The purpose of this study was to compare baseline aerodynamic measurements of voice to measurements repeated after a 10-minute break and a one week break. Average airflow and estimated subglottal pressure measurements were gathered from females between 18 and 24 years of age with healthy voices. Each participant’s frequency and intensity was held constant during each testing session. Results indicated that aerodynamic measurements of average airflow and estimated subglottal pressure were repeatable, as there were no significant differences between mean measurements taken during each testing session. The results of this study provided support for the clinical use of average airflow and estimated subglottal pressure for voice assessments and treatment data.
REPEATABILITY OF AERODYNAMIC MEASUREMENTS OF VOICE

A Thesis

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CHAPTER I
Introduction

Voice Disorders

Communication disorders include a range of disorders affecting various components of communication including hearing, speech, language, cognition, and voice. Because voice is the instrument for verbal communication, voice disorders impact an individual’s ability to communicate. A voice disorder is present when “the structure, the function, or both of the laryngeal mechanism no longer meet the voicing requirements established for the mechanism by the speaker” (Stemple, Glaze, & Klaben, 2000, p. 2). Voice is produced by the laryngeal mechanism, which is located inferior to the pharyngeal region and superior to the lungs. The larynx is comprised of three paired cartilages, three unpaired cartilages, and five intrinsic laryngeal muscles (Andrews, 2006). One set of intrinsic muscles, the thyroarytenoids, or the vocal folds, vibrate to produce the signal for voicing. Respiration provides the power source for voicing. Inspiration is supported by the diaphragm and external intercostals muscles. Expiration, when phonation occurs, is a passive recoil process that does not require effort but can be supported by the internal intercostals and abdominal muscles for forced expiration (Andrews). Phonation during expiration can be controlled by singers, actors, and other speakers who need to extended expiration for long phrases. When the vocal folds adduct, pressure builds below the level of the vocal folds. This subglottic pressure eventually forces the vocal folds apart. The space created when the vocal folds begin to separate causes air pressure to decrease. The elastic nature of the vocal folds and the Bernoulli Principle bring the vocal folds together, and this open and close vibratory pattern continues, resulting in voice (Borden, Harris, & Raphael, 2003). The vocal tract shapes the voice into the individual speech sounds.

Voice disorders can be the result of vocal misuse, medically related etiologies, primary disorder etiologies and personality-related etiologies (Stemple et al., 2000). Behaviors of vocal misuse damage the voice and prevent the laryngeal mechanism from working efficiently. Such behaviors include loud talking, screaming, throat clearing, coughing, and vocal noises. Vocal misuse is one of the most common causes of voice disorders (Colton & Casper, 1990). Voice disorders can also result directly or indirectly from medical or surgical interventions. The voice can be directly affected by surgeries that impact the anatomical structures used for voicing, such as laryngectomees. The voice can be indirectly affected by surgeries that impact the structures on
the path of the recurrent laryngeal nerve and superior laryngeal nerve branches of the vagus cranial nerve, as these branches innervate the larynx. Other chronic medical conditions, such as laryngitis, chronic obstructive pulmonary disease, asthma, arthritis, and gastrointestinal disorders, can negatively affect the voice (Stemple et al.). Voice disorders can also be secondary symptoms of other etiologies. For example, disorders such as cleft palate, deafness, and cerebral palsy frequently result in voice disorders (Stemple et al.). Finally, personality-related etiologies refer to voice disorders that result from whole-body tension that affects the laryngeal mechanism. Stress from various causes and traumatic life events, for example, can result in tension that changes the quality of the voice. Additionally, identity conflicts and psychosexual conflicts can result in voice disorders from individuals struggling to establish their own personality and therefore their own voice (Stemple et al.).

In addition to classification of voice disorders by etiology, voice disorders are often classified by the type of disorder. There are voice disorders of the vocal fold cover, congenital voice disorders, neurological voice disorders, and disorders of voice use. Voice disorders of the vocal fold cover are pathologies of the outer layers of the thyroarytenoid muscles. These types of pathologies change the mass, size, stiffness, flexibility and tension of the folds, while also changing the glottal closure patterns of the folds. Such changes can result in perceptual changes in the quality, pitch, and volume of the voice (Stemple et al., 2000). Examples of pathologies of the vocal fold cover include vocal nodules, polyps, cysts, granulomas, and contact ulcers. Congenital voice disorders can be very serious if resulting in an airway compromise. Congenital voice disorders include laryngomalacia, subglottal stenosis, tracheoesophageal atresia, and congenital laryngeal web (Boone, McFarlane, & Von Berg, 2005). Neurological voice disorders result from impairments in the innervations to the larynx. Impairments can be a result of disease, malformation, or injury. Vocal fold paralyses are a type of neurological voice disorder. Vocal fold paralyses can be unilateral or bilateral, and the folds can be paralyzed in an abducted or adducted position (Colton & Casper, 1990). Spasmodic dysphonia and organic vocal tremor are also types of neurological voice disorders. Additionally, neurological degenerative diseases that affect the entire nervous system often eventually cause voice disorders. For example, many patients with myasthenia gravis, multiple sclerosis, Parkinson’s disease, Huntington’s disease and amyotrophic lateral sclerosis acquire voice disorders (Boone et al., 2005). In some situations, the functional use of the voice can be a source of pathology even when the laryngeal
mechanism is healthy. Examples of voice use disorders include ventricular phonation, puberphonia, persistent glottal fry, and transgender voice (Colton & Casper).

The Diagnostic Voice Evaluation

The primary purpose of the voice evaluation is to assess the structure and function of the voice (American Speech-Language and Hearing Association (ASHA), 2004). The diagnostic voice evaluation also aims to determine any etiologic factors associated with the voice disorder and describe the abnormalities of the quality, pitch, and volume of the voice (Stemple et al., 2000). The voice pathologist should use the diagnostic voice evaluation to gain as much information about the patient and his voice as possible. There are several components that make up the diagnostic voice evaluation. The American Speech-Language Hearing Association recommends that the voice evaluation use standardized and non-standardized methods in conjunction with a thorough patient case history. Standardized and non-standardized methods can include assessment of perceptual aspects of the voice, acoustic parameters, physiological aspects, emotional status and perceptual and instrumental measures (ASHA, 2004).

Patient interview. Each diagnostic voice evaluation should begin with a detailed patient interview. Since the voice is often closely tied to the individual’s emotions and behaviors, it is important that the voice pathologist understand the patient’s personality, behaviors, and lifestyle. The interview should also include gathering the patient’s medical history and social history. It is important for the voice pathologist to gather information regarding the effect of the voice problem on the individual and information regarding how the voice disorder has developed or changed over time, including onset and duration of the problem (Colton & Casper, 1990). During the interview portion of the evaluation the voice pathologist has an opportunity to educate the patient regarding how the voice works and behaviors that affect the voice. Patient education also allows the voice pathologist to establish rapport so that the patient can feel comfortable being honest and sharing information (Boone et al., 2005).

Perceptual voice evaluation. During the perceptual voice evaluation the voice pathologist listens to and judges respiration, phonation, resonance, pitch, loudness, and rate. Various rating scales are used for making perceptual judgments. One commonly used scale is the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V; ASHA, 2006). This tool allows the voice pathologist to use a scale to describe the severity of auditory-perceptual characteristics of a voice disorder. In order to complete the CAPE-V the voice pathologist listens to the patient’s voice
during three testing conditions: sustained vowels, sentences read aloud, and running speech. The voice pathologist rates the attributes of overall severity, roughness, breathiness, strain, pitch, and loudness on a visual analog scale of normal to severe impairment. As with many rating scales, research has shown that intra- and inter-judge agreement on the CAPE-V varies greatly (ASHA, 2006).

**Instrumental voice evaluation.** Instrumental evaluations are an important part of the diagnostic evaluation to be used in conjunction with the perceptual voice evaluation. Laryngeal videostroboscopy provides a visual image of the vocal folds and vocal fold vibratory characteristics during actual speech tasks. These images provide important information for identifying what type of voice disorder is present (Merati & Bielamowicz, 2007). Additionally, videostroboscopy provides a permanent record of the vocal tract images seen during the exam and can be easily shared with other professionals and referral sources (Boone et al., 2005).

Another type of instrumental evaluation is the objective voice evaluation that includes gathering acoustic and aerodynamic data regarding the patient’s voice. Acoustic data of the voice include five common measures: fundamental frequency, intensity, perturbation measures, spectral features, and a ratio of signal to noise. Since normative data are available for each of these measures, acoustic measurements can often be used to discriminate between pathological versus normal voices (Stemple et al., 2000). Objective aerodynamic measurements also provide valuable information during the diagnostic voice evaluation. The two principle aerodynamic components are subglottic pressure and average airflow. These measurements provide quantitative data that can reveal the severity of vocal impairment, and thus be used as a pre-treatment baseline (Sapienza, 1996).

**Aerodynamic Measurements**

Aerodynamic measurements provide important information regarding the functioning of the normal and disordered voice. Aerodynamic measurements provide clinicians with objective quantifiable data not available from listening to the perceptual characteristics of voice. Subtle changes in the voice may be detected more easily by objective data than by the clinician’s subjective judgments. Measurements of aerodynamic data can also provide clinicians with objective data related to the patient’s phonatory characteristics (Sapienza, 1996). Objective aerodynamic measurements alone should not be used to make a specific diagnosis, but they may
be used to confirm what is expected when used in conjunction with a case history, perceptual evaluation, and imaging techniques (Merati & Bielamowicz, 2007).

Two aerodynamic measurements clinically used are average airflow and estimated subglottic pressure. The average airflow measurement simply refers to the amount of air flowing through the larynx. Normative studies have shown that average airflow in healthy adults, during continuous phonation, is expected to be within the range of 142-218 mL/s (Baken & Orlikoff, 2000). Estimated subglottic pressure measurements reflect the pressure of the air below the adducted vocal folds, which is necessary for phonation (Borden et al., 2003). Normative data suggest that intra-oral pressure, which is how subglottic pressure is estimated, should measure within the range of 4.2-6.7 cmH₂O for healthy adults when measured from a consonant-vowel-consonant syllable (Baken & Orlikoff). The subglottic pressure measurement is considered an estimated value, because direct measurements of subglottic pressure require invasive techniques of penetrating the airway below the level of the vocal folds in order to place a sensing tube in the exact region where the pressure originates (Baken & Orlikoff).

Other aerodynamic measurements, in addition to average airflow and estimated subglottic pressure, are frequently used in research. Generally, aerodynamic measurements are related to either pressure or airflow and volume. Airflow measurements include airflow open quotient, maximum flow declination rate, peak average airflow, alternating average airflow, and minimum average airflow (Sapienza, 1998). Other useful aerodynamic measurements are maximum phonation time, glottal resistance, laryngeal resistance, and glottal efficiency (Merati & Bielamowicz, 2007).

In addition to being helpful during the diagnostic voice evaluation to reveal how the voice is functioning, aerodynamic measurements are useful therapeutically. Aerodynamic measurements provide pre-treatment and post-treatment data that can be more objectively compared than subjective perceptual data. Measurements can provide quantitative data showing improvement, which is beneficial for health insurance purposes. Improvement in the quantifiable aerodynamic measurements can provide motivation and reward for patients. In addition to motivation, the measurements provide instant feedback to patients, which is beneficial for learning to make adjustments in vocal use. Aerodynamic measurements also provide an additional means of patient education regarding the physiology of the voice. Patient education is especially important for patients with voice disorders, since voice therapy often involves the
patient understanding how he is using his voice and what he can do to change his voice (Stemple et al., 2000).

**Testing Protocols and Instrumentation**

Since aerodynamic measurements provide objective data, rather than perceptual characteristics of voice, measurements can be used as treatment data. Reliable aerodynamic measurements can be used to determine baselines and treatment outcomes following voice therapy (Sapienza, 1996). In recent years, multiple instruments and protocols have been developed that allow for aerodynamic data to be gathered through relatively simple non-invasive methods. Rothenberg (1973) was the first to introduce a circumferentially-vented pneumotach face mask. Gathering average airflow data require a pneumotach, which measures airflow and air resistance at the mouth when air is exhaled by means of sustaining a vowel sound. (Rothenberg, 1973). In Rothenberg’s design, a small wire cloth inside the pneumotach provides impedance. The impedance provides slight change in pressure, which is proportional to changes in airflow (Sapienza, 1996). The change in pressure occurs in relation to the amount of air flowing through the phonatory system (Zemlin, 1998). Inverse filtering is a technique used to analyze aerodynamic data. This technique uses the oral airflow signal to calculate the spectral components and remove the formant properties so that only glottal measurements remain (Sapienza). Isolating glottal factors allows the clinician to know which factors are related directly to the functioning of the larynx. The pneumotach is capable of performing the inverse filtering in real time.

To gather estimated subglottic pressure data, intra-oral pressure during unvoiced bilabial plosive consonants is measured while the patient is phonating into the face mask portion of the pneumotach. This technique requires an oral catheter to be placed in the mouth with an air-tight seal made by the lips prior to the plosive consonant production. The individual produces approximately seven repetitions of the unvoiced bilabial plosive consonant paired with a vowel on a single exhalation (Baken & Orlikoff, 2000).

The basic protocols for gathering average airflow and subglottic pressure during phonation provide data that can be measured via different instrumentation and computer programs. One clinically useful such instrument is the Phonatory Aerodynamic System (PAS) (KayPENTAX, 2006). A pneumotach device is used in conjunction with the PAS software to
record the measurements of aerodynamic data. The PAS program also runs on Windows and
gathers data related to speech and voice output.
CHAPTER II

Review of the Literature

With the creation of instruments that provide aerodynamic data and the clinical usefulness of aerodynamic data, numerous research studies have been conducted in the past 30 years pertaining to aerodynamic measurements. Recent research in the area exhibits a wide range of specific purposes and populations. Studies have been published investigating (a) the general use of aerodynamic data in the field of speech-language pathology, (b) the use of aerodynamic measurements under various testing conditions, (c) the repeatability of aerodynamic and acoustic measurements, (d) changes in aerodynamic data at different ages, and (e) the use of aerodynamic measurements as a clinical tool for treatment of the disordered voice. Additionally, various demographics of participants have been studied with regards to aerodynamic measurements. Data have been published on the aerodynamic measurement of adults and children with healthy versus pathological voices. Studies have been completed with samples of participants speaking their native languages. The pneumotach was first introduced in the early 1970s, thus beginning the advent of practical methods for gathering aerodynamic data (Rothenberg, 1973). Beginning in 1988 through the present, new findings have been consistently published relating to aerodynamics in voice treatment and assessment.

Use of Aerodynamic Data

Several studies, aimed at collecting normative data with adult participants, provided information about the general use of aerodynamic data to clinicians studying the voice. In a study examining estimated average transglottal pressure and average airflow in adult males and females with healthy voices, Holmberg, Hillman, and Perkell (1988) found that transglottal pressure differs with high and low frequency speaking tasks. Overall, airflow measurements were correlated with vocal intensity more directly than with fundamental frequency. Intensity increased in speakers when fundamental frequency was raised. Additionally, results show that that speaking at both higher and lower frequencies resulted in increased levels of estimated subglottal pressure. These conclusions provided evidence that measurement protocols do indeed need to be standardized, since a measurement of subglottic pressure taken from a speaking task with high pitch is not equivalent to one taken from a speaking task at low pitch. In a separate
study by Sodersten, Hertegard, and Hammarberg (1995), healthy adult Swedish women were evaluated to examine relationships between vocal volume, transaverage airflow, estimated subglottic pressure, and glottal closure patterns. The investigators found that average airflow increased significantly with increased loudness. There were not any significant findings related to estimated subglottic pressure.

Testing Conditions

Other research studies in the area of aerodynamic measurement gathered normative data for the purpose of discovering new relationships between aerodynamic or acoustic measurements and other variables. Many such studies employed various testing conditions or populations to gather new information. One study examined the intra-speaker variation in aerodynamic and acoustic measures across multiple recordings (Holmberg, Hillman, Perkell & Gress, 1994). A small group of participants with healthy voices was recorded performing the voice protocol three times each, with recordings between one and two weeks apart. The investigators found that measures of air pressure and airflow were systematically related to variations in sound pressure levels. However, significant intra-speaker variations did not occur across the repeated recordings (Holmberg et al., 1994). These findings suggested that individual speaker’s aerodynamic data should remain relatively stable, given no changes in anatomy or physiology. A study by Weinrich, Salz, and Hughes (2005) also gathered normative data across different testing conditions. However, the participants in this study were between 6 and 10 years of age. Aerodynamic measurements were collected at low, comfort, and high pitches. Within the different frequencies, no significant differences in aerodynamic measures were found. As in the previously mentioned article, these findings also suggested that aerodynamic measurements stay relatively stable within various conditions.

Repeatability of Aerodynamic and Acoustic Measurements

Lee, Stemple, and Kizer (1999) studied the repeatability of aerodynamic and acoustic measurements made over a span of time. In their study, healthy adult females performed voice recording protocols under various groups of test conditions over a span of 28 days. Testing conditions varied by whether the participants were free to choose their own intensity levels or fundamental frequencies, or if they were required to match those of previous recordings. Results showed that holding frequency and intensity constant resulted in consistency in all measurements taken. Controlling intensity only resulted in significant differences in frequency measurements;
no other measurements were affected. Controlling frequency only resulted in inconsistent acoustic and aerodynamic measurements. In the area of aerodynamic testing, clinicians and researchers should control the testing conditions in order to allow for confidence that measurements accurately reflect changes in physiology and not just changes in testing conditions.

Several other studies have tested the repeatability of vocal acoustic measurements only. Gelfer (1989) gathered fundamental frequency range data from 20 adult participants three times a day on two different days one to two months apart. Generally, the participants’ fundamental frequency ranges differed significantly and were usually several semitones apart. The results of this study demonstrated that consistent measures, when gathered from the same participant at different times, cannot be assumed. In a different study investigating consistency of acoustic measurements of fundamental frequency and perturbation, Fitch (1990) compared test-retest reliability during different speaking conditions 7 to 10 days apart. The rest-retest reliability was highest for reading a passage as opposed to sustaining a vowel or spontaneous speech. Additionally, no significant differences were found in the comparisons of perturbation as gathered from a sustained vowel during two different testing sessions. From the literature, it is clear that testing condition controls are necessary for gathering consistent aerodynamic and acoustic measurements of voice. The literature also demonstrates that acoustic measurements, such as frequency range, may differ from one point in time to another when all other variables remain constant.

**Changes in Aerodynamic Data Related to Age**

Different studies in a similar line of research investigated aerodynamic measurements to identify changes in the aerodynamics of the voice over a continuum of age and development. Netsell, Lotz, Peters and Schulte (1994) used estimated subglottic pressure, average airflow, and laryngeal airway resistance data collected from both children and adults to investigate what changes occur in the measurements due to development. They discovered a pattern of decreased pressure and resistance accompanied by increases in average airflow occurred from early childhood to adulthood. Such patterns in the aerodynamic data allowed the authors to propose conclusions regarding shifts in respiratory patterns throughout development. Similarly, Sapienza and Dutka (1996) studied phonatory changes in adult women as a function of age. Measurements of average airflow were taken to infer any changes that may have occurred in the anatomy and
physiology of the voice between the ages of 20 and 70 years, grouped by decades. However, the statistical results showed that there were no significant differences between each of the grouped ages.

Clinical Use of Aerodynamic Data

An additional line of research focused on how aerodynamic data differ in the disordered voice, the most clinically relevant use of the measurements (Yu, Ouaknine, Revis, & Giovanni, 2001). One study with this purpose aimed to determine the clinical value of obtaining an objective voice assessment. A control group of males with healthy voices and an experimental group of males with dysphonic voices were compared using variables of a perceptual analysis and aerodynamic measurements. Judges making the perceptual ratings of the voices were blind regarding which group the participant was in and the participant’s aerodynamic measurements. The judges’ ratings and the analysis of the data were then used to separately discriminate if each voice was typical or disordered. The statistical results confirmed that analysis from six aerodynamic parameters provided 86% concordance with the perceptual judgments. Very similar conclusions were made by Yiu, Yuen, Whitehill and Winkworth (2004). Investigators aimed to determine if aerodynamic measurements were in fact reliable enough to be used to accurately discriminate between disordered and healthy voices. Using data collected from Cantonese female speakers, the authors found accuracy rates as high as 91% in predicting dysphonic voices from aerodynamic measurements alone. However, due to some overlap in values found in both healthy and disordered voices, the authors still concluded that aerodynamic measures should be considered in conjunction with perceptual examinations.

Statement of Problem

A review of the literature regarding the use of aerodynamic measurements of voice supports the overall usefulness of objective measurements. Studies focusing on normative data have provided information about the typical roles of estimated subglottic pressure and other measurements at different speaking frequencies and intensities (Holmberg et al., 1988; Sodersten et al., 1995). Studies conducted under different testing conditions have demonstrated the need to use a standardized protocol when collecting group data and pre/post-test data (Lee et al., 1999). Studies with participants at different ages have shown the changes in aerodynamic measurements during development from childhood to adulthood. However, researchers have also shown the
relative consistency of measurements within adulthood and within individual speakers (Holmberg et al., 1994; Netsell et al., 1994; Sapienza & Dutka, 1996). Finally, aerodynamic measurement research has demonstrated that aerodynamic measurements provide strong clinical predictions of disordered voices (Yiu et al., 2004; Yu et al., 2001).

While there are studies (Gelfer, 1989; Fitch, 1990) indicating the consistency of intra-individual acoustic measurements, there is a paucity of information regarding consistency and repeatability of aerodynamic measurements of voice. Previous findings have shown the usefulness of aerodynamic measurements clinically and their predictive power in identifying voice disorders. However, previous findings have also shown all the variables that must be controlled as to not invalidate the aerodynamic measurements. Consistency and reliability are crucial for trustworthy measurements that will identify voice disorders and show progress in vocal parameters following treatment. For aerodynamic measurements to be of value to the voice pathologist, the measurements gathered need to be repeatable. Knowing how a speaker’s intensity and frequency affect aerodynamic measurements of voice, such measurements cannot be reliably used clinically to measure pre- and post-treatment changes, without adequate control for those parameters.

Statement of Purpose

One potential method to determine the reliability of aerodynamic measurements, and subsequently the clinical usefulness of aerodynamic measurements, is to compare measurements taken from the same individuals without a voice disorder. The lack of a vocal pathology and vocal treatment regimen suggests that aerodynamic measurements should be stable in an individual from week to week.

The present study aims to investigate if measurements of average airflow and estimated subglottal pressure gathered from the same participants on two separate days will differ when all other variables are held constant. The current study will investigate if measurements from the same healthy individual, at the same time of day, using the same intensity and frequency result in similar measurements of average airflow and estimated subglottal pressure, using the Phonatory Aerodynamic System (KayPENTAX, 2006).

Research Questions

1. Does mean average airflow significantly differ from baseline to 10 minutes later and one week later?
2. Does mean estimated subglottal pressure significantly differ from baseline to 10 minutes later and one week later?
3. Does mean intensity produced during average airflow trials significantly differ from baseline to 10 minutes later and one week later?
4. Does mean frequency produced during average airflow trials significantly differ from baseline to 10 minutes later and one week later?
5. Does mean intensity produced during estimated subglottal pressure trials significantly differ from baseline to 10 minutes later and one week later?
6. Does mean frequency produced during estimated subglottal pressure trials significantly differ from baseline to 10 minutes later and one week later?

Research Hypotheses

1. It is hypothesized that for adult females with normal voices, average airflow measurements taken at baseline, 10 minutes later, and one week later, with intensity and frequency held constant, will not differ significantly.
2. It is hypothesized that for adult females with normal voices, estimated subglottal pressure measurements at baseline, 10 minutes later, and one week later, with intensity and frequency held constant, will not differ significantly.
3. It is hypothesized that for adult females with normal voices, intensity produced during average airflow trials taken at baseline, 10 minutes later, and one week later will not significantly differ.
4. It is hypothesized that for adult females with normal voices, frequency produced during average airflow trials taken at baseline, 10 minutes later, and one week later will not significantly differ.
5. It is hypothesized that for adult females with normal voices, intensity produced during estimated subglottal pressure trials taken at baseline, 10 minutes later, and one week later will not significantly differ.
6. It is hypothesized that for adult females with normal voices, frequency produced during estimated subglottal pressure trials taken at baseline, 10 minutes later, and one week later will not significantly differ.
CHAPTER III
Methods

Participants

This study included 30 participants. A total of 39 participants were recruited; however, nine participants’ data were excluded from data analysis. Five participants were excluded due to problems with the equipment at the time of testing. Two participants were excluded because they were physically unable to complete the protocol due to lack of breath support or asthma. The remaining two excluded participants were unable to attend their session one week later, and were therefore missing data points. All participants were females between the ages of 18 and 25 years. The average age was 21.2 years, with a standard deviation of 1.37 years. Participants were recruited from a university campus.

Inclusion and exclusion criteria were determined prior to participant recruitment. All participants passed a perceptual voice examination and a hearing screening. Additionally, all participants had velopharyngeal adequacy. Velopharyngeal inadequacy allows air to escape from the oral cavity into the nasal cavity and could subsequently invalidate the measurements of introral pressure, which are necessary for estimating subglottal pressure. Each participant was briefed on the nature of the study and signed a letter of informed consent (Appendix A) prior to data collection.

Procedures

The procedures for this study represent one portion of a larger study. Participants were required to attend testing on two separate occasions. The first occasion lasted approximately 50 minutes and the second lasted approximately 20 minutes. After completing the first testing occasion, participants returned exactly one week later for the second testing occasion. During the first testing occasion, participants performed two identical protocols for Session 1 and Session 2. The third testing session (during the second testing occasion) took place at the same time of day within one hour of the first session. Participants completed the same testing protocol during each of the three sessions. Each participant was given the same verbal instruction (Appendix B). Each testing session took place in the same voice laboratory.

Hearing Screening
All participants were given a hearing screening to ensure normal hearing. This was necessary since a hearing loss could contribute to abnormal vocal parameters. The screening was performed by one of two researchers with experience in operating audiometers and administering hearing screenings. Hearing screenings were conducted on a portable audiometer (MAICO, MA40). To pass the hearing screening, participants were required to hear tones bilaterally at 500, 1000, 2000, and 4000 Hz presented at 25 dB.

**Voice Screening**

Participants were given a perceptual voice screening by one of two graduate students in speech-language pathology with experience in voice disorders. The examiners conducted the voice screening by listening to the participant read a portion of the Rainbow Passage (Fairbanks, 1960; Appendix C). The perceptual voice examination assessed pitch, volume, resonance, phonation, respiration, and rate of speech as they relate to the quality of the voice. To be included in the study participant voices were free from hoarseness, resonance problems, or breathiness, as perceived by the examiner.

**Testing Instrumentation/Measures**

The aerodynamic data were gathered using the Phonatory Aerodynamic System (PAS; KayPENTAX, 2006) program running on a Dell desktop computer in conjunction with a pneumotach and face mask. The pneumotach was calibrated prior to each testing session by following the prompts from the PAS using a one-liter syringe of air. Additional equipment used during the testing sessions included a tuning device (Seiko Chromatic Tuner, ST 909) to find the musical note that corresponded to each participant’s comfort pitch, and a sound level meter (Quest Electronics, Model 2700) to record each participant’s intensity in decibels. Additionally, each participant’s pitch was monitored throughout testing trials by using the Voice Range Profile computer program (KayPENTAX, 2006) running on a separate Dell desktop computer from the PAS program.

**Average airflow.** During the first testing session, participants were asked to count aloud to 10 at a comfortable speaking frequency. During this time, the researcher measured the frequency in terms of a musical note on the tuner and the intensity on the sound level meter. The sound level meter was held 15 centimeters away from the participants’ mouth. The participants were verbally instructed to first take a breath, then place the face mask on their faces creating a tight seal, and sustain the vowel /a/ with the same comfortable frequency and intensity.
Participants were observed to make certain that they maintained an air-tight seal with the face mask. An average airflow measurement was calculated and recorded by the PAS using the Voicing Efficiency protocol. This protocol was repeated three times to obtain an average measurement taken. The testing protocol for the larger study, which this study was a part of, required an additional comfortable intensity trial, with a loud intensity trial between the two comfort trials. For the purpose of this study, both comfortable trials (trial one and trial two) were utilized in data collection. Both comfortable trials were monitored for consistent frequency and intensity. The researchers noted the intensity and musical note used for the sustained /a/ during each trial.

Ten minutes later, the same protocol was repeated for testing session two. Within testing session two, participants completed trial one and trial two with a comfortable frequency and intensity three times to obtain an average for each trial. At this time participants matched frequency and intensity to the comfortable frequency and intensity used previously, within a range of +/- one musical note for frequency and +/- 5 dB for intensity. The same equipment was used to measure the matched frequency and intensity, with the sound level meter being held 15 centimeters away from the participants’ mouth.

Exactly one week later each participant returned for the third testing session. During this testing session the participants matched frequency and intensity to the comfortable frequency and intensity used during the first testing session using the same specifications that were used during the previous time, when the protocol was repeated for testing session two. The participants followed the same instructions given during the first testing session to sustain the vowel /a/, which was measured by the PAS. The Voicing Efficiency protocol was completed three times during this session for an average of trial one, and then three times for an average of trial two following the loud intensity trial, which was not included in this study. Average airflow measurements were then recorded and compared to the measurements gathered during the first testing occasion.

Estimated subglottal pressure. In addition to average airflow, a measurement of estimated subglottal pressure was taken during all three testing sessions for each participant. This measure was gathered by using the PAS while running the Voicing Efficiency protocol. Participants were given the instructions to take a breath, place the face mask over their face with the intra-oral catheter between their lips, and then repeat the syllable /pa/ five to seven times on a
single exhalation. During each /pa/ production, the vowel was held for approximately one to two seconds. From this protocol, a measurement of estimated subglottal pressure was determined by assessing intra-oral pressure during the bilabial plosive consonant /p/ production. The participants’ comfortable frequencies and intensities were measured using the same procedure used during the average airflow data collection. The frequency and intensity were monitored, to ensure that they were within the acceptable range of +/- one musical note for frequency and +/- 5 dB for intensity when compared to the frequency and intensity used during the average airflow trials. As with average airflow testing, a loud intensity trial was completed in between the two trials at a comfortable speaking intensity. Only data from the two comfortable trials were included in this study. The tasks were completed three times for an average measurement of trial one and three times for an average of trial two.

The protocol was repeated 10 minutes later for testing session two to assess short-term repeatability. The same protocol was completed and the participants were required to match frequency and intensity to the comfortable frequency and intensity used during the initial testing session prior to the 10-minute break, within a range of +/- one musical note for frequency and +/- 5 dB for intensity.

When the participants returned one week later for the third testing session, the same protocol was completed. As with the average airflow measurement, the participants were to match frequency and intensity to the comfortable frequency and intensity used during the first and second testing sessions. The protocol, which included two comfortable trials completed three times each for airflow and two comfortable trials completed three times each for estimated subglottal pressure, was compared to the previous measures.

Data Analyses

Data analyses for this study involved comparing the two trial means taken during each testing session and comparing the means for data taken at each of the three testing sessions: the initial baseline session, 10 minutes later, and one week later. Each of the three sessions included two trials for each measure. Analysis required comparing the data from each comfort trial (Trials 1 and 2) separately from the data from each session (Testing sessions 1, 2, and 3) and then comparing the interaction of the two effects to determine an overall effect. Therefore, at the completion of data collection, a mixed-model analysis of variance was used to analyze the data. Table 1 displays the comparison of multiple levels during this type of analysis. The mixed-model
analysis of variance determined if there were significant differences between the repeated measures taken. Average airflow and estimated subglottal pressure data were analyzed separately, as were the intensity and frequencies produced for average airflow trials and estimated subglottal pressure trials. All analyses were completed using Statistical Analysis Software (SAS) version 9.1 for Windows.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Session 1</th>
<th>Session 2</th>
<th>Session 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Trial 2</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>Z</td>
<td>Z</td>
</tr>
</tbody>
</table>

Note: In the mixed-model analysis of variance, the two Y’s would be compared to determine any differences at the trial level and the three Z’s would be compared to determine any differences at the session level. The means of Y and X could then be compared to determine the overall interaction effect of both trial and session levels.
CHAPTER IV
Results
The purpose of this study was to examine whether average airflow and estimated subglottal pressure measurements have short-term and long-term repeatability. Participant data were analyzed to determine if the aerodynamic values remain stable when taken 10 minutes after baseline and one week after baseline. The study also examined if mean intensity and frequency significantly differed across testing sessions. Participants were instructed to hold intensity and frequency constant, and measures were taken during data collection to assist in consistency. Mean intensity and frequency taken during average airflow and estimated subglottal pressure measurements were analyzed to determine their consistency and effect on the aerodynamic measurements.

Analysis by Research Question
Research Question 1
Does mean average airflow significantly differ from baseline to 10 minutes later and one week later?
An analysis of variance determined that there was no significant difference for mean average airflow measurements between the two trials \((F=.67, p=.4159)\). Additionally, no significant differences were found between the mean average airflow measurements taken during the three sessions \((F=1.84, p=.1627)\). A repeated measures mixed-model analysis of variance revealed that there was no significant difference overall between the mean average airflow measurements taken during each trial and each session \((F=.28, p=.7561)\). The interaction effect reveals whether significant differences are present between the sets of data overall. Means and standard deviations for each trial during all three sessions are displayed in Table 2 and Figure 1.
Table 2

Mean Average Airflow Values by Trials and Sessions

<table>
<thead>
<tr>
<th>Session</th>
<th>Trial</th>
<th>Mean in mL/s</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>146.2</td>
<td>4.66</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>159.1</td>
<td>5.88</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>167.5</td>
<td>6.38</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>176.9</td>
<td>6.17</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>162.4</td>
<td>4.70</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>160.7</td>
<td>5.58</td>
</tr>
</tbody>
</table>

Figure 1. Mean average airflow values measured in mL/s by trials and sessions.

Research Question 2

Does mean estimated subglottal pressure significantly differ from baseline to 10 minutes later and one week later?

An analysis of variance determined that there was no significant difference for mean estimated subglottal pressure measurements taken between the two trials ($F=2.24, p=.1364$). There was also no significant difference between the mean measures taken during the three testing sessions ($F=2.17, p=.1171$). A repeated measures mixed-model analysis of variance revealed that there
was no significant difference between the overall interaction of mean estimated subglottal pressure measurements taken during each trial and each session \( (F=0.09, p=0.9155) \). Means and standard deviations for each trial during all three sessions are displayed in Table 3 and Figure 2.

Table 3

*Mean Estimated Subglottal Pressure Values by Trials and Sessions*

<table>
<thead>
<tr>
<th>Session</th>
<th>Trial</th>
<th>Mean in cmH2O</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>7.92</td>
<td>1.75</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>8.39</td>
<td>2.10</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>7.83</td>
<td>1.73</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>8.32</td>
<td>1.82</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>8.61</td>
<td>1.62</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>8.87</td>
<td>1.62</td>
</tr>
</tbody>
</table>

*Figure 2.* Mean estimated subglottal pressure values measured in cmH2O by trials and sessions.

*Research Question 3*

Does mean intensity produced during average airflow trials significantly differ from baseline to 10 minutes later and one week later?
There was a significant difference between the mean intensities produced during each trial, regardless of the session ($F=5.66, p=.0185$) as demonstrated by an analysis of variance. There was no significant difference between the mean intensities produced at baseline (Session 1), 10 minutes later (Session 2), and one week later (Session 3) ($F=2.33, p=.1004$). Means and standard deviations for each trial during all three sessions are displayed in Table 4 and Figure 3.

Table 4

<table>
<thead>
<tr>
<th>Session</th>
<th>Trial</th>
<th>Mean dB SPL</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>76.58</td>
<td>4.37</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>78.14</td>
<td>4.39</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>74.81</td>
<td>3.64</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>76.81</td>
<td>3.75</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>76.69</td>
<td>4.72</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>77.49</td>
<td>3.90</td>
</tr>
</tbody>
</table>

Figure 3. Mean intensity values measured in dB SPL during average airflow tasks by trials and sessions.
Research Question 4

Does mean frequency produced during average airflow trials significantly differ from baseline to 10 minutes later and one week later?

An analysis of variance demonstrated that there were no significant differences between the mean frequencies taken during trial one and trial two ($F=1.12, p=.7295$) or between the mean frequencies taken during session one, session two, and session three ($F=1.22, p=.8030$). A mixed-model analysis of variance revealed that there were no significant differences in the interaction of the session and the trial for frequency measurements taken during average airflow testing sessions ($F=1.67, p=.1920$). Means and standard deviations for each trial during all three sessions are displayed in Table 5 and Figure 4.

Table 5

<table>
<thead>
<tr>
<th>Session</th>
<th>Trial</th>
<th>Mean in Hz</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>225.33</td>
<td>20.48</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>215.71</td>
<td>26.36</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>221.95</td>
<td>21.19</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>223.37</td>
<td>21.21</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>217.78</td>
<td>25.14</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>222.49</td>
<td>19.94</td>
</tr>
</tbody>
</table>
Figure 4. Mean frequency values measured in Hz during average airflow tasks by trials and sessions.

Research Question 5

Does mean intensity produced during estimated subglottal pressure trials significantly differ from baseline to 10 minutes later and one week later?

An analysis of variance demonstrated that there were significant differences between the mean intensities produced during the two trials, regardless of the session ($F=7.26, p=.0077$). There was no significant difference between the intensities produced during each testing sessions ($F=.10, p=.9034$). Means and standard deviations for each trial during all three sessions are displayed in Table 6 and Figure 5.

Table 6

<table>
<thead>
<tr>
<th>Session</th>
<th>Trial</th>
<th>Mean in dB SPL</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>74.48</td>
<td>3.41</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>76.27</td>
<td>3.63</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>75.01</td>
<td>3.69</td>
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<tr>
<td>2</td>
<td>2</td>
<td>76.32</td>
<td>3.55</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>74.96</td>
<td>3.63</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>76.22</td>
<td>3.86</td>
</tr>
</tbody>
</table>
Research Question 6

Does mean frequency produced during estimated subglottal pressure trials significantly differ from baseline to 10 minutes later and one week later?

There were no significant differences between the mean frequencies taken during each trial ($F=.27, p=.6021$) as demonstrated by an analysis of variance. An analysis of variance also demonstrated that there were no significant differences between the mean frequencies produced during each testing session ($F=.43, p=.6519$). A mixed-model analysis of variance revealed that there were no significant differences in the interaction of the three sessions and the two trials ($F=.21, p=.8142$). Means and standard deviations for each trial during all three sessions are displayed in Table 7 and Figure 6.
Table 7

*Mean Frequency Values During Estimated Subglottal Pressure Tasks by Trials Sessions*

<table>
<thead>
<tr>
<th>Session</th>
<th>Trial</th>
<th>Mean in Hz</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>218.36</td>
<td>22.91</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>219.04</td>
<td>23.37</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>219.11</td>
<td>20.92</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>223.72</td>
<td>21.16</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>223.13</td>
<td>19.47</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>222.91</td>
<td>22.46</td>
</tr>
</tbody>
</table>

*Figure 6.* Mean frequency values measured in Hz during estimated subglottal pressure tasks by trials and sessions.
CHAPTER V

Discussion

Interpretation by Research Question

Research Question 1

Does mean average airflow significantly differ from baseline to 10 minutes later and one week later?

Analysis of average airflow data demonstrated that there were no significant differences between the measures gathered from participants’ trials and testing sessions. These results provide support for the short-term and long-term repeatability of average airflow measurements, when a speaker’s intensity and frequency are held constant within a given range. The results are consistent with past findings that significant intra-speaker variations in airflow did not occur across repeated recordings (Holmberg et al., 1994).

The results also provide support that both intensity and frequency should be held constant, as in the present study, when examining the repeatability of average airflow. In a previous study, inconsistent repeatability of acoustic and aerodynamic measurements was found when only the frequency was controlled. Additionally, controlling only the intensity resulted in changes only in frequency (Lee et al., 1999).

The results of the current study provide useful information for voice pathologists gathering treatment data. When comparing average airflow measurements, repeatability can be assumed if intensity and frequency have been controlled. Since average airflow measurements did not significantly change 10 minutes and one week later, when intensity and frequency were monitored for consistency, voice pathologists can use aerodynamic measurements to monitor progress in the voice. Because average airflow measurements are repeatable, changes in average airflow would suggest changes in the functioning of the vocal mechanism or changes in the structure of the larynx, if intensity and frequency had not changed.

Research Question 2

Does mean estimated subglottal pressure significantly differ from baseline to 10 minutes later and one week later?

Analysis of estimated subglottal pressure mean values revealed no significant differences between trials and sessions. Like average airflow, estimated subglottal pressure was repeatable.
after a short (10 minutes) and long (one week) lapse in time when speaker intensity and frequency were held constant. The study found similar results for the repeatability of average airflow and estimated subglottal pressure.

A lack of significant difference in estimated subglottal pressure across time results are congruent with what would be expected based on past findings that no intra-speaker pressure variations occurred across repeated recordings (Holmberg et al., 1994). As with the results of the average airflow analysis, the estimated subglottal pressure results provide support for holding intensity and frequency constant when comparing repeated measures.

The estimated subglottal pressure results suggest that this measurement, like average airflow, can be used to monitor treatment progress in a clinical setting. Because estimated subglottal pressure did not significantly change across a short and long lapse in time when intensity and frequency were constant, estimated subglottal pressure can be a reliable measure for perceiving change in the functioning of the vocal mechanism.

Research Question 3

Does mean intensity produced during average airflow trials significantly differ from baseline to 10 minutes later and one week later?

Analysis of mean values for intensity produced during average airflow trials revealed that while there were no significant differences between the mean intensity values produced at each testing session, the two trials within each session did significantly differ. Specifically, the second trial mean was always greater than the first trial mean. As displayed in Table 4, the second trial mean was approximately 2 dB SPL higher than the first trial mean. These results can be attributed to the range of variability in intensity that was accepted by the researchers. As described in the methods section, the researchers monitored participant intensity to ensure that it matched initial intensity within a range of +/- 5 dB. This range was perceptually acceptable as a minimal change in intensity, but statistically resulted in the two trial means differing significantly. The differences between the trial means did not significantly affect the average airflow repeatability.

Based on previous research, it is surprising that significant differences in intensity did not cause significant differences in the repeatability of average airflow measurements. One past study found that airflow measurements were correlated more directly with intensity of the voice,
than with frequency (Holmberg et al., 1988). Additionally, another study found that measures of airflow were systematically related to variations in sound pressure levels (Holmberg et al., 1994).

**Research Question 4**

**Does mean frequency produced during average airflow trials significantly differ from baseline to 10 minutes later and one week later?**

Mean frequency values produced during average airflow trials did not significantly differ by trial or session. When monitoring the frequencies participants produced, the researchers accepted a range of +/- one musical note. This resulted in repeatable frequencies that did not statistically differ when produced for different trials and during different sessions.

Based on past research, it was important that frequency did not significantly differ for this study so that frequency changes would not change average airflow measurements. Thus, steps were taken to ensure consistent frequencies throughout a participant’s testing sessions. Gelfer (1989) found that fundamental frequency ranges, when not controlled, differed significantly when measured days and months apart. Although research has shown that intensity tends to have a greater affect on airflow than frequency does (Holmberg et al., 1988), it is still advantageous that the researchers attempt to control frequency and intensity. Past research found that controlling intensity only resulted in differences in speakers’ frequency (Lee et al., 1999).

**Research Question 5**

**Does mean intensity produced during estimated subglottal pressure trials significantly differ from baseline to 10 minutes later and one week later?**

The analysis of mean intensity values produced during estimated subglottal pressure trials was similar to that of mean intensity produced during average airflow trials. Mean intensity values did not significantly vary across sessions, but did significantly vary between the two trials, regardless of testing session. The second trial intensity was always greater than the first trial intensity. The range of repeatability accepted by the researchers explains this difference. The acceptable range did not affect the repeatability of mean intensity values when comparing testing sessions only.

Measures of air pressure tend to systematically relate to sound pressure levels (Holmberg et al., 1994). Therefore, it is interesting that a significant difference among mean intensity values across trials did not affect the repeatability of the estimated subglottal pressure.
**Research Question 6**

**Does mean frequency produced during estimated subglottal pressure trials significantly differ from baseline to 10 minutes later and one week later?**

Mean frequency values produced during estimated subglottal pressure trials did not significantly differ by trials or by sessions. The frequencies had short-term and long-term repeatability, within +/- one musical note. Since fundamental frequencies can naturally differ significantly when tested at different times (Gelfer, 1989), it is important to know that there were no changes in frequency that could contribute to changes in estimated subglottal pressure, one of the main variables of interest in this study.

**Limitations**

The results of the current study are mildly limited in application. Analyzing only female voices provided more consistency among group measurements; however, because all participants were female, and female voices differ from male voices, the results can only be generalized to female speakers. Additionally, the results can only be generalized to young adult females. Due to the nature of data collection, results may not accurately reflect the patterns of average airflow and estimated subglottal pressure used in natural speaking contexts and environments. The participants in this study were well aware that their voices were being analyzed and monitored during the time of data collection. Participants were also aware that the study included an element of repeatability, because they were asked to complete the same tasks on two separate occasions. Therefore, it is difficult to know if the same results would be drawn from a natural environment, where speakers are unaware that tasks are being compared to an earlier performance to analyze repeatability.

**Clinical Implications**

Despite limitations related to generalizability, the results of this study have clinical application for assessment and treatment of voice disorders. This study found that the aerodynamic measurements of females with healthy voices were repeatable. This means that aerodynamic measurements generally stay the same, given no changes in the functioning of the vocal mechanism. Therefore, it is reasonable to assume that significant changes in average airflow correlate to changes in the structure or functioning of the vocal mechanism. Evidence for
the repeatability of aerodynamic measurements provides support for the use of aerodynamic measurements in clinical voice evaluations and for the use of pre- and post-treatment data.

**Future Research**

Future studies in this line of research should target gathering aerodynamic measurements of voice in various populations. Data collection similar to that done in the current study should be completed in male speakers and in the elderly populations. Measurements from other populations should be compared to that of healthy young women. It would be interesting to examine the variability in repeated measures of average airflow and estimated subglottal pressure with disordered voices. The question of repeatability raised in this study could be expanded in future research. This study confirmed that aerodynamic measurements are repeatable when taken one week apart. Future research could determine if aerodynamic measurements taken one month apart or six months apart, with intensity and frequency held constant, are still repeatable.

In future repeatability research studies, the acceptable range of intensities should be more stringent in order to avoid unexpected significant differences between intensities taken at different trials. In the current study, tools were used to aid the participants in matching intensity and frequency. Despite these tools, because of the acceptable range of +/- 5 dB, significant differences still occurred.
References


Appendix A

Informed Consent

The Repeatability of Aerodynamic Measures and the Influence of Sound Pressure Variation

Description of the Research

A primary component of a voice disorder evaluation is to collect measures of voice production and measures related to the respiration required to support speech. Two such measures are average airflow and estimated subglottal pressure. The purpose of this study is to investigate how repeatable average airflow and estimated subglottal pressure are, as well as the effect of altering volume of speech on these measures. You are being asked to participate in this study because you do not have any problems with your voice production, but the results of this study will be beneficial in developing standard assessment protocols to use with patients who have voice disorders.

Research Procedures

Testing Session 1

Prior to collecting the measurements of your voice, you will be required to pass a basic hearing and voice screening in order to participate. The hearing screening will involve listening to a tone presented at four frequencies in each ear. You will have to raise your hand to indicate hearing each tone. The voice screening will involve the examiners listening to your voice while reading a short passage. You will be seated in a quiet room (Room 49 Bachelor Hall) and instructed to follow directions provided by the investigators. For each task you will wear a face mask that goes over your nose and mouth. This mask will not obstruct your breathing. You will be asked to complete simple speech tasks at various pitches and volumes. During Testing Session One you will be asked to complete the following tasks:

1. You will be asked to sustain “ah” at a comfortable pitch and volume.
2. You will be asked to repeat “pa” five to seven times while holding out the vowel for one to two seconds at a comfortable pitch and volume.
3. You will be asked to sustain “ah” and repeat “pa” at a comfortable volume, a twice as comfortable volume, a half as comfortable volume.

4. You will then be given a 10-minute break. You are welcome to read newspapers and magazines provided in the room or work on anything you brought with you.

5. After the 10-minute break you will again be asked to repeat tasks 1-3 as stated above.

Testing Session 2

You will be required to return to Room 49, Bachelor Hall exactly one week later for Testing Session Two. At this time you will be asked to complete tasks 1-3 listed above.

Time Required for Participation

Your participation will take approximately 30 minutes for Testing Session 1 and 20 minutes for Testing Session 2 (one week later).

Risks

There are no known risks associated with this study and we do not foresee any potential for discomfort.

Benefits

This study has the potential to improve assessment protocols for patients with voice disorders.

Alternative Treatments

There are no alternative treatments in this study.
Confidentiality

The information obtained about you in this study will be kept confidential. Your information will be kept in a locked file cabinet in the investigator’s office. Information saved electronically will be on a password protected computer that does not have public access. Your information will be assigned a code number, and the key for this code will be stored separately from your information. Once your participation in this study is completed, all identifying information that could link your information will be destroyed and your data will be kept in a locked file cabinet as anonymous data.

Voluntary Participation

Your participation in this study is voluntary. You have the right to refuse to participate with no penalty or loss of benefits to which you would otherwise be entitled. You may discontinue your participation in this study at any time and may refuse to answer specific questions without penalty or loss of benefits to which you would otherwise be entitled.

Questions About the Study

You may ask questions regarding the study and the study procedure at any time. You can reach the primary investigators for this study, Susan Baker Brehm, Ph.D. at (513) 529-2553 or bakersel@muohio.edu, and Barbara Weinrich, Ph.D. at (513) 529-2548 or weinriebd@muohio.edu with any questions regarding your rights as a participant in this study.

Questions About Rights of Participants

You may contact the Office for the Advancement of Research and Scholarship at (513) 529-3734 or at humansubjects@muohio.edu with any questions regarding your rights as a participant in this study.
I have been informed about this study’s purpose, procedures, possible benefits, risks, and how my privacy will be protected. I will receive a copy of this form. I have been given the opportunity to ask questions and told that I can ask questions at any time. I voluntarily agree to participate in this study. By signing this form, I am not waiving any of my legal rights.

_______________________________
Signature of Person Consenting

_______________________________
Date
Appendix B

Testing Protocol Verbal Directions

Session 1:

1. Introduce ourselves and the project and present informed consent letter.

2. Screenings
   In order to qualify to be a participant in this study, we have to first do a voice and hearing screening to make sure you don’t have a voice disorder or hearing loss.
   Hearing Screening: I’m going to have you place these headphones over your ears. When you hear a tone, raise your hand to indicate that you heard it.
   Voice Screening: We’re going to have you read this passage aloud so that we can listen to the quality of your voice. Read in your normal comfortable voice.

3. Testing Protocols
   • This is the computer software that we’re going to use to take measurements of your voice. In order for the software to analyze your voice, you’ll have to hold out a vowel and repeat some syllables into this face mask. The mask does not obstruct your breathing. You need to hold it up to your face, covering your nose and mouth, making sure that there are no gaps between your face and the mask. For some of the tests, we’re going to measure how loud or soft and high or low you are speaking. Let’s get started!
   • Please count to 10 in your normal voice (match on tuner and Voice Range Profile). After you’re done, I’m going to count to match your pitch and then hold out “ah” in the pitch you should use.
   • First, you need to take a breath, then place the face mask over your face, and then hold out “ah” for about five seconds at a comfortable pitch and loudness. Be sure to take your breath before you put the mask on.
   • For the next part, you’re going to hold out “ah” three more times. You can take the mask off and take a breath in between each “ah.”
• Now for the second time, say “ah” twice as loud. Take a breath and put on the mask.
• Now we’re going to have you hold out “ah” at your comfortable volume and pitch again. Here is what your comfortable pitch sounded like (play tone on Voice Range Profile).
• And now one last time, say it half as loud.
• Now you’re going to do the same thing, but this time, say a string of “pa’s” about seven times into the mask with this little tube in between your lips. When you say “pa” hold out the “ah” for about 1.5 seconds each time.
• Here’s your pitch (play tone on Voice Range Profile). It will sound like this; join in with me.
• Now do the same thing twice as loud.
• Now let’s do the “pa’s” back at your comfortable loudness. Here’s your pitch (play tone on Voice Range Profile).
• One more time to do the “pa” syllables. Say them half as loud this time.
• Great, now you get to take a 10-minute break and then we’ll run through this whole set of tests one more time. Feel free to work on anything you have with you.
• After the break (second session) and for the third session repeat instructions above as needed.
Appendix C

The Rainbow Passage

When the sunlight strikes raindrops in the air, they act as a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.

Throughout the centuries people have explained the rainbow in various ways. Some have accepted it as a miracle without physical explanation. To the Hebrews it was a token that there would be no more universal floods. The Greeks used to imagine that it was a sign from the gods to foretell war or heavy rain. The Norsemen considered the rainbow as a bridge over which the gods passed from earth to their home in the sky. Others have tried to explain the phenomenon physically. Aristotle thought that the rainbow was caused by reflection of the sun’s rays by the rain.

Since then physicists have found that it is not reflection, but refraction by the raindrops which causes the rainbows. Many complicated ideas about the rainbow have been formed. The difference in the rainbow depends considerably upon the size of the drops, and the width of the colored band increases as the size of the drops increases. The actual primary rainbow observed is said to be the effect of super-imposition of a number of bows. If the red of the second bow falls upon the green of the first, the result is to give a bow with an abnormally wide yellow band, since red and green light, when mixed form yellow. This is a very common type of bow, one showing mainly red and yellow, with little or no green or blue.