| Bachelor | 3.8212 | to | 24.202 |
| Grammar | 12.1297 | to | 13.8139 |
| High School | 8.7087 | to | 24.1218 |
| Master | 3.1695 | to | 25.4026 |
| MD | 12.6083 | to | 21.7575 |
| PHD | 6.7098 | to | 24.5502 |
| Some college | 3.5783 | to | 21.414 |
| Vocational | 15.2961 | | |

| Area | | | |
|---|---|---|---|
| Rural | 4.6963 | to | 23.099 |
| Small Town | 3.5783 | to | 25.4026 |
| Suburb | 3.1695 | to | 21.414 |
| Urban | 3.8212 | to | 24.1218 |

| Height | | | |
|---|---|---|---|
| 4 to 5 | 12.0287 | to | 17.1356 |
| 5.1 to 5.3 | 3.1695 | to | 23.099 |
| 5.4 to 5.6 | 3.8212 | to | 24.202 |
| 5.7 to 5.9 | 4.6963 | to | 24.5502 |
| 5.10 to 6.0 | 6.7098 | to | 25.4026 |
| 6.1 to 6.3 | 9.4881 | to | 21.7575 |
| 6.4 to 6.6 | 10.5669 | | |
| 6.7 to 6.9 | 13.9175 | | |
| 6.10 to 7.0 | 14.0919 | | |

## Difference For X

| Gender | | | |
|---|---|---|---|
| Female | 429.6875 | to | 1371.0938 |
| Male | 542.9688 | to | 1328.125 |

| Ethnicity | | | |
|---|---|---|---|
| African Am | 710.9375 | to | 1371.0938 |
| Asian | 757.8125 | to | 1285.1563 |
| Hispanic | 542.9688 | to | 1281.25 |
| White | 429.6875 | to | 1328.125 |

| **State** | | | |
|---|---|---|---|
| AL | 621.0938 | to | 1285.1563 |
| CA | 542.9688 | to | 1230.4688 |
| CO | 1207.0313 | | |
| DC | 996.0938 | to | 1109.375 |
| FL | 968.75 | to | 1296.875 |
| GA | 429.6875 | to | 1371.0938 |
| IA | 671.875 | to | 1226.5625 |
| ID | 1191.4063 | | |
| IL | 976.5625 | to | 1328.125 |
| KY | 820.3125 | to | 1113.2813 |
| LA | 1039.0625 | to | 1121.0938 |
| MA | 1117.1875 | | |
| MD | 1218.75 | to | 1281.25 |
| MI | 636.7188 | to | 1125 |
| MN | 832.0313 | to | 1148.4375 |
| MO | 675.7813 | to | 1164.0625 |
| MS | 1093.75 | | |
| NC | 648.4375 | to | 1277.3438 |
| NE | 1160.1563 | | |
| NY | 1144.5313 | | |
| OH | 984.375 | to | 1195.3125 |
| OR | 1281.25 | | |
| PA | 1136.7188 | | |
| SC | 1113.2813 | | |
| TN | 1199.2188 | to | 1253.9063 |
| TX | 531.25 | to | 1195.3125 |
| VA | 894.5313 | to | 1132.8125 |
| WA | 878.9063 | to | 1242.1875 |

## Difference For X Continued...

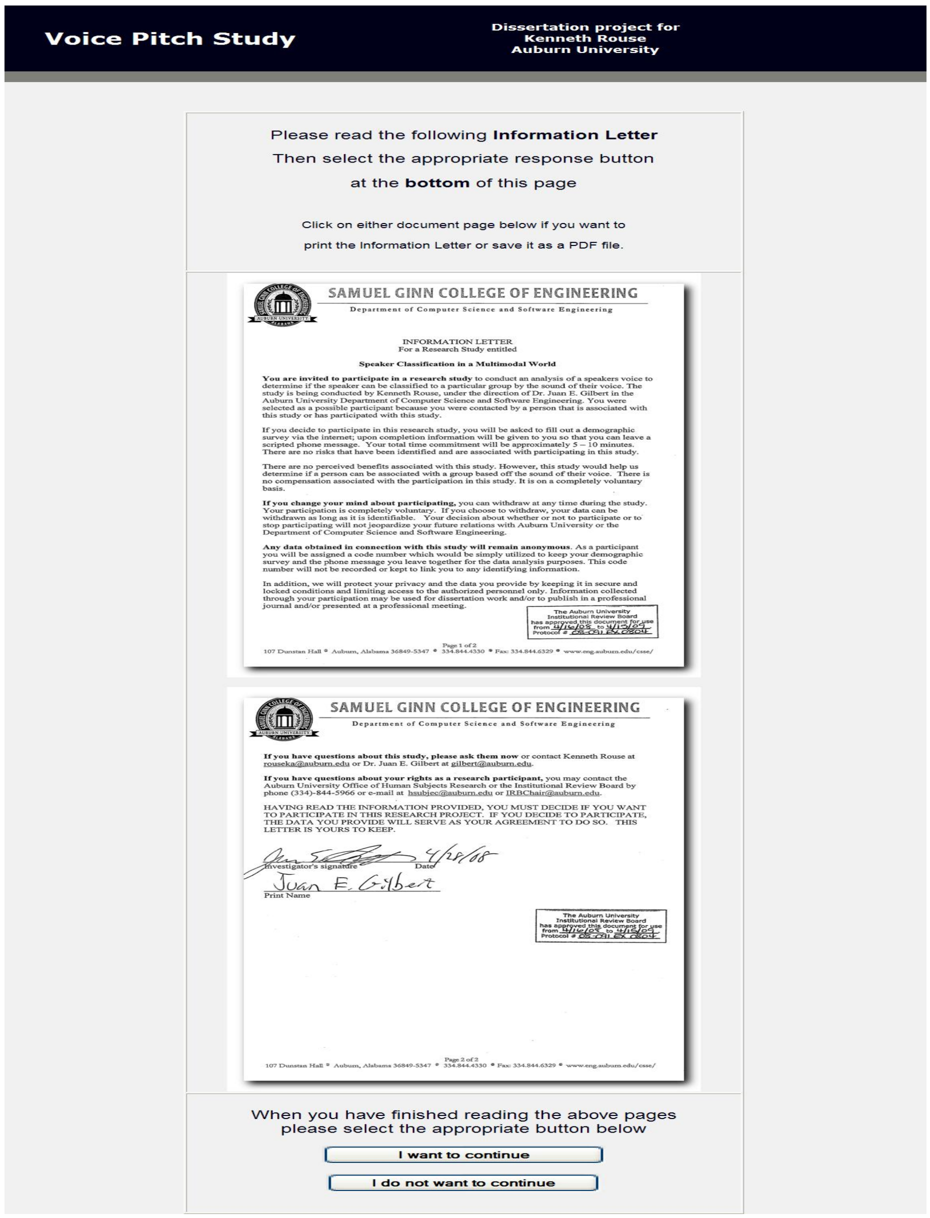
| Education | | | |
|---|---|---|---|
| Bachelor | 429.6875 | to | 1296.875 |
| Grammar | 671.875 | to | 1214.8438 |
| High School | 828.125 | to | 1253.9063 |
| Master | 675.7813 | to | 1371.0938 |
| MD | 976.5625 | to | 1328.125 |
| PHD | 757.8125 | to | 1285.1563 |
| Some college | 621.0938 | to | 1277.3438 |
| Vocational | 988.2813 | | |

| Area | | | |
|---|---|---|---|
| Rural | 621.0938 | to | 1328.125 |
| Small Town | 648.4375 | to | 1296.875 |
| Suburb | 429.6875 | to | 1371.0938 |
| Urban | 542.9688 | to | 1199.2188 |

| Height | | | |
|---|---|---|---|
| 4 to 5 | 925.7813 | to | 1195.3125 |
| 5.1 to 5.3 | 429.6875 | to | 1238.2813 |
| 5.4 to 5.6 | 542.9688 | to | 1371.0938 |
| 5.7 to 5.9 | 531.25 | to | 1285.1563 |
| 5.10 to 6.0 | 671.875 | to | 1250 |
| 6.1 to 6.3 | 722.6563 | to | 1328.125 |
| 6.4 to 6.6 | 1105.4688 | | |
| 6.7 to 6.9 | 1105.4688 | | |
| 6.10 to 7.0 | 933.5938 | | |

# Appendix B

## Screen Shots of HTML Pages Used For Data Collection



Voice Pitch Study

Dissertation project for
Kenneth Rouse
Auburn University

Please read the following **Information Letter**
Then select the appropriate response button
at the **bottom** of this page

Click on either document page below if you want to
print the Information Letter or save it as a PDF file.

SAMUEL GINN COLLEGE OF ENGINEERING
Department of Computer Science and Software Engineering

INFORMATION LETTER
For a Research Study entitled

**Speaker Classification in a Multimodal World**

**You are invited to participate in a research study** to conduct an analysis of a speakers voice to determine if the speaker can be classified to a particular group by the sound of their voice. The study is being conducted by Kenneth Rouse, under the direction of Dr. Juan E. Gilbert in the Auburn University Department of Computer Science and Software Engineering. You were selected as a possible participant because you were contacted by a person that is associated with this study or has participated with this study.

If you decide to participate in this research study, you will be asked to fill out a demographic survey via the internet; upon completion information will be given to you so that you can leave a scripted phone message. Your total time commitment will be approximately 5 – 10 minutes. There are no risks that have been identified and are associated with participating in this study.

There are no perceived benefits associated with this study. However, this study would help us determine if a person can be associated with a group based off the sound of their voice. There is no compensation associated with the participation in this study. It is on a completely voluntary basis.

**If you change your mind about participating,** you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the Department of Computer Science and Software Engineering.

**Any data obtained in connection with this study will remain anonymous**. As a participant you will be assigned a code number which would be simply utilized to keep your demographic survey and the phone message you leave together for the data analysis purposes. This code number will not be recorded or kept to link you to any identifying information.

In addition, we will protect your privacy and the data you provide by keeping it in secure and locked conditions and limiting access to the authorized personnel only. Information collected through your participation may be used for dissertation work and/or to publish in a professional journal and/or presented at a professional meeting.

The Auburn University Institutional Review Board has approved this document for use from 4/16/08 to 4/15/09. Protocol # 08-091 EX 0804

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SAMUEL GINN COLLEGE OF ENGINEERING
Department of Computer Science and Software Engineering

**If you have questions about this study, please ask them now** or contact Kenneth Rouse at rouseka@auburn.edu or Dr. Juan E. Gilbert at gilbert@auburn.edu.

**If you have questions about your rights as a research participant,** you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. IF YOU DECIDE TO PARTICIPATE, THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

Investigator's signature    Date 4/28/08

Juan E. Gilbert
Print Name

The Auburn University Institutional Review Board has approved this document for use from 4/16/08 to 4/15/09. Protocol # 08-091 EX 0804

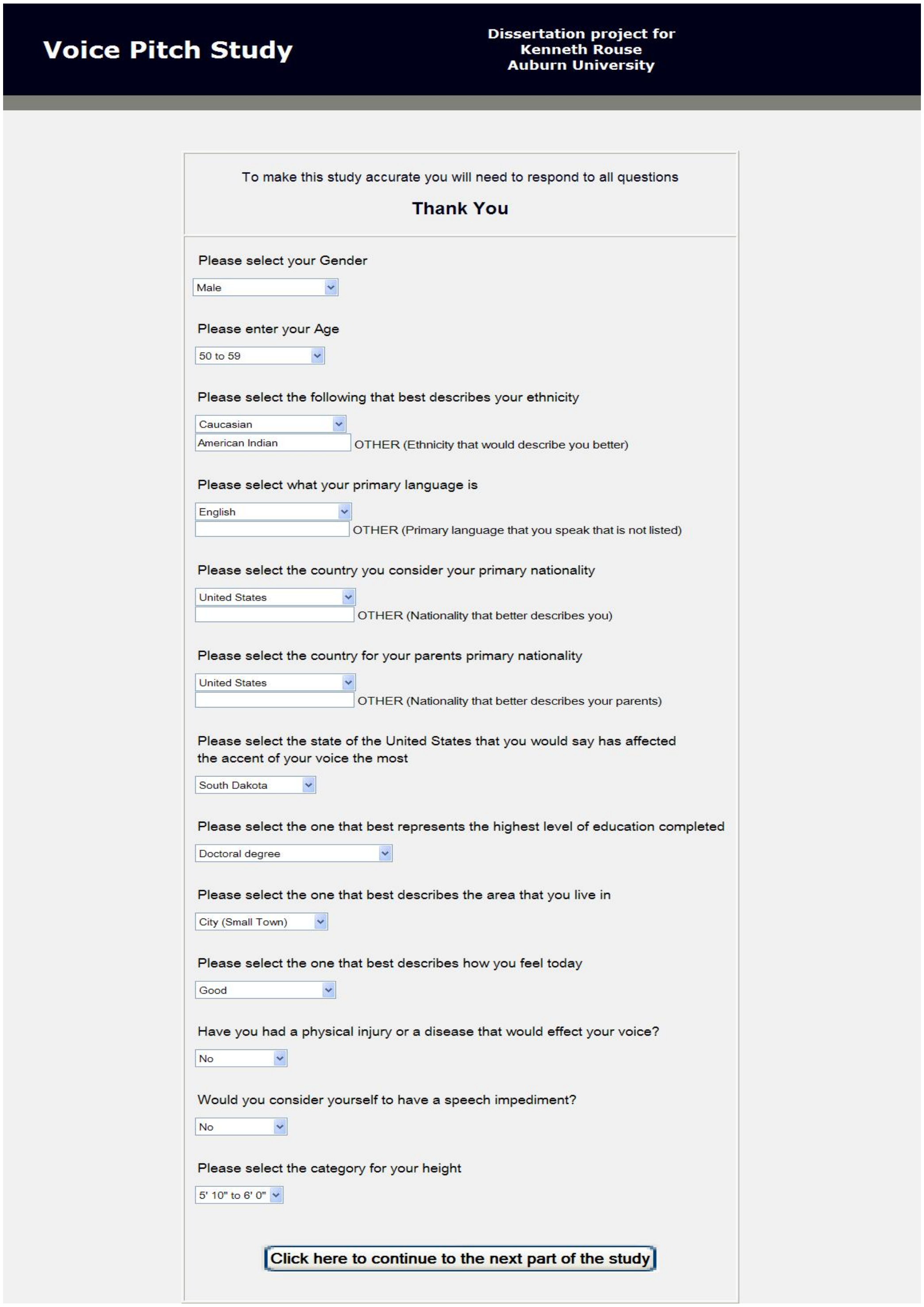
Page 2 of 2
107 Dunstan Hall • Auburn, Alabama 36849-5347 • 334.844.4330 • Fax: 334.844.6329 • www.eng.auburn.edu/csse/

When you have finished reading the above pages
please select the appropriate button below

I want to continue

I do not want to continue

Figure B.1: This is the information page from data gathering website



Voice Pitch Study

Dissertation project for
Kenneth Rouse
Auburn University

To make this study accurate you will need to respond to all questions

**Thank You**

Please select your Gender

Male

Please enter your Age

50 to 59

Please select the following that best describes your ethnicity

Caucasian

American Indian OTHER (Ethnicity that would describe you better)

Please select what your primary language is

English

OTHER (Primary language that you speak that is not listed)

Please select the country you consider your primary nationality

United States

OTHER (Nationality that better describes you)

Please select the country for your parents primary nationality

United States

OTHER (Nationality that better describes your parents)

Please select the state of the United States that you would say has affected the accent of your voice the most

South Dakota

Please select the one that best represents the highest level of education completed

Doctoral degree

Please select the one that best describes the area that you live in

City (Small Town)

Please select the one that best describes how you feel today

Good

Have you had a physical injury or a disease that would effect your voice?

No

Would you consider yourself to have a speech impediment?

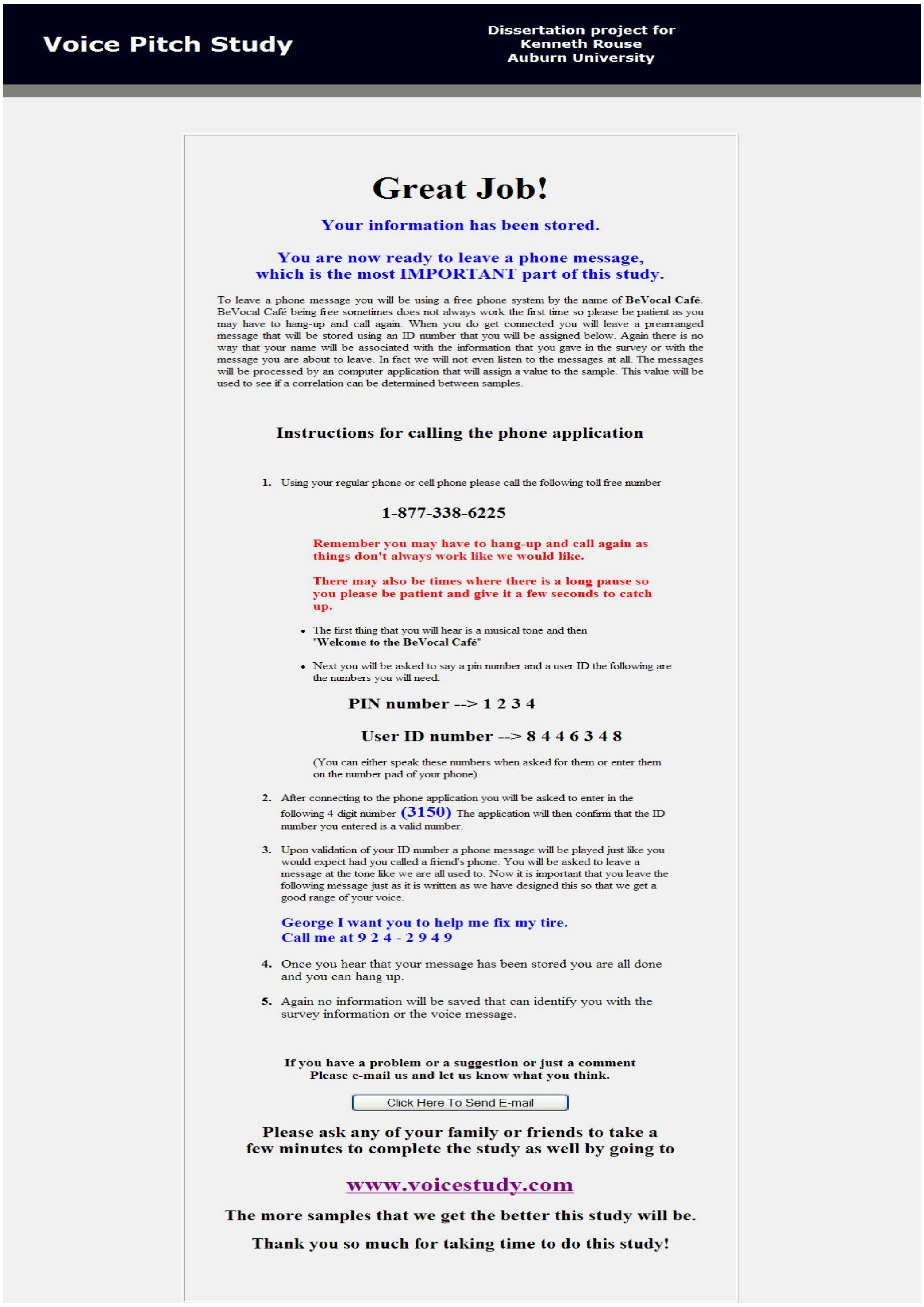
No

Please select the category for your height

5' 10" to 6' 0"

Click here to continue to the next part of the study

Figure B.2: This is the Demographic Survey page from data gathering website



**Voice Pitch Study**

**Dissertation project for**
**Kenneth Rouse**
**Auburn University**

# Great Job!

**Your information has been stored.**

**You are now ready to leave a phone message, which is the most IMPORTANT part of this study.**

To leave a phone message you will be using a free phone system by the name of **BeVocal Café**. BeVocal Café being free sometimes does not always work the first time so please be patient as you may have to hang-up and call again. When you do get connected you will leave a prearranged message that will be stored using an ID number that you will be assigned below. Again there is no way that your name will be associated with the information that you gave in the survey or with the message you are about to leave. In fact we will not even listen to the messages at all. The messages will be processed by an computer application that will assign a value to the sample. This value will be used to see if a correlation can be determined between samples.

## Instructions for calling the phone application

1. Using your regular phone or cell phone please call the following toll free number

   **1-877-338-6225**

   **Remember you may have to hang-up and call again as things don't always work like we would like.**

   **There may also be times where there is a long pause so you please be patient and give it a few seconds to catch up.**

   - The first thing that you will hear is a musical tone and then **"Welcome to the BeVocal Café"**
   - Next you will be asked to say a pin number and a user ID the following are the numbers you will need:

   **PIN number --> 1 2 3 4**

   **User ID number --> 8 4 4 6 3 4 8**

   (You can either speak these numbers when asked for them or enter them on the number pad of your phone)

2. After connecting to the phone application you will be asked to enter in the following 4 digit number **(3150)** The application will then confirm that the ID number you entered is a valid number.
3. Upon validation of your ID number a phone message will be played just like you would expect had you called a friend's phone. You will be asked to leave a message at the tone like we are all used to. Now it is important that you leave the following message just as it is written as we have designed this so that we get a good range of your voice.

   **George I want you to help me fix my tire.**
   **Call me at 9 2 4 - 2 9 4 9**

4. Once you hear that your message has been stored you are all done and you can hang up.
5. Again no information will be saved that can identify you with the survey information or the voice message.

**If you have a problem or a suggestion or just a comment**
**Please e-mail us and let us know what you think.**

Click Here To Send E-mail

**Please ask any of your family or friends to take a few minutes to complete the study as well by going to**

**www.voicestudy.com**

**The more samples that we get the better this study will be.**

**Thank you so much for taking time to do this study!**

Figure B.3: This is the Phone Instruction Page from data gathering website

- The first thing that you will hear is a musical tone and then **"Welcome to the BeVocal Café"**
- Next you will be asked to say a pin number and a user ID the following are the numbers you will need:

**PIN number --> 1 2 3 4**

**User ID number --> 8 4 4 6 3 4 8**

(You can either speak these numbers when asked for them or enter them on the number pad of your phone)

Figure B.4: User ID and PIN given on Phone Instruction Page from data gathering website

**2.** After connecting to the phone application you will be asked to enter in the following 4 digit number **(3150)** The application will then confirm that the ID number you entered is a valid number.

Figure B.5: Four (4) digit number given on Phone Instruction Page from data gathering website

**3.** Upon validation of your ID number a phone message will be played just like you would expect had you called a friend's phone. You will be asked to leave a message at the tone like we are all used to. Now it is important that you leave the following message just as it is written as we have designed this so that we get a good range of your voice.

**George I want you to help me fix my tire.**
**Call me at 9 2 4 - 2 9 4 9**

**4.** Once you hear that your message has been stored you are all done and you can hang up.

**5.** Again no information will be saved that can identify you with the survey information or the voice message.

Figure B.6: The message that all participants will leave located on the Phone Instruction Page from data gathering website