CHARACTERISTICS OF VOCALLY HEALTHY ELDERLY ADULTS AND ELDERLY ADULTS WITH VOICE COMPLAINTS

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CHARACTERISTICS OF VOCALLY HEALTHY ELDERLY ADULTS AND ELDERLY ADULTS WITH VOICE COMPLAINTS

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OBJECTIVES: The number of cases of age-related voice changes associated with increasing age, known as presbyphonia, will increase as the population becomes older. Presbyphonia is the result of multi-system changes related to phonation that naturally occur with aging. Presbyphonia is associated with changes in acoustic, aerodynamic, and auditory-perceptual measurements; however, the literature is sparse on the differences between vocally-healthy elderly adults and elderly adults diagnosed with presbyphonia. The goal of the study is to compare the acoustic, aerodynamic, and auditory-perceptual characteristic of self-perceived vocally-healthy elderly adults and elderly adults with vocal fold atrophy.

STUDY DESIGN: The study is a combined retrospective and prospective, blinded, non-randomized, matched cohort study.

METHODS: Vocally-healthy elderly speakers ages 60-84 (n = 50) and age-matched elderly speakers with vocal fold atrophy (n = 50) recorded samples of the first sentence of the Rainbow Passage. Acoustic and aerodynamic data were collected for the voice samples. Ten blinded raters provided auditory-perceptual voice ratings on a 100mm visual analog scale. Data were analyzed for significant differences in acoustic, aerodynamic, and auditory-perceptual differences between the two participant groups.

RESULTS: Significant differences between the vocally healthy control and atrophy groups were observed in acoustic, aerodynamic, and auditory-perceptual characteristics. Regression analysis revealed the atrophy group had significantly worse mean Voice Handicap Index-10 scores, Cepstral Peak Prominence scores, Cepstral Spectral Index of Dysphonia scores, mean pitch, and duration of voice sample, overall severity, roughness, breathiness, strain, loudness, health of speaker, pleasantness of voice, and strength of voice ($p < .05$).

CONCLUSIONS: This study is the first to demonstrate significant differences between vocally healthy elderly people and elderly people with atrophy across acoustic, aerodynamic and auditory-perceptual measures.

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PREFACE

None of the following work was possible without the support of my family, classmates, and advisors. Each one of you hold a unique place in my memory of the last three years as I changed paths and pursued something that truly makes me excited to get to work. The future is as much a result of hard work as it is your belief in me and the continued encouragement.

Thank you all for everything.

1.0 INTRODUCTION

As society ages the incidence of age-related voice disorders is increasing. In aging voice literature, the adult is defined as elderly at, or above, 65 years of age (Gregory, Chandran, Lurie, & Sataloff, 2012; Takano et al., 2010) According to 2010 Census Bureau data, the number of Americans 65 years of age and older will increase from 39 million in 2008, to 72 million by 2030 (Statistics, 2010). The US Department of Health estimates that 30% of the population will be 65 years old or older by 2030 (Davids, Klein, & Johns, 2012). As humans age, physiologic changes occur in many systems that may affect vocal function. In elderly adults, these changes can lead to age-related dysphonia, also known as presbyphonia. Takano and colleagues defined presbyphonia as a diagnosis of exclusion made in the absence of other laryngeal diseases in the elderly population, and characterized as a weak, breathy, or hoarse voice (Gregory et al., 2012; Takano et al., 2010). Presbyphonia correlates with distinct changes in laryngeal appearance. Concave or "bowed" vocal folds, prominent vocal processes, a gap between vocal folds during phonation, increased amplitude of mucosal wave, mucosal wave asymmetry and even vocal tremor have been reported in the laryngeal examination of the aging larynx (Kendall, 2007). Voice problems in elderly adults affect quality of life such as the ability to comfortably. The number of elderly adults still in the workforce has increased. The Bureau of Labor Statistics has identified an upward trend since the mid-to-late 1990's in the percentage of elderly adults remaining in the workforce. Since 1995 the percentage of men ages 62-64 years old participating in the workforce has increased 8%. For elderly women in the same age category rates increased by 13% since the low participation rates of the 1960's (Statistics, 2010). Elderly adults require functional voice for effective communication in order to remain gainfully employed and socially functional. Up to 33% of patients diagnosed with presbyphonia are still a part of the workforce (Takano et al., 2010). As the population and the workforce increase in age, it is critical that health care professionals can appropriately differentiate processes that are associated with typical aging from those that represent disease in elderly adults. In voice science, research has focused primarily on the study of voice treatment for presbyphonia: behavioral treatment with voice therapy or surgical treatment for correction of glottal incompetence due to vocal fold atrophy. A critical gap in the literature exists on the acoustic, aerodynamic, and auditory-perceptual characteristics of the voices of healthy elderly adults as well as those who report voice impairment. The question remains if presbyphonia is, in fact, a symptom of a voice *disorder*, or rather the vocal characteristic of a typically aging adult. Are we seeing a greater number of those over the age of 65 years with a true voice dysfunction or a society more aware of voice changes and the impact of vocal function (Davids et al., 2012)?

The goal of the current study was to determine if significant differences exist in the acoustic, aerodynamic, and listener-perception of voice between self-perceived vocally healthy elderly adults and elderly adults with voice complaints due to vocal fold atrophy.

2.0 HEALTHY AGING

Aging is defined as a progressive, generalized impairment of function that results in a reduction in the body’s ability to respond to stress and disease in the same effective manner as in younger age (Fillit, Rockwood, Woodhouse, & Brocklehurst, 2010). Aging has also been described as the process by which healthy adults develop a greater vulnerability to injury, illness, and death. Aging is sensitive to both genetic and environmental components. Due to this fact, it is difficult to distinguish between the typical processes of aging and age-related disease.

Aging is caused by gradual accumulation of cell and tissue damage. The effect of these changes varies among species and even individuals within a species, thus variability in function exists as aging progresses. This variability results in elderly adults who incur age-related diseases, and elderly adults who do not. The greatest effects of this aging process are seen in the increasing loss of physical and cognitive function as well as the increasing susceptibility to illnesses.

2.1.1 Typical Aging vs. Diseased aging

It is difficult to distinguish typical effects of vocal aging and the effects of age-related disease on voice. Phonation is a multi-system function that is sensitive to changes in anatomy and physiology of the larynx, respiratory system, nervous system, and endocrine systems. For example, one study of patients with dysphonia over the age of 60 years found that more than half of the patients had a systematic illness; pulmonary and cardiac health complaints were the most common (Woo, Casper, Colton, & Brewer, 1992). The management of voice changes in the aging adult requires going beyond the larynx to consider related systems. It is important to note the difference between physiologic aging and chronologic aging. Physiologic aging refers to the functional changes that occur throughout the body as the person ages regardless of chronological age. Assessing health by physiologic function rather than chronological age makes it possible for an elderly adult, even in old age, to be physiologically healthy in comparison to a younger adult with a physiologic impairment (Pontes, Brasolotto, & Behlau, 2005; Ramig et al., 2001).

Studying the changes that occur as adults age requires observation of multiple body systems. Relevant to phonation, laryngeal, pulmonary, neurologic, muscular and auditory system changes occur as a result of typical aging. A closer look at the primary systems used in phonation and the effect of physiologic impairment as a result of aging which will aid in understanding potential acoustic and perceptual differences measured in the aging voice is the focus of the next section.

3.0 AGING VOICE

3.1.1 Incidence Data

Aging voice refers to the acoustic, aerodynamic, and perceptual changes that typically occur in an adult generally over the age 65 years. Gregory and colleagues found that the most common voice complaints in the elderly presenting at a voice clinic were hoarseness (71%), decreased volume (45%) and throat clearing (43%). Diagnoses in this same population found that 91% of participants had laryngopharyngeal reflux (LPR), 73% of participants had muscle tension dysphonia (MTD), and 72% of participants had paresis, as measured by reduced recruitment from either the left or right vocal fold when measured via laryngeal electromyography (LEMG) and strobovideolaryngoscopy. Nineteen percent of participants showed glottic insufficiency. The study did not provide further information regarding the diagnosis of glottic insufficiency and vocal fold atrophy in this elderly population (Gregory et al., 2012).

The incidence of voice disorders in the elderly population is estimated at 12-35% (Davids et al., 2012). Incidence rates of atrophy in this population study were at 24.5%. Another recent study showed up to 20% of the patient population over the age of 65 years presenting to a voice clinic were found to have vocal fold atrophy resulting in presbyphonia (Takano et al., 2010). It remains difficult to accurately determine the incidence of voice disorders in the elderly as no literature exists, to the best of our knowledge, on characteristics that differentiate healthy elderly adult population to the elderly adult population with presbyphonia.

Dysphonia, when measured by self-report in the elderly population, has been as high as 20% in independent living facilities. Half of the elderly adults with perceived dysphonia reported that their voice problem had a severe impact on their quality of life as identified following the voice-related quality-of-life (V-RQOL) measure (Golub, Chen, Otto, Hapner, & Johns, 2006).

3.1.2 Quality of Life

Quality of life (QOL) data are relevant when considering the aging voice and its impact on elderly adults. National survey data of adults over the age of 65 years reported that when impacted by communication difficulty of any kind, elderly adults show less social interaction and the communication deficit is a predictor for higher levels of loneliness (Palmer, Newsom, & Rook, 2016).

Thirteen percent of people over 65 years of age reported a quality of life reduction due to dysphonia (Johns, Arviso, & Ramadan, 2011). Data have shown a significant progressive change of voice quality over the previous 5 year range in patients who were 50 years old. These age-related voice problems are partly reflected in acoustic and perceptual voice measures, and also prevent elderly adults with a voice problem from participating in social situations (Verdonck-de Leeuw & Mahieu, 2004).

The Voice Handicap Index (VHI) and the 10-item Voice Handicap Index-10 (VHI-10) are instruments commonly used to quantify the handicapping effects of a voice disorder on quality of life. In the elderly adult, VHI scores have been significantly correlated with percent and absolute jitter and shimmer, as well as maximum phonation time (MPT) (Gregory et al., 2012), indicating a relationship between voice handicap and acoustic measures of dysphonia.

4.0 ANATOMY AND PHYSIOLOGY OF AGING

4.1.1 Neurologic Effects of Aging

Neurologic changes associated with normal aging include psychomotor slowing, decreased auditory acuity, especially for spoken language, decreased muscle bulk and mild motor slowing. Despite a decrease in processing speed, cognitive flexibility, visuospatial perception, working memory, and sustained attention, the ability to learn is not eradicated by age (Fillit et al., 2010). Cognitive function in elderly adults appears to exist on a continuum from cognitive changes considered part of normal aging, to mild cognitive impairment, to dementia. Normal cognitive changes in elderly adults can be defined by changes in cognitive processing speed, memory, fine motor, visuospatial, language and executive function abilities. These changes are small and do not result in significant functional impairment (Harada, Natelson Love, & Triebel, 2013). Older adults generally perform timed cognitive tasks at a slower rate than younger adults. Further, reaction times are reduced in the elderly adult. Memory problems are also noted in the aging population, as for example, the ability to remember names or where an object was placed (Johns et al., 2011; Williams et al., 2014). Fine motor abilities also decrease with age and a decrease in abilities may have a direct impact on laryngeal function and voice motor control. During sequential speech tasks, healthy elderly adults have a significant increase in speech errors compared to young adults. These errors are especially present in complex speech tasks and are hypothesized to be a result of neuromuscular changes to fine motor movement ability and other factors including tactile sensibility and decreased muscular endurance (Bilodeau-Mercure et al., 2015). Faster movements are also correlated with greater error in elderly adults due to hypothesized changes in motor recruitment, muscle coordination, and reduced tactical sensitivity (Ballard, Robin, Woodworth, & Zimba, 2001). Phonation requires not only fine motor control of the larynx, but also fine and large motor control in oral-facial and respiratory muscles. With over 100 muscles in these systems, more research is required to understand how changes to fine motor movement abilities impact system functioning in typical and disordered aging (Simonyan & Horwitz, 2011).

4.1.2 Depression and Hearing Loss

Depression has also been noted to affect the aging population more than younger adults. Prevalence rates for major depression are reported to be between 1-2% for elderly in the community and 10-12% for the elderly in the primary care setting (Williams et al., 2014). Depression in elderly adults has been observed for many reasons. Coping with the loss of physiologic function, the early to late stages of system failure, and even pharmacologic side-effects can have an impact on the mental health of elderly adults (U.S. Department of Health and Human Services, 2015). The presence of depression is correlated with a significant increase in the number of reported voice problems. Individuals with depression are also less likely to seek treatment for these problems, and have a lower reported success in treatment than those without depression (Marmor, Horvath, Lim, & Misono, 2016). While mental health does not have a primary role in physiologic phonation, depression may have an impact on an elderly adult's ability to effectively communicate and seek treatment when the communication deficit reaches the level of impairment. A decrease in communication ability combined with an evolving voice change, such as presbyphonia, can result in changes to quality of life.

Hearing and vestibular function also change continually with age. A gradual loss of cochlear hair cells, atrophy of the stria vascular, and thickening of the basal membrane may account for the hearing impairment, primarily in higher frequencies, observed in the aging adult (Fillit et al., 2010). This noted change in hearing is also correlated with a decline in the sensory function of the cranial nerves. Vision, vestibular function, taste and smell are all affected by this age-related change. Declines in sensory function are considered part of the normal aging process (Fillit et al., 2010).

4.1.3 Aging Hormonal System

Hormones affect the body in general and, for our specific interest here, the voice. These affects occur most significantly at two distinct times -- puberty, and for women, menopause. Men have transition in hormonal change similar to menopause called andropause.

Menopause is defined as the end of the reproductive period in women and is characterized by a permanent cessation of menstruation resulting from the loss of ovarian follicular activity. During this time, the levels of the female sex hormones estrogen and progesterone decrease and androgens, another important group of hormones, increase in the female body (D'Haeseleer et al., 2011). It has been known for many years in women that the hormonal changes during menopause have an impact on the voice. The prevalence of voice complains during menopause has been recorded between 17% (Abitbol, Abitbol, & Abitbol, 1999) and 77% (Boulet & Oddens, 1996).

The female voice evolves from childhood to menopause under influence of estrogens, progesterone, and testosterone (Gugatschka et al., 2010). With a reduction in estrogen and an increase in testosterone at menopause, an increase of vocal fold mass has been noted (Gugatschka et al., 2010). A reduction in estrogen has also been correlated with thinner vocal fold mucosa which impacts the vibratory amplitude of the vocal fold (Abitbol et al., 1999).

Androgens, an essential component to male sexuality, and testosterone, a subtype of androgens, play a masculinizing role in the female body as the levels of estrogen decrease throughout menopause. In skeletal muscles, androgens cause hypertrophy of the muscle cells. Just as in puberty, the hormonal climate in aging determines the perceived sound and sex of the voice (Abitbol et al., 1999).

One study of 38 postmenopausal women and 34 premenopausal women revealed significant differences between the groups in aerodynamic parameters (vital capacity and phonation quotient [PQ]), vocal range (lowest frequency), and acoustic parameters. The most significant differences between the two groups were PQ and fundamental frequency (F0). Fundamental frequency in phonation is the lowest frequency produced by an oscillation of the vocal folds, at a given moment in time, distinguishable from harmonics. Auditory-perceptual evaluation found significant differences in roughness, breathiness, and strained quality of the voice with the postmenopausal group showing poorer ratings for these perceived vocal qualities. No significant differences were found in the video stroboscopic evaluation or voice handicap scores (Boulet & Oddens, 1996). In another study, 100 post-menopausal women underwent a laryngeal exam, acoustic voice analysis, and survey of voice self-perception. Seventeen women noticed differences in vocal intensity, vocal fatigue, decreased range with a loss of high notes, and change in timbre in the spoken and singing voice following post menopause. Interestingly, 100% of participants had a measured acoustic difference that impacted voice range and vocal intensity but only 17% self-reported a noticed change in their range and intensity of voice. The threshold difference that correlates with a reported change in the 17% requires further study.

Men are also sensitive to changes in hormones. Unlike women, men have a gradual decrease in hormones (testosterone) with age. These changes are often associated with increased fat mass, low bone and muscle mass, and impaired sexual, cognitive, and physical function (Gugatschka et al., 2010). Little literature exists on the hormonal effects on the elderly male voice. One study found that elderly men with decreased estradiol demonstrated more jitter and shimmer than young men (Gugatschka et al., 2010). The greatest change in the male voice occurs during puberty. Acoustic changes, including pitch, loudness, and tone quality are affected by anatomical changes such as vocal fold length and structure at puberty (Gugatschka et al., 2010).

Another study of hormones in elderly males found that men with lower levels of estrogens had higher means of both lowest and highest frequencies that is an upward shift in voice range (Gugatschka et al., 2010). The impact of hormonal change on the elderly adult body is important to consider when analyzing the elderly adult’s voice.

The above foregoing evidence serves as a foundation for understanding the anatomic and physiologic changes that occur in the elderly adult. Without considering the elderly adult body in a holistic way, the ability to critically assess phonation and its relation to the functional changes that occur in elderly adults is lost.

4.1.4 Aging Respiratory System

Muscular changes throughout the body affect areas involved in phonation. Specifically, decrease in muscle bulk (sarcopenia), strength, and general decrease in speed and movement with aging, contributes to the changes in other systems throughout the aging body (Larsson, Grimby, & Karlsson, 1979; Volpi, Nazemi, & Fujita, 2004). These changes are most relevant to phonation when viewed through the lens of the respiratory system. The respiratory system has the primary role of taking in oxygen and expelling carbon dioxide from the body. The respiratory system develops until the age of 20 years in females and 25 years in males. After this age, lung performance declines steadily for the rest of the lifespan. Barring disease, however, lung function remains adequate for gas exchange (Janssens, Pache, & Nicod, 1999).

Six major anatomical changes are noted in the aging respiratory system and lungs. These changes are: (1) increase in chest wall stiffness, (2) decreased lung elastic recoil, (3) decreased respiratory muscle strength, (4) decreased airway diameter, (5) decreased alveolar surface area, and (6) decreased sensitivity of chemoreceptors altering gas exchange (Burggraf, Kim, & Knight, 2014; Janssens et al., 1999). Two of these (1 and 3) have direct impact on phonation and are reviewed next.

An increase in chest wall stiffness causes a decrease in chest wall compliance. This stiffening is a result of calcification and other structural changes involving the rib cage, ossification of the costal cartilages, and loss of intervertebral disc space. These changes combined with muscle changes produce reduced movement of the chest wall (Fillit et al., 2010). As adults continue to age, a higher rate of dorsal kyphosis, an abnormally rounded back, and increased anteroposterior chest diameter is observed. Moderate to severe kyphosis is present in

68% of elderly adults aged 75-93 years (Edge, Millard, Reid, & Simon, 1964). These changes affect the functionality of both the diaphragm and the compliance of the chest wall for optimum functionality of the lung (Fillit et al., 2010; Janssens et al., 1999). Conflicting data exist concerning airway resistance in elderly adults. While airway resistance has been measured to be lower in elderly over the age of 70 years in both sexes (Makiyama, Yoshihashi, Park, Shimazaki, & Nakai, 2006), when lung volume is controlled, what has also been shown to have no effect (Janssens et al., 1999). Airway resistance may be an indicator of glottal and respiratory efficiency and may correlate with other factors associated with acoustic and aerodynamic measures.

Most important, the diaphragm, making up about 85% of respiratory muscle activity, decreases in strength with age (Polkey et al., 1997). The primary muscles of inspiration (the diaphragm and the external intercostal muscles), primary muscles of expiration (internal intercostal and abdominal muscles), and accessory muscles (scalene muscles, sternocleidomastoid, and pectoralis muscles) diminish in strength as physiologic function changes throughout age (Fillit et al., 2010).

The respiratory muscles are made up of type 1 (slow), type IIa (fast-fatigue resistant), and type IIx (fast-fatigable) fibers. The major age-related change in the respiratory muscles is a reduction in the proportion of type IIa fibers, which thus impairs both strength and endurance. This change puts much more reliance on the diaphragm due to loss of intercostal muscle strength to generate force, which can add to the sensation of breathlessness. (Fillit et al., 2010)

Maximum inspiratory pressure (MIP) and maximum expiratory pressure (MEP) are measures that help in determining the capacity to which the lung is functioning. Along with respiratory muscle function, nutritional status has an impact on the MIP and MEP. With substantial anatomic changes in the aging respiratory system there is a co-occurrence of physiological changes. Respiratory muscle strength decreases with age, which affects MIP, MEP, and sniff nasal inspiratory pressure (Fillit et al., 2010). Undernutrition also has a negative impact on respiratory function (Janssens et al., 1999). Some data point to undernourishment in elderly adults, according to measures of diet quality collected by the Centers for Disease Control and Prevention (Statistics, 2010). Physical deconditioning and sarcopenia, hormone imbalance, and vitamin D deficiency will exacerbate the age-related lung structural changes. Decreased muscle strength is also tied to cardiac function and health. For example, decreasing respiratory muscle function is observed in Parkinson's disease and also is consequence of cerebral vascular disease. Static elastic recoil pressure of the lungs also decreases as a part of normal aging. The alveolar ducts increase in diameter and the alveoli become wider and shallowed. Elastic fibers in the respiratory bronchioles and alveoli degenerate (Fillit et al., 2010).

Pulmonary function tests show a residual volume increase of approximately 50% between the ages of 20 and 70 years of age. An increase in residual volume indicates that the amount of air volume left in the lungs after the greatest forced expiration has increased.

Pulmonary function tests, a common standard assessment of respiratory function, also show a decrease in vital capacity with aging (Janssens et al., 1999; Sharma & Goodwin, 2006). Spirometry also shows an increase in forced expiratory volume, the amount of air that can be forced out of the lung over a given period of time, and forced vital capacity, the amount of air that can be forcibly exhaled in healthy adults until the mid-twenties. After this age point, a continual decrease in function with advancing age is observed (Janssens et al., 1999).

Peak flow rates, the speed of expiration, and flow volume, a measure of the amount of air inhaled or exhaled, also tend to decrease with age (Janssens et al., 1999). Respiratory function has a direct impact on phonatory function. The lungs and larynx work together to produce voicing that is easy and effective for vocal communication. In aging, loss is experienced in both systems. This loss can lead to less functional phonation and impairment in communication.

Human data have shown a decrease in maximum phonation time in the presence of decreased respiratory function due to age and the presence of a glottal gap as a result of laryngeal muscle atrophy (Vaca, Mora, & Cobeta, 2015). These changes to the aging larynx will be addressed in greater detail in a later section.

4.1.5 Aging Speech Production

Biological, psychological, and physiological changes that occur in elderly adults can lead to changes to speech production. Hooper and Cralidis (2009) assessed these changes to speech production by first describing the relationship between five different processes involved in speech production; breathing for speech, phonation, resonation, articulation, and fluency (Hooper, 2009). Changes associated in phonation and breathing for speech will be addressed later in the document. Measures of nasal air flow and adequate velopharyngeal movement and closure remain stable throughout life creating a stabilization of resonance measures in the healthy elderly adult (Hoit, Watson, Hixon, McMahon, & Johnson, 1994). Articulation can be assessed in elderly adults by measuring rate, rhythm, and accuracy (Hooper, 2009). Speech rate has been measured to remain stable throughout the healthy elderly adult life. Speech rate, rhythm and accuracy of articulation, are however susceptible to changes in cognition and stress response in the elderly adult (Caruso, McClowry, & Max, 1997). While many of these changes do not individually indicate a disorder individually, when they occur in combination, they may have a measurable effect on the production of speech in elderly adults.

4.1.6 Aging Larynx

The larynx of the elderly adult goes through anatomical changes in the vocal folds and connecting muscles and cartilages that are associated with changes in acoustic and perceptual measurements of voice. Research regarding intrinsic laryngeal musculature and correlated acoustic and perceptual data reveals that one cause of the voice production in the elderly adult is the result of age-related changes to the larynx.

4.1.6.1 Aging Intrinsic Laryngeal Musculature

One of the most important intrinsic laryngeal muscles, the thyroarytenoid (TA), partially controls adduction of the vocal folds and involves rapid contraction speeds for phonation and other laryngeal tasks such as airway protection (cough) (Kuna, Insalaco, & Woodson, 1988). Changes to neuromuscular junction (NMJ) size and density impact the ability of the TA muscle to fulfill required roles for vocal communication (Connor, Suzuki, Lee, Sewall, & Heisey, 2002). These changes to the NMJ precede atrophy in aging muscle fibers (Deschenes, Roby, Eason, & Harris, 2010). Atrophy has a direct impact on the size of the vocal muscle fibers, making them smaller and thus creating age-related impairment (Martins et al., 2015). This atrophy is a result of sarcopenia, a loss of muscle bulk due to aging (McMullen & Andrade, 2006).

Other laryngeal changes in the elderly adult include cartilage calcification, reduction in the amount and quality of mucus, thickening epithelium, decrease of elastic fibers in the lamina propria, increase in collagen fibers, and changes in hyaluronic acid concentration (Gregory et al., 2012; Kendall, 2007; Pontes et al., 2005; Sato & Hirano, 1997, 1998). Also seen are alterations in the lamina propria (reduced visco-elasticity and thinning), decline in fibroblast activity important for tissue repair, and a diminished vascular supply. These changes collectively result in vocal folds that become less elastic and less pliable with increasing age (Kuhn, 2014).

Histological data show that intrinsic laryngeal muscles are made up of slow and fast twitch fibers. In aged rat models, the TA muscle becomes weaker, slower and more fatigable than in younger rat models (McMullen & Andrade, 2006). Along with weakness and loss of speed, a general disorganization of fibers in the vocal muscles forming the bulk of the vocal ligament is observed in the aging larynx (Madruga de Melo et al., 2003). Changes to the strength and speed of the intrinsic laryngeal muscles can have a direct impact on the ability of the muscles to produce functional communication.

Along with changes to strength and speed, reduction in the number of cells in the vocal folds and changes in the viscoelasticity of the vocal fold mucosa are seen with increase of age (Sato, Hirano, & Nakashima, 2002). Also with increasing age, the larynx descends in the neck, laryngeal cartilages ossify, and the vocal tract changes because of an increase in length and volume of the vocal tract. Secretions also become thicker in the elderly adult than they were in younger age (Johns et al., 2011; Kendall, 2007).

4.1.6.2 Neurologic Laryngeal Changes Associated with Aging

The superior laryngeal nerve (SLN) changes in the aging adult larynx. SLN nerve recruitment declines with age as measured by LEMG. Seventy-four percent of aging patients have a reduced superior laryngeal nerve recruitment of 70-90% of total laryngeal capability in youth. Twenty percent of aging patients demonstrate less than 70% recruitment of superior laryngeal nerve upon phonation, which is a significant reduction when compared to younger adults (Gregory et al., 2012).

5.0 AGING VOICE ASSESSMENT

5.1.1 Visual -Perceptual Findings in the Aging Larynx

Visualization of the elderly adult vocal folds often shows vocal fold bowing, decreased amplitude and reduced mucosal wave (Kuhn, 2014; Pontes et al., 2005). Glottal incompetence resulting in incomplete vocal fold closure during voicing is also typical in the aging larynx. (Butler, Hammond, & Gray, 2001; Linville, 1996; Linville, Skarin, & Fornatto, 1989; Pessin, Tavares, Gramuglia, de Carvalho, & Martins, 2016).

In a study assessing the laryngeal characteristics of 210 participants aged more than 60 years, the presence of vocal fold bowing was 23.8%, and the prominence of vocal processes was 29.5% (Pontes et al., 2005). Frequent occurrence of membranous spindle-shaped glottal gap was also observed. One of the challenges in measuring the incidence of laryngeal appearance changes in elderly adult patients is self-selection. Many studies have a selection bias in that they pull from a voice clinic involving patients actively seeking voice treatment. Laryngeal visualization is also not a standardized measure of assessment and is vulnerable to reviewer bias. Interestingly, Pontes et al. found that these traditional characteristics of presbyphonia did not correlate with the perception of a voice disorder in this population. This finding provides further evidence that the presence of a voice disorder in the elderly adult requires systematic diagnostic work beyond the larynx alone to determine the level of impairment of phonation-related systems.

5.1.2 Auditory-Perceptual Findings in the Aging Larynx

Perceptual voice analysis has been used to measure salient features and characteristics of aging voice. Perceptually, the aging larynx is associated with weak, hoarse, strained and deviant pitched voice. Numerous studies have assessed the perceptual difference between voice in younger adults compared to elderly adults (Benjamin, 1981; Biever, 1989; Ferrand, 2002; Hartman & Danahuer, 1976; Ryan & Burk, 1974; Wilcox, 1980). One such study created four equal number groups of adults, one each of elderly and younger men and women. Each subject produced an /a/ vowel for 3-5 seconds. Ten listeners rated the voices on the most salient perceptual characteristics. Consistent with findings from previous research, the elderly speakers exhibited significantly higher (more “severe”) fundamental frequency (F0), noise-to-harmonic ratio (NHR), and amplitude perturbation (shimmer) impairments than the younger adults (Gorham-Rowan & Laures-Gore, 2006).

As a result of the anatomic changes in the lungs and larynx, functional phonatory aerodynamic and intensity deficits are observed in elderly adults. Sound pressure level is lower in elderly individuals than young adults. Elderly adults are able to produce loudness levels appropriate for general prosodic inflection; however, the ability to increase loudness level decreases with age. This decrease in ability can be attributed to overall weakness of the intrinsic muscles of the larynx and the lungs (Baker, Ramig, Sapir, Luschei, & Smith, 2001; Mueller, Sweeney, & Baribeau, 1984; P. H. S. Ptacek, E.K.; Maloney, W.H.; Roe Jacson, C.C., 1966).

Some authors have hypothesized that professional voice users may be more affected by their perception of age-related voice changes because this group is more highly tuned in to their voices and therefore notice even small changes that may occur with aging. One survey study of

48 female and 24 male singers revealed that 50% of women thought there were voice changes around the age of 50 years and that those changes were due to menopause. Women singers more frequently associated changes to voice at age of 50 years with huskiness, a loss of ability to reach the highest notes, reduced vocal flexibility, and impaired steadiness of the voice. A majority of the 24 men also associated major voice changes with the fifth decade of life. Loss of bulk in vocal folds, change in timbre, and a loss of top notes were most associated in this self-report group (Boulet & Oddens, 1996).

The quality of voice resulting from glottal incompetence, reduced laryngeal tension, tremor, and increased fundamental frequency (F0) may allow listeners to easily differentiate some elderly voices from younger voices (Ryan & Burk, 1974). Listeners have overwhelmingly been able to discriminate younger adult (under 25 years) and elderly adult (over 65 years) voices on prolonged vowel and reading samples (Linville & Fisher, 1985a; P. H. Ptacek & Sander, 1966; Shipp & Hollien, 1969). Specific to age, F0 has measured as a strong indicator of perceived age. Elderly men who show an increase in F0 have been perceived as older whereas elderly woman are perceived as older with a decrease in F0 (Gorham-Rowan & Laures-Gore, 2006; Linville & Fisher, 1985b; Linville & Korabic, 1987).

In a study looking specifically at elderly male voices, perceptual features of speech for males in four age decades were measured. Listeners wrote down salient perceptual speech features of each speaker in reference to perceived age. Pitch, rate of speech, quality of voicing, and articulation were the greatest predictors of age discrimination. Speakers who were judged to be between 50 to 60 years of age were perceived to have low pitch, imprecise articulation, breathiness, slow speech rate, and long pauses during speech (Hartman & Danahuer, 1976).

These data are consistent with other voice research in the aging population (Linville, 1996; Ryan & Burk, 1974).

5.1.3 Acoustic Measurements of Aging Voice

Acoustic data have been used to quantify the auditory-perceptual differences heard in elderly voices. Acoustic data show that tremor, hoarseness, voice breaks, and a shift in fundamental frequency (F0) are specific characteristics in elderly voice. Elderly men experience a small gradual increase of F0 around the age of 50, while women may experience a lowering F0 following menopause (Linville, 1996; Stathopoulos, Huber, & Sussman, 2011). Change of pitch in elderly voices can be attributed to changes in the vocal folds (Abitbol et al., 1999; Kent, 1976) Along with a change of pitch in increasing age, F0 is shown to become unstable with age. This F0 instability is important for perceptual characteristics as F0 stability correlates with a listener's ability to determine the age of the speaker (Gorham-Rowan & Laures-Gore, 2006; Kendall, 2007).

Sound pressure level (SPL) and signal-to-noise ratio (SNR) are common acoustic measurements made in elderly adult voices. SPL has been shown to stay consistent throughout aging with no significant correlation with increasing age (Huber, 2008; Huber & Spruill, 2008; Sapienza & Dutka, 1996). A decrease in SNR has been observed in elderly female voices whereas men remain within normal limits (Stathopoulos et al., 2011). This decrease can be attributed to a hypothesized greater glottal incompetence in women due to changes in the vocal fold with increasing age (Linville, 1992; Pontes, Yamasaki, & Behlau, 2006).

Data are conflicting on jitter and shimmer values for elderly speakers (Gorham-Rowan & Laures-Gore, 2006). Preliminary studies have established normative Multi-Dimensional Voice Program (MDVP) acoustic baselines for relative average perturbation (RAP), shimmer, and noise-to-harmonics ratio (NHR) in elderly participants with perceptually normal voices. Voices of 50 participants from the ages of 60-80 years of age (mean age 69.5 years of age) were compared with younger adult voices. None of the participants had a history of respiratory or neurologic problems. For each of the measurements, significant differences were found between the younger and the elderly populations. The older the individual, the greater the RAP and shimmer, indicating an increase in the instability of pitch and amplitude of vocal fold vibration. These differences are significant (Schaeffer, Knudsen, & Small, 2015).

5.1.4 Aerodynamic Measurements of Aging Voice

Expiratory airflow is the driving force for phonation. Assessment of aerodynamic features in speech in aging voice helps us to begin to connect all of the pieces in the system of phonation. Airway resistance during phonation decreases significantly with age for both men and women (Makiyama et al., 2006). Changes to the respiratory and laryngeal mechanisms are responsible for this decrease in airway resistance.

Data show that mean airflow rate (MFR), amount of expired air over time, correlates positively and significantly with age. A decrease in maximum phonation time (MPT) is also measured with increased age (Takano et al., 2010). When compared with healthy elderly adults, those with acoustic qualities of presbyphonia had a significant increase in MFR.

5.1.5 Speech Breathing

Speakers over the age of 65 years say less words over the same amount of time compared to younger speakers. One explanation for this change lies in age-related changes to the respiratory system and glottal incompetence due to changes in the laryngeal musculature. Data show that adults with glottal incompetence due to unilateral vocal fold paralysis (UVFP) demonstrate a similar effect. When compared with a healthy control group during a reading of the Rainbow Passage, the UVFP group demonstrated more breaths, a longer reading duration, a higher mean airflow rate, longer inspiratory airflow duration and longer expiratory airflow duration. Increases in the above parameters can be directly correlated with glottal incompetence found in this population (Gartner-Schmidt et al., 2015). In elderly adults, both men and women demonstrate a decrease in speech breath length. This decrease in speech breath length resulted in a loss of the number of words spoken before the next breath. These changes are consistent with age-related changes in expiratory volume (Graetzer & Hunter, 2016). Similar to findings for the UVFP group, glottal incompetence in elderly adult speakers may have a significant impact on the ability to produce effective connected speech.

5.1.6 Patient Perception: VHI

Measuring patient’s perceptions of their own voice problems provides valuable information for the voice clinician. The Voice Handicap Index (VHI) was developed to describe functional, physical and emotional factors associated with voice disorders. The goal of the VHI was to help quantify an individual’s self-perceived voice handicap due to voice dysfunction (Jacobson et al., 1997). The VHI-10 is comprised of 10 selected questions from the initial 30 provided in the VHI. Both tools are easy to administer and give a reliable measurement regarding an individual’s perceived voice handicap, which has face validity (Rosen, Lee, Osborne, Zullo, & Murry, 2004).

5.1.7 Social Characteristics

Listeners readily judge social characteristics of voice, such as “pleasantness” and “naturalness” (Goy, Kathleen Pichora-Fuller, & van Lieshout, 2016). Data show that listeners use acoustic qualities to assign social characteristics to a speaker’s voice. Women can accurately estimate a man’s weight and age from listening to a speech sample (Bruckert, Lienard, Lacroix, Kreutzer, & Leboucher, 2006). More relevant to the current investigation are studies that show a voice sample rated as “pleasant” or “attractive.” Women have been shown to rate a male voice “attractive” when the speaker has a lower fundamental frequency (Collins, 2000). Fundamental frequency is a predictor of confidence, competence, and leadership ability in speakers, with preference for all factors given to speakers with a perceived lower pitch whether the speaker is male or female (Klofstad, Anderson, & Nowicki, 2015; Klofstad, Anderson, & Peters, 2012). The perception of leadership ability and competence can impact the life of an elderly working adult. There are no data that exist to help clarify the auditory-perception of social characteristics in elderly adults with and without voice complaints. This gap in data is important for understanding the full impact of a voice disorder in the elderly population and the potential negative perceptual associations.

6.0 SUMMARY

Functional changes in the elderly adult body lead to changes in primary systems involved in phonation. Variability in this functional change exists within the elderly adult population, which may explain why some adults are more affected by presbyphonia than others. The goal of this project is to determine if there is a significant difference between the aerodynamic, acoustic, auditory-perceptual characteristics of elderly adults who identify as having a voice disorder and diagnosed with vocal fold atrophy, versus elderly adults who self-identify as being vocally healthy.

6.1 ANTICIPATED OUTCOMES

Research has shown changes in voice in the elderly adult population that is associated with an increase in age. Literature is available that point to changes that are non-disease related as well as changes that result in disease. There is limited literature in the perception of disordered and non-disordered voice changes in the elderly adult. To investigate the perception of the elderly adult voice more closely, the following questions are being raised. (1) Is there a difference in acoustic, aerodynamic, or auditory-perceptual evaluation of voice characteristics between vocally healthy elderly adults and elderly adults with self-declared presbyphonia? (2) Is gender or age a significant factor in acoustic, aerodynamic, or auditory-perceptual evaluation of voice characteristics in vocally healthy elderly adults and elderly adults with self-declared presbyphonia?

7.0 METHODS

7.1 STUDY DESIGN

The study is a combined retrospective and prospective, blinded, non-randomized, matched cohort study assessing the acoustic, aerodynamic, and perceptual characteristics of voice across two groups of elderly participants.

7.2 PARTICIPANT GROUPS

Vocal Fold Atrophy Group: Data from 50 males and females (25 males, 25 females) 60 years of age and older were included. The data for this participant group came from previously collected patient data at the University of Pittsburgh Voice Center (UPVC), and maintained in a patient database. Inclusion and exclusion criteria were determined by the PI and then used to search the UPVC patient database for individuals who met the criteria. Participants were gender and age- (within 2 years) matched with the control group. Inclusion criteria were: a primary diagnosis of vocal fold atrophy; complete voice samples recorded during the initial, pre-treatment visit; VHI-10 score > 11. Exclusion criteria were a history of smoking (within 15 years of initial visit and of no more than 10-pack years total) or current pulmonary disease.

Vocally Healthy Control Group: Data from 50 males and females (25 males and 25 females) age 60 years or more were included in the control group. Data from control participants were taken from participant data collected as part of an unrelated investigation, and stored in the UPVC research files. Inclusion criteria were: a healthy, non-disordered voice as measured perceptually by a speech-language pathologist; VHI-10 score of <11 indicating absence of a self-perceived voice problem. Exclusion criteria include any history of smoking within 15 years or 10-pack years total of the date of voice recording, pulmonary disease or disorder, and self-reported history of a voice disorder defined as a vocal impairment lasting greater than 2 weeks.

7.3 VOICE SAMPLES

All voice samples used for measures in this study came from previous recordings collected at the UPVC. For the atrophy group, these were retrospective data. Voice samples for the healthy control group were collected from an ongoing study "Aerodynamic Profile of Non-Voice Disordered Individuals" (IRB #PRO13080164). All voice samples consisted of a reading of the first four sentences of the "Rainbow Passage" (Fairbanks, 1960). Voice samples collected for the control participant group were recorded during a non-appointment visit to the Voice Center. All voice samples collected for the elderly participant group were recorded on the participant's initial visit to the Voice Center. The following protocol was applied for both healthy control voice samples and voice samples used for the vocal fold atrophy group.

Voice samples were recorded in a sound-treated exam room at the University of Pittsburgh Voice Center using the Phonatory Aerodynamic System (PAS) 6600 (KayPENTAX, Montvale, NJ), which is comprised of a face mask attacked to a pneumotachometer with a calibrated microphone. The PAS is designed to collect and display phonatory aerodynamic data and analyze the speech signal on a number of parameters (Zraick, Smith-Olinde, & Shotts, 2012b). The system can record and display information such as SPL intensity, intraoral pressure, airflow rate, and fundamental frequency in real-time (Zraick, Smith-Olinde, & Shotts, 2012a). PAS collects and analyzes speech samples at a rate of 22050 Hz. All participants held the face mask over their nose and mouth and were asked to check for air leaks around the face mask. Participants were instructed to use comfortable pitch and loudness and the passage was read into the PAS mask. Speech samples were recorded and saved for later analysis (Gillespie & Gartner-Schmidt, 2016). These voice samples were used for all auditory-perceptual, aerodynamic and acoustic analysis.

7.4 ANALYSIS

7.4.1 Acoustic Analysis

Acoustic analyses were completed with the “All Voiced Sentence” protocol within the Analysis of Dysphonia in Speech and Voice (ADSV) program in the Computerized Speech Lab (CSL) (KayPENTAX). Once opened in the ADSV program, the first two sentences of the Rainbow Passage were selected. The sentences were selected by placing a cursor at voicing onset and offset for subsequent analysis. The intensity tracing was used to determine the correct placement of markers to define selection. The PI listened to each selection to confirm the correct stimulus had been set. The "apply automatic data selection" followed by "compute/display new ADSV results" was selected, which provided the desired computations for the given speech sample. Cepstral peak prominence (CPP), CPP standard deviation (CPP Std Dev), mean CPP fundamental frequency (Mean CPP F0), mean CPP F0 standard deviation, and the cepstral/spectral index of dysphonia (CSID) of the recordings were analyzed. CPP is an acoustic measure that combines measures of waveform and perturbation including amplitude, frequency, or noise, and is a widely used reliable measure of dysphonia in connected speech (Halberstam, 2004; Heman-Ackah et al., 2003; Watts & Awan, 2011). CPP is shown to correlate strongly with breathiness of a voice sample and overall voice severity, perceived hoarseness, and strain severity (Awan, Roy, Jette, Meltzner, & Hillman, 2010; Awan, Roy, & Jiang, 2010; Halberstam, 2004; Lowell, Colton, Kelley, & Hahn, 2011; Lowell, Kelley, Awan, Colton, & Chan, 2012). CSID is a multivariate summary of dysphonia severity calculated within the ADSV program that incorporates spectral and cepstral measures in continuous speech (i.e. The Rainbow Passage). Scores for CSID range between 0 and 100, although numbers above and below these parameters may be found, and respectively indicate an extremely normal or periodic voice sample or an aperiodic or abnormal voice sample (Awan, Roy, & Dromey, 2009; Peterson et al., 2013).

This analysis process was repeated for each voice sample to be included in the data set. Data were collected in an excel spreadsheet saved in a password protected file.

7.4.2 Aerodynamic Analysis

Aerodynamic analyses were performed by the PI using the Phonatory Aerodynamic System 6600 (PAS). The first two sentences of the Rainbow Passage were selected for analysis. The intensity tracing was used to determine the correct placement of markers to define the selection. Number of breaths during recording, length of recording (seconds), mean sound pressure level (SPL) during voicing (dB), mean pitch/fundamental frequency (Hz), total pitch range during voicing (Hz), mean expiratory airflow (milliliters), mean inspiratory airflow (liters), and mean airflow during voicing (milliliters) were collected from each voice sample. This process was repeated for each voice sample included in the data set. Data were saved in a password protected excel spreadsheet.

7.4.3 Auditory-Perceptual Analysis

Voice samples used for auditory-perceptual analysis were the same samples used for acoustic and aerodynamic analysis. Voice samples were opened in the ADSV program used for acoustic analysis. The first two sentences of the Rainbow Passage were selected according to the ADSV protocol and exported from the program for auditory-perceptual analysis (Awan, Roy, & Cohen, 2014; Eadie & Doyle, 2005; Gillespie & Gartner-Schmidt, 2016). Voice samples were converted to .wav files and uploaded into the REDCap system specifically developed for this project.

7.5 RATERS

All raters participating in the study were first or second year graduate students in the Communication Science and Disorders program at the University of Pittsburgh. All raters were required to pass a hearing screening via a MAICO MA 27 (MAICO Diagnostics, Eden Prairie, MN) audiometer. The raters were presented with a pure tone signal at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz at 20dB. Students did not need to have taken a class on voice disorders or have prior experience in rating voice samples to participate. All raters received training from the PI on all relevant and necessary software, rating scales, and procedures for complete severity ratings.

Auditory-perceptual ratings based on the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) scales were used to judge the quality of voices in the voice samples. The CAPE-V is a tool developed to describe the severity of auditory-perceptual attributes of voice (Kempster, Gerratt, Verdolini Abbott, Barkmeier-Kraemer, & Hillman, 2009). Consistent with the parameters in the CAPE-V, the measures used for this study were overall voice severity, roughness, breathiness, strain, pitch, and loudness. Along with traditional CAPE-V ratings, raters were given five additional social characteristics of voicing on which they were instructed to rate the voice samples. These additional characteristics were health of speaker, age of speaker, perceived masculinity/femininity of voice, pleasantness, and strength of voice.

The raters were given no demographic information regarding the voice samples prior to rating including age, gender, or presence of disorder. The presentation of voice samples was randomized individually for each rater to control for order effect. The first two sentences of the Rainbow Passage were used for auditory-perceptual analysis. Listeners rated each perceptual voice measure on a 100mm visual analogue scale (VAS) with exception to “age of speaker”. Raters provided a number when rating the perceived age of a speaker. The rater used a mouse-controlled slider to indicate their ratings. Each VAS was scaled from 0-100 and distance of the rating from the left end of the scale was used as the perceptual rating.

For traditional CAPE-V ratings, a score of 0 indicated perceived normal or typical voice, while a score of 100 indicated a severely abnormal or atypical voice. The social characteristics followed a similar structure with adjustment to accurately measure intended characteristics. For "health of speaker", 0 indicated a score of healthy and 100 indicated a score of unhealthy or sick. For "perceived masculinity/femininity", the 100mm VAS was divided in half and represented the characteristic with a score of 0-50 being the most masculine and a score of 51-100 being the most feminine. "Perceived pleasantness" and "strength of voice" mirrored a similar structure to "health of speaker" with a score of 0 indicating a most pleasant or strong voice, and a score of 100 indicating a least pleasant or weak voice. Raters were asked record a number within the REDCap system for "age of speaker" and were encouraged to use any whole number integer between 0 and 100.

The raters were encouraged to listen to the speech sample as many times as needed to complete all perceptual ratings. The volume of the presented speech samples was set to 80% of computer output prior to listening and was not be adjusted by the raters during the rating session. All raters used Sennheiser HD 457 headphones provided by the PI for all rating sessions.

Research Electronic Data Capture (REDCap), hosted by the University of Pittsburgh, was used to manage all participant data. REDCap is a secure web application for building and managing online surveys and databases. Raters entered their responses directly into the REDCap system developed specifically for this project.

7.6 RELIABILITY

Inter-judge reliability for perceptual ratings were assessed using the intra-class correlation coefficient, a measure of the degree of consistency among judges (Fleiss, 1981). Reliability was set at .7 to identify the most reliable raters. This number is consistent with previous studies in auditory-perceptual ratings of voicing. Ten percent of the recordings were repeated during the task to determine intrarater reliability.

7.7 STATISTICAL ANALYSIS

All statistical consulting and analysis was completed by Jonathan Yabes, PhD, and Diane Comer, M.S., of the University of Pittsburgh Center for Research on Health Care Data Center. Analysis for acoustic, aerodynamic, and auditory-perceptual data was completed using version 9.9.4 of Statistical Analysis Software (SAS). All coding required for de-randomization of rater data was completed using R coding language. A *t*-test was used for all unadjusted *p* values and an ANOVA for all adjusted *p* values to analyze the effect of disorder on acoustic, aerodynamic, and auditory-perceptual measurements. Due to the known effects of aging on respiration (Fillit et al., 2010; Janssens et al., 1999; Vaca et al., 2015), secondary analyses of differences between the atrophy and control groups in mean airflow during voicing and intensity as a function of age group were also conducted. Finally, due to known differences in fundamental frequency between males and females, differences between the atrophy and control groups in fundamental frequency as a function of gender were assessed.

8.0 RESULTS

8.1 PARTICIPANTS

One hundred participants matched criteria for inclusion and their voice samples were used for acoustic, aerodynamic, and auditory-perceptual analysis. Table 1 displays the demographic information for the atrophy and control groups including age, gender, and perceived voice handicap (VHI-10). The participants consisted of 50 males and 50 females split evenly across healthy and control groups. There was no significant difference in age with a mean age for the control and atrophy group of 68.3 (sd = 6.2; *p* = 0.9619). There was a significant difference in VHI-10 scores between the control and atrophy groups. The control group had a mean VHI-10 score of 1.5 (sd = 2.6) and the atrophy group had a mean VHI-10 of 19.9 (sd = 6.0; *p*<0.0001).

Table 1 Participant Demographic

	Total (N=100)	**Atrophy (n=50)**	**Control (n=50)**	**Unadj. (t-test)**	**Corrected (Hochberg)**
Measure	Mean (SD or %)	Mean (SD or %)	Mean (SD or %)	*p* value	*p* value
Female	50 (50%)	25 (50%)	25 (50%)	1.000	--
Age	68.3 (6.2)	68.3 (6.3)	68.3 (6.2)	0.9619	--
VHI-10	10.7 (10.3)	19.9 (6.0)	1.5 (2.6)	<0.0001	0.0009*

*Indicates significant < .05

8.2 PRIMARY OUTCOMES

8.2.1 Aerodynamic and Acoustic Analyses for Control and Atrophy Groups

The primary goal of the study was to determine if significant differences exist in the acoustic and aerodynamic analyses of voice samples of vocally healthy elderly adults (control group) and elderly adults with vocal fold atrophy. Aerodynamic and acoustic analyses of the voice samples included collection of data on: number of breaths taken during the voice sample, duration of the voice sample (seconds), sound pressure level during voicing (dB), mean pitch/fundamental frequency (Hertz), total pitch range during voicing (Hertz), mean expiratory and inspiratory airflow throughout sample (ml and L respectively), mean airflow during voicing (ml), cepstral peak prominent (CPP) and Cepstral Spectral Index of Dysphonia (CSID).

For acoustic analysis, significant findings were found for CPP and CSID. The control group had a significantly greater CPP mean score (*m* = 5.4, *sd* = .9) than the atrophy group (*m* = 4.5, *sd* = 1.2; *p*<0.0009). The control group also had a significantly lower (better) CSID mean score *(*m = -8.8, *sd* = 9.8) than the atrophy group (*m* =3.7, *sd* = 18.5; *p*<0.0009). No significant findings were observed in the differences between the two groups on SPL during voicing, average fundamental frequency, or total pitch range. For aerodynamic analyses, significant findings were found for sample duration. The control group had a significantly shorter mean sample duration (25.2 seconds) than the atrophy group (28.0 seconds; *p*=0.0808). No significant differences were observed across measures of inspiratory or expiratory airflow, or for number of breaths taken during the voice sample. (Table 2)

Table 2 Primary Acoustic and Aerodynamic Analyses

	Total (N=100)	**Atrophy (n=50)**	**Control (n=50)**	**Unadj. (t-test)**	**Corrected (Hochberg)**
Measure	Mean (SD or %)	Mean (SD or %)	Mean (SD or %)	*p* value	*p* value
Acoustic					
CPP	4.9 (1.2)	4.5 (1.2)	5.4 (0.9)	<0.0001	0.0009*
CSID	-2.5 (16.0)	3.7 (18.5)	-8.8 (9.8)	<0.0001	0.0009*
SPL (dB)	77.5 (2.7)	77.3 (2.8)	77.8 (2.6)	0.3737	0.9969
Mean fundamental frequency (Hz)	154.6 (33.5)	161.9 (32.7)	147.3 (33.0)	0.0285	0.1995
Pitch range (Hz)	185.1 (59.8)	187.9 (58.9)	182.3 (61.0)	0.6429	0.9969
Aerodynamic					
Mean expiratory airflow (ml)	158.9 (53.1)	165.4 (57.3)	152.4 (48.2)	0.2224	0.8896
Mean inspiratory airflow (L)	-0.6 (0.3)	-0.6 (0.3)	-0.6 (0.2)	0.9969	0.9969
Mean airflow during voicing (ml)	153.0 (56.6)	160.8 (61.3)	145.2 (51.0)	0.1697	0.8485
Number of breaths	6.0 (2.1)	6.3 (2.4)	5.7 (1.7)	0.1608	0.8485
Duration (seconds)	26.6 (5.4)	28.0 (6.6)	25.2 (3.4)	0.0101	0.0808

*Indicates significant < .05

8.2.2 Acoustic and Aerodynamic Measures Adjusted for Age and Gender

A regression analysis was completed for all acoustic and aerodynamic measures to identify the differences between the healthy control and atrophy groups while controlling for age and gender. Table 3 displays the results of the analysis. Each outcome's mean difference listed below represents the difference between the control and atrophy groups regardless of age or gender. The VHI-10 score had a significant mean difference of 18.42 ($p = 0.0009$) between the control and atrophy groups. CPP and CSID, with mean difference scores of -0.95 ($p = 0.0009$) and 12.53 ($p=0.0009$) respectively, were found to be significant acoustic characteristics between the atrophy and control groups. Mean fundamental frequency was observed to have a 14.54hz ($p=0.0136$) difference between the two groups when controlling for age and gender with the control group experiencing a lower measured frequency. The only aerodynamic measure found to be significantly different between the two groups was duration of sample, with a mean difference of 2.75 seconds ($p=0.0336$). No significant differences were identified in the regression analysis for SPL, pitch range, number of breaths, mean expiratory airflow, mean inspiratory airflow, or mean airflow during voicing. Table 3

Table 3 Acoustic and Aerodynamic Analyses Adjusted for Age and Gender

Measure	Mean Difference (Atrophy-Control)	Std Err	Unadjusted (t-test)	Corrected (Hochberg)
VHI-10	18.42	0.92	<.0001	0.0009*
Acoustic				
CPP	-0.95	0.22	<.0001	0.0009*
CSID	12.53	2.98	<.0001	0.0009*
SPL (dB)	-0.49	0.54	0.3695	0.9996
Mean fundamental frequency (Hz)	14.54	4.50	0.0017	0.0136*
Pitch range (Hz)	5.58	11.54	0.6300	0.9996
Aerodynamic				
Mean expiratory	13.09	9.49	0.1709	0.6836

Table 3 (continued)

airflow (ml)				
Mean inspiratory airflow (L)	-0.00	0.05	0.9996	0.9996
Mean airflow during voicing (ml)	15.70	10.70	0.1456	0.6836
Number of breaths	0.59	0.41	0.1507	0.6836
Duration (seconds)	2.75	0.95	0.0048	0.0336*

*Indicates significant < .05

8.2.3 Auditory-Perceptual Analysis for Control and Atrophy Groups

Another goal of the study was to determine if a significant difference exists in the auditory-perceptual evaluation of voice samples of vocally healthy elderly adults and elderly adults with vocal fold atrophy. Ten graduate student raters completed all auditory-perceptual evaluations for all voice samples. The data provided below are the outcomes of those perceptual ratings.

8.2.3.1 Auditory-Perceptual Analysis for All Raters

Figure 9.3 displays the auditory-perceptual data for all raters across all perceptual ratings categories. Significant findings were found for overall severity, roughness, breathiness, strain, health of speaker, pleasantness, and strength of voice ($p<0.05$ for all comparisons). The control group had a significantly lower (better) mean overall severity ($m = 31.0$, $sd = 15.0$) than the atrophy group ($m = 49.7$, $sd = 19.0$; $p<.001$), a difference of 18.69. For roughness, the control group had a significantly lower (better) mean score ($m = 26.3$, $sd = 11.9$) than the atrophy group (*m* = 43.1, *sd* = 17.0; *p*<.001), a difference of 16.74. The control group had significantly lower (better) mean breathiness score (*m* = 27.3, *sd* = 12.3) than the atrophy group (*m* = 37.5, *sd* = 13.0; *p*<.001), a difference of 10.26. For strain, the control group had a significantly lower (better) mean score (*m* = 22.3, *sd* = 13.7) than the atrophy group (*m* = 41.3, *sd* = 22.4; *p*<.001), a difference of 18.94. For loudness, the control group had a significantly greater (louder) mean score (*m* = 54.1, *sd* = 12.1) than the atrophy group (*m* = 45.4, *sd* = 21.0; *p*<.05), a difference of 8.78. On perceived health of speaker, the control group had a lower (perceived as healthier) mean score (*m* = 32.7, *sd* = 13.8) than the atrophy group (*m* = 48.3, *sd* = 17.1; p<.001), a difference of 15.57. For pleasantness, the control group had a lower (more pleasant) mean score (*m* = 40.5, *sd* = *11.4*) than the atrophy group (*m* = 51.7, *sd* =*13.5; p*<.001), a difference of 11.23. On perceived strength of voice, the control group had a lower (stronger) mean score (*m* = 38.8, *sd* =*11.5*) than the atrophy group (*m* = 52.9, *sd* = 13.4; p<.001), a difference of 14.05. No significant differences were observed for perceived pitch, perceived masculinity/femininity, or age of speaker. Table 4

Table 4 Auditory-Perceptual Analysis: All Raters

	Total (N=100)	**Atrophy (n=50)**	**Control (n=50)**	**Mean Difference (Atrophy-Control)**	**Unadjusted (t-test)**	**Corrected (Hochberg)**
Measure	Mean (SD)	Mean (SD)	Mean (SD)	Mean	*p* value	*p* value
Overall Severity	40.3 (19.5)	49.7 (19.0)	31.0 (15.0)	18.69	<0.0001	0.0005*
Roughness	34.7 (16.8)	43.1 (17.0)	26.3 (11.9)	16.74	<0.0001	0.0005*

Table 4 (continued)

Breathiness	32.4 (13.6)	37.5 (13.0)	27.3 (12.3)	10.26	0.0001	0.0005*
Strain	31.8 (20.8)	41.3 (22.4)	22.3 (13.7)	18.94	<0.0001	0.0005*
Pitch	44.4 (21.5)	45.5 (21.0)	43.2 (22.1)	2.35	0.5865	0.7824
Loudness	49.8 (13.9)	45.4 (14.4)	54.1 (12.1)	-8.78	0.0013	0.0052*
Health of Speaker	40.5 (17.4)	48.3 (17.1)	32.7 (13.8)	15.57	<0.0001	0.0005*
Masculinity/Femininity	48.1 (28.3)	48.9 (28.3)	47.3 (28.6)	1.58	0.7824	0.7824
Pleasantness	46.1 (13.6)	51.7 (13.5)	40.5 (11.4)	11.23	<0.0001	0.0005*
Strength of Voice	45.9 (14.3)	52.9 (13.4)	38.8 (11.5)	14.05	<0.0001	0.0005*
Age of Speaker	60.0 (6.9)	61.4 (7.0)	58.5 (6.6)	2.89	0.0354	0.1062

*Indicates significant < .05

8.2.3.2 Auditory-Perceptual Analysis for Reliable Raters

Figure 9.4 displays the auditory-perceptual data for raters identified as most reliable (ICC of .7) across all perceptual ratings categories. Significant findings were found for overall severity, roughness, breathiness, strain, health of speaker, pleasantness, and strength of voice (p<0.05). The control group had a significantly lower (better) mean overall severity score (*m* =27.4, *sd* =

16.6) than the atrophy group (*m* = 47.5, *sd* = 20.5; *p*<.001), a difference of 20.10. For roughness, the control group had a significantly lower (better) mean score (*m* = 20.2, *sd =12.1*) than the atrophy group (*m* = 41.1, *sd* = 20.5; *p*<.001), a difference of 20.90. The control group had a significantly lower (better) mean breathiness score (*m* = 25.3, *sd = 16.2*) than the atrophy group (*m* = 38.7, *sd* = 15.6; *p*<.001), a difference of 13.35. For strain, the control group had a significantly lower (better) mean score (*m* = 19.4, *sd = 14.6*) than the atrophy group (*m* = 41.8, *sd = 24.8*; *p*<.001), a difference of 22.34. For loudness, the control group had a significantly greater (louder) mean score (*m* = 55.6, *sd* =11.1) than the atrophy group (*m* = 47.2, *sd* = 17.0; *p*<.05), a difference of 8.45. On perceived health of speaker, the control group had a significantly lower (healthier) mean score (*m* = 25.6, *sd = 15.2*) than the atrophy group (*m* = 43.5, *sd* = 20.6; p<.001), a difference of 17.93. For pleasantness, the control group had a significantly lower (more pleasant) mean score (*m* = 39.7, *sd* = 14.5) than the atrophy group (*m* = 53.6, *sd* = 16.3;*p*<.001), a difference of 13.89. On perceived strength of voice, the control group had a significantly lower (stronger) mean score (*m* = 32.4, *sd = 13.8*) than the atrophy group (*m* = 50.2, *sd* = 17.6; p<.001), a difference of 17.76. No significant differences were observed for perceived pitch, perceived masculinity/femininity, or age of speaker. (Table 5)

Table 5 Auditory-Perceptual Analyses: Reliable Raters

	Total (N=100)	**Atrophy (n=50)**	**Control (n=50)**	**Mean Difference (Atrophy-Control)**	**Unadjusted (t-test)**	**Corrected (Hochberg)**
Measure	Mean (SD)	Mean (SD)	Mean (SD)	Mean	*p* value	*p* value
Overall Severity	37.5 (21.1)	47.5 (20.5)	27.4 (16.6)	20.10	<0.0001	0.0005*
Roughness	30.6 (19.8)	41.1 (20.5)	20.2 (12.1)	20.90	<0.0001	0.0005*

Table 5 (continued)

Breathiness	32.0 (17.2)	38.7 (15.6)	25.3 (16.2)	13.35	<0.0001	0.0005*
Strain	30.6 (23.2)	41.8 (24.8)	19.4 (14.6)	22.34	<0.0001	0.0005*
Pitch	44.5 (26.5)	45.7 (26.5)	43.3 (26.7)	2.41	0.6508	0.6508
Loudness	51.4 (14.9)	47.2 (17.0)	55.6 (11.1)	-8.45	0.0042	0.0168*
Health of Speaker	34.6 (20.2)	43.5 (20.6)	25.6 (15.2)	17.93	<0.0001	0.0005*
Masculinity/Femininity	46.7 (33.7)	48.2 (34.0)	45.1 (33.7)	3.12	0.6455	0.6508
Pleasantness	46.7 (16.9)	53.6 (16.3)	39.7 (14.5)	13.89	<0.0001	0.0005*
Strength of Voice	41.3 (18.1)	50.2 (17.6)	32.4 (13.8)	17.76	<0.0001	0.0005*
Age of Speaker	59.6 (9.0)	61.0 (9.0)	58.2 (8.8)	2.79	0.1204	0.3612

*Indicates significant < .05

8.2.3.3 Auditory-Perceptual Measures Adjusted for Age and Gender: Reliable Raters

A regression analysis was completed for all auditory-perceptual measures to identify the difference between the auditory-perceptual characteristics of the healthy control and atrophy groups while controlling for age and gender. Table 6 displays the results of the analysis. Each outcome's mean difference listed below represents the difference between the control and atrophy groups regardless of age or gender. All mean difference scores reflect the positive or negative score difference between the control and atrophy groups.

Overall severity had a significant mean difference of 20.04 ($p < 0.001$) between the control and atrophy groups. Roughness had a significant mean difference of 20.85 ($p < 0.001$)

between the control and atrophy groups. Breathiness had a significant mean difference of 13.33 ($p < 0.001$) between the control and atrophy groups. Strain had a significant mean difference of 22.29 ($p < 0.001$) between the control and atrophy groups. Loudness had a significant mean difference of -8.44 ($p < 0.05$) between the control and atrophy groups. Health of speaker had a significant mean difference of 17.87 ($p < 0.001$) between the control and atrophy groups. Pleasantness and Strength of voice had a significant mean difference of 13.83 ($p < 0.001$) and 17.71 ($p < 0.001$) respectively between the control and atrophy groups. No significant differences were observed for perception of pitch, masculinity/femininity, or age of speaker when adjusted for age and gender. Table 6

Table 6 Auditory Perceptual Analyses Adjusted for Age and Gender

Measure	Mean Difference (Atrophy-Control)	StdErr	Unadj. (t-test)	Corrected (Hochberg)
Overall Severity	20.04	3.51	<.0001	0.0005*
Roughness	20.85	3.26	<.0001	0.0005*
Breathiness	13.33	3.15	<.0001	0.0005*
Strain	22.29	3.82	<.0001	0.0005*
Pitch	2.40	1.83	0.1919	0.1919
Loudness	-8.44	2.80	0.0032	0.0128*
Health of Speaker	17.87	3.36	<.0001	0.0005*
Masculinity/Femininity	3.11	1.78	0.0841	0.1919
Pleasantness	13.84	2.92	<.0001	0.0005*
Strength of Voice	17.71	2.84	<.0001	0.0005*
Age of Speaker	2.76	1.67	0.1017	0.1919

*Indicates significant < .05

8.2.3.4 Intraclass Correlation Coefficient (ICC) for All Raters

Table 7 displays the ICC for all raters across all rating categories. Highlighted rows identify an individual raters ICC score of .7, indicating good rater reliability. The raters who reached an average ICC score across all ratings were rater 1, rater 4, rater 5, and rater 10.

Table 7 Intraclass Correlation Coefficient: All Raters

	Voice Severity	Roughness	Breathiness	Strain	Pitch	Loudness	Health	Masculinity/ Femininity	Pleasantness	Strength	Age	Average
Rater1	0.80	0.37	0.71	0.71	0.79	0.70	0.76	0.99	0.77	0.85	0.22	0.7
Rater2	0.65	0.77	0.14	0.66	0.40	0.48	0.72	0.97	0.33	0.50	0.48	0.56
Rater3	0.85	0.50	0.18	0.84	0.85	0.03	0.76	0.88	0.69	0.71	0.54	0.62
Rater4	0.75	0.88	0.47	0.86	0.42	0.73	0.84	0.88	0.80	0.57	0.66	0.71
Rater5	0.67	0.73	0.53	0.88	0.85	0.67	0.85	0.94	0.76	0.61	0.47	0.72
Rater6	0.89	0.78	0.76	0.94	0.00	0.20	0.62	0.83	0.64	0.25	0.27	0.56
Rater7	0.45	0.21	0.83	0.93	0.61	0.25	0.33	0.89	0.49	0.49	0.45	0.54
Rater8	0.62	0.44	0.44	0.87	0.76	0.41	0.71	0.87	0.65	0.73	0.53	0.64
Rater9	0.53	0.00	0.01	0.50	0.30	0.55	0.00	0.87	0.46	0.47	0.62	0.39
Rater10	0.75	0.71	0.92	0.96	0.98	0.71	0.93	0.94	0.58	0.71	0.83	0.82

Reliable raters are highlighted (average ICC ≥ 0.7)

8.3 SECONDARY OUTCOMES

Secondary analyses of the data were completed to assess the significance of aerodynamic, acoustic, and auditory-perceptual characteristics when observed by gender and age groups. For analysis by gender, all participants were assessed by gender across age groups (male and female). For analysis by age group, all participants aged 60-69, and 70+ were analyzed across genders.

8.3.1 Aerodynamic and Acoustic Analysis by age and gender

Four aerodynamic and acoustic measures were identified by the investigators as being areas of interest for further analysis by age and gender. SPL and mean airflow during voicing was assessed by age within the control and atrophy groups regardless of gender category. Average fundamental frequency and duration of sample was assessed by gender within the control and atrophy groups regardless of age category. Table 8 displays the results of the aerodynamic and acoustic analysis by gender. Table 9 displays the results of the aerodynamic and acoustic analysis by age.

Significant findings were found for males in mean fundamental frequency and durations of sample ($p<0.05$ for all comparisons). The control group had a significantly lower mean fundamental frequency (m = 121.0hz, sd = 22.7) than the atrophy group (m = 142.4hz, sd = 30.8; $p<.05$), a difference of 21.4hz. For duration of sample, the control group had a significantly shorter mean sample duration (*m* = 25.4, *sd* = 3.1) than the atrophy group (*m* = 29.7, *sd* = 8.4; *p*<.05), a difference of 4.3 seconds. No significant differences were observed for mean fundamental frequency or duration of sample in the female control and atrophy groups. No significant differences were observed in any of the acoustic or aerodynamic analyses by age group.

Table 8 Acoustic and Aerodynamic Analyses by Gender

Gender	**Total Participants (Control : Atrophy)**	**Measure**	**Atrophy Mean (SD)**	**Control Mean (SD)**	**p value**
Female	50 (25:25)	Mean fundamental frequency (Hz)	181.4 (21.1)	173.6 (16.2)	0.1525
		Duration (seconds)	26.3 (3.4)	25.1 (3.8)	0.2476
Male	50 (25:25)	Mean fundamental frequency (Hz)	142.4 (30.8)	121.0 (22.7)	.0072*
		Duration (seconds)	29.7 (8.4)	25.4 (3.1)	0.0214*

*Indicates significant < .05

Table 9 Acoustic and Aerodynamic Analyses by Age

Age	**Total Participants (Control : Atrophy)**	**Measure**	**Atrophy Mean (SD)**	**Control Mean (SD)**	**p value**
60-69	50 (25:25)	SPL (dB)	77.1 (2.8)	77.7 (2.1)	0.3835
		Mean airflow during voicing (ml)	170.3 (64.5)	147.1 (52.9)	0.1092
70	50 (25:25)	SPL (dB)	77.6 (2.9)	78.0 (3.4)	0.7345
		Mean airflow during voicing (ml)	140.6 (50.0)	141.3 (47.9)	0.9714

*Indicates significant < .05

8.3.2 Auditory-Perceptual Analysis by age and gender

Three auditory-perceptual measures were identified by the investigators as being areas of interest for further analysis by age and gender. Perception of age was assessed by age within the control and atrophy groups regardless of gender category. Perception of pitch and perceived masculinity/femininity were assessed by gender within the control and atrophy groups regardless of age category. Only reliable raters were used for these analyses. Table 10 displays the results of the auditory-perceptual analyses by gender. Table 11 displays the results of the auditory-perceptual analysis by age.

Significant findings were found for the 60-69 age group in perception of age ($p<0.05$). The control group had a significantly lower age perception ($m = 56.0$, $sd = 8.2$) than the atrophy group ($m = 60.3$, $sd = 9.5$; $p<.05$), a difference of 4.3. No significant differences were observed for perception of pitch or perceived masculinity/femininity in the female or male control and atrophy groups. No significant differences were observed for perception of age in the 70+ age group.

Table 10 Auditory Perceptual Analyses by Gender

Gender	Total Participants (Control : Atrophy)	Measure	Atrophy Mean (SD)	Control Mean (SD)	p value
Female	50 (25:25)	Perception of pitch	69.7 (8.4)	68.7 (7.6)	0.6456
		Perceived masculinity/femininity	80.2 (7.0)	77.8 (7.0)	0.2425
Male	50 (25:25)	Perception of pitch	21.7 (12.5)	17.9 (7.3)	0.1985
		Perceived masculinity femininity	16.3 (13.7)	12.4 (5.8)	0.2001

*Indicates significant < .05

Table 11 Auditory-Perceptual Analyses by Age

Age	Total Participants (Control : Atrophy)	Measure	Atrophy Mean (SD)	Control Mean (SD)	p value
60-69	68 (34:34)	Perception of age	60.3 (9.5)	56.0 (8.2)	0.0479*
70	32 (16:16)	Perception of age	62.3 (8.0)	62.8 (8.4)	0.8622

*Indicates significant < .05

9.0 DISCUSSION

9.1 PRIMARY AND SECONDARY OUTCOMES

Previous data have shown significant differences in acoustic, aerodynamic, and auditory-perceptual measures in elderly adults compared to young adults. These differences are often reported in the literature to be further exaggerated in the presence of vocal fold atrophy. For the current study, voice characteristics of self-identifying vocally healthy elderly adults and elderly adults with vocal fold atrophy were compared in an attempt to further delineate the typical and atypical voice changes that occur as a function of aging.

Significant differences were found in voice handicap, acoustic, aerodynamic, and auditory-perceptual characteristics across the two participant groups. Table 12 lists the significant differences associated with the atrophy group when compared to the control group.

Table 12 Significant differences between vocally healthy control group and atrophy group.

Significant Characteristics of Voice (Atrophy Group)	
• VHI-10 (higher) **Acoustic** • CPP (higher) • CSID (higher) • Mean fundamental frequency (higher) o Male group only **Aerodynamic** • Sample duration (longer) o Male group only	**Auditory-Perceptual** • Overall severity (higher) • Roughness (higher) • Breathiness (higher) • Strain (higher) • Loudness (lower) • Less healthy • Less pleasant • Less strong • Older (60-69 group only)

Many of the results in the current study corroborate other findings in the literature. The perceived voice handicap differences between the atrophy and control groups correlate with studies that demonstrated similar results (Golub et al., 2006; Johns et al., 2011). With regard to fundamental frequency, results support past research showing an increase in pitch in males with age (Gugatschka et al., 2010), which was more severe in the atrophy than control group in the current study.

Many studies have shown abnormal vocal acoustics in people with atrophy. In the current study, the acoustic measures of CSID and CPP were significantly different between the two groups, with the atrophy group demonstrating worse values in both acoustic measures than the control group. While the differences between the two groups reached statistical significance, the mean scores are not definitively indicative of *clinical* significance. The mean scores for both CSID and CPP in the atrophy group are within normal limits and not alone representative of voice abnormality (Awan, Solomon, Helou, & Stojadinovic, 2013; Heman-Ackah et al., 2014). This finding is interesting given that the atrophy participants rated their voice handicap (VHI-10) as significantly higher than the healthy control group and this rating was corroborated by worse auditory-perceptual ratings assigned to the atrophy group than the control group. Further, other studies have demonstrated a correlation between increased VHI-10 scores and abnormal acoustic measures in elderly adults (Gregory et al., 2012). These data indicate that there may be other factors severely impacting the patient with atrophy's perception and functionality of voice that are not captured with standard cepstral acoustic measurements. Past research has also demonstrated a lack of change in both time- and frequency-based acoustic measurements following surgical treatment of vocal fold atrophy (Gillespie, Dastolfo, Magid, & Gartner-Schmidt, 2014). That study also hypothesized that one reason for a lack of change could be that the acoustic measures analyzed did not accurately capture the disordered atrophy voice.

Contrary to findings in much of the existing literature on people with vocal fold atrophy, the patients with atrophy in the current study did not demonstrate greater airflow during speaking than the vocally healthy control group. These data exist in contrast with previous data that suggest vocal fold atrophy may cause glottal incompetence in a similar way to unilateral vocal fold paralysis, thus impacting overall voice production with more breaths and a higher airflow rate (Gartner-Schmidt et al., 2015; Gregory et al., 2012; Vaca et al., 2015). Specifically, Takano and colleagues found an increase in mean airflow rates during speaking in patients with atrophy compared to healthy controls (Takano et al., 2010). Atrophy patients in the current study also did not require more inhalations when speaking compared to the control group, which indicates that the patients with atrophy did not need to replenish air lost during speaking at greater rates than the control group. This finding also supports the results showing equal average airflow during voicing between the atrophy and control groups.

One unexpected finding was the difference in sample duration between the groups. Previous studies suggested that as age increases, the number of syllables or words per breath decrease as a result of the anatomic and physiologic change in the respiratory aging respiratory system. The current data set showed that males with atrophy had significantly longer sample duration that healthy control males. There was no significant increase in sample duration measured for females in the atrophy group compared to the control group. Three possible explanations can be proposed for this result. One, the males with atrophy may have taken more breaths when speaking. However, no significant difference was observed in the average number of breaths taken between participants in the healthy control and atrophy group; therefore an increased number of breaths did not account for the increase in total sample duration. Second, the participants in the atrophy group may have produced speech at a slower rate than the healthy control group. This finding contradicts past literature, which showed that rate of speech remains stable throughout the healthy elderly adult life. However, speech rate is susceptible to changes in cognition and stress response in the elderly adult, which may have influenced the sample duration of the males with atrophy in the current study (Caruso et al., 1997). Speech rate may also be affected by changes to fine motor skills observed in older adults, which may have impacted the males with atrophy greater than the other groups (Ballard et al., 2001). Third, participants in the atrophy group may have taken longer inhalations than those in the healthy control group, which could account for the observed longer duration in total speaking time.

Across auditory perceptual analyses, the atrophy group was rated as more severely dysphonic than the control group. These findings are interesting in light of this study's acoustic findings, which, while they demonstrated statistically significantly worse values in the atrophy than the control group, did not reveal acoustic ratings outside the normal range. Likewise, no significant differences in phonatory aerodynamics were observed between the groups, despite the vocal fold atrophy group being rated as having perceptually greater breathiness than the vocally healthy control group. Breathiness is the perceptual correlate of increased airflow; however the atrophy group did not show greater phonatory airflow than the control group. Of note, the atrophy group did show greater perceptual ratings of strain than the control group. This difference in strain may account for the relatively normal acoustic and aerodynamic values. CSID and CPP are sensitive to breathiness (Awan & Roy, 2009; Awan, Roy, Jette, et al., 2010). If the atrophy group participants were hyper adducting their vocal folds to overcome glottal incompetence, perhaps the strained phonatory posture resulted in greater vocal fold adduction, lower phonatory airflow values, and lower CSID and CPP scores. Despite similar average airflow values, the control group was perceived as louder than the atrophy group. Loudness is related to airflow; typically an increase in AC airflow, at least, results in an increase in loudness. Past studies have shown that loudness does not change as a function of typical aging (Huber & Spruill, 2008; Sapienza & Dutka, 1996); therefore the decreased perception of loudness in the atrophy group may be another indicator of the voice disorder.

Results of the current study add to the literature on auditory perception of voice, which has demonstrate that listeners can perceive a difference between the voices of old and young adults (Linville, 1996; P. H. Ptacek & Sander, 1966). The current results contribute the knowledge that listeners can perceive a difference between vocally healthy older adults and those with vocal fold atrophy.

Finally, one possible laryngeal deficit in patients with vocal fold atrophy that was not explored in this study is that of vocal fold tone. Patients with atrophy are hypothesized to lack not only muscle bulk, which leads to increased breathiness and phonatory airflow, but also muscle tone, including a decrease in visco-elasticity of the vocal fold lamina propria, which affects vibration (Kuhn, 2014; Madruga de Melo et al., 2003; Martins et al., 2015; McMullen &

Andrade, 2006). Perhaps the findings of equivalent phonatory aerodynamics in the current study could be explained through an analysis of vocal fold tone differences between the groups. The atrophy group and control group may have had similar vocal fold bulk, but may have differed in vocal fold tone, which could explain the perceptual and acoustic differences found. Unfortunately, a valid measure of vocal fold tone does not currently exist, so it would be difficult to test this hypothesis.

9.2 LIMITATIONS

The study had at least three limitations. First, the study was completed as a combined retrospective and prospective voice sample analysis. Acoustic and aerodynamic data analyzed for the project were collected from voice samples in existence from clinical voice recordings or from samples collected as part of another research investigation. Therefore, the voice samples and participants were collected from a convenience sample of existing data and no power analysis was completed to assess the necessary participants needed to achieve significance, although power was clearly sufficient to obtain significant results for several parameters. This study did, however, adhere to strict inclusion and exclusion criteria for all participants, including gender matching and age matching within one year.

The second limitation involves the acoustic analysis of aerodynamic recordings. All voice samples were recorded with the PAS6600. For PAS recordings, a mask is placed around the speaker’s face. That mask may have acted as a low-pass filter of the acoustic signal. However, the mask was worn for all participants, therefore would have impacted all samples across groups equally.

Finally, laryngeal examinations of the vocally healthy group were not completed; therefore, it is unknown if participants in this group had laryngoscopic features of vocal fold atrophy that did not impact their perception of voice handicap. However, despite not knowing the laryngeal status of the control group, this group was rated as vocally “better” on all perceptual measures compared to the atrophy group.

10.0 FUTURE DIRECTIONS

The current study revealed that elderly adults with voice complaints and a diagnosis of vocal fold atrophy had significantly higher VHI-10, CPP, and CSID scores, and longer speaking durations than the elderly vocally healthy control group. Males with atrophy also had longer speaking durations than control males. Patients with atrophy aged 60-69 were perceived as being older than the vocally healthy age-matched controls. No significant differences were found in phonatory aerodynamics between the atrophy and control groups. These findings are in contrast to the available atrophy literature as well as current voice disorder dogma, which states that individuals with vocal fold atrophy have glottal incompetence, which causes greater airflow during speaking, as well as a breathy voice quality. Several future directions are identified.

First, all aspects of the study should be conducted prospectively to control for extraneous factors that were limited due to the retrospective nature of chart review and sample analysis. In a prospective study, a power analysis would reveal the appropriate participant enrollment to measure differences across health and control groups, age, and gender, which were identified as being the most susceptible factors in age related changes in the elderly voice. Data should be collected on participant perceived vocal effort and patterns of voice use as this may have been a cause of significant differences in VHI-10 scores between groups.

Second, data should also be collected to further investigate the aerodynamic difference in vocally healthy elderly adults and elderly adults with vocal fold atrophy. Historically in vocal fold atrophy, the voice is characterized as having an increase in airflow due to the bowed nature of the vocal folds and subsequent escape of air during phonation (Martins et al., 2015; McMullen & Andrade, 2006). While a significant difference in aerodynamic measures of the atrophy group were not observed in the current study, a more comprehensive approach to measuring aerodynamic functioning for speech in elderly adults would be included. MPT, subglottal pressure (SGP), and laryngeal resistance data may provide important information for differentiating the aerodynamic characteristics of the vocally healthy elderly adult and the elderly adult with vocal fold atrophy.

BIBLIOGRAPHY

Abitbol, J., Abitbol, P., & Abitbol, B. (1999). Sex hormones and the female voice. *Journal of Voice, 13*(3), 424-446. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10498059

Awan, S. N., & Roy, N. (2009). Outcomes measurement in voice disorders: application of an acoustic index of dysphonia severity. *J Speech Lang Hear Res, 52*(2), 482-499. doi:52/2/482 [pii]10.1044/1092-4388(2009/08-0034) [doi]

Awan, S. N., Roy, N., & Cohen, S. M. (2014). Exploring the relationship between spectral and cepstral measures of voice and the Voice Handicap Index (VHI). *Journal of Voice, 28*(4), 430-439. doi:10.1016/j.jvoice.2013.12.008

Awan, S. N., Roy, N., & Dromey, C. (2009). Estimating dysphonia severity in continuous speech: application of a multi-parameter spectral/cepstral model. *Clinical Linguistics and Phonetics, 23*(11), 825-841. doi:10.3109/02699200903242988

Awan, S. N., Roy, N., Jette, M. E., Meltzner, G. S., & Hillman, R. E. (2010). Quantifying dysphonia severity using a spectral/cepstral-based acoustic index: Comparisons with auditory-perceptual judgements from the CAPE-V. *Clinical Linguistics and Phonetics, 24*(9), 742-758. doi:10.3109/02699206.2010.492446

Awan, S. N., Roy, N., & Jiang, J. J. (2010). Nonlinear dynamic analysis of disordered voice: the relationship between the correlation dimension (D2) and pre-/post-treatment change in perceived dysphonia severity. *J Voice, 24*(3), 285-293. doi:10.1016/j.jvoice.2008.11.003

Awan, S. N., Solomon, N. P., Helou, L. B., & Stojadinovic, A. (2013). Spectral-cepstral estimation of dysphonia severity: external validation. *Annals of Otology, Rhinology and Laryngology, 122*(1), 40-48. doi:10.1177/000348941312200108

Baker, K. K., Ramig, L. O., Sapir, S., Luschei, E. S., & Smith, M. E. (2001). Control of vocal loudness in young and old adults. *Journal of Speech, Language, and Hearing Research, 44*(2), 297-305. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11324652

Ballard, K. J., Robin, D. A., Woodworth, G., & Zimba, L. D. (2001). Age-related changes in motor control during articulator visuomotor tracking. *Journal of Speech, Language, and*

Hearing Research, 44(4), 763-777. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11521770

Benjamin, B. J. (1981). Frequency variability in the aged voice. *Journal of Gerontology, 36*(6), 722-726. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7299089

Biever, D. B., D. . (1989). Vibratory characteristics of the vocal folds of young adult and geriatric women *Journal of Voice, 3*, 120-131.

Bilodeau-Mercure, M., Kirouac, V., Langlois, N., Ouellet, C., Gasse, I., & Tremblay, P. (2015). Movement sequencing in normal aging: speech, oro-facial, and finger movements. *Age, 37*(4), 9813. doi:10.1007/s11357-015-9813-x

Boulet, M. J., & Oddens, B. J. (1996). Female voice changes around and after the menopause--an initial investigation. *Maturitas, 23*(1), 15-21. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8861082

Bruckert, L., Lienard, J. S., Lacroix, A., Kreutzer, M., & Leboucher, G. (2006). Women use voice parameters to assess men's characteristics. *Proceedings: Biological sciences, The Royal Society, 273*(1582), 83-89. doi:10.1098/rspb.2005.3265

Burggraf, V., Kim, K. Y., & Knight, A. L. (2014). *Healthy aging : principles and clinical practice for clinicians*. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins.

Butler, J. E., Hammond, T. H., & Gray, S. D. (2001). Gender-related differences of hyaluronic acid distribution in the human vocal fold. *Laryngoscope, 111*(5), 907-911. doi:10.1097/00005537-200105000-00029

Caruso, A. J., McClowry, M. T., & Max, L. (1997). Age-related effects on speech fluency. *Seminars in Speech and Language, 18*(2), 171-179; quiz 179-180. doi:10.1055/s-2008-1064071

Collins, S. A. (2000). Men's voices and women's choices. *Animal Behaviour, 60*(6), 773-780. doi:10.1006/anbe.2000.1523

Connor, N. P., Suzuki, T., Lee, K., Sewall, G. K., & Heisey, D. M. (2002). Neuromuscular junction changes in aged rat thyroarytenoid muscle. *Annals of Otology, Rhinology and Laryngology, 111*(7 Pt 1), 579-586. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12126012

D'Haeseleer, E., Depypere, H., Claeys, S., Wuyts, F. L., De Ley, S., & Van Lierde, K. M. (2011). The impact of menopause on vocal quality. *Menopause, 18*(3), 267-272. doi:10.1097/gme.0b013e3181f3ee36

Davids, T., Klein, A. M., & Johns, M. M., 3rd. (2012). Current dysphonia trends in patients over the age of 65: is vocal atrophy becoming more prevalent? *Laryngoscope, 122*(2), 332-335. doi:10.1002/lary.22397

Deschenes, M. R., Roby, M. A., Eason, M. K., & Harris, M. B. (2010). Remodeling of the neuromuscular junction precedes sarcopenia related alterations in myofibers. *Experimental Gerontology, 45*(5), 389-393. doi:10.1016/j.exger.2010.03.007

Eadie, T. L., & Doyle, P. C. (2005). Classification of dysphonic voice: acoustic and auditory-perceptual measures. *Journal of Voice, 19*(1), 1-14. doi:10.1016/j.jvoice.2004.02.002

Edge, J. R., Millard, F. J., Reid, L., & Simon, G. (1964). The Radiographic Appearances of the Chest in Persons of Advanced Age. *British Journal of Radiology, 37*, 769-774. doi:10.1259/0007-1285-37-442-769

Fairbanks, G. (1960). *Voice and articulation drillbook*. New York: Harper & Row.

Ferrand, C. T. (2002). Harmonics-to-noise ratio: an index of vocal aging. *Journal of Voice, 16*(4), 480-487. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12512635

Fillit, H., Rockwood, K., Woodhouse, K. W., & Brocklehurst, J. C. (2010). *Brocklehurst's textbook of geriatric medicine and gerontology* (7th ed.). Philadelphia, PA: Saunders/Elsevier.

Gartner-Schmidt, J. L., Hirai, R., Dastolfo, C., Rosen, C. A., Yu, L., & Gillespie, A. I. (2015). Phonatory aerodynamics in connected speech. *Laryngoscope, 125*(12), 2764-2771. doi:10.1002/lary.25458

Gillespie, A. I., Dastolfo, C., Magid, N., & Gartner-Schmidt, J. (2014). Acoustic Analysis of Four Common Voice Diagnoses: Moving Toward Disorder-Specific Assessment. *J Voice*. doi:10.1016/j.jvoice.2014.02.002

Gillespie, A. I., & Gartner-Schmidt, J. (2016). Immediate Effect of Stimulability Assessment on Acoustic, Aerodynamic, and Patient-Perceptual Measures of Voice. *Journal of Voice, 30*(4), 507 e509-507 e514. doi:10.1016/j.jvoice.2015.06.004

Golub, J. S., Chen, P. H., Otto, K. J., Hapner, E., & Johns, M. M., 3rd. (2006). Prevalence of perceived dysphonia in a geriatric population. *Journal of the American Geriatrics Society*, *54*(11), 1736-1739. doi:10.1111/j.1532-5415.2006.00915.x

Gorham-Rowan, M. M., & Laures-Gore, J. (2006). Acoustic-perceptual correlates of voice quality in elderly men and women. *Journal of Communication Disorders, 39*(3), 171-184. doi:10.1016/j.jcomdis.2005.11.005

Goy, H., Kathleen Pichora-Fuller, M., & van Lieshout, P. (2016). Effects of age on speech and voice quality ratings. *Journal of the Acoustical Society of America, 139*(4), 1648. doi:10.1121/1.4945094

Graetzer, S., & Hunter, E. J. (2016). A longitudinal study of the effects of aging on speech breathing: Evidence of decreased expiratory volume in speech recordings. *The Journal of* *the Acoustical Society of America, 139*(4), 2046-2046. doi:doi:http://dx.doi.org/10.1121/1.4950055

Gregory, N. D., Chandran, S., Lurie, D., & Sataloff, R. T. (2012). Voice disorders in the elderly. *Journal of Voice, 26*(2), 254-258. doi:10.1016/j.jvoice.2010.10.024

Gugatschka, M., Kiesler, K., Obermayer-Pietsch, B., Schoekler, B., Schmid, C., Groselj-Strele, A., & Friedrich, G. (2010). Sex hormones and the elderly male voice. *Journal of Voice, 24*(3), 369-373. doi:10.1016/j.jvoice.2008.07.004

Halberstam, B. (2004). Acoustic and perceptual parameters relating to connected speech are more reliable measures of hoarseness than parameters relating to sustained vowels. *ORL; Journal of Oto-Rhino-Laryngology and Its Related Specialties, 66*(2), 70-73. doi:10.1159/000077798

Harada, C. N., Natelson Love, M. C., & Triebel, K. L. (2013). Normal cognitive aging. *Clinics in Geriatric Medicine, 29*(4), 737-752. doi:10.1016/j.cger.2013.07.002

Hartman, D. E., & Danahuer, J. L. (1976). Perceptual features of speech for males in four perceived age decades. *Journal of the Acoustical Society of America, 59*(3), 713-715. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1254800

Heman-Ackah, Y. D., Heuer, R. J., Michael, D. D., Ostrowski, R., Horman, M., Baroody, M. M., . . . Sataloff, R. T. (2003). Cepstral peak prominence: a more reliable measure of dysphonia. *Annals of Otology, Rhinology and Laryngology, 112*(4), 324-333. doi:10.1177/000348940311200406

Heman-Ackah, Y. D., Sataloff, R. T., Laureyns, G., Lurie, D., Michael, D. D., Heuer, R., . . . Hillenbrand, J. (2014). Quantifying the cepstral peak prominence, a measure of dysphonia. *Journal of Voice, 28*(6), 783-788. doi:10.1016/j.jvoice.2014.05.005

Hoit, J. D., Watson, P. J., Hixon, K. E., McMahon, P., & Johnson, C. L. (1994). Age and velopharyngeal function during speech production. *Journal of Speech and Hearing Research, 37*(2), 295-302. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8028310

Hooper, C. R. C., A. . (2009). Normal Changes in the Speech of Older Adults: You've still got what it takes; it just takes a little longer! *Perspectives on Gerontology, 14*, 47-56. doi:10.1044/gero14.2.47

Huber, J. E. (2008). Effects of utterance length and vocal loudness on speech breathing in older adults. *Respiratory Physiology and Neurobiology, 164*(3), 323-330. doi:10.1016/j.resp.2008.08.007

Huber, J. E., & Spruill, J., 3rd. (2008). Age-related changes to speech breathing with increased vocal loudness. *Journal of Speech, Language, and Hearing Research, 51*(3), 651-668. doi:10.1044/1092-4388(2008/047)

Jacobson, B. H., Johnson, A., Grywalski, A., Silbergleit, A., Jacobson, G., Benninger, M. S., & Newman, C. W. (1997). The Voice Handicap Index (VHI):Development and Validation. *American Journal of Speech-Language Pathology, 6*, 66-70. doi:10.1044/1058-0360.0603.66

Janssens, J. P., Pache, J. C., & Nicod, L. P. (1999). Physiological changes in respiratory function associated with ageing. *European Respiratory Journal, 13*(1), 197-205. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10836348

Johns, M. M., 3rd, Arviso, L. C., & Ramadan, F. (2011). Challenges and opportunities in the management of the aging voice. *Otolaryngology - Head and Neck Surgery, 145*(1), 1-6. doi:10.1177/0194599811404640

Kempster, G. B., Gerratt, B. R., Verdolini Abbott, K., Barkmeier-Kraemer, J., & Hillman, R. E. (2009). Consensus auditory-perceptual evaluation of voice: development of a standardized clinical protocol. *American Journal of Speech-Language Pathology, 18*(2), 124-132. doi:10.1044/1058-0360(2008/08-0017)

Kendall, K. (2007). Presbyphonia: a review. *Curr Opin Otolaryngol Head Neck Surg, 15*(3), 137-140. doi:10.1097/MOO.0b013e328166794f

Kent, R. D. (1976). Anatomical and neuromuscular maturation of the speech mechanism: evidence from acoustic studies. *Journal of Speech and Hearing Research, 19*(3), 421-447. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/979206

Klofstad, C. A., Anderson, R. C., & Nowicki, S. (2015). Perceptions of Competence, Strength, and Age Influence Voters to Select Leaders with Lower-Pitched Voices. *PLoS One, 10*(8), e0133779. doi:10.1371/journal.pone.0133779

Klofstad, C. A., Anderson, R. C., & Peters, S. (2012). Sounds like a winner: voice pitch influences perception of leadership capacity in both men and women. *Proceedings: Biological sciences, The Royal Society, 279*(1738), 2698-2704. doi:10.1098/rspb.2012.0311

Kuhn, M. A. (2014). Histological changes in vocal fold growth and aging. *Curr Opin Otolaryngol Head Neck Surg, 22*(6), 460-465. doi:10.1097/MOO.0000000000000108

Kuna, S. T., Insalaco, G., & Woodson, G. E. (1988). Thyroarytenoid muscle activity during wakefulness and sleep in normal adults. *J Appl Physiol (1985), 65*(3), 1332-1339. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3182503

Larsson, L., Grimby, G., & Karlsson, J. (1979). Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol Respir Environ Exerc Physiol, 46*(3), 451-456. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/438011

Linville, S. E. (1992). Glottal gap configurations in two age groups of women. *Journal of Speech and Hearing Research, 35*(6), 1209-1215. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1494266

Linville, S. E. (1996). The sound of senescence. *Journal of Voice, 10*(2), 190-200. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8734394

Linville, S. E., & Fisher, H. B. (1985a). Acoustic characteristics of perceived versus actual vocal age in controlled phonation by adult females. *Journal of the Acoustical Society of America, 78*(1 Pt 1), 40-48. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/4019906

Linville, S. E., & Fisher, H. B. (1985b). Acoustic characteristics of women's voices with advancing age. *Journal of Gerontology, 40*(3), 324-330. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3989246

Linville, S. E., & Korabic, E. W. (1987). Fundamental frequency stability characteristics of elderly women's voices. *Journal of the Acoustical Society of America, 81*(4), 1196-1199. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3571731

Linville, S. E., Skarin, B. D., & Fornatto, E. (1989). The interrelationship of measures related to vocal function, speech rate, and laryngeal appearance in elderly women. *Journal of Speech and Hearing Research, 32*(2), 323-330. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2739384

Lowell, S. Y., Colton, R. H., Kelley, R. T., & Hahn, Y. C. (2011). Spectral- and cepstral-based measures during continuous speech: capacity to distinguish dysphonia and consistency within a speaker. *Journal of Voice, 25*(5), e223-232. doi:10.1016/j.jvoice.2010.06.007

Lowell, S. Y., Kelley, R. T., Awan, S. N., Colton, R. H., & Chan, N. H. (2012). Spectral- and cepstral-based acoustic features of dysphonic, strained voice quality. *Annals of Otology, Rhinology and Laryngology, 121*(8), 539-548. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/22953661

Madruga de Melo, E. C., Lemos, M., Aragao Ximenes Filho, J., Sennes, L. U., Nascimento Saldiva, P. H., & Tsuji, D. H. (2003). Distribution of collagen in the lamina propria of the human vocal fold. *Laryngoscope, 113*(12), 2187-2191. doi:10.1097/00005537-200312000-00027

Makiyama, K., Yoshihashi, H., Park, R., Shimazaki, N., & Nakai, M. (2006). Assessment of phonatory function by the airway interruption method: age-related changes. *Otolaryngology - Head and Neck Surgery, 134*(3), 407-412. doi:10.1016/j.otohns.2005.11.009

Marmor, S., Horvath, K. J., Lim, K. O., & Misono, S. (2016). Voice problems and depression among adults in the United States. *Laryngoscope, 126*(8), 1859-1864. doi:10.1002/lary.25819

Martins, R. H., Benito Pessin, A. B., Nassib, D. J., Branco, A., Rodrigues, S. A., & Matheus, S. M. (2015). Aging voice and the laryngeal muscle atrophy. *Laryngoscope*, *125*(11), 2518-2521. doi:10.1002/lary.25398

McMullen, C. A., & Andrade, F. H. (2006). Contractile dysfunction and altered metabolic profile of the aging rat thyroarytenoid muscle. *J Appl Physiol (1985), 100*(2), 602-608. doi:10.1152/japplphysiol.01066.2005

Mueller, P. B., Sweeney, R. J., & Baribeau, L. J. (1984). Acoustic and morphologic study of the senescent voice. *Ear, Nose, and Throat Journal, 63*(6), 292-295. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/6745132

Palmer, A. D., Newsom, J. T., & Rook, K. S. (2016). How does difficulty communicating affect the social relationships of older adults? An exploration using data from a national survey. *Journal of Communication Disorders, 62*, 131-146. doi:10.1016/j.jcomdis.2016.06.002

Pessin, A. B., Tavares, E. L., Gramuglia, A. C., de Carvalho, L. R., & Martins, R. H. (2016). Voice and aging: clinical, endoscopic and acoustic investigation. *Clinical Otolaryngology*. doi:10.1111/coa.12725

Peterson, E. A., Roy, N., Awan, S. N., Merrill, R. M., Banks, R., & Tanner, K. (2013). Toward validation of the cepstral spectral index of dysphonia (CSID) as an objective treatment outcomes measure. *Journal of Voice, 27*(4), 401-410. doi:10.1016/j.jvoice.2013.04.002

Polkey, M. I., Harris, M. L., Hughes, P. D., Hamnegard, C. H., Lyons, D., Green, M., & Moxham, J. (1997). The contractile properties of the elderly human diaphragm. *American Journal of Respiratory and Critical Care Medicine, 155*(5), 1560-1564. doi:10.1164/ajrccm.155.5.9154857

Pontes, P., Brasolotto, A., & Behlau, M. (2005). Glottic characteristics and voice complaint in the elderly. *Journal of Voice, 19*(1), 84-94. doi:10.1016/j.jvoice.2004.09.002

Pontes, P., Yamasaki, R., & Behlau, M. (2006). Morphological and functional aspects of the senile larynx. *Folia Phoniatrica et Logopedica, 58*(3), 151-158. doi:10.1159/000091729

Ptacek, P. H., & Sander, E. K. (1966). Age recognition from voice. *Journal of Speech and Hearing Research, 9*(2), 273-277. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/5925532

Ptacek, P. H. S., E.K.; Maloney, W.H.; Roe Jacson, C.C. (1966). Phonatory and Related Changes with Advanced Age. *Journal of Speech, Language, and Hearing Research, 9*, 353-360. doi:10.1044/jshr.0903.353

Ramig, L. O., Gray, S., Baker, K., Corbin-Lewis, K., Buder, E., Luschei, E., . . . Smith, M. (2001). The aging voice: a review, treatment data and familial and genetic perspectives. *Folia Phoniatrica et Logopedica, 53*(5), 252-265. doi:52680

Rosen, C. A., Lee, A. S., Osborne, J., Zullo, T., & Murry, T. (2004). Development and validation of the voice handicap index-10. *Laryngoscope, 114*(9), 1549-1556. doi:10.1097/00005537-200409000-00009

Ryan, W. J., & Burk, K. W. (1974). Perceptual and acoustic correlates of aging in the speech of males. *Journal of Communication Disorders, 7*(2), 181-192. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/4841332

Sapienza, C. M., & Dutka, J. (1996). Glottal airflow characteristics of women's voice production along an aging continuum. *Journal of Speech and Hearing Research, 39*(2), 322-328. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8729920

Sato, K., & Hirano, M. (1997). Age-related changes of elastic fibers in the superficial layer of the lamina propria of vocal folds. *Annals of Otology, Rhinology and Laryngology, 106*(1), 44-48. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9006361

Sato, K., & Hirano, M. (1998). Age-related changes in the human laryngeal glands. *Annals of Otology, Rhinology and Laryngology, 107*(6), 525-529. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9635464

Sato, K., Hirano, M., & Nakashima, T. (2002). Age-related changes of collagenous fibers in the human vocal fold mucosa. *Annals of Otology, Rhinology and Laryngology, 111*(1), 15-20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11800365

Schaeffer, N., Knudsen, M., & Small, A. (2015). Multidimensional Voice Data on Participants With Perceptually Normal Voices From Ages 60 to 80: A Preliminary Acoustic Reference for the Elderly Population. *Journal of Voice, 29*(5), 631-637. doi:10.1016/j.jvoice.2014.10.003

Sharma, G., & Goodwin, J. (2006). Effect of aging on respiratory system physiology and immunology. *Clinical Interventions in Aging, 1*(3), 253-260. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18046878

Shipp, T., & Hollien, H. (1969). Perception of the aging male voice. *Journal of Speech and Hearing Research, 12*(4), 703-710. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/5385720

Simonyan, K., & Horwitz, B. (2011). Laryngeal motor cortex and control of speech in humans. *Neuroscientist, 17*(2), 197-208. doi:10.1177/1073858410386727

Stathopoulos, E. T., Huber, J. E., & Sussman, J. E. (2011). Changes in acoustic characteristics of the voice across the life span: measures from individuals 4-93 years of age. *Journal of*

Speech, Language, and Hearing Research, 54(4), 1011-1021. doi:10.1044/1092-4388(2010/10-0036)

Statistics, F. I. F. o. A. R. (2010). *Older Americans 2010: Key Indicators of Well-Being*. U.S. Government Printing Office.

Takano, S., Kimura, M., Nito, T., Imagawa, H., Sakakibara, K., & Tayama, N. (2010). Clinical analysis of presbylarynx--vocal fold atrophy in elderly individuals. *Auris, Nasus, Larynx, 37*(4), 461-464. doi:10.1016/j.anl.2009.11.013

U.S. Department of Health and Human Services, N. I. o. H., National Institute of Mental Health. (2015). *Depression (NIH Publication No. 15-3561)*. Bethesda, MD: U.S. Government Printing Office.

Vaca, M., Mora, E., & Cobeta, I. (2015). The Aging Voice: Influence of Respiratory and Laryngeal Changes. *Otolaryngology - Head and Neck Surgery, 153*(3), 409-413. doi:10.1177/0194599815592373

Verdonck-de Leeuw, I. M., & Mahieu, H. F. (2004). Vocal aging and the impact on daily life: a longitudinal study. *Journal of Voice, 18*(2), 193-202. doi:10.1016/j.jvoice.2003.10.002

Volpi, E., Nazemi, R., & Fujita, S. (2004). Muscle tissue changes with aging. *Current Opinion in Clinical Nutrition and Metabolic Care, 7*(4), 405-410. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15192443

Watts, C. R., & Awan, S. N. (2011). Use of spectral/cepstral analyses for differentiating normal from hypofunctional voices in sustained vowel and continuous speech contexts. *Journal of Speech, Language, and Hearing Research, 54*(6), 1525-1537. doi:10.1044/1092-4388(2011/10-0209)

Wilcox, K. A. Y., H. . (1980). Age and Changes in Vocal Jitter. *Journal of Gerontology, 35*(2), 194-198. doi:10.1093/geronj/35.2.194

Williams, B. A., Chang, A., Ahalt, C., Conant, R., Ritchie, C. S., Chen, H. L., . . . Yukawa, M. (2014). *Current diagnosis and treatment : geriatrics* (pp. 1 online resource).

Woo, P., Casper, J., Colton, R., & Brewer, D. (1992). Dysphonia in the aging: physiology versus disease. *Laryngoscope, 102*(2), 139-144. doi:10.1288/00005537-199202000-00007

Zraick, R. I., Smith-Olinde, L., & Shotts, L. L. (2012a). Adult normative data for the KayPENTAX Phonatory Aerodynamic System Model 6600. *Journal of Voice, 26*(2), 164-176. doi:10.1016/j.jvoice.2011.01.006

Zraick, R. I., Smith-Olinde, L., & Shotts, L. L. (2012b). Adult normative data for the KayPENTAX Phonatory Aerodynamic System Model 6600. *Journal of Voice, 26*(2), 164-176. doi:10.1016/j.jvoice.2011.01.006