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MEASUREMENT OF LARYNGEAL DIADOCHOKINETIC STRENGTH IN ADULT MEN AND WOMEN BETWEEN 40 AND 59 YEARS OF AGE

A Thesis

Submitted to the School of Graduate Studies and Research

in Partial Fulfillment of the

Requirements for the Degree

Master of Science

Alaina M. Howse

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Indiana University of Pennsylvania
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Title: Measurement of Laryngeal Diadochokinetic Strength in Adult Men and Women Between 40 and 59 Years of Age

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Laryngeal Diadochokinesis (L-DDK) is a task used to assess fine motor control of the vocal mechanism. L-DDK is a task in which an individual repetitively produces the syllables /ʌ/ and /hʌ/ as rapidly and consistently as possible for a duration of seven seconds. L-DDK is useful because it provides information about rate, strength, and consistency of neuromotor control, allowing clinicians to determine if further testing is required. Current literature regarding L-DDK does not provide normative data for strength of laryngeal functioning based on L-DDK measures in the adult population. Development of normative data would assist speech-language pathologists in assessment of laryngeal strength and motor control of the larynx, as well as help to identify patients presenting with neurologic diseases such as ALS and Parkinson's, among others. This study serves to provide normative data for L-DDK measures of strength for the adult population between 40 and 59 years of age.

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CHAPTER I

REVIEW OF LITERATURE

Laryngeal Diadochokinesis (L-DDK) is a task used by speech-language pathologists to assess the fine motor control of a patient's vocal mechanism. Laryngeal diadochokinesis has been shown to predict normal and abnormal functioning in phonation in past studies (Canter, 1965; Renout, 1995; Leeper, 1991; Verdolini & Palmer, 1997). Phonation is the coordination of respiration & vocal fold vibration to produce voice. Laryngeal diadochokinesis is a task in which a patient repetitively produces the syllables /ʌ/ and /hʌ/ as rapidly and consistently as possible. L-DDK is useful because rate, strength, and consistency data provide information about neuromotor control of the larynx and allow clinicians to determine if further testing of a patient is required. However, there are no comprehensive normative data on L-DDK tasks, particularly the strength of productions. Clinicians may use L-DDK tasks with patients, but have no information with which to compare their results. This lack of normative data on the strength of diadochokinetic productions prevents clinicians from distinguishing between normally functioning and disordered patients. Certain degenerative disorders, such as Parkinson's disease and Amyotrophic Lateral Sclerosis (ALS), have detrimental effects on the larynx and strength of phonation as the disease processes progress. Laryngeal diadochokinesis may prove to be useful in identifying these disorders early on. Development of normative data will assist speech-language pathologists with structuring therapy goals and intervention strategies effectively and efficiently once a degenerative disorder is identified.

Normative L-DDK data are also needed to determine what is normal and abnormal across age and sex demographics. Normative data must be collected and analyzed in order for L-DDK to be truly clinically and diagnostically effective. Collected data can be analyzed for rate, strength, and consistency of L-DDK tasks to interpret how these components change within and among populations and age groups. The tasks also measure maximum laryngeal effort, meaning that it tests the upper limits of the laryngeal system and maximum functioning of the individual. The available literature does not provide standardized data or studies with a significant number of participants in varying age groups to offer comparison across populations. Therefore, the current study specifically investigated the strength of L-DDK tasks in normally functioning men and women between 40 and 59 years of age.

In order to understand L-DDK in reference to the diagnosis, prognosis, and intervention of degenerative disorders, a review of the anatomy and physiology that support L-DDK is required. The following sections describe the neuromotor innervation and physiology of the vocal folds, tests of laryngeal function, the impact of aging on the larynx, and diseases that affect the laryngeal system.

Anatomy and Innervation of the Larynx

The larynx is an anatomical structure in the body that is primarily responsible for phonation and the production of sound. It sits on top of the trachea and is composed of both muscle and cartilage (Seikel, King, & Drumright, 2010). The thyroid cartilage is the largest cartilage, and is connected to the cricoid cartilage via the cricothyroid joint (Seikel, et al, 2010). The cricothyroid joint allows both cartilages to have greater mobility, tilting the thyroid forward and lengthening the vocal folds (Seikel, et al, 2010). The arytenoid cartilages are paired and pyramidal in shape, and they attach the vocal folds posteriorly (Seikel, et al, 2010). The arytenoid cartilages are attached to the cricoid cartilage through the cricoarytenoid joint, which allows the vocal folds to adduct and abduct. In addition to cartilages and joints, the larynx is also composed of muscles, both intrinsic and extrinsic. The intrinsic muscles of the larynx have attachments within the larynx and assist with phonatory function (Seikel, et al, 2010). The intrinsic laryngeal muscles responsible for adducting the vocal folds are the thyroarytenoids, interarytenoids, and lateral cricoarytenoids. The only intrinsic laryngeal muscle responsible for abducting the vocal folds is the posterior cricoarytenoid (Seikel, et al, 2010). The cricothyroid and thyrovocalis muscles are responsible for lengthening and tensing the vocal folds, whereas the thyromuscularis relaxes the vocal folds (Seikel, et al, 2010). The extrinsic muscles of the larynx are primarily responsible for gross motor laryngeal movement, including raising and lowering the larynx (Stemple, et al, 2000). These cartilages, joints, and muscles are necessary for sound production and phonation. The histologic structure of the vocal folds is also necessary for measurement of vocal fold strength and production of sound.

The histologic structure of the vocal folds involves five layers of tissue. The most superficial layer is the epithelium. This layer is made up of squamous cell tissue and provides the outer lining of the vocal folds (Stemple,et al, 2000). Proteins called proteoglycans in the epithelium provide viscosity and moisture control (Seikel, et al, 2010). The next layer is the superficial layer of the lamina propria (SLLP) and is composed of elastin fibers. Elastin fibers cushion the vocal folds and allow them to stretch (Seikel, et al, 2010). The next layer is the intermediate layer of the lamina propria (ILP) and is also made up of elastin fibers. Elastin in this layer runs opposite of the SLLP, resulting in cross-hatching of fibers that supply flexibility and strength to the vocal folds (Stemple, et al, 2000). The following layer is the deep layer of the lamina propria (DLP) and contains supportive, dense collagen fibers. Together, the ILP and DLP compose the vocal ligament (Seikel, et al, 2010). The final layer of the vocal folds is the thyroarytenoid muscle (thyrovocalis and thyromuscularis). The thyroarytenoid makes up most of the vocal folds. This muscle accounts for more active movements of the vocal folds, whereas the lamina propria account for more passive elements, including strength, elasticity, and supportive cushioning (Seikel, et al, 2010). According to the Body-Cover Theory, the thyroarytenoid acts as the “body,” while the epithelium and lamina propria act as the vibratory “cover” (Seikel, et al, 2010). During vibration, the body closes first and the cover follows (Seikel, et al, 2010). The vocal folds are a complicated anatomical structure necessary for sound production and phonation. The structural makeup of the larynx provides elasticity, strength, flexibility, and supportive cushioning that are all necessary for the vocal folds to vibrate and produce sound.

Neurological innervation of the larynx is also important to understand when discussing sound production and motor control of the larynx. The vagus nerve (cranial nerve X), innervates the larynx. Also known as the “wandering nerve,” the vagus nerve extends from the skull down through the chest (Ford, Bless, & Garrett, 1991). It has two branches that are relevant to voice production: the recurrent laryngeal nerve (RLN) and the superior laryngeal nerve (SLN) (Ford, et al, 1991). The RLN primarily innervates all the intrinsic muscles of the larynx, excluding the cricothyroid (Ford, et al, 1991). It is responsible for abducting, adducting, and relaxing the vocal folds. Without this innervation, the vocal folds would not be able to close enough to produce sound (Seikel, et al, 2010). The RLN also supplies sensory information from the subglottic area to sense any aspiration of substances into the airway (Ford, et al, 1991). The SLN is primarily responsible for supplying laryngeal sensory and secretory innervation through the internal branch and innervation of the cricothyroid muscle through the external branch (Ford, et al, 1991). Sensation of the larynx is useful for detecting laryngeal penetration. Innervation of the cricothyroid muscle allows it to lengthen and tense to alter the pitch of one’s voice (Seikel, et al, 2010). Together, the RLN and SLN work together to innervate fine motor coordination of the larynx required for phonation (Stemple, et al, 2000). The aging process can highly influence changes in anatomy and innervation of the larynx throughout the lifespan. In the adult population, changes in anatomy and innervation of the larynx due to aging can have an effect of strength on L-DDK tasks.

Development and Aging of the Larynx

The current study explored L-DDK performance on middle-aged men and women between 40 and 59 years of age to contribute to normative data collection for L-DDK. Exploring the effects of development and aging of the larynx is increasingly important due to the increase in the geriatric population. Aging of the larynx, also referred to as presbylaryngeus, is a natural part of the aging process. However, it is important to be able to distinguish what is normal in the aging process and what is identifiable as laryngeal pathology. Aging of the larynx includes different components of the vocal system, such as acoustic measures of phonation, perceptions of voice quality, physical changes to the larynx, and others (Seikel, King, & Drumright, 2010). Ferrand states that three distinctions must be made before exploring the effects of aging on the larynx: age-related changes are gradual, laryngeal changes are highly varied between individuals, and gender has different effects on laryngeal changes (Ferrand, 2012).

Puberty

Puberty is a period of time occurring in adolescence where men and women experience hormonal and physiological changes. Puberty manifests a variety of changes in men and women. Androgen and estrogen hormones determine regulation of growth, both of which are present in men and women. Higher levels of androgens are present in males, and higher levels of estrogen are present in females. Laryngeal changes are more pronounced in males due to the changes in androgen hormones, with male larynges increasing two to three times more in length than females (Ferrand, 2012). The vocal folds also increase in length about 11.57mm (approximately 63%) in males and approximately 4.16mm (approximately 34%) in females (Ferrand, 2012). The angle of the thyroid cartilage also changes significantly during puberty. In males, the angle shifts to a more acute angle of about 90 degrees in males, and stays at about 120 degrees in females. The dramatic shift in males lengthens and tightens the vocal folds, resulting in decreased fundamental frequency (pitch). Males also experience a more dramatic perceptual shift in vocal quality throughout puberty, resulting in multiple pitch breaks as laryngeal structures change.

Aging of the Larynx

The natural aging process effects different anatomical changes to laryngeal structures. Cartilages in the larynx begin ossifying in as early as the third decade of life (Ferrand, 2012). Ossification typically affects the cricoid or thyroid cartilage and is more significant in males than females. Joints in the larynx are also subject to degenerative changes. Loss of elasticity and surface irregularities may contribute to increased difficulty with adduction and abduction of the vocal folds, resulting in breathy voice quality (Ferrand, 2012). Degenerative changes have the largest effect on the cricoarytenoid joint. Degenerative changes in muscle elasticity may also have an effect on joint functioning. The thyroarytenoid muscle tends to atrophy, leading to increased effort to phonate and incomplete approximation of the vocal folds (Ferrand, 2012). Changes in neurological innervation due to age also effect movement of the laryngeal muscles (Ferrand, 2012). Degenerative changes to the epithelium and lamina propria are numerous and can have significantly different effects on men and women. The epithelium tends to thicken in females. The epithelium becomes dehydrated due to atrophy of mucous glands, interfering with vocal fold vibration by increasing stiffness and causing increased vocal effort or vocal fatigue (Ferrand, 2012). Elastin and collagen fibers in the larynx also degenerate, causing changes to the elasticity of the vocal fold and resulting in consequences in acoustic voice quality such as breathiness and weakness (Ferrand, 2012). Reduced intensity levels in the geriatric population have been associated with reduced respiratory functioning, including decreased vital capacity and reduced strength of respiratory muscles. Decreased intensity levels may also contribute to breathy voice quality, due to atrophy of laryngeal muscles.

Structural degenerative changes to the larynx have effects on the acoustic measures of older men and women. Changes in fundamental frequency are a primary acoustic change, due to the aging process. Researchers have found that fundamental frequency changes in males are variable, increasing in some studies, and staying the same in others (Ferrand, 2012). These differences are usually dependent on hormonal changes that come with age in males. For example, males with increased estrogen levels have a higher fundamental frequency (Ferrand, 2012). Conversely, males with increased testosterone levels demonstrate a lower fundamental frequency (Ferrand, 2012). Older females tend to have a lower fundamental frequency due to edema in the vocal folds during menopause. Edema in the vocal folds increases mass and decreases rate of vibration, resulting in lower fundamental frequency. Dehydration of mucosa, as mentioned before, may also have lead to an acoustically hoarse voice quality due to the natural aging process (Ferrand, 2012).

Changes to the larynx due to the aging process should result in effects on L-DDK performance. Muscle atrophy due to age would have an effect on the strength of L-DDK tasks, reflecting decreased amplitude in productions of the /ʌ/ and /hʌ/ syllables. Normative data would identify these differences across age groups. It is important to remember that changes in the larynx due to the normal aging process should effect differences in L-DDK performance. Normative data would help to identify these differences across age groups.

Tests of Laryngeal Function

According to Stemple, et al (2000), clinicians must consider the following when choosing equipment to assess laryngeal functioning: reliability of the equipment, potential restraints on the speech mechanism caused by equipment, adequate availability of normative references, and efficiency and cost effectiveness of protocols. The following tests have problems with reliability and physical invasiveness, indicating that L-DDK tasks are more efficient to administer.

Needle electromyography (EMG) is a diagnostic protocol used to determine patterns of electrical activity in the larynx. Needle EMG is different from surface EMG, which involves placement of electrodes on the surface laryngeal area of the skin and is non-invasive (Tomblin, 2000). Electrodes are blindly inserted into laryngeal muscles and individuals are asked to perform a series of vocal tasks to confirm placement of the electrodes. For example, placement on the cricothyroid muscle would be accurate if EMG activity is active during high-pitched productions and inactive during quiet inspiration (Stemple et al, 2000). EMG is used to determine if individuals present with neurological impairment, but may also be used to determine normal functioning or mechanical fixation (Stemple et al, 2000). EMG determines pathology based on onset and timing of laryngeal muscles from the following four tasks: timing of muscle activity and the pattern, number, and amplitude of muscle action potentials (Stemple et al, 2000). EMG is particularly useful in identifying vocal fold neuropathy, such as paralysis or other neuromuscular disorders (Tomblin, 2000). It provides biofeedback about functioning of the laryngeal muscles. However, clinical use is limited for speech-language pathologists because only a neurologist or otolaryngologist may perform the assessment (Stemple et al, 2000). This procedure is also invasive, expensive to administer, and vocal tasks used during assessment do not measure maximal laryngeal effort.

Electroglottography (EGG) is a measure of laryngeal function that is used to infer vibratory patterns of the vocal folds. It involves placement of electrodes on the surface of the neck between two points of the thyroid cartilage (Stemple, et al, 2000). Small electrical signals measure resistance during vocal fold vibration (typically a sustained phonation task). The electrodes send signals that are converted to waveforms to be interpreted (Stemple, et al, 2000). These waveforms are represented as peaks and troughs to represent maximum open and closure patterns of the vocal folds (Stemple, et al, 2000). Advantages of EGG are that it is noninvasive and provides useful visualization of vocal fold closure patterns. One limitation of EGG includes room for errors depending on placement of the electrodes resulting in variability of results across administrations (Stemple, 2000). This assessment also does not measure maximum laryngeal effort because participants are not required to rapidly adduct and abduct the vocal folds.

Endoscopy is a form of equipment used to visualize the laryngeal system using intraoral or transnasal approaches. Only clinicians and physicians trained in the task may perform endoscopy. Both rigid or flexible endoscopy allow visualization of vocal fold vibration. With a stroboscopy feature, observation of cyclic patterns of vibration are possible in a ‘slow motion’ effect (Stemple, et al, 2000). However, rigid endoscopy does not quantify fine motor abnormalities in abduction and adduction. Endoscopy allows only perceptual judgments of vocal fold and laryngeal anatomy and function.

Limitations of endoscopy include invasiveness, accessibility, and issues with perceptual interpretation. Although endoscopy provides high-quality visualization of the larynx, interpretations remain perceptual and may vary between speech-language pathologists. Visualization allows interpreters to view the larynx during varied phonatory tasks, though tasks are not always representative of maximum laryngeal performance. Endoscopy is typically available in a hospital or otolaryngologist’s office, and it is not readily available for speech-language pathologists working in a clinical setting. Maintenance of the equipment and the equipment itself are also expensive and may cause physical strain for the client because of its invasiveness.

Though the tests discussed provide useful clinical information, all are unable to be used regularly in all clinical settings and have several limitations. All of these tests are expensive and not readily accessible for speech-language pathologists. The tests discussed are invasive and not all protocols measure maximum laryngeal effort. Maximum laryngeal effort is important to assess because it tests the upper limits of the laryngeal system and maximum functioning of the individual. Unlike other tests of laryngeal function, oral and laryngeal DDK are practical for a clinical setting and can be analyzed quickly (Tomblin, 2000). Diadochokinesis is the only form of assessment that evaluates coordination and neuromotor control of the articulatory and laryngeal system both quickly and effectively. Other procedures are not representative of maximum laryngeal effort and require an excess of time and money to administer.

Diadochokinesis

Oral Diadochokinesis

Oral DDK is often performed as part of an oral mechanism examination to provide information about the oral cavity and articulatory skills of the client. Oral DDK is defined by Fletcher (1978) to be "the study of motor control integrity…through performance in rapidly altering movements…including syllable repetition at a maximum rate of utterance" (p. 768). The tasks typically involve an individual repeating the labial, alveolar, and velar plosive consonants (/p/, /t/, /k/) paired with the vowel /ʌ/. Individuals are asked to repeat the /pʌ/, /tʌ/, and /kʌ/

syllables individually as rapidly as possible for seven seconds, then combine the three together (/pʌtəkə/) and produce them again as rapidly as possible for an additional seven seconds. The productions are added (total number of productions for each syllable) and divided by seven (number of seconds per task) to generate the individual's rate of production.

Ruscello (1982) described components of the Oral Speech Mechanism Screening Examination (OSMSE) and considered the effectiveness of its use. The OSMSE is administered routinely before diagnostic evaluations of speech and language. The examination includes perceptual evaluation of the lips, jaw, tongue, teeth, hard palate, soft palate, pharynx, respiration, and oral diadochokinesis. Scoring of the assessment is primarily through a plus or minus tally system. After examining all structures listed, oral DDK is performed to measure motor coordination and control of articulators (Ruscello, 1982). Examiners may decide if they want to simultaneously record the number of productions and time duration, or record responses to be counted at a later time. During development of the test, normative data were collected from sixty participants ranging from second grade through college age. Intra-rater and intra-examiner reliability were administered with trained speech-language pathologists for collecting data on tasks of oral DDK, which was a strength of the study. Ruscello concluded that results of the study demonstrated "satisfactory intra- and inter-examiner reliability and is suitable for use with both children and adults" (1982, p. 329). Though the OSMSE screening tool is commonly used in a clinical setting, normative study results indicate that this study is flawed. Researchers did not include a wide enough age range of participants and completely eliminated middle-aged adults and geriatric populations. The study did not have adequate inclusion or exclusion criteria to control for factors outside of the study, such as history of neurological disorder.

Fletcher (1972) looked at time-by-count measurement of oral DDK syllable rate in opposition to the traditionally used count-by-time measurement. Time-by-count measurement involves starting a stopwatch for the oral DDK tasks as the individual begins and subsequently focusing on syllable count. Count-by-time measurement involves timing the productions of an individual and subsequently counting the produced syllables. Fletcher described that measuring oral DDK through count-by-time measurement is flawed because it takes more time and effort for clinicians to measure results. He explained that this measurement approach is unreliable because clinicians must divide their attention, so data collection may be inaccurate. Fletcher proposed that a time-by-count measurement system is more useful because it allows clinicians to collect measurements in “sequential, rather than overlapping tasks” and it eliminates “overlapping attentional requirements” (Fletcher, 1972, p. 763). The author randomly selected 24 men and women from each age group ranging from 6 to 13 years of age. Participants were required to perform oral DDK tasks on a number of syllables, including: /pʌ/, /tʌ/, /kʌ/, /fʌ/, /lʌ/, /pʌtə/, tʌkə/, and /pʌtəkə/. Examiners were required to use the same script for each task, and tasks were presented in varying order. Examiners recorded productions to test reliability of data collection, which was a strength of the study. Examiners created the following criteria for production of tasks prior to the study: 20 repetitions of single-syllable productions, 15 repetitions for two-syllable productions, and ten repetitions for the three-syllable productions (Fletcher, 1972). Results from oscillographic patterns and stopwatch records revealed that the two methods were not statistically different. These findings suggest that the two methods of data collection are essentially interchangeable. However, results of this study can only be applied to an equivalent clinical group of children ranging from 6 to 13 years of age. This study is relevant to tasks of oral DDK. However, the procedures did not include tests of L-DDK, and so functioning at the level of the vocal folds cannot be inferred.

Another study by Gadesmann (2007) investigated the reliability of oral DDK measurement. Gadesmann made the distinction that reliability of clinical use of oral DDK is necessary to establish the efficacy of the task. Many reliability studies of oral DDK use acoustic waveforms and equipment to measure performance. However, clinical use of oral DDK is most often performed through timing with a stopwatch and counting syllables and there is no uniform method to administer oral DDK (Gadesmann, 2007). The purpose of this study is to provide information about the reliability of clinical use of oral DDK through investigation of inter and intra-reliability measures. The study included two groups: ten female speech-language pathologists and ten untrained individuals with no prior connection to speech-language pathology. Participants were asked to rate twelve different oral DDK samples on six characteristics: rate of syllable repetition in the first five seconds, rate of syllable repetition of the speech sample, regularity of rhythm, distinctness, and loudness, and overall impressions (Gadesmann, 2007). The 12 recorded samples consisted of varied neurological dysfunction, including Parkinson's disease, dystonia, and essential tremor. Two samples were repeated to compare data collection among individuals. Results demonstrated that inter-rater reliability measures were statistically significant (*p*-value, $<.05$), indicating that participants collected data collection reliably. Gadesmann also found that inter-rater percentage agreement was 84.4% within the range of ± one syllable (Gadesmann, 2007). However, Gadesmann reports that the control group often rated qualitative measures at either end of the extreme, and their responses were products of response bias. Intra-rater reliability for each measurement demonstrated that only eleven out of forty measurements were statistically significant, suggesting that intra-rater agreement of oral DDK tasks is poor. Gadesmann admits that many limitations are present in this study, including that participants were not adequately trained prior to the study, lack of formal descriptions for qualitative scales, and small sample size. However, this study provides useful information for future research and establishes that reliability of oral DDK is highly variable. Gadesmann suggests that future research on oral DDK focus on reliability of its clinical application and use larger sample sizes.

Oral DDK is useful because it provides clinicians with easily obtainable and non-invasive information about functioning of the articulatory system and the oral cavity. The studies discussed provide useful information on oral DDK, although they also demonstrate flaws. Fletcher and Ruscello do not include middle age or geriatric populations in their collection of participants and

Gadesmann had small sample sizes and recognized response bias in their study. According to Mason (1976), “the ability of the tongue to produce rapid sequencing is thought to be of paramount importance in speech diagnostics” (pg. 159). It provides speech-language pathologists with a quick way to screen for neurological dysfunction. Oral DDK provides useful information about functioning of the oral cavity. However, it does not provide clinicians with a way to assess functioning at the level of the vocal folds and the studies discussed do not include normative information for adults and geriatric populations. Further research must be conducted to determine reliability of clinical use of oral DDK procedures.

Laryngeal Diadochokinesis

As mentioned before, L-DDK is an assessment tool used by speech-language pathologists to measure laryngeal functioning. Unlike oral DDK, which evaluates oral and articulatory motor coordination, L-DDK measures characteristics of phonation, which is the product of respiration and vocal fold vibration. L-DDK is defined by Shanks (1966) to be the “maximum ability to rapidly abduct and adduct the vocal folds while repeatedly uttering a syllable containing a glottal fricative and a vowel” (pg. 1). L-DDK is also commonly referred to as vocal fold diadochokinesis because it measures characteristics of vocal fold closure and functioning.

Both oral and laryngeal DDK have the ability to measure strength of sound production. However, L-DDK can additionally measure strength of the phonatory system and vocal fold closure. Oral DDK is limited to measuring strength of the oral cavity and articulation. Both tasks are measures of the upper limits of the speech sound production system, though L-DDK has the ability to provide information about functioning of the laryngeal system, particularly the functioning of the vocal folds. Fletcher (1972) describes maximum laryngeal effort as “the maximum rate at which the muscles could move the structures of during speech performances” (pg. 767). A review of available literature on L-DDK that supports that the current study is necessary.

Ptacek (1965) investigated changes associated with age when performing laryngeal and respiratory tasks. Ptacek hypothesized that significant respiratory, phonatory, and articulatory changes occur between younger adults and the geriatric population (Ptacek, 1965). Researchers also hypothesized that performance differences in young adult versus geriatric populations would be more significant to compare rather than measuring habitual functioning of the geriatric population (Ptacek, 1965). Researchers included 105 participants, 56 of whom were men and women over 68 years of age, and 49 of whom were men and women under 40 years of age. Participants were excluded from the study if they had previous diagnoses of dysphagia, neurological disorder affecting the speech or phonatory system, structural laryngeal abnormalities, and other exclusion criteria (Ptacek, 1965). Researchers assigned participants to perform tasks that reflect respiratory and laryngeal functioning. Measurements included assessments of pitch range, diadochokinesis (both oral and laryngeal), maximum vowel intensity, maximum vowel duration, maximum intraoral breath pressure, and vital capacity.

Ptacek found that "significant differences were found between adult and geriatric subjects in vital capacity, maximum vowel duration, maximum intraoral pressure, and maximum vowel intensity." Ptacek postulated that a decrease in vital capacity (lung capacity) and intraoral pressure (pressure in the oral cavity) may contribute to the decrease in maximum vowel duration and intensity (Ptacek, 1965). Examiners also found that L-DDK measures were significantly lower in the geriatric test group. Authors of the study attribute reduced performance in tasks to lost elasticity of respiratory muscles, and degenerative changes in the larynx. Ptacek summarized that significant differences exist between age groups on all administered tasks and should be considered in future assessment of individuals' performance.

Ptacek (1965) effectively demonstrated the need for normative data on L-DDK measures. The study, however, poses threats to validity by explaining that outcomes on their geriatric age group could also be affected by cognitive abilities of the participants. Ptacek did not control for participants presenting with dementia or cognitive deficits. The authors also did not explain if examiners were adequately trained or blinded to the purpose or hypotheses of this study. The author did not adequately explain any reliability procedures, so collected data may be inaccurate or biased by the examiners. Though the results are statistically significant, they must be interpreted with caution since reliability data are not reported and instrumentation limits the reliability of the results. The results of this study suggest that further research must be conducted to explore the clinical significance of L-DDK tasks.

Verdolini and Palmer (1997) conducted a study that attempted to provide a "profiles" approach for assessment of voice disorders. The study investigated the extent to which L-DDK tasks detect and distinguish organic laryngeal pathology (Verdolini & Palmer, 1997). The researchers attempted to provide a clinically useful and simple way to identify organic pathology in the larynx. Authors included forty-five participants diagnosed with structural, organic, and normally functioning laryngeal systems. Specific protocols for diagnosis were employed prior to the study to ensure that results were not skewed due to pathology. Participants determined as normal served as a control group. Participants were selected and matched to groups depending upon their laryngeal pathology. Groups were organized by the following laryngeal pathologies: vocal nodules, granuloma, unilateral abductor vocal fold paralysis, Parkinson's disease, functional voice disorder, and control (normal functioning).

Verdolini and Palmer predicted that performance on s:z ratios and L-DDK tasks would differ according to laryngeal pathology. The authors predicted that all organic pathologies in the study except for Parkinson's and abductor vocal fold paralysis would have "good" strength results. They predicted that participants with Parkinson's disease would be "poor" for strength because of "hypometria related to acceleration phenomena and rigidity" (Verdolini et al, 1997, pg. 220). Researchers also suggested that strength would be "poor" due to vocal fold bowing, a common occurrence in Parkinson's disease (Verdolini and Palmer, 1997). In participants with abductor vocal fold paralysis, researchers predicted strength to be "poor" because "muscle weakness characterizes paralytic conditions in general" (Verdolini et al, 1997, pg. 220). Researchers indicated that participants with vocal fold paralysis would demonstrate significant difficulty adducting vocal folds to produce an adequate glottal stop (Verdolini et al, 1997).

Researchers used both s:z ratios and L-DDK tasks to identify pathology in the larynx. The s:z ratios are a form of assessment in which an individual is required to produce /s/ for as long as possible (Tomblin, 2000). Two maximally produced /s/ durations are then divided by a maximally produced /z/ (Tomblin, 2000). This task has been previously proven to assist in detecting membranous vocal fold closure characteristics (Verdolini et al, 1997). Participants were informed about the purpose of the study and subsequently underwent voice testing. Examiners were blinded to the subjects' diagnostic conditions and could not be easily biased by participants' physical characteristics. The researchers then collected data for several voice assessment measures. For the purpose of this study, the researcher only analyzed data for the s:z ratios and L-DDK tasks. Evaluations included brief conversation to collect auditory perceptions of voice quality, L-DDK tasks, s:z ratio, voice range profile, and others. The researchers ended the comprehensive evaluation with video endoscopy to confirm or deny diagnostic predictions.

Results of the study found that both s:z ratios and L-DDK measures combined were able to correctly identify individuals with organic laryngeal pathology. Researchers identified 22 out of 25 participants demonstrating organic pathology. Of these participants, 8 had Parkinson's disease, 4 demonstrated vocal fold paralysis, and 7 presented with vocal nodules (Verdolini et al, 1997).

The examiners were blinded to the diagnosis of the participants and the hypothesis of this study, which was a strength and helped to control for experimenter bias. Extensive reliability procedures were employed but were identified as a weakness in the study. The researchers used “intrajudge, interjudge, and judge vs. oscilloscope stability of the measures.” These reliability measures involve comparing examiner and equipment data collection. The researchers employed a “good” versus “poor” perceptual rating of the strength of closure of glottal stops. The researchers identified this measure as a weakness because the perceptual rating did not fully represent the range of vocal strength (Verdolini et al, 1997).

Overall, the results of this study revealed that the researchers’ predictions about strength of L-DDK results in participants with Parkinson’s disease and abducted vocal fold paralysis were accurate. Participants with these diagnoses demonstrated not only decreased strength, but also decreased rate and consistency during L-DDK tasks (p-value $<.0001$). Participants with these diagnoses had significant difficulty adducting the vocal folds due to muscle weakness and vocal fold bowing (Verdolini et al, 1997). Overall, results of this study provided statistically significant, though non-normative, findings for the clinical and diagnostic use of L-DDK because L-DDK tasks effectively identified disordered populations.

Another study conducted by Leeper and Jones explored the temporal and aerodynamic properties of L-DDK tasks. The study was performed in an attempt to provide clinically useful information regarding assessment of laryngeal functioning and integrity through exploring respiratory functioning and airflow characteristics of L-DDK. (Leeper & Jones, 1991). Researchers indicate that information is needed “concerning the timing and amount of air used during rapid voluntary opening and closing of the vocal folds” (pg. 880). This study included eighteen women between 20 and 25 years old who did not have a significant history of respiratory, neurological, or hearing difficulties. Prior to the study, the researchers used a wet spirometer to measure peak inspiratory volume and obtained pneumographic patterns to view upper rib cage motion in order to measure depth and consistency of respiratory volume. Researchers also measured vocal intensity and frequency range prior to the study.

Each participant was required to produce the vowel /ʌ/ as rapidly as possible for five seconds at varying frequencies and intensities. Leeper and Jones used a pressure transducer, pneumotachograph, and amplifier equipment to measure acoustic and aerodynamic voice properties during L-DDK tasks. Trials of the tasks were recorded and repeated if frequency and intensity varied by more than ± 2% (Leeper & Jones, 1991). Examiners analyzed data collected from the middle three second segments of the recorded task to determine peak airflow rate and rate of production of the vowel /ʌ/.

Results from this study indicated that vocal intensity (loudness) has the largest influence on L-DDK syllable rate and airflow regulation (Leeper & Jones, 1991). Participants demonstrated statistically significant (*p*-values, <.01) differences in transglottal airflow rate and intensity. For example, participants had more air flowing through the glottis when producing the vowel /ʌ/ at an increased intensity, creating a louder sound. Conversely, participants had less air escaping through the glottis when producing the vowel /ʌ/ at a decreased intensity, resulting in a quieter production. These results suggest that laryngeal strength has a large influence on vocal intensity and airflow at the level of the vocal folds. The researchers found that vocal intensity had the largest impact on L-DDK production, influencing both rate and consistency of L-DDK tasks. The researchers suggested that this supported recent study findings, saying that "at low vocal frequency, glottal resistance functioned to vary intensity, while at high vocal frequency phonation, intensity was controlled by airflow rate via expiratory muscle force" (Leeper & Jones, 1991, pg. 882). These results suggest that strength of the laryngeal system can have a potentially large impact on performance of L-DDK tasks.

The results of this study, though significant, may only be accurately applied to women between the ages of 20 and 25, preventing generalization of results. The study also had a small sample size (n = 18) and participants were entirely female. More diverse populations must be used to collect normative data in order to definitively justify purposes of administering L-DDK tasks. The study results are also limited in clinical application because the study used a facemask pneumotachograph system to gather data, and this may not be readily available to clinicians working in a clinical setting. However, because this study used equipment to more accurately assess laryngeal and respiratory functioning compared to Verdolini and Palmer, the results are reliable.

Diseases Affecting Laryngeal Functioning

Degenerative neurological disorders have a significant impact on the larynx, especially as they progress. This section will explore degenerative effects on the larynx specific to Parkinson's disease and amyotrophic lateral sclerosis (ALS).

Parkinson's Disease

Parkinson's disease is a degenerative neurological disorder characterized by "resting tremor, muscular stiffness (e.g. rigidity), and slowness of body movement (i.e. bradykinesia) (Bassich-Zeren, 2004). The most common form of Parkinson's disease is idiopathic, and typical onset is between 50 and 69 years of age (Bassich-Zeren, 2004). Each year, approximately 60,000 individuals are diagnosed with Parkinson's, and there are many cases that remain undiagnosed (Parkinson's Disease Foundation website). Individuals with Parkinson's disease often develop hypokinetic dysarthria, a motor speech disorder caused by damage to the basal ganglia. Individuals with hypokinetic dysarthria demonstrate harsh, breathy voice quality. They also characteristically demonstrate accelerated rate of speech and significantly reduced intensity. Past studies have demonstrated that L-DDK measures are effective in identifying individuals with Parkinson's disease because they demonstrate significant difficulty performing the L-DDK task (Verdolini et al, 1997).

Canter (1965) conducted a study that addressed L-DDK performance in individuals with Parkinson's disease. The purpose of the study was to examine speech characteristics of individuals with Parkinson's disease through articulation, diadochokinesis (both oral and laryngeal), and overall speech adequacy. The study included seventeen males with Parkinson's disease and seventeen normally functioning males who served as a control group. The researchers used L-DDK tasks to assess vocal fold adduction and abduction skills in participants. The researchers measured diadochokinetic rates by recording 30-seconds samples of participants. However, many participants with Parkinson's disease demonstrated significant difficulty sustaining phonation for thirty seconds, and some participants could not perform the rapid movements. The results of these tasks indicated that all participants with Parkinson's were impaired in their performance of diadochokinesis (Canter, 1965). Canter (1965) made the observation that "the Parkinsonian group showed impaired ability to perform rapid movements of the tongue, lips, and vocal folds" (Canter, 1965, pg. 223). This study provides useful information about the effects of Parkinson's disease on tasks of diadochokinesis and effects of the disease on articulatory skill. However, the sample size is small (n = 34) and includes only middle-aged males, limiting generalization to other populations.

Another study by Bassich-Zeren (2004) explored vocal dysfunction in young-onset Parkinson's disease (YOPD). The study served to examine perceptual characteristics and the impact of voice quality on quality of life, compare young-onset Parkinson's disease and normally functioning individuals on tasks of L-DDK and other measures, and compare performance in producing onset/offset gestures in different phonetic contexts (Bassich-Zeren, 2004). These onset/offset gestures involve productions of vowels across positions of words.

The study included 12 young-onset Parkinson's disease individuals ranging from 35-57 years of age and 12 normally functioning individuals ranging from 30-57 years of age. Participants were required to perform L-DDK and sustained phonation tasks. L-DDK tasks were initiated after the participant rehearsed the task. The researchers clarified that data collected from L-DDK tasks could not be compared to normative data because they were not available at the time of the study (Bassich-Zeren, 2004). The researchers also assessed voice quality and perceptions of quality of life through additional measures, such as questionnaires, the Voice Handicap Index (VHI), reading of a fairy tale passage, voice productions in varied phonetic contexts, and conversational tasks. The researchers split L-DDK tasks into adductory and abductory measures when interpreting results. The results of this study indicated that participants with YOPD demonstrated significantly decreased rate of syllable repetition in adductory measures and increased number of pauses to maintain syllable repetition in abductory measures (Bassich-Zeren, 2004). The results of this study were that L-DDK tasks were significantly impaired in participants with young onset Parkinson's disease *(p*-value, <.01). This study provides useful information about the impact of voice quality on individuals with young-onset Parkinson's disease. However, the sample size for this study was small (n = 24), and results cannot be generalized because most individuals with Parkinson's disease are diagnosed at an older age. The range of disease onset in participants ranged from 30-49 years of age, whereas typical age of onset in Parkinson's disease is 50-69 years of age (Parkinson's Disease Foundation website).

Amyotrophic Lateral Sclerosis

Amyotrophic Lateral Sclerosis (ALS), also known as Lou Gehrig's disease, is a progressive degenerative neurological disorder involving both upper and motor neurons. The disease is manifested by muscle weakness, spasticity, and atrophy. Most individuals diagnosed with ALS live about 3-5 years and typically die due to respiratory failure caused by the disease. ALS affects motor functioning throughout the body. Once degeneration begins, disintegration continually progresses until a low level of functioning is reached (Renout, 1995). Individuals with ALS may or may not have bulbar involvement, meaning that the brainstem or cranial nerves are effected, compromising speech and swallowing abilities. Though ALS eventually effects all voluntary muscles in the body, this section will explore the effects of ALS on the motor speech mechanism.

Renout (1995) explained that changes to the speech system due to ALS may occur at different times throughout the progression of the disorder. Primary characteristics of changes to the speech system due to ALS are imprecise articulation, hypernasality, breathy, harsh, low-pitch/low intensity, slow speaking rate, and difficulty with prosody (Renout, 2010). Individuals with ALS may also demonstrate flaccidity or spasticity of muscle tone, depending on the manifestation of the disease. Renout makes the distinction that acoustic analysis of voice and speech productions are useful in differential diagnosis, detection, and monitoring of disease progression (Renout, 2010). Evaluation of laryngeal motor control can be extremely useful in diseases such as ALS, where motor degeneration is a primary characteristic.

The study by Renout (1995) explored the functioning of L-DDK tasks in individuals with ALS. The purpose of this study was to explore the laryngeal function of bulbar and non-bulbar individuals with ALS through the use of L-DDK tasks at different points throughout the disease progression. The participants were fifteen men and eleven women with confirmed diagnoses of ALS, ranging from 40 to 78 years of age who were evaluated over an 18-month period. Twelve participants presented with bulbar involvement, and 14 participants did not. The examiners required participants to perform the L-DDK task twice for each testing period and subsequently evaluated the rate and periodicity of the task. The results indicate that participants with bulbar involvement demonstrated significantly reduced rate and periodicity of the L-DDK task (Renout, 2010). The researchers also found that participants without bulbar involvement demonstrated significantly more abduction than bulbar patients. Overall, researchers found that all participants had difficulty meeting the demands of the L-DDK task and characteristically increased the length of either adduction or abduction patterns, resulting in inability to complete the task (Renout, 2010). These results suggest that individuals with ALS have difficulty “cessating one motor impulse and substituting a diametrically opposite one” (Renout, 2010, pg. 78). This study did not specify beforehand if participants demonstrated symptoms of flaccidity or spasticity and had significant differences in age range of participants. However, results are useful when considering the use of L-DDK to detect and differentially diagnosis individuals with ALS.

Clinical Reliability of Laryngeal Diadochokinesis

Although some research supports the use of L-DDK, there are currently no studies on the reliability of L-DDK measurement. L-DDK is often analyzed perceptually, making the assessment less reliable when strength, rate, and consistency are rated. Standardized normative data using objective waveform analysis is needed to ensure reliability of clinical use of L-DDK procedures.

The current research (Ptacek, 1996; Verdolini & Palmer, 1997; Leeper & Jones, 1991) provides useful information about clinical use and available data for L-DDK tasks. However, many of these studies have limitations that make it difficult to apply results clinically and justify the use of L-DDK. Only one of these studies (Leeper and Jones) offers normative information, and the information provided is only applicable to young adult women. Reliability measures in these studies are lacking and vary across studies. Some researchers use perceptual ratings, and others use equipment-based measures. Reliability procedures are not always reported, and some results are more reliable than others. For example, Leeper and Jones used a face-mask pneumotachograph to collect data, whereas Ptacek employed perceptual ratings of L-DDK tasks. Future researchers must take extra care to ensure that they follow consistent procedures to ensure reliability of results. Gaps in these research studies, such as lack of information, small sample sizes, and inadequate reliability procedures indicate that more research is required to provide clinicians with adequate and accurate normative data for the clinical use of L-DDK. These studies produce useful information about the clinical use of L-DDK, but do not provide normative information for clinicians to compare results of individuals to an adequately normed population. Results of these studies also have no normative data with which to compare participants' performance.

L-DDK has the potential to be an effective tool for clinicians to differentially diagnose and monitor progression of neurological disorders (Ptacek, 1996; Verdolini & Palmer, 1997; Leeper & Jones, 1991). L-DDK assessment is ideal for a clinical setting because it allows clinicians to quickly record and interpret data and it may assist in development of treatment goals and objectives. Compared to other tests of laryngeal function, L-DDK is non-invasive, inexpensive, and easy to perform clinically. L-DDK effectively measures maximum laryngeal functioning and provides both subjective and objective data for clinicians. Development of normative data for this task will allow clinicians to detect normal versus abnormal respiratory, phonatory, and laryngeal functioning.

CHAPTER II

PURPOSE

The current study served as a subset of a larger IRB-approved study to collect samples from normally functioning individuals for the purpose of obtaining normative data. For this research to be clinically relevant, the larger study selected 50 males and 50 females from each age subset of the adult population. The current study gathered normative data on men and women between the age of 40 and 59 without regard to race. This study analyzes strength of L-DDK performance in middle-aged men and women.

The current literature regarding L-DDK does not provide normative data for strength of laryngeal functioning based on L-DDK measures in the adult population. Development of normative data would assist speech-language pathologists in assessment of laryngeal strength and motor coordination of the larynx, as well as help identify individuals presenting with diseases such as ALS, Parkinson’s, or other degenerative neurological diseases. At this time, there are no normative measures of L-DDK that assist in identification of normal or abnormal functioning of adult laryngeal strength. Normative results regarding L-DDK strength would allow speech-language pathologists to assess patients who present with a voice disorder and evaluate laryngeal motor control. Due to gaps in the current literature, the current study addressed the following three questions:

1. What are the normative values of L-DDK tasks in men and women between the ages of 40 and 59 years of age?

2. Is there a difference between the adductory task /ʌ/ and the abductory task /hʌ/ in the adult population between the ages of 40 and 59 years of age?
3. Is there a difference between normative values of L-DDK strength between men and women in adults between the ages of 40 and 59 years of age?

CHAPTER III

METHODS

Design

This study was conducted as a subset under the existing Indiana University of Pennsylvania Institutional Review Board (IRB) approved study (11-131) by Dr. Lori Lombard to collect, assess, and standardize normative data on strength, rate, and consistency of laryngeal diadochokinesis across the adult lifespan (ages 20-90). The co-investigator on the present study collected and analyzed L-DDK data in the normal adult population (ages 40-59) in both male and female participants.

This study used a differential research design to compare the strength of both adductory and abductory L-DDK tasks. The study used two groups (male and female) to assess and compare the dependent variable. The independent variable was gender and the dependent variable was L-DDK tasks.

Participants

Recruitment

Men and women between the ages of 40 and 59 who met the inclusion criteria were recruited to be participants in this study. Investigators recruited family, friends, co-workers, and neighbors to be included in the study. Prior to their participation, participants filled out an *Informed Consent Form*. The form included information about the risks, benefits, process, and purpose of the study. Participants were also required to complete a *Voluntary Consent Form* prior to participation in the study. This form explained requirements to participate in the study and consent to participate. The IRB approved both of these forms and procedures (Log No. 15-243).

Inclusion and Exclusion Criteria

Inclusion criteria for this study included normal vocal quality as perceived by the investigator, and no known laryngeal abnormalities. An experienced speech-language pathologist specializing in voice disorders evaluated each participants' vocal quality using the Consensus Auditory-Perceptual Evaluation of Voice ("Consensus Auditory-Perceptual Evaluation of Voice [CAPE-V], 2006). Participants who received a score of 20 or lower presented with a clear vocal quality and were considered eligible to participate in the study.

Exclusion criteria included the following: (a) symptoms of cold or illness on the day of testing, (b) history of respiratory, laryngeal, or neurological disease, (c) previous surgeries of the larynx, (d) history of structural or functional laryngeal abnormalities, (e) profound hearing loss, (f) inability to comprehend the task, (g) a rating of greater than 20 on the CAPE-V (2006). Any participant who met any of these criteria was not included in the study.

Final Sample Size

The final sample size included 115 participants between the ages of 40 and 59 years. Thirty-six participants were male, and 79 were female. The mean age of all participants was 50 years, ranging from 40 to 59 years. The mean age of male participants in this study was 51.5 years, ranging from 41 to 59 years. The mean age of female participants in the study was 50 years, ranging from 40 to 59 years of age.

Data Collection Procedures

Collection of data for this study began once participants completed the *Informed Consent Form* (Appendix A) and *Voluntary Consent Form* (Appendix B). Completion of these forms validated participants' consent to participate in the study. Data collection procedures were conducted in a quiet room with limited background noise at a participants' residence or workplace. Participants' completed the following tasks: (a) repeat the adductory /ʌ/ and abductory /hʌ/ L-DDK tasks consistently and rapidly for seven consecutive seconds, three times each, (b) sustain the vowels /a/ and /i/ for five seconds, three times each, (c) read a series of six pre-determined sentences, (d) speak conversationally for thirty seconds. Participants were positioned six inches away from an Audio-Technica ATR20 Dynamic Cardioid Low Impedance Professional Microphone. All tasks were recorded using a Roland CD-2 CF/CD Recorder. All recordings were copied onto a compact disk.

Data collection began with the two L-DDK tasks. Participants' given instructions adapted from Fletcher's (1972) study:

> I want you to say some sounds for me. They aren't words, just sounds. I'll show you how to make it first, and then you can say it with me. The first sound is…(/ʌ/ or /hʌ/). Try it with me. (Have participant rehearse tasks to ensure they are producing it correctly). I am now going to record you performing that same task. I will tell you when to start and when to stop. You will take a deep breath, and repeat the…(/ʌ/ or /hʌ/) as fast as you can, keeping the sound precise for seven seconds. Don't stop until I tell

you. Ready? (Start recording). Now I would like you to perform the same task, but this time with the sound…(/ʌ/ or /hʌ/).

Before performing L-DDK tasks, the investigator demonstrated the task by producing /ʌ/ and /hʌ/ as rapidly, consistently, and precisely as possible. Participants then produced the /ʌ/ and /hʌ/ both simultaneously with the investigator and independently before they were recorded. During recording, participants produced three trials of each task. Tasks were randomized for each participant to reduce potential fatigue and eliminate threats to validity, such as test practice effects (Bassich-Zeren, 2004).

After completing L-DDK tasks, participants completed tasks from the CAPE-V to assess vocal quality and phonatory function (2006). Participants first sustained the lax vowel /a/ and the tense vowel /i/ for five seconds, three times each. The following task on the CAPE-V required participants to produce the following six pre-determined sentences: (a) The blue spot is on the key again; (b) How hard did he hit him; (c) We were away a year ago; (d) We eat eggs every Easter; (e) My mama makes lemon muffins; (f) Peter will keep at the peak. The final task required participants to speak in a conversational manner for thirty seconds in response to the prompt: “Tell me what you did yesterday” (CAPE-V, 2006).

Measurement

Objective evaluation of L-DDK strength was analyzed using the Kay Pentax Multidimensional Voice Program™ (MDVP) digital software. Each of the seven-second L-DDK audio-recorded trials were converted into waveforms to calculate syllable production rate. The first 0.5 seconds of each sample were trimmed from the analysis to prevent outliers and eliminate vocal instability at the beginning of the task (Bassich-Zeren, 2004; Ptacek et al, 1966; Verdolini & Palmer, 1997). The following five seconds of each trial were then trimmed and used for analysis. Each individual amplitude peak on the waveforms accounted for one repetition of a glottal pulse (/ʌ/ or /hʌ/). These amplitude peaks were calculated in the 5-second sample to measure syllable production rate. The trial containing the highest number of glottal pulse repetitions per 5-second sample was considered the best performance and therefore used for further analysis. Once a participants' best performance trial was determined for both the adductory task /ʌ/ and the abductory task /hʌ/, they were then analyzed for strength. The LDDK sample was imported into the Motor Speech Profilie (MSP) (Model 5141) software by KayPentax. The MSP Diadochokinetic Rate Protocol was applied. The DDKava measure was applied which measures the average level of syllable intensity in decibels (dB).

Ethical Use of Data

Data collected for this study were used only for the purpose of this study and the larger IRB-approved study of which this study is a subset. Any identifying personal information filled out on the *Voluntary Consent Form* was viewed only by the investigator of this study and investigators of the larger IRB-approved study. Content on the consent form was not published or recorded. All participants were assigned a number corresponding to all paperwork and digital files to eliminate identifying information. All identifying information was secured in a locked closet throughout the duration of this study and only the investigators had access. All identifying information will be destroyed once the larger study is completed.

Statistical Analysis

Statistical analysis was computed using the SPSS® Statistics Data Editor software (SPSS Statistics Data Editor, 2010). This software was used to answer the questions researched in this study: (a) What are the normative values of L-DDK tasks in men and women between the ages of 40 and 59 years of age?; (b) Is there a difference between the adductory task /ʌ/ and the abductory task /hʌ/ in the adult population between the ages of 40 and 59 years of age?; and (c) Is there a difference between normative values of L-DDK strength in adult men and women between 40-59 years of age?

The first question proposed in this study used descriptive statistics to analyze normative values of L-DDK strength in the adult population. These statistics computed the mean, standard deviation, and minimum and maximum values of L-DDK strength from participants in the study. The second and third questions proposed in this study investigated differences between productions of /ʌ/ and /hʌ/ in adults and differences in normative values of L-DDK strength between adult men and women. These questions were analyzed using the t-test for Equality of Means. The statistical analysis analyzed two sets of data to determine if they were significantly different from one another.

CHAPTER IV

RESULTS

Data for the research questions proposed in this study were analyzed and computed. No statistically significant differences were found for differences in L-DDK strength on performance between /ʌ/ and /hʌ/. Additionally, no statistically significant differences were found in normative values of L-DDK strength between men and women.

The first analysis determined normative values for L-DDK strength for adult men and women between 40 and 59 years of age for both the adductory task /ʌ/ and abductory task /hʌ/. For male participants, the normative decibel values for /ʌ/ ranged between 44.34-70.13 (M = 53.86, SD = 5.81) and the normative values for /hʌ/ ranged between 38.99-70.96 (M = 54, SD = 6.2,). For female participants, the normative decibel values for /ʌ/ ranged between 39.29-68.85 (M = 79, SD = 6.01) and the normative values for /hʌ/ ranged between 40.62-66.51 (M = 79, SD = 5.48). Normative decibel values for men and women combined for /ʌ/ were 39.29-70.13 (M = 53.74, SD = 5.92) and the normative values for /hʌ/ were 38.99-70.96 (M = 52.7, SD = 5.75). These statistics are described in Table 1, *Descriptive Statistics for Strength of L-DDK Production*.

Table 1
Descriptive Statistics for Strength of L-DDK Production

Task	Gender	N	Minimum	Maximum	Mean (M)	Standard Deviation (SD)
/ʌ/	Male	36	44.34	70.13	53.86	5.81
	Female	79	39.29	68.85	53.69	6.01
	Total	115	39.29	70.13	53.74	5.92
/hʌ/	Male	36	38.99	70.96	54	6.2
	Female	79	40.62	66.51	52.1	5.48
	Total	115	38.99	70.96	52.7	5.75

The t-test for Equality of Means was used to compute any differences between productions of /ʌ/ and /hʌ/ in adults, men and women combined. Results of this analysis found that there was no statistically significant difference between production strength of /ʌ/ and /hʌ/ in adult men and women combined between 40 and 59 years of age (*p*-value = .001). These statistics are described in Table 2, *Descriptive Statistics for /ʌ/ versus /hʌ/ Production Strength (dB) in Adult Men and Women*.

Table 2
Descriptive Statistics for /ʌ/ versus /hʌ/ Production Strength (dB) in Adult Men and Women

	Paired Differences (95% Confidence Interval of the Difference)	*t*	df	Sig. (2-tailed)
/ʌ/ vs. /hʌ/	1.68	3.28	114	.001

The t-test for Equality of Means was also used to compute any differences in normative values of L-DDK strength between adult men and women. Data from this analysis found that there was no statistically significant difference in /ʌ/ between males and female (p-value = .89). Results also indicated that there was no statistically significant difference in values of /hʌ/ between adult male and female participants (*p*-value = .102). These statistics are described in Table 3, *Descriptive Statistics for Strength (dB) of L-DDK in Adult Males vs. Women.*

Table 3
Descriptive Statistics for Strength (dB) of L-DDK in Adult Men vs. Women

Task	df	Sig. (2-tailed)	Mean Difference
/ʌ/	113	.89	-1.65
/hʌ/	113	.102	-1.9

CHAPTER V

DISCUSSION

Prior research results have supported that L-DDK tasks may be a significant measurement of strength of laryngeal functioning (Bassich-Zeren, 2004; Leeper & Jones, 1991; Verdolini & Palmer, 1997). However, in order for L-DDK to be used as a prognostic or diagnostic evaluation tool, normative data must be available to distinguish what is normal for different age groups. The current research study sought to answer the following questions: (a) What are the normative values of L-DDK tasks in men and women between the ages of 40 and 59 years of age?; (b) Is there a difference between the adductory task /ʌ/ and the abductory task /hʌ/ in the adult population between the ages of 40 and 59 years of age?; and (c) Is there a difference between normative values of L-DDK strength in adult men and women between 40-59 years of age?

To answer the first question postulated, normative values of minimum and maximum, mean, and standard deviation were computed to measure values of strength of L-DDK. In order for data collected in this study to be clinically effective, normative values for both men and women were collected. Previous research studies, such as Leeper & Jones (1991) and Shanks (1996), collected normative values for only female participants. The limitations of normative values in these studies diminished their validity and clinical potential. Validity of the current study was also strengthened by including both the adductory task /ʌ/ and the abductory task /hʌ/. Previous research studies did not include both tasks, which limited the clinical effectiveness of their results (Leeper & Jones, 1991;

Verdolini & Palmer, 1997). Measuring and comparing both /ʌ/ and /hʌ/ results in both men and women is necessary for L-DDK to be clinically significant.

The current study also compared differences between the adductory task /ʌ/ and the abductory task /hʌ/ in adults between 40 and 59 years of age. Similarities between these two tasks is valuable because it allows clinicians to understand if the tasks are measuring the same laryngeal function in adults without neurogenic disease and can be used interchangeably. Findings for this result were not statistically significant (p-value ≤ .05). This finding indicates that either abductory or adductory tasks can be used to predict functioning of the larynx. However, until normative data is available for adults between 20-90 years of age, both tasks should continue to be used in future research.

The final research question compared differences in L-DDK strength results between male and female adults. Analysis of these results found no statistical significance with regard to the normal adult population. This finding indicates that changes to anatomical and physiological structures of the larynx are similar between sexes throughout the adult lifespan. As previously noted in the literature, adults experience anatomical changes to the larynx, such as atrophy, ossification of cartilages, and thickening of the epithelium, among others. These changes are important to remember when comparing L-DDK strength across age populations, as they can have an effect on vocal quality. Findings from this study indicate that L-DDK tasks provide valuable information regarding functioning of the larynx. However, future research should investigate differences in L-DDK strength across the adult lifespan. Additionally, development of normative and reliable data concerning strength of L-DDK is needed before a conclusion can be reached.

CHAPTER VI

LIMITATIONS

Despite accounting for threats to internal and external validity, there were limitations to this study. One limitation is that performance of L-DDK tasks could have been inhibited by behavioral, cognitive, and systemic influences across participants. Participants were excluded from the study if they were unable to understand directions or did not understand the task. However, additional cognitive differences (e.g. anxiety, distraction, apprehension towards the task) could have affected L-DDK performance. Systemic influences, such as history of alcohol, tobacco, drug, or caffeine intake, gastroesophageal reflux disease, pharmaceuticals, allergies, and hormones may have effected execution of L-DDK tasks regarding respiratory and laryngeal control, despite sufficient scores on the CAPE-V. Future studies should include efforts to reduce cognitive, behavioral, or systemic influences on L-DDK performance by adding these to their exclusion criteria or accounting for these differences prior to measuring task performance.

Previous research studies have varied in their methods of data collection. Verdolini & Palmer (1997) used subjective measures of “good” versus “bad” to rate their participants intensity perceptually. Leeper & Jones (1991) used a pneumotachograph to objectively measure airflow and intensity of tasks. The current study used objective data analysis measures of an acoustic waveform. However, the manipulations to the waveform can be time-consuming, making it difficult to be clinically convenient. L-DDK is a swift measurement compared to other tests of laryngeal functioning (e.g. electroglottography, electromyography, and endoscopy), so future research should consider alternative methods of analyzing objective data in order for L-DDK to be useful in a fast-paced clinical setting. Future research should also consider contrasting the use of perceptual to objective ratings used in this study to measure correlations between these types of ratings.

Another limitation of L-DDK is that it does not provide clinicians with a definitive diagnosis and may only be used as a screening measure. However, development of normative data may become the foundation of future research on L-DDK functioning as an effective diagnostic tool.

A limitation of this study is that the tasks must be normed for adults throughout the lifespan. The current study only sampled laryngeal functioning of adults between the ages of 40 and 59 years of age. In order for L-DDK to be clinically and diagnostically useful, tasks must be normed for adults between 20 and 90 years of age. Further research must be conducted on the early adult population (20-39 years of age) and the geriatric population (60-90 years of age).

Degenerative neurological disorders, such as Parkinson's disease and ALS, may have onset of symptoms earlier in the lifespan. Collecting normative data is imperative so that L-DDK may be used as a predictive and diagnostic tool. Once normative data are collected, future research can focus on comparing disordered populations with available normative data to identify symptoms secondary to the disease process. The aforementioned diseases may present with subtle differences in vocal quality prior to symptoms that are also secondary to the disease process. Because of this, L-DDK strength measures may be helpful in earlier detection of degenerative neurological disorders.

CHAPTER VII

IMPLICATIONS

The findings of this study should be used as the groundwork in understanding normative measurement of L-DDK strength tasks. These findings, though significant, are preliminary and should be further researched to measure the effectiveness of use of L-DDK in a clinical setting. Future studies should address limitations found in this study and consider the following: (a) comparison of objective and perceptual ratings in determining reliability between scoring methods, (b) develop alternative, more efficient ways of analyzing data, (c) account for cognitive, behavioral, and systemic influences across participants, (d) collect L-DDK strength measures for the early adult and geriatric population, and (e) compare normative values of L-DDK strength with L-DDK strength values in disordered populations. Through the establishment of a collection of normative data, L-DDK tasks could become a widely used and efficient clinical tool in the differential diagnosis and early identification of disordered populations.

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Appendix A

Informed Consent Form

Project Title: Laryngeal Diadokokinesis: Clinical measurement and age related values.

You are invited to participate in this research study. The following information is provided in order to help you to make an informed decision whether or not to participate. If you have any questions please do not hesitate to ask. You are eligible to participate because you are an adult with no known laryngeal or neurological disease.

The purpose of this study is to identify your performance on a voice production task. We want to identify how your performance varies with differences in task complexity. We also want to identify your overall voice quality and your perception of your voice and swallowing function using questionnaires. We will compare your performance to other adults of varied age ranges. Participation in this study will require approximately 20 minutes of your time. All data will be collected in one session. The study involves two questionnaires and a voice recording. First you will complete a questionnaire about swallowing symptoms and another about voice symptoms. Each questionnaire has approximately 30 questions. Then we will record your voice to a CD as you: 1) repeat an 'uh' several times, 2) read 6 sentences, 3) hold out an 'ah' for 5 seconds, and 4) answer a brief question about your voice. A head-worn microphone will be placed on your head. The microphone will be placed approximately 6 cm from the corner of your mouth.

There will be no personal identifying information about you recorded on the CD. The recordings will be kept in a locked cabinet in 437 Davis Hall at the Indiana University of Pennsylvania. Only the principal and co-investigators involved in this study will have access to your recording and questionnaire responses. Your measurements will be considered only in combination with those from other participants. All data will be held in strict confidence. The information obtained in the study may be published in scientific journals or presented at scientific meetings but your identity will be kept strictly confidential. There are no known risks or discomforts associated with this research. The possible benefit is for you to have access to measurements of your voice and swallowing function. No other compensation is available for your participation.

Your participation in this study is voluntary. You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or IUP. Your decision will not result in any loss of benefits to which you are otherwise entitled. If you choose to participate, you may withdraw at any time by notifying the Project Director or informing the person administering the data collection. Upon your request to withdraw, all information pertaining to you will be destroyed. If you choose to participate, all information will be held in strict confidence. If you have any questions or concerns, please feel free to contact the principal investigator (continued on next page):

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This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Subjects (Phone: 724/357-7730).

Appendix B

Voluntary Consent Form

I have read and understand the information on the form and I consent to volunteer to be a subject in this study. I understand that my responses are completely confidential and that I have the right to withdraw at any time. I have received an unsigned copy of this informed Consent Form to keep in my possession.

Name (PLEASE PRINT)

____

Signature

____

Date ________________________

Phone number or location where you can be reached:

____

Best days and times to reach you:

____

I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participating in this research study, have answered any questions that have been raised, and have witnessed the above signature.

____

Date **Investigator's Signature**