This is to certify that the

thesis entitled

Measurement of Fundamental Frequency via Acoustic and Inductive Microphones

presented by

Holly Beth Hochroth

has been accepted towards fulfillment of the requirements for

Master of Arts degree in Speech-Language Pathology

Major professor

Date July 27, 1993

MEASUREMENT OF FUNDAMENTAL FREQUENCY VIA ACOUSTIC AND INDUCTIVE MICROPHONES

By

Holly Beth Hochroth

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF ARTS

Audiology and Speech Sciences

1993

ABSTRACT

MEASURMENT OF FUNDAMENTAL FREQUENCY VIA ACOUSTIC AND INDUCTIVE MICROPHONES

By

Holly Beth Hochroth

The purpose of this study was to determine whether measurements of fundamental frequency derived from 2 different microphones were valid when compared to accepted acoustic measurements. This study involved 25 normal subjects. Acoustic data were collected via the hand-held Visi-Pitch microphone placed directly in front of the mouth. Frequency measurements derived from stroboscopic instrumentation were obtained via an inductive microphone placed on the surface of the neck on the thyroid lamina of the larynx. Both microphones were utilized simultaneously to elicit the same segment of voicing for the vowels /a/ and /i/. A strong positive correlation was found to exist between the frequency measurements obtained. The frequency differences between the measurements with each microphone indicated a statistically significant difference. Frequency differences obtained were < 1.0 Hz. The measurement of fundamental frequency of steady state vowels with the acoustic and inductive microphones were found to be clinically comparable.

dedicated to

Mark Scott Kluger

for being patient through the long nights

ACKNOWLEDGMENTS

My heartfelt appreciation goes to Dr. Peter LaPine, for spending so much time and effort in helping reach my goals; to Dr. Paul Cooke and Dr. Leo Deal for being on my thesis committee and for being so patient; to Ms. Jan Lewin, for allowing me to complete my research when I thought no one else would.

I want to thank my parents for allowing me the opportunity to explore all my options and to pursue all of my dreams. I could not have done this without both of you. To Mark, thanks for being there when I needed you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

Introduction

Introduction

Voice is usually the first audible indication of a person's gender, personality, health and even emotional state. A "shaky" voice can indicate nervousness, tension or fear. A speaker with a strong and clear voice may be perceived as having strength, confidence and security. Voice allows the listener to distinguish a person's gender and age. Children at young ages typically have high pitched voices; however, a high pitched voice similar to that of a child is inappropriate when produced by an adult (Colton and Casper, 1990). As a person ages, voice changes. If a large man has a very high pitched voice, similar to that of a woman or a child, his character may be judged as feminine, boyish or weak. First impressions are produced as soon as a person speaks; therefore, voice is an important part of an individual's personality.

Voice is also the first audible indication that there might be a physical problem in the larynx. Zemlin (1988) provides a description of the function of the larynx:

> The larynx is a modification of the uppermost tracheal cartilages. It forms a highly specialized valvular mechanism that may open or close the air passageway. An extremely important function of the larynx is to serve as a protective device. (p. 35)

Stemple (1984) described the larynx as "A tube with several folds. It is composed of ligaments, muscles, and mucous membranes" (p.13). The vocal folds are located within the larynx, and are located superior to the trachea, or wind pipe. Expired air from the trachea and lungs vibrates the vocal folds and produces sound.

The morphological structure of a vocal fold is described by Hirano (1974) as having five discrete layers: 1) the epithelium, which helps maintain the shape of the vocal fold; 2) the superficial layer of the lamina propria, also known as Reinke's space; 3) the intermediate layer of the lamina propria, consisting of elastic fibers that act like soft rubber bands; 4) the deep layer of the lamina propria, made up mostly of collagenous fibers; and 5) the vocalis muscle, the main body of the vocal fold (Zemlin, 1988). The structural properties of the vocal folds allows for elasticity to change during voice production. The vocal folds have the property of mass which varies for different persons, varies as a function of fundamental frequency, varies during the vibratory cycle, or varies when augmented by pathological growth or disease (Colton, 1988). When there is a change in the morphological structure of the vocal fold(s), normal production of voice is altered. A polyp, for example, adds mass to the vocal folds, thereby changing the normal vibration of the folds. As a result, a lower pitch and a change in vocal quality are produced. When voice is produced, it is typically perceived by a listener with respect to its quality, loudness and pitch (Colton and Casper, 1990). When a person speaks, these broad perceptual categories can be described by a listener. Adjectives are a necessary component in describing what a person's voice sounds like. Therefore, voice may be evaluated and described clinically using adjectives from these three categories.

Colton and Casper (1990) suggested the following eight terms to define the subjective parameters of quality: hoarseness and roughness, breathiness, tension, tremor, strain/struggle behavior, sudden interruption of voicing, and diplophonia. These differing vocal qualities can indicate various voice disorders. For example, a hoarse voice may result after shouting all day at an exciting football game. Physical changes like edema, or specifically swelling of the vocal folds, may be the culprit in this case. Any physical change to the vocal folds will affect the resulting vocal quality. The additional fluids present as swelling occurs makes normal vibration difficult.

Loudness is the psychological sensation that can be measured as intensity. Intensity is the physical property of an acoustic signal, and the loudness of that signal is related to its intensity (Borden and Harris, 1984). Loudness is a subjective measure because the ear does not hear all sounds with the same sensitivity (Martin, 1986). It is often necessary to adjust the loudness level of voice in various situations. For example, the loudness level of voice that is appropriate in a library is not appropriate in public speaking. Speech loudness level is regulated by the surroundings and auditory feedback in a person with normal hearing,.

Pitch is the psychological perception of frequency of vibration. Pitch can be described subjectively by a listener as being low or high, or audible. Although perception of quality, loudness and pitch perception are the first components in determining a voice disorder, viewing the vocal folds and the vocal tract allow for a more thorough diagnosis of the voice.

<u>Statement of the Problem</u>

Many different methods are available to evaluate and diagnose voice disorders. Subjective diagnostic methods are considered reliable but are not always considered valid. It is becoming increasingly important to have objective and valid methods with which professionals can measure voice and diagnose causal relationships. It is necessary to compare different measurements obtained by new diagnostic tools to determine validity and relevance for a thorough diagnosis and a subsequent therapy plan, if appropriate.

Some technology available today allows for viewing the vocal folds at both a normal rate of vocal fold vibration and at a seemingly slower rate able to extract a simultaneous measure of frequency. Measurement of voice production can be obtained with different types of endoscopes in combination with an instrument known as a synchronstroboscope. Boone and McFarlane (1988) described an endoscope as:

> An instrument that is introduced intraorally or intranasally; the light on the tip of the scope (which comes fiberoptically from an external light source) illuminates the nasal and oral pharynx that is viewed through a window lens on the tip of the endoscope. When the oral or nasal endoscope is attached to a small video camera, the examination is termed a videoendoscopic evaluation. When using a stroboscopic light source instead of a steady state light source, a slow motion observation of the vocal physiology is produced. (p.91-92)

Rigid oral endoscopes and flexible fiberoptic nasopharyngoscopes are used commonly today. Both the oral and nasal endoscopes are illuminated by an external light source. Watterson and McFarlane (1991) referred to these light sources as "cold lights" because heat is not transferred through the endoscope but is dispersed externally. Another light source used is the strobe light. Watterson and McFarlane (1991) stated that "Stroboscopic light sources illuminate the vocal folds at intervals corresponding to vocal frequency. Thus, while high-speed photography samples successive points within each vibratory cycle, stroboscopy samples successive points across vibratory cycles" (p.81). This light source allows the examiner to view the vocal folds and make determinations regarding structure, symmetry, and mucosal wave. The frequency of the strobe light is generated by the fundamental frequency that is produced. This is accomplished via the inductive microphone, connected by a cable to the synchronstroboscope, that is held against the neck at the level of the thyroid lamina of the larynx. In discussing fundamental frequency (F_0), it is important to keep in mind the source of the sound. Colton (1988) discussed the three physical properties of the vocal folds that affect fundamental frequency: tension, mass, and length. He stated that control of the vibrating frequency of the vocal folds is caused by manipulating one or more of these 3 properties. For each individual, the manipulation needed to change these properties of the vocal folds is different. There are differences in these 3 variables between men and women, adults and children. These differences are demonstrated in the pitches produced by men and women. By lengthening the vocal folds, pitch increases because of the decreased mass and increased tightness of the vocal folds. This lengthening allows the vocal folds to vibrate at a faster rate. Mass is the thickness of the vocal folds. The thinner and tighter the vocal folds, the higher the resulting pitch will be. Conversely, the thicker and more lax the folds, the lower the resulting pitch. The tension of the vocal ligament is regulated through the rocking of the arytenoid cartilages along the cricoarytenoid joints. Similar to a rubber band, when the vocal ligament is pulled tightly, it will vibrate at an increased rate. When lax, the rate of vibration is decreased.

The rate of vibration of the vocal folds is frequency, that is, the number of the cycles at which the vocal folds vibrate; and the acoustical and psychological perception of frequency can be called pitch. Colton and Casper (1990) defined the term fundamental frequency as "The most frequently or commonly occurring frequency that characterizes a particular vocal production" (p. 184). According to the definition of fundamental frequency by Colton and Casper (1990), during a single production of a steady state vowel, the frequency that occurs most often is considered the fundamental. The other frequencies that are often present are the overtones, or harmonics. Fundamental frequency is the lowest component of a complex tone (Borden and Harris, 1984). Sustained vowel phonation and conversational speech are comprised of complex tones. The frequencies produced at the level of the larynx are changed as they travel through the vocal tract. When measuring the fundamental frequency of a complex tone, such as speech, it is the lowest component of the tones that are produced that is considered the fundamental. The unit of measurement for fundamental frequency is cycles per second (cps). However, in recent years, the term hertz (Hz) has been adopted instead of cps in honor of the nineteenth century German physicist Heinrich Hertz" (Martin, 1986, p.21). The terms "Hertz" and "cps" can be used interchangeably.

Zemlin (1988) described the vibratory cycle in terms of phases: the opening phase, the closing phase and the closed phase. The vibratory cycle is periodic during normal phonation. Borden and Harris (1984) discuss that, "During sustained vowels, for example, the folds open and close in a certain pattern of movement which nearly repeats itself. This action produces a barrage of air bursts that set up an audible pressure wave (sound) at the glottis" (p.84). The Myoelastic Aerodynamic theory of vocal fold vibration explains how the vocal folds are set in motion to create the vibratory cycle and phonation:

> This theory suggests that the vocal folds are set into vibration by interaction of subglottic air pressure and the passively approximated vocal folds. In short, the vocal folds adduct and approximate at the midline. Subglottic air pressure from the lungs rises against the resistance of the closed folds. This pressure eventually

> overcomes the resistance, forcing the folds apart and releasing a small puff of air. This release of air creates a sudden drop in air pressure at the level of the vocal folds, creating a suction. This suction, called the Bernoulli effect, along with the static positioning of the adducted folds, begin to draw the folds back together. The closer the folds draw, the greater the suction, until the folds snap shut, completing one vibratory cycle. (Stemple, 1984, p. 46)

Increases in subglottic air pressure work to change both the frequency level and the intensity. The vocal folds are pulled together with increased force, and increased force is therefore necessary to blow the folds apart to begin phonation. Frequency will increase if the vocal folds are tense; intensity will increase with the amount of subglottic air and force necessary to blow the folds apart. The ability to increase or decrease subglottic air pressure allows a speaker to change vocal pitch to fit a situation appropriately.

There are differences in the ranges of fundamental frequencies produced by the human voice. Men may have a speaking fundamental frequency range that is typically between 80 and 150 Hz, whereas women's fundamental frequencies may range anywhere between 150 and 250 Hz. However, it is not uncommon for any individual's speaking fundamental frequency to be outside of these particular ranges. This difference in frequency range is largely due to the physical size differences between the larynges of men and women. The frequencies that are present in a periodic complex sound, known as harmonics, are described by Martin (1986) as:

> whole number multiples of the fundamental. These tones, which occur over the fundamental, are called harmonics or overtones. With respect to periodic signals, the only difference between overtones and harmonics is the way in which they are numbered: the first harmonic is the fundamental frequency, the second is twice the fundamental, and so on. The first overtone is equal to the second harmonic, and further overtones are numbered consecutively. (p.35)

The parameter to be examined in this research is fundamental frequency (F_0). Different conditions can cause fundamental frequency to change. Benign lesions, such as a nodule or vocal polyp, lower pitch and quality and voice is thereby perceived by a listener as hoarse and breathy. Edema, or swelling of the vocal folds, can also cause the fundamental frequency to decrease. Too much tension in the larynx can cause cracking and breaking of the voice; laryngitis may result. Different positioning of the larynx during laryngeal examinations can also affect voice production. By repositioning the larynx, the vocal tract is altered, and sound production varies. It can be said that the human voice has variability from day to day depending on a person's mood, speaking context, and general health.

Purpose

The purpose of this research is to determine whether the measurement of the fundamental frequency for the vowels /a/ and /i/ with the Visi-Pitch microphone and the Stroboscope inductive microphone differ in a systematic way. A second purpose is to determine if the frequency measurements obtained with these microphones and instruments are reliable?

Research Questions

This research will examine the following questions:

1) Does the measurement of frequency differ for the vowels /a/ and /i/ in a systematic way using the Visi-Pitch acoustic microphone and the stroboscope inductive microphone?

2) Are the frequency measurements obtained with the Visi-Pitch acoustic microphone and the stroboscope inductive microphone valid?

Hypothesis

There is no difference in the fundamental frequency measurements for the vowels /a/ and /i/ when measured using the synchronstroboscope and an inductive microphone and the Visi-Pitch with the acoustic microphone.

Chapter II

Review of the Literature

<u>History of the Measurement of Fundamental Frequency</u>

Fundamental frequency, the acoustic correlate of "pitch," is measured using a variety of different methods and techniques. Baken (1987) described how past methods of fundamental frequency measurement were difficult, time consuming and expensive. The earlier methods did not work with electronic circuits. Baken (1987) described methods including the phonodeik by Anderson in 1925 which "used light reflections from a mirror on a wire made to vibrate by collecting sound power with a diaphragm to produce curves on a photographic film" (p.128). Baken further described other methods of determining fundamental frequency by measuring graphic readouts and counting tape striations from a recorded sample. One example of this is the reading of a spectrogram.

The spectrograph was developed in the 1940s at Bell Laboratories by Ralph Potter (Borden and Harris, 1984). This instrument "allowed investigators to conveniently analyze the frequencies represented in speech across time, producing a visual display called a spectrogram" (Borden and Harris, 1984, p.21). Baken (1987) explains that although sound spectrography is a powerful tool, "The interpretation of spectrograms rests on a thorough knowledge of the acoustics and physiology of speech, on familiarity with the way in which spectrograms are generated, on experience, and on a trained eye" (p.316). Sound spectrography can be difficult and time-consuming for the examiner, and interpretation of the data may be difficult.

Another inductive method to determine fundamental frequency is the Fundamental Frequency Indicator. A microphone is held against the larynx or placed under the nose while producing a sustained vowel or the consonant /m/. Pitch levels are read from the dial, and the frequency bands can be set to indicate when a certain pitch is achieved

(Boone and McFarlane, 1988). This instrument is useful in facilitating a new pitch level in voice patients.

There are also other noninstrumental measurements of fundamental frequency that are judged to be valid. Boone and McFarlane (1988) state that "It is possible to measure frequency range and make other measures of frequency without instrumentation other than a piano or a pitch pipe. An initial voice recording made at the time of a patient's first clinic visit is a useful tool for analyzing the patient's habitual pitch level. This analysis can be made after the patient has left the clinic. One method we have used is to stop the recorder at random points and attempt to match the voice pitch level with a *pitch pipe* or a piano. After some experience with a pitch pipe, it is possible to match pitch levels between the pitch pipe frequency and the patient's voice" (p. 103). These methods require perceptual judgments to be made by the examiner. One important aspect that is measured in this way is the concept of habitual pitch. Coleman and Markham (1991) define habitual pitch as a "Single pitch or narrow range of pitches that the individual uses most of the time" (p.173). Habitual pitch extracted as the fundamental frequency is the parameter to be measured in the present study.

Present Instrumentation

The Visi-Pitch (Kay Elemetrics) is an instrument that can be used to measure fundamental frequency. Karnell (1991) states that "The Kay Elemetrics Visi-Pitch has become increasingly popular as a research tool for measuring fundamental frequency and pitch perturbation" (p.91). When the Visi-Pitch 6097 or 6098 are used in combination with a computer interface, the instruments offers features that the Visi-Pitch 6087DS alone does not. Karnell (1991) describe the functions of the computer interface:

> The sole function of the microcomputer is to perform the frequency, amplitude, and perturbation calculations and to display the graphics. All of the waveform processing, pitch extraction, and measurement processes are completed using the undigitized, or analog, signal. This is a major advantage of the Visi-Pitch, particularly for clinical applications, because analog processing is faster than digital

> processing. Consequently, fundamental frequency data can be calculated and plotted on the computer screen almost as quickly as it is input to the device (p.91).

The computer interface allows the examiner to save time by calculating the statistics during voice production. Horii (1983) described the Visi-Pitch as a "...portable instrument that extracts and displays F_0 in real time, either from a live voice via a microphone or from a tape recording" (p.468). A hand-held microphone is connected to the unit, and a measurement of fundamental frequency can be taken alone or in combination with intensity. The microphone used with a Visi-Pitch to obtain voice recordings is an acoustic microphone. These types of microphones are responsive to sound pressure wave variation and convert the pressure variations into time-varying electrical signals (Decker, 1990). These types of microphones can be uni- or multi-directional. Decker (1990) stated that a higher signal-to-noise ratio is achieved when a unidirectional microphone is placed very close to and directly in front of the mouth. It is important to have a microphone that is not sensitive to ambient noise. Holding the acoustic microphone in close proximity to the lips facilitates the higher signal-to-noise ratio and the microphone does not pick up as much ambient noise.

In order to collect data, the microphone trigger must be depressed during input. The Visi-Pitch 6097 averages the frequencies within a chosen time frame and calculates the frequency range. The computer interface can be adapted to analyze a maximum length of utterance analyzable of one minute (Horii, 1983, p.468).

The Visi-Pitch 6087DS has four different analysis filters, depending on the voice being measured. The filters are based on different ranges of frequencies -- Filter A: 50-300 Hz; B: 100-600 Hz; C: 250-800 Hz; D: 500-1550 Hz -- and are selected with a switch on the front of the instrument (Horii, 1983). The overlap in frequencies between the different filters allows the examiner to measure different ranges that a person's voice may fall in without excluding any frequencies. When using the Visi-Pitch to measure fundamental frequency, determining the correct filter for the voice being analyzed is necessary to extract an accurate frequency measurement from the instrument. The extracted F_O contour is displayed on the storage oscilloscope on the Visi-Pitch 6087DS.

The Visi-Pitch 6097 and 6098 with the computer interface have identical software. The computer interface, along with measuring fundamental frequency, is equipped with statistical software that can calculate the frequency range, pitch perturbation, average intensity and other parameters. The Visi-Pitch 6097 or 6098 is capable of communicating, displaying, and manipulating the speech parameters extracted with the Visi-Pitch 6087DS (Visi-Pitch Manual, Kay Elemetrics, 1987). The Visi-Pitch 6087DS and 6097 interface are used simultaneously. The computer program is menu driven, so the ranges chosen on the 6087DS must match those chosen with the computer. The frequency range, time displayed and the display format must be selected for the 6097 computer interface prior to data collection.

Boone and McFarlane (1988) described the Visi-Pitch as an "excellent clinical instrument for measuring different aspects of frequency: frequency range, optimal pitch, and habitual pitch. The Visi-Pitch offers both a digital display of frequency and an oscilloscopic display" (p.100). Along with measuring fundamental frequency, the Visi-Pitch can be used in voice therapy to help facilitate new pitch levels. A patient is able to view a wave form or a desirable pitch level on either the Visi-Pitch unit or the computer interface and can then attempt to match the desired level.

History of Stroboscopy

The principle of stroboscopy was simultaneously discovered by Plateau in Brussels and von Stampfer in Vienna in 1833. Izdebski, Ross and Klein (1990) stated that the meaning of stroboscopy is "observing an image" (p.20). By 1878, Oertel had extended the use of stroboscopy to laryngology (Faure and Muller, 1992). Wendler (1992) stated that "Oertel first observed the larynx of a living human being with the aid of a light that was periodically interrupted by a rotating disk. By this means he was able to see the vibration of the vocal folds" (p. 149). Izdebski et al. (1990) discuss how:

> The fundamentals of stroboscopy known since the 19th century are based on the principle that the human retina retains an afterimage for about 200 msec. Application of stroboscopy for laryngeal examination is therefore natural, since the eye is not capable of discrete temporal resolution matching human voice frequency range (p.20).

This principle of stroboscopy is derived from Talbot's Law. Wendler (1992) stated that "According to the Talbot law, images projected on the retina leave positive after images lasting 0.2 s. Thus, a brief sequence of individual stimuli presented at intervals <0.2 s appears as a continuously moving picture" (p. 149).

The use of a laryngeal mirror to view the vocal folds has been standard practice for many years. The combination of the laryngeal mirror and the pulsed light source has given laryngologists the means to view both the structure and the function of the larynx. The use of a pulsed light source such as a stroboscope to illuminate segments of the vocal folds allows the user to see what is perceived as slow motion.

There are two different ways to utilize a stroboscope. Bless, Hirano & Feder (1987) use the terms "synchronization" and "asynchronization" to distinguish the two types of pulses generated by the stroboscope. These pulses can be seen when the stroboscope is used in combination with an endoscope. When the stroboscope is used without an endoscope, the flashes cannot be seen; but the stroboscope tracks the frequency being produced in the same manner as it would when used in combination with an endoscope. The frequency for the pulses is generated by the frequency being produced by the human voice because of vocal fold vibration. Wendler (1992) described how the stroboscope generates the light along the vibratory cycle:

> Exact coincidence of the frequency of light flashes and the position of the moving object provides a sharp and clear still picture, because points at the same phase angle of the object's motion are repeatedly illuminated. Slight differences between the frequency of the flashing light source and the frequency of the object's motion produces the well-known slow motion effect (p.149).

The first type of flashes generated by the stroboscope that can be used is the strobe that illuminates the vocal folds at the same frequency of vibration as the frequency being produced by the patient. Illuminated points are synchronized in time and are equal in frequency to the "flashes" of light to provide an averaged vibratory pattern over successive cycles. Bless et al. (1987) stated that:

> Under usual circumstances, the synchronized flashes will illuminate the same portion of the folds' cycle for each flash with aperiodic vibration so that the folds will appear to stand still. When movement is observable, the clinician can assume the presence of aperiodicity in the vocal cord's vibration. Thus, folds that appear to shimmer or to continue moving under synchronized stroboscopic light indicate aperiodic vibration (p.91).

The aperiodic vibration is an indication that the vocal folds are not functioning normally. The aperiodic vibration of the vocal folds results in the perception of a harsh vocal quality, which may be demonstrated by the frequency reading obtained by the strobe unit. One of the characteristics typically assessed by the stroboscope is fundamental frequency (Sataloff and Spiegel, 1988; Sataloff, 1987; Wendler, 1992). It is important that the patient be able to produce an acoustic sound that can generate a simultaneous frequency in the strobe generator. Woo, Colton, Casper and Brewer (1991) found that "A major cause of poor quality recording was the inability of the patient's voice to pace the stroboscope, i.e., to produce an acoustic source for the strobe to flash in synchrony with vocal fold vibration" (p.234). When determining fundamental frequency based on a videostroboscopic examination, this is a necessary factor to consider. If a patient has a weak voice, other measures may be more accurate than a measure obtained from a strobe generator.

The second type of flashes generated by the stroboscope initiates the flashes at a slightly slower rate of vibration than the frequency produced by the patient. Faure and Muller (1992) stated that "The problem of resolving the too-rapid motion is solved by illuminating the larynx with brief flashes of light at a frequency just slightly less than their vibratory rate" (p.139). Colton and Casper (1990) explained that "At a frequency slightly less or greater than the frequency of vocal fold vibration (+ 2 Hz), the image is the averaged vibratory pattern over several successive cycles and takes on the appearance of slow motion movement of the vocal folds" (p. 180). The actual rate of vibration is not slowed; rather the vibrations are averaged at different positions across the cycles to provide the appearance of slow motion.

According to Faure and Muller (1992), present-day stroboscopes usually indicate the frequency of the phonatory signal and, occasionally, its intensity. Hirano and Bless (1986) stated that the fundamental frequency is transmitted to the stroboscope by electronic pulses. The unit is typically equipped with either a frequency meter or a digital display, depending on the model in use. Wendler (1992) stated that measuring the frequency presents no problem, because it is generally done by the stroboscopic unit (p.150). According to Wendler (1992), "Instruments should be made small, light, and inexpensive. The same outlet should deliver continuous or pulsed light, as needed, and should be adaptable for mirrors, endoscopes, and microscopes, with optional provisions for photography and video recordings, and should provide information on the frequency and intensity of phonation" (p.152). The pulses are obtained via an inductive microphone that is attached to the stroboscope and is typically held by the patient at the level of the thyroid lamina. Izdebski et al. (1990) stated that "Since vibrations are pitch and intensity dependent, evidence about voice fundamental frequency during which the image was recorded should be provided. This can be obtained directly during the exam, or can be extracted later on from the recorded tape and estimated by pitch matching" (p.20). The combination of an endoscope, an inductive microphone and a stroboscope allows for the frequency of the phonatory signal to be obtained, and both video and audio recordings are possible.

The frequency of the strobe light is generated by the frequency being produced by the patient. This is accomplished via the inductive microphone that is held in place against the neck at the level of the thyroid lamina of the larynx (Colton and Casper, 1990). Baken

(1987) described the inductive, or contact, microphone as a device that is fashioned to perceive acoustic signals, or vibrations from the body surface, and is almost totally insensitive to airborne sounds. They are held in intimate contact with the skin by an adhesive or strap mounting. Baken (1987) stated that the speech signal is badly degraded by transmission through the tissues of the body, but vocal fundamental frequency is unaltered.

The strobe generator is able to distinguish a range of frequencies that encompass the typical range of human voice, allowing for use with a wide variety of patients. Wendler (1992) suggested that the frequency range of stroboscopes "should be sufficiently broad to cover the mean speaking fundamental frequency for adults and children (50-400 Hz)" (p.152). For example, the Nagashima Laryngo-Stroboscope has a frequency range of synchronous flashing from 50-500 Hz (Nagashima Medical Instruments Catalog).

Fundamental Frequencies of Vowels

The measurement of fundamental frequency using the Visi-Pitch can be accomplished for either steady state vowels or conversational speech. This is possible because of the use of the acoustic microphone for data collection. The acoustic microphone does not enter the vocal tract; therefore, it does not inhibit or change voice productions. However, when different endoscopes are used in combination with the stroboscope, the voice productions that result depend on the type of scope used. Isshiki (1989) stated that "Vocal pitch of sustained vowel productions can easily be measured with various instruments: stroboscope, which usually shows the vocal pitch (Hz) on a meter; display of the sound wave on a cathode ray oscilloscope permitting calculation of the fundamental frequency; pitch calculation on sonagram; and various types of pitch indicator" (p.50). Conversational speech is possible with a flexible nasal endoscope, and a patient's fundamental frequency to generate the strobe is obtained via the inductive microphone. With a rigid endoscopic evaluation, the tongue is pulled forward resulting in the larynx being raised in the vocal tract. This makes conversational speech impossible, and vowels are therefore used to measure fundamental frequency. It is important to have some knowledge of the fundamental frequencies of vowels when measuring fundamental frequency with both the acoustic microphone and the inductive microphone.

Vowels are produced with the vocal tract unobstructed and with the vocal folds almost always vibrating. Vowels are classified according their articulatory dimensions: height, frontness, lip rounding, tongue root position and velar position (Mackey,1987). The English language has 13 vowel sounds. Each of these vowel sounds has a particular fundamental frequency. The tendency of high vowels (e.g., /i/ and /u/) to be produced with higher fundamental frequency (F_0) than low vowels (e.g., /a/) in the same phonetic context is known as the 'intrinsic pitch of vowels' (Sapir, 1989, p.44). The fundamental frequency of vowels for men, women and children was studied in 1952 by Peterson and Barney. This research yielded both average fundamental frequencies and the formant frequencies of vowels. The vowel frequencies in their study were measured in the consonantal context of /h_d/. In the present study, the vowels /a/ and /i/ are to be used as the stimuli. Peterson and Barney (1952) found that the average fundamental frequencies for /a/ for men was 124 Hz and for women was 212 Hz; for the vowel /i/, the fundamental for men was 136 Hz and for women was 235 Hz (p.183). These data show that there is in fact inherent differences between the vowels according to the positioning of the articulators.

The present study will determine the difference in the fundamental frequency measurements obtained for the vowels /a/ and /i/ in isolation using the Visi-Pitch acoustic microphone and thestroboscope inductive microphone.

Chapter III

Methodology

Subject Selection

A group of twenty-five persons between the ages of 24-46 were the subjects for this study. Sixteen females, average age 31.9, ranging from 24 to 43 years, and nine males, average age 33.3, ranging from 24 to 46 years, participated in this study.

Eligibility for this study was based on the following criteria as obtained through a case history checklist:

1-no history of formal voice training for singing or public speaking
2-English is primary language
3-no history of neuropathology or cleft palate
4-non-smoker for at least the past 5 years
5-no medications that will affect voice are being taken during the study
6-no previous therapy for voice disorders

The subjects were judged with respect to overall vocal quality and pitch. Subjects were dismissed if vocal quality was perceived by the examiner as harsh, hoarse, if any dysphonia was present, if pitch was judged inappropriate, too high or too low for gender and age; and if any of the criteria from the case history checklist was not met (See Appendix D). Each subject was assigned a 1-2 digit number to insure confidentiality. Subjects were required to sign a consent form agreeing to participate in this study after being informed of its purpose (See Appendix E). Typically, the subjects that were not selected were present smokers or those who had quit smoking within the last five years.

Data collection took place in the voice laboratory at the Otolaryngology Department at the University of Michigan Hospital. This room is typically used for videoendoscopic and videostroboscopic voice evaluations. The room was not sound treated, however, the door was closed during each examination to eliminate extraneous noise that might have been recorded by the acoustic microphone. The acoustic microphone was placed directly in front of the subject's mouth in order to facilitate the best recording possible.

Data Collection

Subjects had to sustain vowel phonation for a period of eight seconds during both procedures. A frequency measurement was obtained for each subject using both Visi-Pitch 6087DS and 6098 and a Bruel and Kjaer Stroboscope inductive microphones.

Both procedures involved placement of a microphone to obtain sound. The microphones were put in place at the same time at different locations on the body in order to obtain an estimate of the same segment of voicing for comparison. For each vowel, /a/ and /i/, the subject produced four trials. The first trial was phonated for at least five seconds to insure that the subject was capable of sustaining voicing. The trial for each vowel was also necessary to determine whether the microphones were properly placed for data collection.

To counter balance the effects of one vowel on the other, one half of the subjects phonated /a/ first, the other half phonated /i/ first. Each of the three trials that followed were recorded and measured. The reason for using /a/ and /i/ in this study was the inherent differences in pitch between a low back vowel, /a/, and a high front vowel, /i/. The vowel /a/ is typically produced with a lower fundamental frequency than the vowel /i/. The place of production for each of these vowels is also different. The fundamental frequencies for the vowels obtained with each instrument were compared. The scores obtained for the two vowels were not compared to each other; rather, the frequency data obtained with each instrument for the same vowel production, /a/ or /i/, was compared.

Procedures and Instrumentation

Visi-Pitch

The Visi-Pitch 6087DS is a self-contained analog fundamental frequency analyzer (Baken, 1987). Baken (1987) described how the Visi-Pitch "displays the fundamental frequency of each cycle of the speech input, rather than the average Fo of a number of cycles" (p.136). It was necessary to omit the onset of voicing and the termination of voicing using the cursors to allow for the best results possible. Each subject phonated individual vowels, allowing the examiner to obtain a stable and constant signal of voicing.

The analysis filters for the Visi-Pitch that were used in this study were filter A for the men and filter C for the women. The Visi-Pitch was also capable of measuring intensity at the same time it measures frequency. For the purposes of this study, the option chosen was pitch only. Subjects were instructed to phonate at a comfortable speaking level without taking a deep inhalation prior to phonation. As a method to check the calibration of the Visi-Pitch, the examiner utilized a pitch pipe . A steady tone (middle C - 256.1 Hz) was produced with the pitch pipe and then directed into the acoustic microphone. Using the Visi-Pitch interface statistical calculations, the measurement was calculated accurately. The vowel productions for sixteen females were recorded by Visi-Pitch using the C range (200-760 cps), and the productions for nine males were recorded using the A range (50-300 cps).

Each subject was instructed to hold the Visi-Pitch acoustic microphone with the left hand directly in front of the mouth as close to the lips as possible in order to obtain fundamental frequency. The subject held the microphone directly in front of the mouth.

The subject was given a practice trial. The subject phonated the vowel /u/ for five seconds or greater, to demonstrate to the subject what was required with this task. Before the actual task began, the cursors that denote time periods were set in position. The total time window was 8 seconds. The left and right cursors were set 1.5 seconds into the window to frame the 5 second window from which pitch was extracted and analyzed. The subject was required to sustain the vowels /i/ and /a/ for as long a duration as possible. A frequency reading using the inductive microphone and the synchronstroboscope was obtained simultaneously for both vowel productions.

Stroboscope with Inductive microphone

A Bruel and Kjaer model 4914 sychronstroboscope microphone was used to collect frequency information from each subject. The synchronstroboscope flash rate tracked the fundamental frequency being produced by the subject (Baken, 1987) and the microphone obtained the frequencies that were produced. The subject's Fo controlled the rate of the flashes being produced. The subject's fundamental frequency was obtained through the inductive microphone that is attached to the synchronstroboscope.

The microphone was placed on the subject's neck along the lateral aspect of the thyroid lamina to measure the fundamental frequency of the voice (Colton and Casper, 1990). Each subject held the inductive microphone (Bruel and Kjaer synchronstroboscope, model 4914) with the right hand against the neck at the level of the thyroid lamina. The choice of which side to place the inductive microphone was dictated by the positioning of the instruments in the room.

Prior to any data collection, each subject was instructed to produce a steady state vowel in order to determine whether the inductive microphone was properly placed. The subject produced the vowel /a/ for approximately 8 seconds while holding the inductive microphone in place. The Visi-Pitch acoustic microphone was sanitized with an alcohol pad prior to use by each subject. The examiner explained to each subject that the vowels needed to be phonated for at least eight seconds each. Each subject was able to see the computer screen as it was set up for data collection. Each subject was instructed to "Phonate the vowels /a/ and /i/ in both a comfortable speaking pitch and at a comfortable loudness level".

With the inductive microphone in position, the subject phonated /i/ and /a/, sustaining duration for approximately eight seconds. The subject produced three trials for each vowel while the same recording was obtained with Visi-Pitch.

Data Analysis

Each subject produced six individual phonations: three phonations of /a/, and three phonations of /i/. A comparison of the scores was obtained and were calculated for each production for each instrument

<u>Statistical Analysis:</u>

A paired t-test was used for statistical analysis. The t-test is used for measured variables when comparing two means. The paired t-test compares two paired observations on the same individual or on matched individuals. In this case, productions of /a/ on the Visi-Pitch microphone were compared with productions of /a/ obtained with the inductive microphone; the same was true for /i/. The averages for /a/ and /i/ were determined using measures of central tendency.

A Pearson correlation was calculated to determine the strength of the relationship between the two variables. This type of analysis determined the linear relationship between the two variables.

Measures of central tendency and dispersion of scores were also analyzed. Measures of central tendency provided average frequency scores for the sample for each microphone score.

Chapter IV

Results

Results

The present study was designed to determine whether the measurement of fundamental frequency for the vowels /a/ and /i/ with the acoustic microphone and the inductive microphone are different. It was important to determine if the differences between the measurements obtained with these microphones are relevant when measuring fundamental frequency in clinical practice.

Average fundamental frequency data for the vowels /a/ and /i/ were calculated for the 9 males and 16 females, N= 25, as measured with the Visi-Pitch acoustic microphone and the inductive microphone attached to the B& K synchronstroboscope. Results are summarized in Table 1 and displayed in Figures 1a and 1b.

Table 1. Mean fundamental frequency measurements for males, females, and the sample population for each vowel production using the Visi-Pitch acoustic microphone (Ac) and the Inductive microphone (Ind.).

Stimuli	Males	Females	SD	Total Average (Hz)
Ac /a/ Trial 1	114.03	208.9	57.88	174.74
Ac /a/ Trial 2	113.31	209.1	57.34	174.62
Ac /a/ Trial 3	115.62	210.5	57.88	176.35
Ind. /a/ Trial 1	115.16	209.38	57.63	175.46
Ind. /a/ Trial 2	113.91	210.01	56.24	175.42
Ind. /a/ Trial 3	116.41	211.29	57.86	177.14
Means /a/	**114.74**	**209.86**	**57.47**	**175.62**
Ac /i/ Trial 1	122.75	218.31	57.61	183.91
Ac /i/ Trial 2	123.41	219.2	57.57	184.72
Ac /i/ Trial 3	123.58	222.025	59.77	186.59
Ind. /i/ Trial 1	122.53	218.95	58.06	184.24
Ind. /i/ Trial 2	123.67	220.29	58.26	185.51
Ind. /i/ Trial 3	124.45	222.35	59.72	187.11
Means /i/	**123.39**	**220.19**	**58.50**	**185.35**

As demonstrated in Table 1, the productions for each vowel over the three trials are consistent. Intrasubject variability between the average frequency productions is typically within 5 cycles per second. The mean frequencies shown in Table 1 for each vowel an each microphone demonstrate minimal intersubject variability between productions. In addition, most subjects demonstrated a pattern of the 2nd and 3rd productions for both vowels and for both microphones either both being higher or both being lower in frequency than the first (See Appendix A). This pattern is reflected in Table 1 for the females for both vowels, and for the males for the vowel /i/. Figures 1a and 1b show the mean frequencies for males and females. These figures demonstrate the frequency differences between males and females for the vowels /a/ and /i/.

Figure 1a. Mean frequencies for males and females and the sample population for the phoneme /a/.

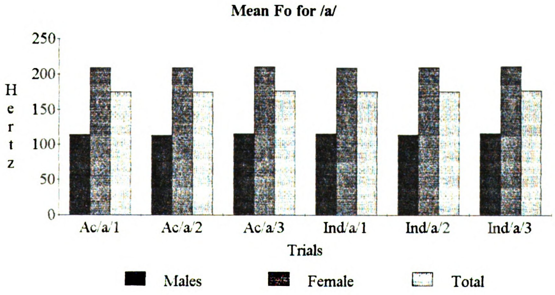
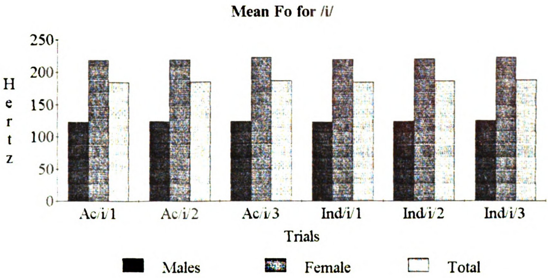


Figure 1b. Mean Fo for males and females and the sample for the phoneme /i/.



It was necessary to determine the average fundamental frequencies for each subject for each vowel in order to determine the differences between the frequencies as measured with each microphone. Raw data for each subject's fundamental frequencies as measured with each microphone are indicated Appendix A. The fundamental frequency differences between the measurements obtained with each microphone were calculated for each of the subject's six vowel productions. The mean differences of the difference (MDD) was calculated for each subjects three trials of /a/ and three trials of /i/. The average differences between the fundamental frequency measurements by the acoustic microphone and the inductive microphone are shown in Table 2.

Table 2. Mean Differences of the calculated differences for 3 trials for each subject.

S #	/a/	/i/	S#	/a/	/i/
1	0.73	-0.8	13	0.76	1.3
2	-0.16	0.83	14	0.80	0.46
3	0.56	0.56	15	0.80	1.125
4	0.75	0.9	16	-0.70	1.03
5	0.93	0.73	17	0.83	-3.48
6	0.92	0.9	18	0.63	0.59
7	0.43	-1.86	19	1.23	1.46
8	0.56	0.23	20	0.86	2.26
9	0.83	0.86	21	0.77	0.44
10	1.9	1.06	22	0.36	1.96
11	0.43	0.575	23	1.46	0.26
12	0.8	-0.53	24	0.97	0.30
			25	0.67	-0.09

The mean of the frequency differences (MFD) and the standard deviation were determined in order to perform the Paired t-test. The Paired t-test was used to examine these differences by using the following formula:

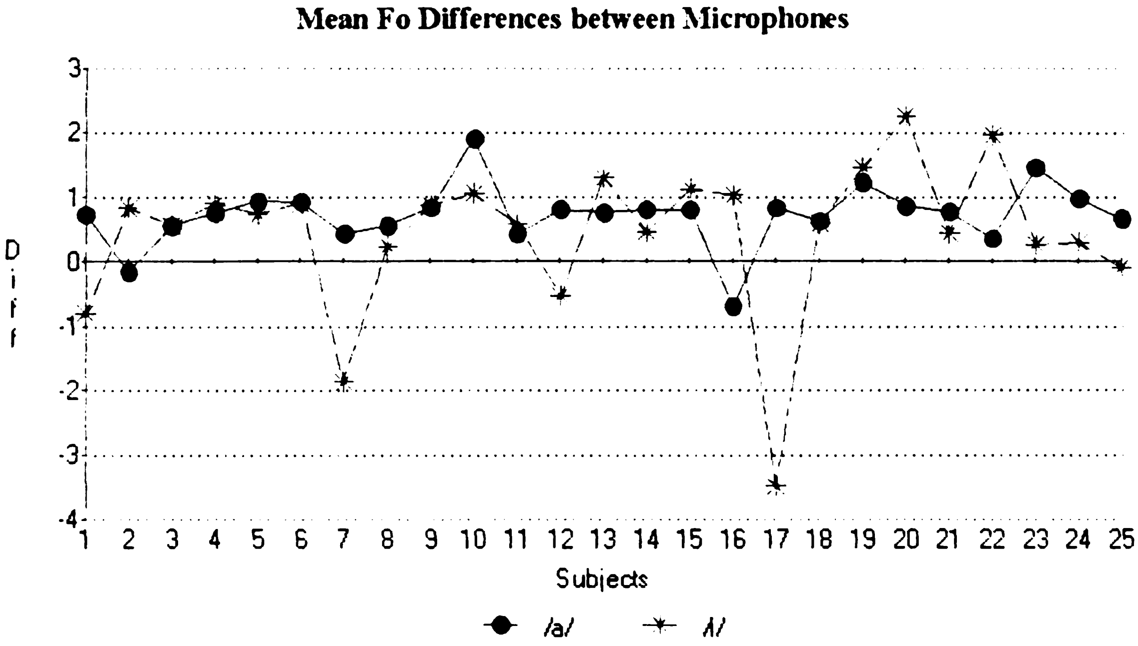
$$t = \overline{X} \;/\; SD/\sqrt{N}$$

The differences are between the frequency measurements obtained for either /a/ or /i/ using the acoustic and inductive microphones. As demonstrated in Table 2, the differences are consistently small, within 1-2 Hz for both vowel productions for all subjects. The greatest difference noted is -3.48 for the vowel /i/ for subject 17. The t-score is high as a result of the small differences. The small differences indicate that the data have a narrow distribution and therefore result in a small SD. The MFD is then divided by that small SD for that vowel. Because the MFD is a value greater than the SD, the resulting value is high. If the distribution had been wider, the resulting value would have been a low t-score because the mean and the SD would have been more similar in value. The t-value results are summarized in Table 3.

Table 3. t-values for /a/ and /i/ for entire sample (N= 25).

Measures	/a/	/i/
Mean of the Differences	.7248	.4428
Standard Deviation	.4815	1.1727
t-values	**7.526**	**1.887**

Figure 2. MFD between microphones for all subjects.



Based on a two-tailed t-test, assuming that the alpha error was occurring at both ends of the distribution, and using alpha level of .01, any value greater than 2.797 (Linton and Gallo, Jr., 1975) for 25 subjects would be statistically significant. Alpha level is the probability of rejecting the null hypothesis (Linton and Gallo, Jr., 1975). The tabled value 2.797 is derived from the t-value relative to the degrees of freedom (df =24). The t-value for /a/ for the fundamental frequencies obtained with the acoustic microphone and the inductive microphone is 7.526, which is greater than 2.797. This t-value indicates that there is a statistically significant difference in the average fundamental frequencies for /a/ as measured with the two instruments via the microphones and their input. However, the t-value of 1.887 for /i/ is less than 2.797, indicating that the differences are not statistically significant for this vowel. It should be noted these results change when the results from subject #17 are eliminated from the Paired t-test. This change illustrates that the differences in fundamental frequency measurement of these two vowels by the acoustic microphone and the inductive microphone are both statistically significant at the .01 alpha level. The difference between frequency measurements for this subject for the vowel /i/ on the first trial is -8.1 (See Appendix A). This number creates a bias that is reflected in a low t-value. The t-values for an N = 24 is demonstrated in Table 4.

Table 4. t-values for sample size N=24.

Measures	/a/	/i/
Mean	.7204	.6063
St. D	.4913	.8591
t-values	**7.175**	**3.45**

With these t-values calculated, the degrees of freedom in this case would be 23, and the critical value therefore changes to 2.807. The resulting t-values when #17 is excluded from the calculations demonstrates a statistically significant difference that allows the examiner to reject the null hypothesis stating that there is no difference in the fundamental frequency measurements as obtained via the acoustic and inductive microphones.

The difference across instruments for each subsequent trial for each vowel is less than or equal to a 1.0 Hz for 67% of the total trials; 33% were greater than or equal to a 1.0 Hz difference, with the greatest difference being noted for subject #17's first trial of /i/, which is 8.1 Hz. The averages of the frequencies produced for both vowels with both microphones were calculated for each subject. Results are shown in Appendix B. Average fundamental frequencies for subjects 11, (F_0 /a/ = 86.22 and /i/ 83.62), and 20 (F_0 /a/ = 348.27 and /i/ =343.34), were the lowest and the highest, respectively.

The range of the frequencies produced by all of the subjects was calculated. Table 5 demonstrates the ranges calculated for each of the vowel productions as measured with both microphones.

Table 5. Ranges for the mean F_0 produced.

Acoustic	R	(R - outlier)	Inductive	R	(R - outlier)
/a/ 1	262.7	168.6	/a/ 1	262.9	168.6
/a/ 2	259.3	154.4	/a/ 2	260.4	155.7
/a/ 3	263.5	154.9	/a/ 3	263.5	155.5
/i/ 1	263.4	172.4	/i/ 1	264.3	173.7
/i/ 2	254.4	180.1	/i/ 2	258.5	180.1
/i/ 3	258.8	181.1	/i/ 3	258.9	180.5

Subject 20 produced fundamental frequency averages well above the other subjects averages. For each production, the range was calculated including the outlier (subject 20) and excluding the outlier. The range (represented by R), which determines the width of the entire distribution, was affected by this subject's productions. The range value without the scores from subject 20 was not as wide. The range values for each production without subject 20 indicated a more narrow distribution of scores than the R for the entire sample.

Results of the measures of central tendency are demonstrated in Table 6. Measures of central tendency were calculated using the entire sample of 25. The measures of central tendency show where the data were clustering. The mean fundamental frequencies for the total sample for both /a/ and /i/ were

Table 6. Measures of Central Tendency for entire sample (N= 25).

Measure	Ac/a/	Ind/a/	Ac/i/	Ind/i/
X	175.2	176.0	185.0	185.62
SD	56.71	57.24	58.31	58.68
R	267.1	266.3	262.6	264.3

The mean value for the entire sample for both vowels shows that the frequencies measured with the two different microphones are within 1 Hz of each other. The standard deviation showed how widely the frequencies produced varied from the mean. The range showed the difference between the highest frequency and the lowest for each vowel with each microphone.

A Pearson correlation was also calculated to determine the strength of the relationship between the average of the 3 frequencies measured using the Visi-Pitch acoustic microphone and the inductive microphone with the synchronstroboscope. The correlation coefficient for the vowel /a/ is $r = +.99991$. The coefficient for the vowel /i/ is $r = +.9998$. These numbers indicate an almost perfect positive correlation between the two sets of measurements. According to Sprinthall (1990), correlations can provide better than chance predictions. If two events are correlated, then a knowledge of one of those events allows a researcher to predict the occurrence of the other (Sprinthall, 1990). In this case, the events, or the different microphones, are closely related in the frequency information that is recorded. Clinically, these two microphones extract frequency information that would complement each other, not contradict.

The fundamental frequencies produced by the majority of the subjects in this study fall within ranges of fundamental frequency norms as found in previous studies. Although there is no hard and fast rule for what an individual's fundamental frequency should be, ranges are typically used to determine whether one compares favorably with other persons of the same age and gender. In the present study, the stimuli were steady state vowels. Fundamental frequency is frequently discussed in terms of speaking fundamental frequency (SFF). Many of the norms that are in place have been determined via measurement of frequency when a patient is reading a passage, such as the "Rainbow Passage" (Fairbanks, 1937). However, the results from the present study can be generalized to fit the SFF norms (See Appendix C). As with the males subjects from the Hollien and Shipp (1972) study, the averages from Stoicheff's study were determined according to speaking fundamental frequency. According to the norms from Hollien and Shipp (1972) and Stoicheff (1981), the average fundamental frequencies for both male and female subjects in the present study are within normal limits for their age ranges and gender.

Chapter V

Discussion, Summary and Conclusions

Introduction

In the clinical evaluation of voice, obtaining a measure of a patient's fundamental frequency is often necessary. The instruments that are used to measure fundamental frequency vary from using a pitch pipe as a pitch matching device to using instruments such as a spectrograph to view the wave form to make specific determinations and calculations about frequency. As technology changes, it is important to determine whether or not the instruments are measuring fundamental frequency accurately. In other words, are the instruments used in clinical practice valid?

The goal of the present study was to determine whether the fundamental frequency measurements obtained with the Visi-Pitch acoustic microphone and the Synchronstroboscope inductive microphone differ from each other in a systematic way.

The purpose of the present study was to determine whether any differences were present between the measurements obtained from two different microphones and not to identify any specific pathology. The stimuli for this experiment were the vowels /a/ and /i/, to be phonated by each subject three times each. To counter balance any effects one vowel might have on the other, 12 of the subjects phonated /a/ first, 13 phonated /i/ first. The number of subjects for the study totalled 25, comprised of 16 females and 9 males. For each subjects six vowel productions, the inductive microphone was held with the right hand against the neck at the level of the thyroid lamina, and the acoustic microphone was held with the left hand directly in front of the mouth as close to the lips as possible. The microphones were utilized simultaneously to facilitate measurement of the same segment of voicing.

Summary and Discussion

Fundamental frequency of steady state vowels was measured with two instruments: the Visi-Pitch via the acoustic microphone and the synchronstroboscope via the inductive microphone. The two microphones, although both measure fundamental frequency, are different mechanically. The acoustic microphone measures fundamental frequency through the sound pressure levels produced by the subject. The inductive microphone measures fundamental frequency through the vibrations produced in the larynx during phonation. The inductive microphone, unlike the acoustic microphone, does not measure sound pressure levels; extraneous noises, therefore, do not effect the fundamental frequency.

In the present study, the fundamental frequency measurements of the steady state vowels /a/ and /i/ were found to have statistically significant differences between the frequencies for the two microphones. A pattern emerged whereas 94% of the measurements obtained with the inductive microphone were slightly higher than the measurements with the acoustic microphone. When the differences for all 25 subjects were averaged, it was found that the differences for /a/ were statistically significant, but the differences for /i/ were not. This discrepancy was the result of the data from one subject. With that subject's data removed from the total, it was determined that the differences for both /a/ and /i/ were, in fact, statistically significant. However, although the fundamental frequencies were higher, most were less than or equal to 1.0 cps higher. Rejection of the null hypothesis according to the paired t-test would suggest that there is a statistically significant difference in the measurement of fundamental frequency as measured with the acoustic microphone and the synchronstroboscope inductive microphone.

Although the findings from the present study were statistically significant, differences of approximately 1-2 Hz between microphones would not be considered clinically significant during a voice evaluation. Considering the minimal differences in the acoustic microphone , the fundamental frequency measurement with the inductive microphone is a valid measure of fundamental frequency as it measures what it purports to measure.

In clinical practice, fundamental frequency is measured for both steady state vowels and conversational speech. The acoustic microphone is capable of measuring fundamental frequency for both types of stimuli. The Visi-Pitch is described in the literature as an accepted instrument for the measurement of different aspects of frequency as well as a clinical therapy tool (Boone & McFarlane, 1988; Horii, 1983). This is because the acoustic microphone in no way impedes the vocal tract. On the contrary, the inductive microphone is used clinically with videoendoscopy or videostroboscopy. Much of the literature states that this frequency reading from the synchronstroboscope is the patient's fundamental frequency. In various studies utilizing the synchronstroboscope with the inductive microphone, it is stated that the fundamental frequency measurement is not a problem to extract because it done by the stroboscope (Faure & Muller, 1992; Izdebski, Ross and Klein, 1990). Wendler (1992) specifically stated that "Measuring frequency presents no problem, because it is generally done by the stroboscopic instrument" (p.150). The present study utilized steady state vowels as stimuli, as is often used in endoscopic examinations. Quite often, when a flexible nasopharyngoscope is utilized for vocal fold visualization, it is possible to have the patient phonate vowels in order to examine the vibration during conversational speech because the flexible endoscope does not interfere with the normal functioning of the vocal tract. However, when a rigid endoscope is utilized, the shape of the vocal tract is changed and the larynx is elevated due to the tongue being pulled forward during examination. This obviously makes speech impossible. The resulting fundamental frequency as measured with the inductive microphone may be inaccurate because of the changed shape of the vocal tract. The user of these instruments must be cognizant of the stimuli being used to elicit fundamental frequency. In the context of steady state vowels, fundamental frequency can be measured accurately with these instruments.

The findings of the Pearson correlation would concur that there is a strong, positive relationship between the microphones for the measurement of steady state vowels. The correlation for the vowel /a/ is $r = +.99991$, and for the vowel /i/ is $r = +.9998$. These coefficients indicate an almost perfect positive correlation between the frequency measurements with the acoustic microphone and the measurements with the inductive microphone. These correlations would indicate that with the measurements from either the inductive or acoustic microphone, it is possible to predict the results that the other will produce.

The mean fundamental frequency for the males, n=9, for all trials for /a/ and /i/, was equal to 119.07 Hz. According to Hollien and Shipp (1972), this average is within normal limits for speaking fundamental frequency for males. The females in the present study, n=16, produced a mean fundamental frequency of 215.06 Hz. Stoicheff (1981), in a study of SFF, found results similar to that of the present study. Although the present study utilized steady state vowel phonation, it can be generalized that the subjects were producing these vowels in a habitual pitch, much the same as the subjects produced speaking fundamental frequency in the previous studies. The findings of the present study are in agreement with previous studies of the fundamental frequencies of vowels (Peterson & Barney, 1952; Sapir, 1989). It was found that the fundamental frequency productions for the vowel /i/ were consistently higher than for the vowel /a/ for both males and females. In previous studies pertaining to the measurement of the fundamental frequencies of vowels, this was also found to be the case (Peterson & Barney, 1952; Sapir, 1989).

<u>Conclusions</u>

Based on the results of the present study, it may be concluded that although there is a statistically significant difference between the fundamental frequencies as measured with the two microphones, although the difference is not considered to be clinically significant.

In the measurement of fundamental frequency, a difference of < 1 cps does not affect the results of a clinical evaluation in an adverse way. Clinical application, unlike speech science and basic research, does not require frequency specificity of this degree. Conversational speech is a range of frequencies; thus the cyclic limits are not clinically practical. Further, the instruments were shown to be highly correlated, indicating that the frequency measurements via the acoustic and inductive microphones are strongly related. Future research might focus on whether fundamental frequency measurements differ when using flexible nasopharyngolaryngoscopy and rigid endoscopy to determine the validity of the frequency measurement with the inductive microphone when the vocal tract is altered.

GLOSSARY

1. amplitude - the amount of vibratory displacement; how far an object moves describes its amplitude. (Yost and Nielson, 1985 p. 7).

2. Cycles per second - the frequency of a sinusoid is the number of cycles a sine wave completes per unit of time, for instance, the number of times per second an object moves back and forth. (Yost and Nielson, 1985, p.4) A cycle is the complete sequence of values of a periodic quantity that occurs during one period.

3. decibel - a quantitative unit of relative sound intensity or sound pressure. Referent = .0002 dynes/cm2 (Zemlin,1988)

4. direct laryngoscopy - an invasive surgical procedure requiring that the person be anesthetized. Direct laryngoscopy permits more detailed examination of laryngeal structures, including the actual manipulation (Colton and Casper, 1990, p.177).

5. endoscope - an instrument inserted intraorally or intranasally to view the vocal folds.

6. fiberoptics - a thin transparent homogeneous fiber of glass or plastic that is enclosed by material of lower index of refraction and transmits light throughout its length by internal reflections; a bundle of such fibers used in an instrument for bending light or seeing around corners (Webster, 1973, p.424).

7. input filtering -there are three types of filters: low pass- which attenuates high frequency energy but passes low; high pass- which attenuates low frequency energy but passes high; and octave band - which attenuate a band of high or low frequencies, passing the remaining.

8. Flexible Nasopharyngolaryngoscopy- the use of a flexible fiberoptic endoscope used for viewing the vocal folds.

9. frequency - the number of complete vibrations or cycles per unit time and is usually measured in Hz or cps.

10. fundamental frequency (Fo) - fundamental frequency refers to the most frequently or commonly occurring frequency that characterizes a particular vocal production (Colton and Casper, 1990, p. 184). The fundamental is the lowest component of a complex tone.

11. harmonics - are whole number multiples of the fundamental frequency. These tones, which occur over the fundamental, are called harmonics or overtones.

12. Hertz (Hz) - most commonly used symbol to denote frequency.

13. indirect laryngoscopy - the traditional means of examining the larynx through the use of a laryngeal mirror (Colton and Casper, 1990, p.176)

14. intensity - Intensity is the physical property of an acoustic signal, and the loudness of that signal is related to its intensity (Borden and Harris, 1984).

15. invasive - an instrument, such as an endoscope, is inserted into a body cavity.

16. larynx - The larynx is a tube with several folds. It is composed of ligaments, muscles, and mucous membranes. Its framework is cartilage, and it is suspended in the neck by a series of flat strap muscles. Its superior support is via the nonarticulated hyoid bone, and it is connected inferiorly to the trachea, just superior to the first tracheal ring. Nervous supply to the larynx is provided by vagus, the tenth cranial nerve; and its blood supply is from a branch of the common carotid artery (Stemple, 1984, p.13).

17. light source - in conjunction with the use of an endoscope, a steady stream of light or a pulsed light (strobe). The light is generated externally to the endoscope, and travels through the endoscope via fiberoptic cables.

18. loudness - Loudness is the subjective impression of the power of sound (Martin, 1986, p.55).

19. mucosal wave - a wave-like motion of the vocal folds is seen on the superior surface (lamina propria) in normal speakers when examined with an endoscope. This wave-like motion reflects their complex structure and movement. Any change in the normal movement patterns will be reflected in the appearance of the mucosal wave (Colton and Casper, 1990, p.28). Mucosal wave is a stroboscopic phenomenon.

20. non-invasive - a measurement procedure that does not involve placing any instrument into a body cavity. Sound is measured acoustically.

21. nasopharynx - the area where the back of the nose and the throat meet, at the level of the soft palate. Bounded above by the rostrum of the sphenoid bone and the pharyngeal protuberance of the occipital bone, the nasopharynx is limited inferiorly at the level of the soft palate. It communicates anteriorly with the posterior nares or the choanea of the nasal cavities and laterally with the pharyngeal orifice of the auditory tube (Zemlin, 1988, p.223).

22. phase - a term used in describing vibratory as well as wave motion and is useful in describing the relationship between two or more vibrations or wave motions. Phase may be defined as the portion of a cycle through which a vibrating body has passed up to a given instant (Zemlin, 1988, p.412). Phase symmetry of the vocal folds refers to differences in appearance between the moving vocal folds (Colton and Casper, 1990, p. 29).

23. pitch - Pitch is the psychological subjective perception of frequency.

24. quality - The sharpness of resonance of a sound system. The vividness or identifying characteristics of a sound (Martin, 1986, p.55). The psychological perception of a wave form.

25. Rigid Videostroboscopy - a procedure for viewing the vocal folds at a perceived slower rate, and capable of emulating fundamental frequency.

26. stroboscopy - the use of a strobe light source in combination with an endoscope. The vibratory image portrayed by stroboscopy appears to be in slow motion but is, instead, a composite image pieced together from many different cycles (Watterson and McFarlane, 1991, p.81).

27. Visi-Pitch - a portable instrument that extracts and displays frequency in real time, either from a live voice via a microphone or from a tape recording. (Horii, 1983)

28. vocal fold - Each fold consists of a bundle of muscle tissue; The main part of the vocal cord consists of the vocalis muscle. The vocalis muscle is covered with the elastic conus, which is markedly thick near the edge of the fold, comprising the vocal ligament. Superficial to the elastic conus lies the mucous membrane (mucosa) which consists of the very thin epithelial layer and the lamina propria (Hirano, 1974, p. 1-3). The vocal folds are located in the larynx and appear shelflike when viewed from a superior angle. The vocal folds vibrate when air from the lungs is passed between them, in the area called the glottis, in order to produce sound. The vocal folds can also act as a protective valve for the trachea (airway), closing off to protect against foreign objects (such as food or liquid during a swallow).

29. vocal tract - an extended tube starting immediately within the larynx and extending up the throat into the oral cavity, coupled with the nasal cavity. The resonating tubes of the vocal tract include the hypopharynx, the oropharynx, and the nasal cavities. Sound is produced at the level of the vocal folds, and vibrates within these resonating cavities. (Boone and McFarlane , 1988).

APPENDICES

APPENDIX A

APPENDIX A

Averages for each subject's vowel productions: Ss 1-12

S #		Trial	VP /a/	Inductive /a/	Diff.	VP /i/	Inductive /i/	Diff.
S	1	1	173.8	175.0	+1.2	180.7	179.5	-1.2
	1	2	187.1	188.0	+.90	178.9	179.3	+.40
	1	3	174.7	175.7	+.10	195.5	193.87	-1.625
S	2	1	178.9	179.4	+.50	183.1	184.1	+1.0
	2	2	177.1	177.75	+.40	199.1	198.5	+.60
	2	3	177.4	176.0	-1.4	189.5	190.4	+.90
S	3	1	182.6	183.1	+.50	193.2	193.5	+.30
	3	2	187.3	188.0	+.70	190.8	192.1	+1.3
	3	3	188.0	188.5	+.5	192.9	193.0	+.10
S	4	1	185.8	186.0	+.2	192.0	192.8	+.80
	4	2	187.7	188.75	+1.05	193.1	194.6	+1.5
	4	3	190.5	191.5	+1.0	193.9	194.3	+.40
S	5	1	253.4	253.8	+.40	253.8	255.2	+1.4
	5	2	240.5	241.8	+1.3	263.5	264.2	+.70
	5	3	242.4	243.5	+1.1	260.1	260.4	+.10
S	6	1	193.4	194.75	+1.35	197.1	198.5	+1.4
	6	2	192.2	192.8	+.60	195.4	196.3	+.90
	6	3	192.5	193.3	+.80	195.2	195.6	+.40
S	7	1	205.4	206.0	+.60	230.4	230.8	+.40
	7	2	215.4	215.6	+.20	230.3	231.3	+1.0
	7	3	218.9	219.4	+.50	228.3	222.2	-6.1
S	8	1	220.5	221.2	+.70	211.8	211.5	-.30
	8	2	221.9	222.2	+.30	215.6	216.8	+1.2
	8	3	218.1	218.8	+.70	214.8	214.6	-.20
S	9	1	101.4	103.0	+1.6	108.7	109.0	+.30
	9	2	98.4	98.8	+.40	106.8	107.6	+.80
	9	3	97.0	97.5	+.50	106.1	107.6	+1.5
S	10	1	112.8	117.4	+4.6	133.1	134.3	+1.2
	10	2	117.2	117.8	+.60	135.7	136.1	+.40
	10	3	118.8	119.3	+.50	137.6	139.2	+1.6
S	11	1	84.4	85.2	+.80	81.4	81.5	+.10
	11	2	86.1	86.1	=	83.4	84.125	+.725
	11	3	87.5	88.0	+.50	85.2	86.1	+.90
S	12	1	121.1	122.1	+1.0	143.4	143.7	+.30
	12	2	125.3	125.8	+.50	142.0	139.6	-2.4
	12	3	127.2	128.1	+.90	143.3	143.8	+.50

Appendix A (cont'd)

Ss13-25

S	13	1	150.0	150.1	+.10	152.6	154.3	+1.7
	13	2	142.2	143.3	+1.1	154.6	155.6	-1.0
	13	3	141.3	142.4	+1.1	151.4	154.6	+3.2
S	14	1	119.2	120.1	+.90	131.7	132.5	+.80
	14	2	120.8	121.7	+.90	142.0	142.4	+.40
	14	3	134.0	134.6	+.60	140.6	140.8	+.20
S	15	1	99.7	100.2	+.50	107.1	107.75	+.65
	15	2	100.4	101.5	+1.2	103.9	105.625	+1.725
	15	3	100.3	101.0	+.70	102.1	102.0	+1.0
S	16	1	120.8	121.0	+.20	119.1	120.2	+1.1
	16	2	114.6	114.8	+.20	123.4	124.5	+1.1
	16	3	117.9	115.4	-2.5	125.8	126.7	+.90
S	17	1	116.9	117.4	+.50	127.7	119.6	-8.1
	17	2	114.8	115.4	+.60	118.9	117.5	-1.4
	17	3	116.6	118.0	+1.4	120.2	119.25	-.95
S	18	1	206.9	207.4	+.50	242.9	243.375	+.475
	18	2	211.3	212.125	+.825	244.7	245.7	+1.0
	18	3	214.8	215.375	+.575	266.3	266.6	+.30
S	19	1	206.2	206.5	+.30	210.8	211.85	+1.05
	19	2	205.6	206.7	+1.1	209.1	210.83	+1.73
	19	3	206.2	208.5	+2.3	207.6	208.0	+1.6
S	20	1	347.7	348.1	+1.0	344.8	345.8	+1.0
	20	2	345.4	346.5	+1.1	337.8	342.6	+4.8
	20	3	351.0	351.5	+.50	344.0	345.0	+1.0
S	21	1	199.0	199.83	+.83	200.9	201.83	+.93
	21	2	196.5	197.1	+.60	202.0	202.2	+.20
	21	3	196.4	197.3	+.90	205.0	205.2	+.20
S	22	1	200.3	199.57	-.73	213.7	213.6	-.10
	22	2	206.9	207.6	+.70	225.4	230.2	+4.8
	22	3	207.9	209.0	+1.1	234.2	235.4	+1.2
S	23	1	177.8	178.1	+.30	197.0	197.5	+.50
	23	2	177.5	179.0	+1.5	183.8	184.1	+.30
	23	3	176.2	178.8	+2.6	168.6	168.6	=
S	24	1	214.0	214.83	+.83	209.8	210.5	+.70
	24	2	191.2	192.4	+1.2	213.5	213.6	+.10
	24	3	199.7	200.6	+.90	230.5	230.6	+.10
S	25	1	206.0	206.3	+.30	222.4	223.16	+.76
	25	2	208.4	209.6	+1.2	218.0	217.0	-1.0
	25	3	216.7	217.2	+.50	222.9	222.86	-.04

APPENDIX B

APPENDIX B

Mean F_o for subjects three vowel trials and mean frequency differences.

S#	/a/ Ac	/a/ Ind	Diff.	/i/ Ac	/i/ Ind	Diff.
1	178.5	179.5	+1.0	185.0	184.93	-.07
2	177.8	177.6	-.20	190.5	191	+.50
3	185.9	186.5	+.60	192.3	192.86	+.56
4	188.0	188.75	+.75	193	193.9	+.90
5	245.4	246.3	+.90	259.1	259.9	+.80
6	192.7	193.6	+.90	195.9	196.8	+.90
7	213.2	213.6	+.40	229.6	228.1	-1.5
8	220.1	220.73	+.63	214.06	214.3	+.24
9	98.93	99.77	+.93	107.2	108.07	+.87
10	116.27	118.17	+1.9	135.47	136.53	+1.06
11	86	86.43	+.43	83.33	83.91	+.58
12	124.83	125.33	+.50	142.9	142.37	-.53
13	144.5	142.27	-2.23	152.87	154.83	+1.96
14	124.67	125.47	+.80	138.1	138.57	+.47
15	100.13	100.9	+.77	104.37	105.12	+.75
16	117.77	117.07	-.60	122.77	123.8	+1.03
17	116.1	116.93	+.83	122.27	118.78	-3.49
18	211	211.63	+.63	251.3	251.89	+.59
19	206	207.23	+1.23	209.1	210.23	+1.13
20	347.83	348.7	+.87	342.2	344.47	+2.27
21	197.3	198.08	+.78	202.3	203.08	+.78
22	205.03	205.39	+.36	224.4	226.4	+2.0

Appendix B (cont'd)

23	177.17	178.63	+1.46	183.1	183.4	+.30
24	201.63	202.61	+.98	217.9	218.23	+.33
25	210.37	211.03	+.66	221.1	221.01	-.09

APPENDIX C

APPENDIX C

Norms for Speaking Fundamental Frequency according to age ranges and gender

Hollien and Shipp (1972) Norms for Males:

AGES	Norms for Males
20-29	F_o =120 Hz
30-39	F_o =112 Hz
40-49	F_o =107 Hz

Present study finding for males for sustained vowel phonation:

Ages	/a/	/i/
20-29	126 Hz	144 Hz
30-39	117 Hz	129 Hz
40-49	101 Hz	110 Hz

In a study of SFF characteristics of nonsmoking female adults, Stoicheff (1981) study of nonsmoking female adults found:

Ages	Norms for Females
20-29	224.3
30-39	213.3
40-49	220.8.

Present study findings for females for sustained vowel phonation:

Ages	/a/	/i/
20-29	210 Hz	224 Hz
30-39	211 Hz	218 Hz
40-49	206 Hz	218 Hz.

APPENDIX D

APPENDIX D

Case History Checklist

Name
Subject Number
Age
Gender M F

1. Have you ever had any formal voice training or public speaking training?
yes no

2. Is English your primary language?
yes no

3. Do you have any history of neuropathology or cleft palate?
yes no

4. Have you been a non-smoker for at least the past 5 years?
yes no

5. Are you presently taking any medications that will or do affect your voice?
yes no

6. Have you had any previous therapy for any voice disorders?

yes no

APPENDIX E

APPENDIX E

Informed Consent

I agree to participate in a study of the reproduction of human voice and for the analysis of a selected acoustic parameter, specifically fundamental frequency, associated with normal voice production. I understand that I will be asked to produce a series of vowels and that recordings of my voice will be obtained for analysis via an acoustic microphone that will be hand held, and an inductive microphone that will be placed on the side of my throat and held in place with a velcro strap. Participation in the study is expected to last approximately 20 minutes.

My signature below indicates that I have read this consent form and have been advised about the following:

--I understand that my participation in this study is strictly voluntary;

--I understand that there will be no financial compensation for my participation in this study;

--I understand that there are no fees or charges for any of the procedures;

--I understand that I can withdraw voluntarily from the study at any time without penalty;

--I understand that the results of my personal performance in this study will be kept confidential;

--I have been advised that it is likely that the results of the study will be presented in an educational and/or professional setting and that my name will remain confidential at all times.

I have read this consent form and have agreed to participate in the study.

(Signature)

(Date)

REFERENCES

REFERENCES

Baken, R. J. (1987). Vocal Fundamental Frequency. Clinical Measurement of Speech and Voice. Boston: College Hill Press.

Bless, Diane M., Hirano, M., & Feder, Robert J. (1987). Videostroboscopic Evaluation of the Larynx. Ear, Nose and Throat Journal, 66.

Boone, Daniel R. & McFarlane, Stephen C. (1988). The Voice and Voice Therapy. Englewood Cliffs, NJ: Prentice Hall.

Coleman, Robert F. & Markham, Ira W. (1991) Normal Variations in Habitual Pitch. Journal of Voice, 5, 173-177.

Colton, Raymond H. (1988). Physiological Mechanisms of Vocal Frequency Control: The Role of Tension. Journal of Voice, 2, 208-220.

Decker, T. N. (1990). Instrumentation: An Introduction for Students in the Speech and Hearing Sciences. New York: Longman.

Fairbanks, Grant. (1937). Voice and Articulation Drillbook (2nd ed.). New York: Harper and Row, Publishers.

Faure, Marie-Agnes & Muller, Andre. (1992). Stroboscopy. Journal of Voice, 6, 139-148.

Gould, Wilbur J. (1984). The Clinical Voice Laboratory: Clinical Application of Voice Research. Annals of Otology, Rhinology, and Laryngology, 93, 346-350.

Hirano, M. & Bless, D.M. (1986). Stroboscopic Evaluation of the Larynx. Boston:College Hill Press.

Hirano, Minoru. (1974). Morphological Structure of the Vocal Cord as a Vibrator and its Variations. Folia Phoniatrica, 26, 89-94.

Hollien, H., Dew, D., & Philips, P. (1971). Phonational Frequency Ranges of Adults. Journal of Speech and Hearing Research, 14, 755-760.

Hollien, H. & Shipp, T. (1972). Speaking Fundamental Frequency and Chronologic Age in Males. Journal of Speech and Hearing Research, 15, 155-159.

Horii, Yoshiyuki. (1975). Some Statistical Characteristics of Voice Fundamental Frequency. Journal of Speech and Hearing Research, 18, 192-201.

Horii, Yoshiyuki. (1983). Automatic Analysis of Voice Fundamental Frequency and Intensity Using a Visi-Pitch. Journal of Speech and Hearing Research, 26, 467-471.

Isshiki, Nobuhiko. (1989). Phonosurgery: Theory and Practice. Tokyo: Springer-Verlag.

Izdebski, K., Ross, Joel C. & Klein, James C. (1990). Transoral Rigid Laryngovideostroboscopy (Phonoscopy). Seminars in Speech and Language: Videolaryngoendoscopy and Voice Disorders, 11, 16-26.

Karnell, Michael P. (1989). Synchronized Videostroboscopy and Electroglottography. Journal of Voice, 3, 68-75.

Kay Elemetrics. (1987). Visi-Pitch/IBM PC Interface: Models 6097 and 6098, Manual.

Linton, Marigold & Gallo, Philip S. Jr. (1975). The Practical Statistician: Simplified Handbook of Statistics. Monterey, CA: Brooks/Cole Publishing Co.

Mackay, Ian. (1987). Phonetics: The Science of Speech Production. Boston: A College-Hill Publication-Little, Brown and Co.

Martin, Frederick N. (1986). Introduction to Audiology. Englewood Cliffs, NJ: Prentice Hall.

Nagashima Medical Instruments Catolog.

Peterson, Gordon E., & Barney, Harold L. (1952). Control Methods Used in a Study of Vowels. The Journal of the Acoustical Society of America, 24, 175-184.

Sataloff, Robert T. (1987). Clinical Evaluation of the Professional Singer. Ear, Nose, and Throat Journal, 66, 267-277.

Sataloff, Robert T. (1987). The Professional Voice: Part II. Physical Examination. Journal of Voice, 1, 191-201.

Sataloff, Robert T. (1987). Voice: A New Subspecialty. Ear, Nose, and Throat Journal, 66.

Sataloff, Robert T. & Speigel, Joseph R. (1988). Objective Evaluation of the Voice. Medical Problems of Performing Artists, 105-108.

Saxman, J.H. & Burk, K.W. (1967). Speaking Fundamental Frequency Characteristics of Middle-Aged Females. Folia Phoniatrica, 19, 167-172.

Stemple, Joseph C. (1984). Clinical Voice Pathology: Theory and Mangement. Columbus, OH::Charles E. Merrill Publishing Co.

Stoicheff, Margaret L. Speaking Fundamental Frequency Characteristics of Nonsmoking Female Adults. Journal of Speech and Hearing Research, 24, 437-441.

Watterson, Thomas L. & McFarlane, Stephen C. (1991). Transoral and Transnasal Laryngeal Endoscopy. Seminars in Speech and Language, 77-87.

Wendler, Juergen. (1992). Stroboscopy. Journal of Voice, 6, 149-154.

Woo, P., Colton, R., Casper, J. & Brewer, D. (1991). Diagnostic Value of Stroboscopic Examination in Hoarse Patients. Journal of Voice, 5, 231-238.

Zemlin, Willard R. (1988). Speech and Hearing Science: Anatomy and Physiology (3rd ed.). Englewood Cliffs, NJ: Prentice Hall.

BIBLIOGRAPHY

BIBLIOGRAPHY

Ad Hoc Committee on Advances in Clinical Practice. (1992). Vocal Tract Visualization and Imaging. American Speech and Hearing Research, Supplement, 34, 37-40.

Biever, Dawn M. & Bless, Diane M. (1989). Vibratory Characteristics of the Vocal Folds in Young Adult and Geriatric Women. Journal of Voice, 3, 120-131.

Brewer, David W. & McCall, Gerald. (1974). Visible Laryngeal Changes During Voice Therapy. Annals of Otolaryngology, 83, 423-427.

Cantarella, Giovanna. (1988). Value of Flexible Videolaryngoscopy in the Study of Laryngeal Morphology and Functions. Journal of Voice, 1, 353-358.

Casper, Janina K., Brewer, David W., & Colton, Raymond H. (1988). Pitfalls and Problems in Flexible Fiberoptic Videolaryngoscopy. Journal of Voice, 1, 347-352.

Colton, Raymond H., Brewer, David W., & Rothenberg, Martin. (1983). Evaluating Vocal Fold Function. The Journal of Otolaryngology, 12, 291-294.

Deal, Randolph E. & Emanuel, Floyd, W. (1978). Some Waveform and Spectral Features of Vowel Roughness. Journal of Speech and Hearing Research, 21, 250-264.

Dempsey, M.E., Draegert, G.L., Siskind, R.P., & Steer, M.D. (1950).The Purdue Pitch Meter- A Direct Fundamental Frequency Analyzer. Journal of Speech and Hearing Research 15, 135-141.

Gabrielsson, A., Schenkman, Bo N., & Hagerman, B. (1988). The Effects of Different Frequency Responses on Sound Quality Judgements and Speech Intelligibility. Journal of Speech and Hearing Research, 31, 166-177.

Gelfer, Marylou P. (1988). Perceptual Attributes of Voice: Development and Use of Rating Scales. Journal of Voice, 2, 320-326.

Gossett, Claude W. (1989). Electromyographic Investigation of the Relationship of the Effects of Selected Parameters on Concurrent Study of Voice and Oboe. Journal of Voice, 3, 52-64.

Gould, Wilbur J., Kojima, H., & Lambiase, A. (1979). A Technique for Stroboscopic Examination of the Vocal Folds Using Fiberoptics. Archives of Otolaryngology, 105, 285.

Hicks, D.M. & Teas, E. (1987). An Electroglottographic Study of Vocal Vibrato. Journal of Voice, 1, 142-147.

Hirano, M., Kurita, S. & Nakashima, T. (1981). The Structure of the Vocal Folds. In Stevens and Hirano (Eds.), Vocal Fold Physiology (pp.33-41). Tokyo: University of Tokyo Press.

Hirano, M., Yoshida, T., Yoshida, Y., & Tateishi, O. (1985). Strobosfiberscopic Video Recording of Vocal Fold Vibration. Annals of Otology, Rhinology, and Laryngology, 94, 588-590.

McFarlane, Stephen C. & Lavorato, Alfred S. (1984). The Use of Video Endoscopy in the Evaluation and Treatment of Dysphonia. Communicative Disorders, 9, 117-126.

Morrison, M.D. (1984). A Clinical Voice Laboratory: Videotape and Stroboscopic Instrumentation. Otolaryngology-Head and Neck Surgery, 92, 487-488.

Murry, T. & Doherty, E.T. (1980). Selected Acoustic Characteristics of Pathologic and Normal Speakers. Journal of Speech and Hearing Research, 23, 361-369.

Murry, Thomas. (1988). Vocal Tract Parameters Associated with Voice Quality and Preference. Journal of Voice, 2, 111-117.

Myers, Denise & Michel, John. (1987). Vibrato and Pitch Transitions. Journal of Voice, 1,157-161.

Peppard, Robert C., Bless, Diane M., & Milenkovic, Paul. (1988). Comparison of Young Adult Singers and Nonsingers with Vocal Nodules. Journal of Voice, 2, 250-260.

Rontal, E., Rontal, M., Jacob, J.H., & Rolnick, M.I. (1983). Quantitative and Objective Evaluation of Vocal Cord Function. Annals of Otology, Rhinology, and Laryngology, 92, 421-423.

Saito, S., Fukuda, H., Kitahara, S., & Kokawa, N. (1978). Stroboscopic Observation of Vocal Fold Vibration with Fiberoptics. Folia Phoniatrica, 30, 241-244.

Saito, S., Fukuda, H., Isogai, Y., & Ono, H. (1981). X-Ray Stroboscopy. In Stevens and Hirano (Eds.), Vocal Fold Physiology (pp. 95-103). Tokyo: University of Tokyo Press.

Schmidt, P., Klingholz, F., & Martin, F. (1988). Influence of Pitch, Voice Sound Pressure, and Vowel Quality on the Maximum Phonation Time. Journal of Voice, 2, 245-249.

Walker, J.S. (1988). An Investigation of the Whistle Register in the Female Voice. Journal of Voice, .2,140-150.

Watterson, Thomas L., McFarlane, Stephen C., & Brophy, John W. (1990). Some Issues and Ethics in Oral and Nasal Video-Endoscopy. Seminars in Speech and Language, 1-7.

White, James F. & Knight, Robert E. (1984). Office Videofiberoptic Laryngoscopy. Laryngoscope, 94, 1166-1169.

Williams, G. T., Farquharson, I. M., & Anthony, J. (1975). Fibreoptic Laryngoscopy in the Assessment of Laryngeal Disorders. The Journal of Laryngology and Otology, 89, 299-315.

Yanagisawa, E., Casuccio, J.R., & Suzuki, M. (1981). Video Laryngoscopy Using a Rigid Telescope and Video Home System Color Camera - A Useful Office Procedure. Annals of Otology, Rhinology and Laryngoscopy, 90, 346-350.

Yanagisawa, Eiji. (1982). Office Telescopic Photography of the Larynx. Annals of Otology, Rhinology, and Laryngology, 91, 354-358.