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Laryngeal Diadochokinetic Consistency in the Adult Population

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LARYNGEAL DIADOCHOKINETIC CONSISTENCY

IN THE ADULT POPULATION

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Laryngeal diadochokinesis (LDDK) tasks examine fine motor function of the vocal folds. Existing literature lacks normative LDDK data. The purpose of this study was to establish normative LDDK consistency values for adults ages 40 to 60 years, determine if there is a difference in consistency of production between the adductory task /ʌ/ and the abductory task /hʌ/, and determine if there is a difference in consistency of production between male and female participants. Participants included fifty-seven adults aged 40-60 who were instructed to produce three trials of /ʌ/ and /hʌ/ for seven seconds each. Trials were analyzed for consistency. Normative values were recorded. Results indicated a difference in consistency of production between /ʌ/ and /hʌ/. However, results indicated no differences in consistency of productions between genders. The data established in this study provides a foundation for future research to collect additional data on LDDK rate, consistency, and strength of production.

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CHAPTER I

REVIEW OF LITERATURE

Diadochokinesis (DDK) is the production of rapid repetitions of simple patterns of opposite muscular contractions. Oral DDK is believed to reflect neuromotor maturation and integration of the structures involved in speech, such as the lips and tongue. According to Baken and Orlikoff, laryngeal diadochokinesis (LDDK) assesses laryngeal function by "analyzing the control of fast and regular opening and closing of the vocal folds" (as cited in Modolo, Berretin-Felix, Genaro, & Brasolotto, 2010, p. 1). Diadochokinetic tasks typically involve the production of a vowel or consonant-vowel sequence as fast and as consistently as possible for a specific time interval, while maintaining clarity with each production. Both oral and laryngeal DDK tasks have been used in the assessment of motor speech disorders and neurological diseases in adults (Modolo, 2010). The measure also plays a role in "detecting abnormality, monitoring speech performance changes, and classifying syndromes" (Gadesmann, & Miller, 2008, p. 41).

Oral Diadochokinesis

Clinicians typically use oral DDK tasks during oral mechanism examinations to assess the motor coordination of the articulators such as the lips, tongue, and velum. The task involves single syllable repetitions of /pʌ/, /tʌ/, and /kʌ/ and multi-syllable repetitions within a specific amount of time. Clinicians typically count to determine the rate of oral DDK (i.e., number of repetitions per second). However, Mason and Simon (1977) recommend focusing on the consistency and pattern of diadochokinetic repetitions rather than the number per second. In addition to rate, consistency and strength of oral

DDK productions are factors that provide crucial insight to the motor function and coordination of the articulators. Gadesmann and Miller (2008) determined that oral DDK performance,

> has been shown to be a valid and sensitive method to detect mild or otherwise unobvious neuromuscular impairment in the lips, tongue and velum; providing a key component in the assessment and differential diagnosis of developmental disorders, of emerging progressive neurological deterioration, and potentially sensitive in quantifying change at the impairment level. (p. 53)

Normative data for oral DDK have been established so that they can be compared with data collected from disordered populations. Various studies have examined the use of oral DDK in disordered populations, including patients with Parkinson's disease, adductor spasmodic dysphonia (ADSD), Amyotrophic Lateral Sclerosis (ALS), and developmental apraxia of speech. Results from the following four studies demonstrate that oral DDK is a clinically useful measure of oral motor coordination.

In the first study, Canter (1965) examined the oral DDK performance of 17 Parkinsonian patients. Although this study is not recent, it used a research design at a high level of constraint. For example, he compared the oral DDK performance of 17 Parkinsonian patients with an age-matched control group. This study is a level two constraint, quasi-experimental study where participants are matched by age across two groups. A study that uses a high level of constraint imposes more control on the experiment, increasing the trustworthiness of the results. Results concluded, "the Parkinsonian group showed impaired ability to perform rapid movements of the tongue tip, back of the tongue, lips, and vocal folds" (Canter, 1965, p. 223). The study also found that oral DDK was highly correlated with clarity of articulation (Canter, 1965). Therefore, oral DDK was shown to be a clinically useful measure.

Normative data for oral DDK can be useful in differentiating and identifying populations that have a progressive neurological disease. In a second study, oral DDK tasks were used to compare 14 patients with Amyotrophic Lateral Sclerosis (ALS) with 15 normal participants. Results of this differential study revealed the ALS patients who had dysarthria were impaired in all oral DDK tasks when compared to normal participants (Langmore & Lehman, 1994). This study demonstrates that DDK is a valid and useful measure for oral motor coordination, and is representative of both disordered and normal populations. When normative data are present, clinicians are able to easily identify data that are disordered.

A third study by Lundy, Roy, Xue, Casiano, and Jassir (2004) involved a differential study comparing three groups of patients with different disorders; they sought to determine if adductor spasmodic dysphonia (ADSD), tremor and Amyotrophic Lateral Sclerosis (ALS) could be differentiated by acoustic and motor speech parameters. The participants in the study were the first eight people who met the required inclusion criteria for each disordered group defined by the researchers. Although there were not a large number of participants, the researchers were very detailed with their data collection and methods, which increased the reliability of the study. Results revealed oral DDK rates for ALS and tremor groups were significantly slower than rates for the ADSD group (Lundy et al., 2004). In addition, all groups had abnormally increased irregularity in syllable repetition but the ADSD group still had lower rates than the ALS and tremor groups, (Lundy et al., 2004). Also, intensity levels during DDK tasks were “mildly reduced for all three subject groups, with significantly increased variability in the loudness level of each syllable for the ALS and tremor groups" (Lundy et al., 2004, p. 151). The Lundy et al. study succeeded in using oral DDK rate, strength, and consistency to establish measures that would distinguish various populations from one another, proving its usefulness as a diagnostic tool and clinical measure.

A fourth example of the usefulness of oral DDK as a measure for differentiating disordered populations was present in a study conducted by Yoss and Darley (1974). In this study, the researchers attempted "to identify behaviors which might distinguish developmental apraxia of speech from 'functional' articulation disorders" (Yoss & Darley, 1974, p. 399). This study was a level two constraint, quasi-experimental study comparing a group of children with disordered articulation to a matched control group. Results of the study found that in a group of 30 children with moderate to severe articulation problems who were identified as having characteristics consistent with developmental apraxia of speech, "rates of oral DDK, such as repetition of /pʌ/, /tʌ/, especially /kʌ/, and /pʌtʌkʌ/ are slower than rates from the control group and repetitions of the combined syllables are often produced with incorrect syllable sequence" (Yoss & Darley, 1974, p. 412). These results provide support for the theory that oral DDK is a useful measure to differentiate between disordered and normal populations; however, this study reveals that it can be clinically useful in children as well.

The aforementioned studies have demonstrated oral DDK's success as a clinically useful measure in identifying and differentiating multiple progressive neurological diseases in adults and a developmental speech disorder in children. However, normative data are necessary when using oral DDK as a diagnostic tool or clinical measure to identify the presence of a disorder. Without normative data, clinicians would be unable to compare oral DDK results of disordered populations to what would be considered "normal" DDK data. Because normative data for measures of oral DDK rate, consistency, and strength are available, oral DDK is a clinically useful measure.

Evidence for Clinical Usefulness of Laryngeal Diadochokinesis

Laryngeal diadochokinesis (LDDK) tasks are very similar to oral DDK tasks, but focus on the vocal folds instead of the tongue. LDDK examines the function of adduction (opening) and abduction (closing) of the vocal folds by asking the patient to produce /ʌ/ (adduction) and /hʌ/ (abduction) as fast, consistently, and clearly as possible for a specified amount of time. The task allows for assessment of the vocal folds through the use of rapid alternating motions by "arresting one motor impulse and substituting one that is diametrically opposed" (Leeper & Jones,1991, p. 880). When measuring LDDK, clinicians typically measure the rate of LDDK by counting the number of repetitions per second. However, rate, strength, and consistency all need to be examined because various neurologic disorders may affect these aspects of vocal function differently. For example, a neurological disease may affect the rate and strength of productions but not consistency, or vice versa. Rate, strength, and consistency of LDDK productions all provide essential information regarding fine motor control of the larynx, and, therefore, normative data encompassing all aspects of vocal function are necessary to examine when using LDDK as a diagnostic tool. There is a lack of normative data for LDDK across a wide span of age groups. Specifically, there is a lack of normative data examining LDDK consistency. This lack of data causes a problem when clinicians use LDDK as a diagnostic tool or laryngeal measure with disordered populations because there is no way to compare a patient's results to what would be considered a normal rate for his or her age and gender.

Leeper and Jones (1991) attempted to collect normative data for LDDK by examining the rate and strength of LDDK productions of 18 women between the ages of 20 and 25. They concluded that during the production of /ʌ/, intensity appears to be a primary factor in syllable rate of LDDK (Leeper & Jones, 1991). Although this study collected normative data, the data were only collected from a small sample of young adult females. Also, the researchers only measured the production of /ʌ/, which examines vocal fold adduction, and failed to also measure production of /hʌ / to look at abduction. Finally, Leeper and Jones only examined the effects of rate and intensity of LDDK so they did not collect any data on consistency or strength of LDDK in young adult females. Because of these limitations, this study is not a particularly useful source of normative data.

In the aforementioned example, only LDDK rate and intensity, or strength, were analyzed. Leeper and Jones (1991) failed to analyze consistency of LDDK productions. Moreover, this analysis was limited to certain tasks such as vocal fold adduction. Clinicians are in need of additional normative data across adult populations that examine rate, consistency, and strength of LDDK measures so that they can then compare data from disordered patients to see whether they deviate from those who do not exhibit a disorder. Despite the lack of normative data, studies have still been conducted on measures of LDDK in various disordered populations.

Currently, LDDK tasks are being used in studies to assess vocal function across various disordered populations. Some clinicians use LDDK as a diagnostic screening tool, and some studies focus on collecting LDDK data in disordered populations. These populations include individuals diagnosed with ALS and patients with unilateral paralysis or glottal incompetence. Although LDDK data needs to be collected from disordered populations, it will be more useful as a clinical diagnostic tool when it can be compared to normative data.

Laryngeal Diadochokinesis has been used as a screening tool in individuals with benign vocal fold lesions to assess vocal rate, strength, consistency, and level of devoicing (Gartner-Schmidt & Rosen, 2009). With regard to the use of LDDK as a screening tool, there is evidence that "the combination of S:Z ratio and LDDK rate, strength, and rhythmia may produce profiles that have some value in detecting the presence of organic abnormality affecting the larynx, with the exception of granulomas of the vocal processes" (Verdolini & Palmer, 1997, p. 230). Verdolini and Palmer's (1997) study was a level three constraint, correlational research design. They focused on more than just rate; they also sought to assess consistency and strength of LDDK. Gartner-Schmidt and Rosen (2009) and Verdolini and Palmer provide examples of how LDDK can be used in a clinical setting as a screening tool. However, Gartner-Schmidt and Rosen's screening process is limited because they only discuss LDDK's potential in screening individuals with benign vocal fold lesions. It would be beneficial if the data collected during both screening processes could be compared to normative data so that the results from the screening would have clinical significance.

A study by Renout, Leeper, Bandur, and Hudson (1995) examined vocal fold diadochokinetic function in individuals with ALS. Researchers studied the rate, pattern and consistency (regularity of rate of LDDK) of LDDK at points in time over the course of the disease. Results of this study found that "ALS patients demonstrated reduced and aperiodic vocal fold diadochokinesis over a selected time period of the investigation" (Renout, Leeper, Bandur, & Hudson, 1995, p. 78). These results mean that over a period of time, LDDK productions revealed increased inconsistency. Furthermore, these results indicated that consistency of LDDK production was impacted by neurological disease. Additionally, the study found that LDDK "may be useful for early detection of deterioration of one part of the speech system, or as a method of monitoring and quantifying the often subtle changes that may be occurring because of disease progression and/or treatment effects" (Renout et al., 1995, p. 78). In this study, the researchers only examined the measure /hʌ/, which is a limitation because they only looked at the pattern of abduction. However, the researchers did demonstrate the potential for using LDDK as a method of monitoring changes, and they collected data for the ALS population.

Another population studied included patients who were treated for glottal incompetence by receiving injections of calcium hydroxylapatite to improve their vocal fold closure (Rosen et al., 2007). LDDK was used as an objective voice assessment measure pre-injection, as well as 1 month, 3 months, and 6 months post-injection. The study design involved multiple participants who received the same treatment, a level three constraint. Among other measures, LDDK showed statistically significant improvement when comparing vocal function from pre-injection to 1, 3, and 6 months post-injection (Rosen et al., 2007). This study demonstrated the use of LDDK as a way to measure change over time in patients who were treated for glottal incompetence. If the treatment were successful, then pre-injection LDDK measures would be expected to be worse than LDDK measures post-treatment. In this case, LDDK was used as a tool to monitor improvement and was capable of revealing the effects of the treatment over time. Although this study shows a potential use of LDDK, the researchers did not have normative data with which they could compare the results, which would have made their results stronger by indicating if participants achieved normal LDDK function.

These examples from the literature show that LDDK is a promising tool to measure vocal function. It is currently being used to assess vocal function in a variety of patients with previously diagnosed disorders. LDDK can be useful clinically to show change over time, regarding both benefits of treatment and deterioration caused by the disease. However, clinicians are in need of additional normative data in order to improve the diagnostic ability of LDDK outcomes to identify the presence of a disorder. Also, if normative data were available, clinicians would have the potential to facilitate a clinical diagnosis before other symptoms are present. Given the successful clinical implications of oral DDK, as well as the use of LDDK thus far in a few studies on disordered populations, LDDK is quite promising as a measure of detecting neurologic diseases that affect vocal function.

Anatomy and Physiology of the Larynx

In order to better comprehend LDDK and other measurements of laryngeal function, it is important to understand the anatomy and physiology of the larynx. The laryngeal anatomy and physiology is best explained by Seikel, King, and Drumright, (2005). The vocal folds are located within the larynx, which is responsible for phonation (sound production) and airway protection. Phonation occurs when air passes through the vocal folds, causing the vocal folds to vibrate rapidly. The larynx is a cartilaginous tube located just superior to the trachea and suspended from the hyoid bone, which is typically at the vertical level of the 3rd cervical vertebrae.

The larynx is made up of several types of cartilages, including the thyroid cartilage, cricoid cartilage, the epiglottis, corniculates, cuneiforms, and arytenoids. Together these cartilages provide the framework surrounding the vocal folds. The larynx assists in airway protection by closing the laryngeal passageway to the lungs. During a swallow, the larynx is elevated, tilting the epiglottis over the airway.

Within the larynx are intrinsic muscles that are responsible for phonation. The thyroarytenoids are the vocal folds themselves, and assist in adduction. Within the thyroarytenoids are the thyrovocalis (medial) and the thyromuscularis (lateral). Other intrinsic muscles that assist in adduction are the lateral cricoarytenoid, the interarytenoids, and the cricothyroid. The only intrinsic muscle that is responsible for abduction of the vocal folds is the posterior cricoarytenoid. LDDK assesses the ability of the vocal folds to adduct and abduct. LDDK rate, consistency, and strength can be examined to determine if the muscles of the larynx are working properly.

Histology is also of importance to better understand the vocal folds. The vocal folds are made up of five layers: epithelium, superficial laminia propria, intermediate lamina propria, deep lamina propria, and the thyroarytenoid muscle. These layers vary with age; children have only three layers (epithelium, lamina propria, and thyroarytenoid) until they reach puberty. The epithelium, superficial, and intermediate layers of the lamina propria make up the cover of the vocal folds, while the deep layer of the lamina propria and the thyroarytenoid muscle make up the body. The layers that make up the cover of the vocal folds are fluid-like and elastic in property, while the inner layers that make up the body help to open, close, and tighten the vocal folds. Many vocal fold lesions, such as nodules and polyps, occur within the epithelium of the superficial layer of the lamina propria. As a result, knowledge of histology is essential if there is damage to these areas (Seikel, King, & Drumright, 2005).

Innervation

In addition to structural pathologies, damage to cranial nerves may result in vocal fold injury, so a basic understanding of laryngeal innervation is key. The location of the damage in the larynx provides clues that narrow down which nerve may be damaged. Siekel et al. (2005) explain the innervation of the larynx as well. The vagus nerve is responsible for innervation of the larynx. However, the vagus nerve separates into two main nerve branches: the superior laryngeal nerve and the recurrent laryngeal nerve. The recurrent laryngeal nerve innervates the intrinsic muscles of the larynx, with the exception of the cricothyroid. The recurrent laryngeal nerve is responsible for sensation at the level of the vocal folds (glottis) and below the vocal folds (subglottis), as well as sensation to the proximal trachea and esophagus. The superior laryngeal nerve is responsible for the motor innervation of the cricothyroid muscle. It is also responsible for providing sensation of the glottis and above the vocal folds (supraglottis). Injury to the external branch of the superior laryngeal nerve is reported to cause flaccidity and bowing of the vocal fold, and decreased vocal range and laryngeal rotation. Together, these nerves are crucial to establishing fine motor control of the vocal folds (Seikel et al. 2005). Measures of LDDK consistency may be used to identify changes in motor control of the larynx.

Aging

As with other body systems, the aging process affects the respiratory and phonatory systems as well. Ferrand (2012) describes ways to differentiate normal signs of aging when compared to pathological voice changes. When discussing the aging process, Ferrand mentioned a study by Kahane (1990) that examined cellular and tissue changes in normal male and female larynges in individuals between the ages of 30 and 80. Kahane found that age-related changes begin in the 30s in males and the 40s in females. As a person's age increased so did the extent of the changes in the larynx, demonstrating that laryngeal changes are gradual with age. Kahane also found that laryngeal changes are variable between individuals, and gender affects the laryngeal aging process. Males begin to decline sooner than females and have a greater amount of degeneration; however, reported changes in females who experienced menopause included vocal fatigue, decreased vocal intensity, muscular atrophy, and thinning of the vocal fold mucosa among other changes (Kahane, 1990).

Structural changes within the larynx occur with age as well. The cartilage of the larynx ossifies with age, and the movements of the cartilage become less flexible, possibly affecting vocal fold vibration (Ferrand, 2012). Studies have found that this ossification process can begin as early as in the 30's, and possibly sooner. Some studies found that ossification is more prevalent and extensive in men than in women (Ferrand, 2012). Muscles atrophy with age, which results in lessened speed, force, strength, and endurance of muscle contractions. In turn, the atrophy results in incomplete approximation of vocal folds during phonation. All of these factors combined contribute to a weak, breathy vocal quality (Ferrand, 2012). According to Ferrand, changes in the nervous system and innervation may also reduce muscle efficiency due to a decreased speed of nerve conduction to the muscles. LDDK can be used as a diagnostic or screening tool to identify when these changes may begin to occur. If normative data were available for LDDK, they would document these changes that are due to normal aging. Normative LDDK data would allow speech pathologists to determine whether a patient's LDDK score was commensurate with other people his or her age or whether the score deviated substantially, suggesting the existence of a disorder.

The epithelium of the vocal fold can change with age as well. For example, in females, the epithelium of the vocal fold is reported to thicken and become dehydrated with age, which increases the thickness of the vocal fold cover and affects vibration of the vocal folds (Ferrand, 2012). The stiffness of the vocal fold cover can affect the symmetry of vibration and result in increased vocal effort, vocal fatigue, and poorer voice quality. Changes to the lamina propria also occur during the aging process. For example, particularly in males, the deep layer of the lamina propria becomes less dense, resulting in bowing and irregularities along the medial edge of the vocal fold (Ferrand, 2012).

Ptacek, Sander, Maloney, and Jackson (1966) examined the effects of aging on LDDK by conducting a study with younger adults (under age 40) and geriatric (over age 65) participants. This study was a cross-sectional design, evaluating and comparing differences between groups. The participants were assessed on maximum pitch range, LDDK, maximum vowel intensity, maximum vowel duration, maximum intraoral breath pressure, and vital capacity. Results indicated that geriatric participants presented significantly reduced scores on all of the tasks when compared to younger adults, suggesting that age affects the respiratory, phonatory, and articulatory systems (Ptacek, Sander, Maloney, & Jackson, 1966). However, because this study only included young adults and geriatric participants rather than a full range of ages, and because they lacked normative data on LDDK, they were unable to elaborate on the extent to which the respiratory, phonatory, and articulation systems were affected with age.

There are several age-related disorders that affect the larynx. LDDK could be used as a measure to detect some of these age-related disorders when they begin to occur. If normative data were available, clinicians would be able to compare data for an individual patient to determine whether their symptoms are within normal limits or whether they are beginning to exhibit one of these age-related disorders.

Pulmonary diseases can disrupt the airflow through the vocal folds and cause variability in loudness and pitch control; some pulmonary diseases that occur with age include emphysema and chronic obstructive pulmonary disorder (COPD; Ferrand, 2012). Also, coronary artery disease can affect respiratory and laryngeal function; therefore, changes in voice quality may act as a diagnostic indicator for hypertension (Ferrand, 2012). LDDK could be used as a diagnostic tool to measure those changes in voice quality and identify symptoms of pulmonary diseases such as COPD or coronary artery disease.

As a person ages, the likelihood of developing certain disorders increases. For example, central nervous system disorders that are more likely to occur with age, such as ALS and Parkinson's disease, may affect the larynx. Both ALS and Parkinson's disease may begin to cause symptoms in an individual as early as age 50 (Ferrand, 2012).

Ferrand (2012) examined health status and age-related vocal diseases. "Ringel and Chodzko-Zajko (1987) found that younger, unhealthy patients exhibited vocal characteristics similar to those of much older patients" (as cited in Ferrand, 2012, p. 82). Gathering normative LDDK data is vital in order to use it as a diagnostic or maintenance measure. We need to know how the vocal folds function at various ages so that we can identify a potential disorder as soon as possible. For example, if LDDK is used on a client in his 40's, and his LDDK results are consistent with normative LDDK data of a 70-year-old male, it may be an indication of damage to the neurological system.

Tests of Laryngeal Function

LDDK is only one measure of laryngeal function. Several other popular measures of laryngeal function include endoscopy, electromyography (EMG) and electroglottography (EGG). These are currently the most commonly used measures of laryngeal function. Although they have some advantages, there are also disadvantages that diminish their usefulness.

Endoscopy and Stroboscopy

Endoscopy is a direct measure of laryngeal function. An endoscope is an instrument that contains a fiberoptic camera used to view the vocal folds. This endoscope can be either a flexible tube that is inserted through the nose, or a rigid rod inserted through the mouth. Both types of endoscopy, flexible and rigid, can contain a strobe light to alter the image of the vocal folds.

As previously stated, a flexible endoscopy is inserted through the nose. The method of insertion associated with this technique allows for a view of velopharyngeal movement and laryngeal movement. It also allows the assessment of laryngeal and vocal function during connected speech, sustained phonation, and swallowing. Since a rigid endoscopy is inserted orally, it is only able to assess vocal function during sustained phonation (Ferrand, 2012). However, it provides greater magnification than flexible endoscopy. Both methods of endoscopy are able to assess vocal function at rest and during respiration.

Stroboscopy is often used alongside endoscopy. In this procedure, a light flashes on the vocal fold vibratory cycle and slows down the image of vocal fold vibration. Without stroboscopy, the examiner would be unable to see the sequence of vocal fold vibration because the vocal folds vibrate so quickly. Endoscopy and stroboscopy are commonly used as methods of helping to diagnose voice disorders.

There are several limitations to this method of measurement. It is an invasive procedure that can be uncomfortable for the patient. Endoscopy and stroboscopy also require equipment that may not be readily available to speech language pathologists or other professionals. The necessary equipment to perform this procedure is costly and, therefore, the cost of the procedure can be prohibitive. Finally, this procedure relies on the perceptual abilities of the examiner, which may cause issues of reliability since examiners may interpret the information differently.

Electromyography

Electromyography (EMG) is a procedure in which a needle is inserted into the thyroarytenoid and cricothyroid muscles percutaneously through the neck. The needle measures muscular patterns and electrical activity of the vocal folds during phonation. The results of this measure are portrayed on a graph. It is often used as a prognostic tool to assess probability of nerve recovery. This measure is an invasive procedure that the patient may not be comfortable with, it requires costly equipment increasing expense to the patient, and it must be performed by an otolaryngologist or a neurologist (Stager &

Bielamowicz, 2010; Stemple, et al., 2000). Due to these limitations, EMG is not a measure that is realistic as a screening tool for daily use in a clinical setting.

Electroglottography

Electroglottography (EEG) is a noninvasive procedure. It consists of placing two electrodes on the neck of the patient, located on each side of the thyroid cartilage. This procedure measures the electric current that is transmitted from one electrode to the other through the vocal folds when they are in contact. Results of this procedure are portrayed as a graph, which illustrates the points of contact during the vibratory cycle of the vocal folds. As with endoscopy and EMG, this procedure is expensive and requires equipment that may not be available to professionals in some clinical settings.

Why LDDK?

The measures of laryngeal function just described all have disadvantages, some of which make them impossible as a clinically useful tool. Alternatively, LDDK offers a promising measure of laryngeal function, and has strong potential to identify abnormal vocal function. It has already been identified that consistency of LDDK production is affected by neurological disease. If clinicians had normative data to compare with data from disordered populations, LDDK could be used reliably as a clinical measure. When compared to endoscopy, electromyography and electroglottography, LDDK is a preferable test of laryngeal function. It is a non-invasive procedure, and it does not require costly equipment. Furthermore, it can be an objective, rather than perceptual, measure when tasks are recorded and submitted for acoustic analysis. Finally, it is a quick assessment that takes no more than a few minutes. However, in order for LDDK to be applied clinically, we need a sufficient base of normative data so that practicing clinicians can reliably use it as a test of laryngeal function. Some studies exist on LDDK; however, there are few studies that have collected normative data and several studies that have collected data on various disordered populations. Those that have collected normative data have focused on small samples of the adult population and only examined rate and strength of LDDK. The goal of the current study is to collect normative LDDK consistency data from adults across the lifespan so that when LDDK is used as a clinical tool to assess vocal function, data taken from disordered populations can be compared to the normative data sample.

CHAPTER I

PURPOSE

LDDK is a diagnostic assessment tool that is non-invasive, inexpensive, and can be administered easily in any clinical setting. Currently, existing literature does not provide adequate normative data for the adult population, which limits the clinical usefulness of LDDK. Also, the data that is currently available was collected using inconsistent procedures, which makes it difficult to compare. The current study is part of a larger investigation to collect normative data for rate, consistency, and strength of LDDK productions in normal adults between the ages of 20 and 90 years, to compare production tasks of /ʌ/ and /hʌ, and to identify gender differences. The purpose of this specific study is to collect and compare LDDK production tasks of /ʌ/ and /hʌ/ in normal adults between the ages of 40 and 60 years using standardized procedures. Specifically, this study seeks to identify normative values for the consistency of LDDK productions in individuals grouped by gender and age (40-60 years). The following research questions were addressed:

1. Is there a difference between laryngeal diadochokinetic production consistency for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 40 and 60 years?
2. What are the normative values for laryngeal diadochokinetic consistency of production for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 40 and 60 years?
3. Is there a difference between normative values of laryngeal diadochokinetic consistency of production for male and female participants?

CHAPTER III

METHOD

Design

This study is a part of an ongoing Indiana University of Pennsylvania (IUP) Institutional Review Board (IRB) approved study conducted by Dr. Lori Lombard. A cross-sectional research design was used to compare consistency of production of the adductory and abductory LDDK tasks. The participants are grouped by gender; therefore, the independent variable is gender and the dependent variables are the LDDK tasks /ʌ/ and /hʌ/.

Participants

Recruitment

Participants in this study were recruited by investigators, and include family members, friends, co-workers, and members of the community. Participants were provided with Informed Consent and Voluntary Consent Forms prior to participation in the study. Following review of the Informed Consent Form, participants were required to complete the Voluntary Consent Form, acknowledging their willingness to participate, as well as their understanding of the risks, benefits, and requirements of participation as provided in the Informed Consent Form. The IUP Institutional Review Board reviewed and approved the Informed Consent Form, the Voluntary Consent Form, and the study protocol (Log No. 11-131).

Inclusion and Exclusion Criteria

Inclusion criteria for the study required that the participants have a near normal vocal quality as determined by an experienced speech-language pathologist specializing in the evaluation and treatment of voice disorders. Participants' voice samples were screened for abnormal voice quality using the Consensus Auditory-Perceptual Evaluation of Voice ("Consensus Auditory-Perceptual Evaluation of Voice [CAPE-V]," 2006). Participants who received a disorder rating of 20 or below were included in the study.

Exclusion criteria included the following: 1) a disordered rating score greater than 20 on the CAPE-V (2006); 2) vulnerability; 3) symptoms of cold or illness on the day of testing; 4) history of respiratory, laryngeal, or neurologic disease; 5) previous surgeries of the larynx; 6) history of structural or dynamic laryngeal abnormalities; 7) reported hearing loss of a profound degree; and 8) lack of comprehension of the task. Participants who exhibited any of these criteria were excluded from the study.

Final Sample Size

The final sample size included 57 participants between the ages of 40 and 60 years old. Of the 57 participants, 14 were males and 43 were females.

Data Collection Procedures

Informed consent and willingness to participate was obtained from each participant prior to data collection. Data was collected in a quiet room. Participants were required to perform both LDDK and CAPE-V tasks: 1) produce /ʌ/ and /hʌ/ for seven seconds, three times each; 2) sustain the vowels /a/ and /i/ for five seconds, three times each; 3) read six sentences; and 4) maintain natural conversation for 30 seconds. All tasks were recorded using a Roland CD-2 CF/CD Recorder and copied to a compact disk.

Each participant was instructed to sit with his or her mouth positioned approximately six inches from the Audio-Technica ATR20 Dynamic Cardioid Low Impedance Professional Microphone per the recommendations of Leeper and Jones

(1991). Verbal instructions for the LDDK tasks were modeled after Fletcher's (1972) study and were as follows:

> "I want you to say some sounds for me. They aren't words, just sounds. I'll show you how to do it first, then you can say it with me. Then you try it yourself, repeating the sound as quickly and consistently as you can. The first sound is… (/ʌ/ or /hʌ/). Try it with me. (Have participant practice to ensure they are producing the task correctly). Now I want you to do it once more. I am going to have you repeat the sound as quickly and consistently as you can for seven seconds, three times. I'll tell you when to start. 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/)."

After providing instruction, the investigator demonstrated the task by producing /ʌ/ or /hʌ/ as fast and consistently as possible for approximately 3 seconds. The participant was given the opportunity to practice the task before it was recorded. Each participant completed three trials of each glottal syllable. The order of the two LDDK tasks /ʌ/ and /hʌ/ were randomized across participants (Bassich-Zeren, 2004) to prevent fatigue or practice effects. Following completion of the two LDDK tasks, participants were required to complete three additional tasks derived from the CAPE-V (2006) in order to evaluate phonatory function. The first CAPE-V (2006) task was to sustain the lax vowel /a/ and the tense vowel /i/ three times, for five seconds each. The next task was to orally read the following six sentences in order to measure various laryngeal behaviors: 1) The blue spot is on the key again; 2) How hard did he hit him; 3) We were away a year ago; 4) We eat eggs every Easter; 5) My mama makes lemon muffins; and 6) Peter will keep at the peak. The final task required participants to produce a conversational language sample for 30 seconds, responding to the prompt “Tell me what you did yesterday/today” (CAPE-V, 2006).

Measurement

After the LDDK data were collected, all /ʌ/ and /hʌ/ tasks were converted from audio-recordings to oscillograms using the KayPentax Multidimensional Voice Program^{TM} (MDVP) software in order to objectively measure rate and consistency of syllable production (Shanks, 1966). The first 0.5 seconds of each trial of /ʌ/ and /hʌ/ were removed before rate and consistency were measured in order to reduce the effect of instability at the onset of a new task (Bassich-Zeren, 2004; Ptacek et al., 1966; Verdolini & Palmer, 1997). The following five seconds of each oscillogram were used for analysis of rate and consistency. To measure rate, the number of amplitude peaks in each five-second sample were counted, with each peak representing one production of a glottal syllable (i.e., /ʌ/ or /hʌ/) (Leeper & Jones, 1991; Ptacek et al., 1966; Renout et al., 1995; Shanks, 1966). The best trial (i.e., greatest number of peaks in a five-second period) was identified for each participant and analyzed for consistency. Consistency was measured using a ratio of voiced segment to the total of voiced and the voiceless segments of the acoustic signal. Voiced segments were measured placing one cursor at the onset of the phonatory pulse of one peak, and placing the second cursor at the conclusion of the phonatory pulse. The time was then recorded in milliseconds. Voiceless segments were measured by recording the time between phonatory pulses, with one cursor at the conclusion of a phonatory pulse and the second cursor at the onset of the next phonatory pulse. The total of voiced and voiceless segments was a sum of the two segments. The ratio of voiced segment to total segment was calculated by dividing the total by the voiced segments. The variance of voiced ratio was calculated using IBM® SPSS® Statistics Data Editor software (SPSS Statistics Data Editor, 2010). Decreased levels of variance indicate low variability, and therefore increased consistency.

Use of Data

Data collected as part of this study were used only for the purpose of this study and the larger study that includes a collection of normative data across the adult lifespan, of which this study is a subset. Personally identifiable information was not used on digital audio files or paper documents. All data, recordings, and paperwork were kept in a locked office at all times, and were only available to the current investigator and investigators of the larger study. Upon completion of the larger study, all documentation that includes personally identifiable information will be destroyed.

Statistical Analysis

Statistical analyses were completed using IBM® SPSS® Statistics Data Editor software (SPSS Statistics Data Editor, 2010) to obtain answers for the three research questions posed: (a) Is there a difference between laryngeal diadochokinetic consistency of production for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 40 and 60 years; (b) What are the normative values for laryngeal diadochokinetic consistency of production for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 40 and 60 years; and (c) Is there a difference between normative values of laryngeal diadochokinetic consistency of production for male and female participants?

To answer the first question, consistency of production data for the LDDK adductory task /ʌ/ and the abductory task /hʌ/ were compared using an independent sample t-test. Interaction effect, main effect, and between-subjects effects were analyzed and reported as Wilks' Λ (Lambda) values with a probability level of $p=0.05$. These effects were analyzed to determine if t-test results were influenced by other independent variables, such as chance or gender (Haynes & Johnson, 2009). This analysis was performed to determine if the two LDDK tasks /ʌ/ and /hʌ/ (i.e. the two independent groups) differed significantly on the consistency of production (i.e. the dependent variable; Haynes & Johnson, 2009).

To generate normative data for LDDK tasks /ʌ/ and /hʌ/ in adults ages 40-60, summary statistical values of mean, range, and standard deviation were determined for each LDDK task. The independent groups were the two tasks and genders, while the dependent variables were the summary values (Haynes & Johnson, 2009).

The effect of gender on LDDK tasks was analyzed using and independent sample t-test. The independent groups were the male and female participants, and the dependent variables were the normative values. This analysis determined if the male and female participants differed significantly in their normative values.

CHAPTER IV

RESULTS

The first question analyzed was, “Is there a difference between laryngeal diadochokinetic production consistency for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 40 and 60 years?” the data from both male and female participants were combined, and an independent sample t-test was performed to compare task differences. Results indicated that a difference in variance was found between /ʌ/ and /hʌ/ (t-statistic = 3.517, p-value = <0.05). See Table 1 for descriptive data from LDDK tasks. Results of the independent sample t-test are summarized in Table 2.

Table 1

LDDK Tasks

Consistency Variable	Task	N	Mean	Std. Deviation	Std. Error Mean
Variance	/ʌ/	57	0.0078	0.005	0.001
	/hʌ/	56	0.0060	0.004	0.001

Table 2

Independent Sample t-test for Task Comparisons

Variance	t-test for Equality of Means						
	t	*df*	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	2.074	111	0.040	0.002	0.001	0.000	0.003
Equal Variances Not Assumed	2.077	109.376	0.040	0.002	0.001	0.000	0.003

Normative values were also calculated for laryngeal diadochokinetic consistency of production for the adductory task /ʌ/ and the abductory task /hʌ/ in males and females between the ages of 40 and 60 years. For male participants, the normative value for consistency of /ʌ/ productions was M = 0.0072 (range = 0.002-0.019; SD = 0.005). For male participants, the normative value for consistency of /hʌ/ productions was M = 0.0071 (range = 0.002-0.017; SD = 0.005. For female participants, the normative value for consistency of /ʌ/ productions was M = 0.0080 (range = 0.002-0.019; SD = 0.005). For female participants, the normative value for consistency of /hʌ/ productions was M = 0.0057 (range = 0.001-0.016; SD = 0.004). Results are summarized in Table 3, *Descriptive Statistics for Consistency of LDDK Production Tasks.*

Table 3

Descriptive Statistics for Consistency of LDDK Production Tasks

Consistency Variable	Task	Gender	N	Minimum	Maximum	Mean (M)	Standard Deviation (SD)
Variance	/ʌ/	Male	14	0.002	0.019	0.0072	0.005
		Female	43	0.002	0.019	0.0080	0.005
		Total	57	0.002	0.019	0.0078	0.005
	/hʌ/	Male	14	0.002	0.017	0.0071	0.005
		Female	42	0.001	0.016	0.0057	0.004
		Total	56	0.001	0.017	0.0060	0.004

Finally, to address the third question, "Is there a difference between normative values of laryngeal diadochokinetic consistency of production for male and female participants?" the dataset from both tasks were combined, and an independent sample t-test was performed to compare gender differences. Results indicated that there is no difference in variance, or consistency of LDDK productions, between males and females (t-statistic = -0.252; p-value = >0.05). See Table 4 for the gender differences dataset.

Results of the independent sample t-test for tasks male and female participants are summarized in Table 5.

Table 4

Gender Differences

Consistency Variable	Gender	N	Mean	Std. Deviation	Std. Error Mean
Variance	Male	28	0.0071	0.005	0.001
	Female	85	0.0069	0.004	0.000

Table 5

Independent Sample t-test for Gender Differences

Variance	t-test for Equality of Means						
	t	*df*	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal Variances Assumed	-0.252	111	0.801	0.000	0.001	-0.002	0.002
Equal Variances Not Assumed	-0.241	42.723	0.811	0.000	0.001	-0.002	0.002

In summary, statistical analyses revealed a statistically significant difference in consistency of LDDK productions between the adductory task /ʌ/ and the abductory task /hʌ/. Normative values including range (minimum and maximum), mean, and standard deviation were generated for male and female participants between 40 and 60 years of age. Additionally, no statistically significant differences were found in consistency of LDDK productions between male and female participants.

CHAPTER V

DISCUSSION

LDDK is an inexpensive, noninvasive, and objective measure of laryngeal function as compared to other measures of vocal function, making it ideal for clinical use. However, existing literature lacks normative LDDK data, and the data that does exist is flawed or subjective. Furthermore, although there is data on strength and rate, very limited data exist on LDDK consistency. Normative data for LDDK is necessary to fulfill its potential as a reliable clinical measure to assess vocal function. The current study helps to fill the current gap in normative LDDK data in the adult population.

This study compared LDDK consistency of production for the adductory task /ʌ/ and the abductory task /hʌ/. Results indicated that a statistically significant difference was found in consistency of production between the two tasks /ʌ/ and /hʌ/ in the normal population. These results suggest that fine neuromotor control of abductory and adductory laryngeal muscles in adults aged 40-60 may be slightly unstable. However, the current sample size was relatively small and included more female participants than male participants, so future research should continue to collect normative data on LDDK consistency with equal male and female group sizes, and also across the entire adult lifespan.

Normative values of LDDK were collected for male and female participants ages 40 to 60, for each task /ʌ/ and /hʌ/, and in total. The normative values were calculated for variance and include minimum, maximum, mean, and standard deviation. Previous studies have measured consistency among disordered populations, however, it was measured perceptually. While perceptual measures may be convenient in a clinical setting, objective measures allow consistency to be analyzed with greater specificity. This study increases the validity of LDDK data and fills gaps in current literature because it objectively calculates consistency of production for both male and female participants in the normal population and for both tasks /ʌ/ and /hʌ/, unlike previous studies. As previously stated, there is extremely limited data examining LDDK consistency in the normal population. Although only 57 adults between the ages of 40 and 60 participated in this study, it provides a foundation for other studies to build upon in the future.

This study also compared consistency of LDDK productions between male and female participants in the normal adult population, and no significant differences were found between the genders. This result is slightly unexpected due to structural differences (i.e. mass, length) between males and females. However, these results may indicate that LDDK is more representative of physiology and neuromotor control rather than anatomy. This hypothesis is supported by Verdolini and Palmer (1997), who found no differences in rate between normal patients and patients with structural vocal fold lesions, but did find differences between normal patients and patients with neurologic disease. The current study only examined a small sample size with an uneven number of males and females, so a larger sample size with equal male and female group sizes will be important in order to explore these results further.

CHAPTER VI

LIMITATIONS

This study provides a foundation for normative LDDK data in adults from ages 40 to 60 years. Data collection procedures as well as recording equipment were controlled in order to increase internal and external validity. Still, there are several limitations that must be considered. The first is sample size. Although this study provides a foundation for normative LDDK data in adults aged 40 to 60, the sample size is only 57 participants: 14 males and 43 females. In addition to a small sample size, there was a difference in group sizes between males and females. A larger sample size would better represent the population and strengthen the results. For example, comparisons among decades rather than an age group spanning 20 years would provide a stronger foundation of normative data, but a larger number of participants is required in order to make a comparison among decades. In addition to increasing sample size, future research should also strive to create equal male and female group sizes to be sure that any clinically significant differences in LDDK production between male and female participants is not a result of unequal group sizes.

Another limitation present in this study is participant diversity. Researchers recruited a convenience sample including family, friends, and coworkers to participate in the study. Due to this recruitment method, the current sample does not accurately represent the diversity of the general population. If future studies recruit a more diverse participant sample including a variety of races and ethnicities, the generalizability of results will be increased.

Furthermore, this study only analyzed consistency of LDDK production in the normal population. In addition to examining consistency, analyzing rate and the strength of syllable productions may provide more insight into laryngeal function. Normative data needs to be gathered on rate, consistency, and strength of LDDK to increase its potential as a clinical diagnostic tool. After a normative database is established, data also need to be collected from disordered populations as well to determine how the measure can be used clinically.

CHAPTER VII

IMPLICATIONS

This study provides the groundwork for LDDK consistency data in the normal adult population. In order to increase the potential of LDDK as a diagnostic tool, future studies should address: a) increasing the sample size with equal male and female group sizes; b) targeting additional age groups; c) increasing participant diversity; d) continuing to measure consistency as well as strength and rate of LDDK; and e) comparing normative LDDK data to LDDK data from disordered populations. In the future, LDDK has the potential to be a reliable, quick, simple clinical tool used to measure laryngeal function. In turn, it may be used to identify a progressive neurological disease in its early stages if neuromotor function of the larynx is affected. The more normative data that is collected, the more successful LDDK will be as a clinical diagnostic tool.

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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:

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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**