Measurement of Laryngeal Diadochokinesis in the Early Adult Population

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MEASUREMENT OF LARYNGEAL DIADOCHOKINESIS IN THE EARLY
ADULT POPULATION

A Thesis
Submitted to the School of Graduate Studies and Research
in Partial Fulfillment of the
Requirements for the Degree
Master of Science

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Measurement of laryngeal diadochokinesis (L-DDK) is used by speech-language pathologists to assess the fine motor function of the vocal folds. To date, research has been conducted using measures of L-DDK as assessment data, but normative data and standardized procedures are scant and inconsistent. Measurement of L-DDK has been found to facilitate early detection of various disorders and laryngeal abnormalities. Thus, normative L-DDK rates are necessary among all age groups in order for it to be used as a meaningful diagnostic tool. The current study focused specifically on the early adult population. Thirty-nine participants, both male and female, between the ages of 20 and 40 years were recruited for the study.

Normative values were collected for L-DDK rate for the adductory task /ʌ/ and the abductory task /ɐ/ in adults between the ages of 20 and 40 years. Each participant was required to produce these L-DDK tasks for 7 seconds over three trials. The number of productions in 5 seconds of each trial was divided by five to calculate the rate per second. Rates for males and females are provided. Results also consider if there is a difference in rate between the L-DDK tasks (adductory task /ʌ/ and abductory task /ɐ/) as well as if there are differences in rates between males and females.
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CHAPTER 1

REVIEW OF LITERATURE

Currently, there are few clinical tools for assessing the function of the larynx. The assessment measures that do exist, such as endoscopy and electroglottography, are perceptual tools and provide limited objective results. These measures also are of high cost and can be invasive. A more cost-efficient, non-invasive, and reliable measure is needed to assess laryngeal functioning.

Research suggests that the measurement of laryngeal diadochokinesis (L-DDK) has excellent potential as a tool for assessing vocal fold function and for the early detection of laryngeal abnormalities. There is clinical precedent for using diadochokinetic tasks of articulatory movements to assess function of the lips and tongue. Given some evidence of reliability and the wide use of oral DDK measures for oral mechanism assessment among speech-language pathologists, L-DDK rates should be a more frequently used tool in gathering information about the larynx to help speech-language pathologists detect impairment.

However, in order for a speech-language pathologist to identify laryngeal abnormalities using L-DDK rates, norms must be available for comparison. To date, research has been conducted regarding the use of the measurement of L-DDK as an assessment tool but normative data do not exist. Thus, the current study attempts to fill in this gap by providing normative data on L-DDK rates for individuals between the ages of 20 and 40 years. The following sections highlight the review of literature including oral DDK, L-DDK, the anatomy and physiology of the larynx, the effects of aging on the larynx, diseases of the larynx, current assessment measures of laryngeal
function, and the reliability of L-DDK as all components are necessary in understanding the rationale for the current study.

**Diadochokinesis**

According to Seikel, King, and Drumright (2005), oral DDK refers to the movement of the articulators based on the number of productions of a single or multiple syllables per second. These rates have been used widely to assess the phonatory and articulatory systems of individuals. Gadesmann and Miller (2008) highlight the clinical implications of diadochokinesis by stating, “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; developmental disorders, of emerging progressive neurological deterioration; and potentially sensitive to qualifying change at the impairment level” (53). Studies have been reported in the oral DDK literature that provide both normative data as well as data on disordered populations.

In terms of normative data for oral DDK, limitations exist due to few studies targeting norms. Williams and Stackhouse (2000) conducted a study to determine oral DDK performance rates in typically developing children. They acknowledge the wide use of oral DDK rates as an assessment tool to measure oral-motor skills and recognize that disordered child populations, such as children with verbal dyspraxia, may have difficulty with these tasks. Their research was done as a necessary step in understanding normal function. The study included 30 typically developing children between the ages of 3 and 5. These children were divided into three groups based...
upon age. Age groups were divided into 3-, 4-, and 5-year-olds. Oral DDK tasks included timed real word repetitions, timed non-word repetitions, and timed syllable sequence repetitions of /pʌtʌkʌ/. Accuracy, consistency, and rate of oral DDK measures were scored. Accuracy was assessed by comparing to an adult model, consistency was assessed by determining the child’s ability to repeat an item in a consistent form, and rate was assessed by calculating the mean time in seconds to produce five repetitions of each item.

Results of this study showed that age was a significant factor in how rapidly and accurately a person can perform an oral DDK task. The 3-year old children performed more poorly on oral DDK tasks compared to 4- and 5-year-olds ($p<0.01$). In terms of consistency, researchers identified that most participants had rapid rates suggesting that consistency of oral DDK rates (repetition identical to first repetition) in children should be measured and compared to an adult model, regardless of inaccuracy. This study provided normative data for the oral DDK measures for young children, however, the limited number of participants must not be overlooked and the one-year age difference between groups may not be a large enough gap. While flaws in this study do exist, the researchers acknowledged the necessary step of establishing normative data to validate oral DDK as an assessment tool in identifying disordered populations. The same approach is needed in order to establish normative data for comparison on oral DDK tasks for adult populations. The study provides a good model for determining normative data for L-DDK tasks as well.

Research has also been conducted using oral DDK as a measure for understanding articulatory systems in disordered populations. Research done by
Langmore and Lehman (1994) looked at patients with amyotrophic lateral sclerosis (ALS) to determine oral DDK rates compared to a control group. Researchers suggest that dysarthric or dysphasic symptoms are often present in the corticobulbar (upper motor neuron damage) classification of ALS. Their study was developed to identify a loss of speed of movement in articulation due to the damage to the upper motor neurons in patients with certain classifications of ALS.

Three groups of patients with different classifications of ALS (bulbar, corticobulbar, and spinal) and a control group were asked to perform oral DDK tasks. The tasks included producing /pʌ/ and /tʌ/ as rapidly as possible; rate was recorded as the number of repetitions per second. Results showed that there was a significant difference in rates across the four groups, \( p < .005 \), for both /pʌ/ and /tʌ/. The control group was also found to be significantly faster than each of the three ALS groups, regardless of the presentation of dysarthria. Additionally, the corticobulbar group was significantly faster than the bulbar ALS group for the production of /tʌ/. These findings suggest that oral DDK rates can be used in assessment of disordered populations to predict and understand neurological damage. It is clear, then, that oral DDK has been researched and measurements have been used as a tool to understand and predict articulatory deficits. Similarly, if normative data were available, measures of L-DDK could be used as a helpful clinical tool for speech-language pathologists to evaluate the laryngeal and phonatory functions of their patients.
Laryngeal Diadochokinesis

As mentioned previously, oral DDK has been proven to be an effective measure of articulatory function and is used frequently as an assessment tool. The wide use of oral DDK measurements serves as a model for researchers to study and understand L-DDK as a measurement of vocal fold function. Laryngeal diadochokinetic rates can be measured in the same way as oral DDK rates, by producing syllables at a rapid pace and calculating the number of syllables produced per second. Laryngeal diadochokinesis relies on the vocal folds, rather than the tongue and lips, to act as articulators and tasks include the repetition of the syllable /hʌ/ and /ʌ/ to identify “the physiologic process of coordinating rapid, repetitive adduction and abduction of the vocal folds” (Canter, 1965, p. 2). Researchers believe that L-DDK assessments of individuals can be useful in determining normal versus abnormal laryngeal function.

One of the few studies on laryngeal functioning with the use of L-DDK measures was conducted by Shanks (1966), who determined that the characteristics of rate, periodicity, and pattern should be assessed. Shanks also analyzed the effects of pitch and intensity on L-DDK tasks. Participants of the study included only women divided into four age groups: (a) young adult (20-40); (b) later maturity (40-60); (c) late senescence (60-80); (d) and individuals ranging in age with disruption in sensory feedback. Participants were asked to repeat the syllable /hʌ/ as quickly as possible for three 5-second trials using a comfortable pitch and intensity. Additional masking trials were also conducted. Trials were recorded and then transformed to graphic representations to be interpreted by the author of the study.
Findings revealed that, when masked, participants produced slower L-DDK rates suggesting that auditory feedback is helpful to achieve maximal L-DDK rates. Additionally, rate, pattern, and periodicity were not affected by disrupted laryngeal sensory feedback. Results suggest that measurements should be obtained with the patient’s most comfortable pitch and intensity. Although Shanks (1966) does provide important methodology for the use of L-DDK and acknowledges the need for normative data on L-DDK tasks to render it clinically useful, several weaknesses leave gaps in the knowledge base. With research providing assessment information on both /ha/ and /a/ L-DDK tasks, this study is limited to findings on the singular task of /ha/. The difference in the L-DDK syllable production of /ha/ versus /a/ has yet to be addressed in research and therefore the two tasks can not be interchanged in L-DDK measurement. Both tasks, then, must be considered in L-DDK measures at this point in research because there is no evidence that both tasks provide similar information about laryngeal function. Since each of the two L-DDK tasks assess the function of the vocal folds but in opposite ways, it is necessary to use both the adductory task /a/ and the abductory task /ha/ to measure L-DDK rate. Finally, only women were included as participants in the study, and therefore, generalization to men is not possible. Normative information is necessary for both males and females.

Another study conducted by Leeper and Jones (1991) assessed the characteristics of L-DDK. Eighteen women between the ages of 20 and 25 with normal respiratory, neurological, and hearing functions were included in the study. Each participant repeated the vowel /a/ at three levels of frequency and intensity including the 25th, 50th, and 75th percentiles of their frequency and intensity ranges.
Participants used their fastest syllable rates when they produced the syllables at the 50th percentile of intensity, and they produced their slowest rate when speaking at the 75th percentile of intensity and frequency. These findings suggest that intensity is a controlling factor in L-DDK during repetition of /ʌ/. With this information at hand, L-DDK rates must be produced at a person’s most comfortable pitch and loudness to produce the fastest syllable productions. This research is vital to understanding typical laryngeal function and characteristics that may control the rate of production. While this study lacks strong external validity due to a limited inclusion criteria because it included only women, the age group chosen provides necessary information on a population with a mature, non-disordered larynx.

Like oral diadochokinesis, then, there is some evidence that the measurement of L-DDK can be a useful tool in assessing laryngeal function and could provide useful information to speech-language pathologists. To further understand the implications of L-DDK as an assessment tool, it is necessary to understand the anatomical make-up of the larynx and the innervation involved in its function.

**Anatomy and Innervation**

In understanding the role of the larynx in phonation, it is essential to first discuss its anatomy. The larynx is the muscular-cartilaginous housing of the vocal folds. In terms of location, the larynx begins at the superior end of the trachea, anterior to the esophagus. It is composed of both unpaired and paired cartilage. On top of the trachea sits a signet ring of cartilage known at the cricoid (Seikel, King, & Drumright, 2005). Articulating with the cricoid above is an open-backed larger
cartilage known as the thyroid. The inner surface of the thyroid provides the attachment of the vocal folds anteriorly. The vocal folds attach posteriorly to paired cartilage structures known as the arytenoids. The arytenoids are pyramidal in shape and sit on the upper back portion of the cricoid cartilage. The anterior portions of the pyramids that make up each arytenoid are known as the vocal processes (where the vocal folds actually attach). The lateral portions of the pyramids are known as the muscular processes because muscles attach to them in order to move the vocal folds.

The vocal folds themselves are made up of five layers. The first thin layer is known as the epithelial layer with the purpose of hydrating the vocal folds with mucous. The lamina propria makes up the next three tissue layers: superficial, intermediate, and deep. Both the superficial and intermediate lamina propria are composed of elastin fibers while the deep layer is made up of collagen that restricts extension. The final vocal fold layer is made up of muscle known as the thyrovocalis (Seikel, King, and Drumright, 2005). During phonation the arytenoids rock, rotate, and glide with help from surrounding muscles in order to open and close the vocal folds. Adducting involves bringing the vocal folds together (closing) for voiced sounds such the vowel /ʌ/. Abducting the vocal folds pulls them apart (opening) for voiceless sounds like the fricative /h/.

While lesions such as nodules contribute to structural changes due to growth on the vocal fold layers, many other disorders of voice may be caused by cranial nerve damage. Therefore, it is also important to understand the innervation of the larynx. The nerve responsible for laryngeal function is the vagus nerve (cranial nerve X) whose origin is at the medulla oblongata of the brainstem.
Three branches of the vagus include the pharyngeal, recurrent laryngeal, and superior laryngeal branches. The pharyngeal branch is responsible for sending sensory information from the base of the tongue and the upper pharynx. The recurrent and superior branches function by sending both motor and sensory information between the larynx and brain. The right recurrent branch extends behind the subclavian artery and ascends between the trachea and esophagus. The left recurrent branch loops under the aortic arch and ascends between the trachea and esophagus innervating mucosa beneath the vocal folds. This branch sends information from intrinsic muscles of the larynx (all but the cricothyroid) and the inferior pharyngeal constrictor (Seikel, King, & Drumright, 2005). Thus, with a lesion to this branch, a person may have difficulty phonating and swallowing. According to Verdolini and Palmer (1997) vocal fold adduction/abduction impairment is usually due to abnormalities and lesions of the recurrent laryngeal nerve because of its role of supplying motor information to the vocal folds.

The other branch responsible for normal laryngeal functioning for phonation is the superior laryngeal branch of the vagus nerve. This branch separates into both an internal and external portion. The internal section receives information from the laryngeal region above the vocal folds while the external innervates the cricothyroid muscle responsible for lengthening the vocal folds (Seikel, King, & Drumright, 2005). Lesions to this branch of the vagus nerve can cause an inability to fluctuate pitch resulting in a monotone voice. Overall, the vagus nerve controls the ability for the larynx to function normally. With injury to this nerve, whether isolated or systemic, normal laryngeal functioning will be impaired. L-DDK measures can thus
be a tool in helping speech-language pathologists document changes in laryngeal function and provide early referrals for patients suffering from nerve damage. This measurement tool could potentially result in earlier diagnosis of a disease and earlier access to treatment.

**Aging Larynx**

As with all parts of the body, there is change in the larynx throughout the lifespan. In order to accurately detect and diagnose disorders of the larynx, it is essential to be able to distinguish natural aging from a disorder. During childhood, the vocal folds begin to lengthen with the larynx and the larynx lowers (Ferrand, 2012). As a child reaches puberty, there is continued change in the larynx and vocal folds for both males and females. Males, in particular, experience more laryngeal growth and thus vocal fold growth than females due to the release of androgens (i.e., testosterone). Changes also occur with the angle of the thyroid cartilage. While females’ thyroid cartilages remain in the same position, the thyroid angle of males decreases to 90° creating a notch, also known as “Adam’s apple”(Ferrand, 2012).

In terms of fundamental frequency, there is a significant change in pitch as a child matures through puberty. This change is due to a longer vocal tract as the larynx descends and vocal fold mass increases. Most often this change in fundamental frequency stabilizes by the age of 18 when the larynx is fully mature (Ferrand, 2012).

The stability in adult fundamental frequency can be compromised with hormonal changes, particularly in females. Slight fluctuations in vocal fold vibrations have been identified during hormonal variability related to menstruation and
pregnancy. During pregnancy specifically, an increase in estrogen and progesterone may act together to change normal laryngeal function. This boost in estrogen causes increased secretion of typically regulating cells above the vocal folds leading to a reduction in mucosal viscosity. Progesterone may result in abnormalities such as dehydration of mucosa and tissue congestion while androgens can cause irreversible decreases in fundamental frequency (Ferrand, 2012). Because of such varied changes due to hormonal fluctuations in women during pregnancy, it is important to understand that these changes are atypical as compared to the mature larynx and must not be considered when understanding normative function. Menstrual fluctuations may also occur in some women due to hormonal changes throughout each cycle such as vocal fatigue, loss of vocal power, and loss of some high harmonics, however these symptoms are not present for all women and are found to be less of an issue with the use of oral contraceptives (Ferrand, 2012). Aside from the hormonal fluctuations described above, the larynx beyond puberty stabilizes in terms of its structure and function.

The larynx begins to age as early as between 30 and 40 years in both males and females. This process, however, is very gradual and individual differences exist (Ferrand, 2012). Structural changes in the larynx can be found in cartilage, joints, muscles, and the layers of the vocal folds. Cartilage begins to ossify with age resulting in limited flexibility. This decrease in flexibility can affect vibration of the vocal folds. In terms of joints, with age there is often the risk of issues such as erosion, thinning, and the breakdown of collagen fibers. With joint erosion and other joint issues, there may be limited range of motion therefore limiting adduction and
abduction of the vocal folds (Ferrand, 2012). With age, muscle fibers may be replaced with loose connective tissue and fat, decreasing the speed and force of these fibers and limiting full approximation of the vocal folds. The epithelium can become dehydrated and thicken as a result, which may increase vocal effort and fatigue. The lamina propria, consisting of elastins and collagen fibers, can become bowed along the medial edge due to fiber separation.

All of these structural changes to the larynx and vocal folds can result in acoustic changes to the voice with age. For aging males, pitch often increases due to thinning and stiffening of tissue. For aging females, pitch often decreases after menopause due to mild swelling or edema of the vocal folds as well as hormonal changes (Ferrand, 2012). Unstable vibration during sustained vowels, reduced intensity, and increased breathiness have also been shown to be typical voice patterns of the aging larynx. These normal findings of the aging larynx are necessary to understand to help predict laryngeal pathology.

A study by Ptacek and Sander (1966) was conducted to look specifically at changes in phonatory tasks due to age. They acknowledged that speed of physiologic response and timing are necessary ways of assessing changes in the aging nervous system. Two groups of normative participants were measured. One group was composed of younger adults (under 40) and the other of geriatrics (over 65). Measurements included pitch range, DDK, maximum vowel intensity, maximum vowel duration, maximum intraoral pressure, and vital capacity. Oral DDK movements included /pʌ/, /tʌ/, /kʌ/, /pʌtʌkʌ/, and the L-DDK syllable /ʌ/. Participants
repeated each sound as quickly as possible for 7 seconds. The rates of the middle 5 seconds were counted using an oscillographic recorder.

Results of the Ptacek and Sanders (1996) study indicated that oral DDK measures were significantly different for the geriatric population compared to the younger adult. Slower DDK rates were found for the geriatric population for all oral and laryngeal movements. For both groups /ʌ/ was slower compared to other sound movements which Ptacek and Sanders (1966) attribute to the difference in articulators where /ʌ/ uses the “vocal folds alone to initiate and terminate sound” (359). While this study is essential to understanding the differences between age groups on phonatory tasks, there is a gap in truly understanding normative data on laryngeal movements alone. One reason is that this study included only one of the L-DDK measures, /ʌ/, and not /hʌ/. Another reason is that they contrasted participants under age 40 with those over age 65, which fails to reveal how phonation is affected across the adult lifespan. With these gaps in mind, normative L-DDK rates using both tasks and throughout the adult lifespan must be collected in order to understand laryngeal abnormality compared to normal functioning and the potential for assessment and therapy in these disordered populations.

A study by Sauder, et al. (2010) looked at nine elderly patients with presbylaryngis (aging of the larynx) to determine if therapy by vocal function exercises would reduce age related changes in the voice. All participants were categorized as having presbylaryngis and had no other disorder to explain their dysphonia. Additionally, all participants presented with bowing vocal folds and incomplete closure during phonation, a common characteristic of the aging larynx.
(Sauder et al., 2010). All participants underwent a six-week course of therapy with some tasks including sustained vowels, stretching, and power exercises. Pre-post therapy measures were assessed. Acoustic analysis consisted of a recording of the “Rainbow Passage”, sustained vowel /ʌ/, and maximum sustained phonation of /ʌ/. Voice samples were scored based on auditory-perceptual ratings of severity, breathiness, and strain. Trained speech-language pathology graduate students analyzed the samples and were blind to the study. Self-ratings by the Voice Handicap Index were reported as well as a self-assessment of effort and severity based on their own speech samples. Finally, visual-perceptual ratings were used to assess changes based on endoscopy.

Results of the Sauder et al. (2010) study indicated no significant pre- and post-treatment differences in terms of acoustic analysis. In terms of auditory-perceptual ratings, blind listeners perceptually rated breathiness and strain to have significantly improved. There was also statistical significance in participants’ self-ratings for the Voice Handicap Index, as well as their own severity and effort rating. Finally, no significant visual-perceptual differences in laryngeal structure and function were found based on videostroboscopy examinations from pre- to post-test measures (Sauder et al., 2010). Thus, participants did improve based on their own reports of severity and effort, and based on external ratings of their breathiness and strain. However, acoustic analyses and videostroboscopy did not reveal significant pre- to post-test changes.

Findings of the Sauder et al., (2010) study are essential to understanding the potential benefit of therapy for adults suffering from voice changes due to age. While
acoustic and visual-perceptual measures did not change significantly, the participants’ overall voice ratings improved, suggesting the potential treatment to be of benefit to those suffering from age-related voice complaints. The study provided a glimpse of acoustic, visual-perceptual, and self-reported age related changes in the larynx and laryngeal function. More information on physiologic changes in laryngeal function associated with normal aging is necessary to identify the value of L-DDK measures as a clinical assessment tool both in diagnostic and treatment outcomes.

**Diseases Affecting the Larynx**

It is essential to understand natural aging in order to know how disease can affect the larynx. Natural aging of the larynx can vary from one individual to the next but the ability to separate normal aging from disorder during assessment is a necessary skill for the potential early detection of disease. Outside of aging, there are numerous disorders of the larynx affecting its function. Inflammation, structural lesions, benign lesions, fatigue, movement disorders, and neurological degeneration all negatively affect normal laryngeal functioning and are different than the effects of aging alone. It is thus necessary to understand the ways in which abnormalities affect L-DDK rates in order to identify the importance of using these rates to diagnose and treat certain disordered populations.

Verdolini and Palmer (1997) attempted to understand the disorders that affect L-DDK rates. Their study highlighted structural disorders such as abnormalities of the membranous vocal folds and abnormalities of the posterior larynx as well as dynamic abnormalities caused by both peripheral and central nervous system issues. Verdolini
and Palmer (1997) used L-DDK rates as a measurement of arytenoid control and predicted that dynamic abnormalities, such as vocal fold paralysis and Parkinson’s disease, would decrease these rates. They also predicted that structural changes, such as nodules and granulomas, would not affect L-DDK measures.

Forty-five participants with varying disorders of the larynx performed L-DDK tasks. These disorders included structural (nodules, granulomas), dynamic (abducted paralysis, Parkinson’s), and non-organic (functional voice disorder, control). Rate, strength, and rhythmia were all measured. Rate was defined by how quickly and consistently a participant could produce /ʌ/ in a 7 second time frame. The total number of repetitions was divided by seven, the number of seconds produced, to determine a rate per second. Strength and rhythmia were judged perceptually with a measure of “good” versus “bad.”

Results were consistent with the hypothesis that L-DDK rate, strength, and rhythmia were “normal” for structural abnormalities as well as non-organic disorders. Results also revealed that L-DDK rate, strength, and rhythmia, were poor for dynamic abnormalities of the larynx, and this was consistent with what the researchers’ had hypothesized. These findings suggest that L-DDK rates can be used to help detect certain disorders and these measures are clinically useful with populations with suspected nerve damage or degeneration. Two weaknesses require caution in interpreting their findings. First, their sample size was small, with 45 participants overall and less than eight in some disorder groups. Second, as Verdolini and Palmer (1997) acknowledge, there are currently no normative rates when interpreting L-DDK data. Although they did find differences between disorder groups, without normative
data, it is not possible to use L-DDK as a measurement tool when diagnosing new patients.

Understanding the deficits in speech associated with Parkinson’s disease has led researchers to investigate L-DDK rates in this population. Unlike Verdolini and Palmer (1997), Canter (1965) asked 17 participants diagnosed with mild-moderate Parkinson’s disease to produce the syllable /hʌ/ as quickly as possible for 5 second periods. Participants often had difficulty producing distinct syllables which Canter described as “freezing.” This inability to perform the L-DDK task was found often in participants with Parkinson’s who had difficulty with other articulatory tasks as well. These findings suggest that there is a relationship between the severity of the disorder and L-DDK rate. While these findings are crucial to understanding the deficits found in patients with Parkinson’s disease, Canter had no normative data for comparison. While there were controls, having normative data in all age ranges is necessary to use as a comparison. Additionally, the study used only the singular L-DDK task /hʌ/ which again creates limitations in the ability to compare to other L-DDK research.

Amyotrophic lateral sclerosis (ALS) has also been an area of research in terms of L-DDK rates. Renout et al. (1995) acknowledges the lack of L-DDK research compared to oral DDK research, especially in patients with a progressive motor neuron disease like ALS. Participants included both male and females (N=26) with about half presenting with bulbar ALS (more rapid neuromotor deterioration) and the other half presenting with nonbulbar type ALS. Each participant was asked to produce the syllable /hʌ/ as quickly as possible.
Findings revealed that bulbar-type participants showed significantly slower rates than the nonbulbar group. These findings are consistent with characteristics of ALS patients presenting with bulbar symptoms including weakness, slowness of movement, and atrophy of muscles in the larynx, face, and lingual musculature (Renout et al, 2005). These findings indicate that L-DDK can potentially detect early symptoms of neural degeneration. Disease affecting the larynx, then, contributes to changes that can be assessed with the use of L-DDK measures. Given this evidence, it is important to understand what diagnostic tools are typically used in understanding laryngeal function.

Tests of Laryngeal Function

When a person experiences disruption to laryngeal function, it is necessary to conduct thorough evaluations in order to diagnose the pathology and describe its effects on voice production. However, currently there are few protocols used to evaluate laryngeal function. The most common evaluations of laryngeal function are explained below.

Endoscopy

Use of endoscopy is currently considered to be the gold standard in evaluating laryngeal function. In this procedure, an endoscope is inserted through either the nose or mouth until a view of the larynx is possible. A rigid endoscope is one that is inserted through the mouth while a flexible endoscope is one that is inserted through the nose. Both procedures project an image of the larynx in order to evaluate the structure and function during specific tasks. The flexible scope, however, allows for
more thorough observation because patterns of phonation can be evaluated during speech and swallowing. Comparatively, the rigid scope is restricted to phonation of a single vowel /i/ (Ferrand, 2012). A tool such as endoscopy is helpful in evaluating the vocal folds at rest, during breathing, as well as during phonation. Tasks during endoscopy examinations include normal respiration, prolonged /i/, repetition of “hi” or “he”, production of /i/ with lowest and highest pitch, coughing, whistling, singing, and talking both in connected speech as well as specific target sentences. These tasks may vary between individual assessments based on symptoms.

In addition to endoscopy, videostroboscopy is often paired with endoscopy as a tool to assess laryngeal functioning. Specifically, videostroboscopy can determine structure and function of the larynx such as vocal fold edges, glottic closure, extent of opening, phase closure, mucosal wave, amplitude of vibration, symmetry, periodicity, supraglottic activity, and vertical level of approximation (Ferrand, 2012). All of these characteristics help to determine abnormalities in laryngeal function.

Videostroboscopy is performed by shining a light source onto the vocal folds and interrupting the light source at consecutive points throughout the vibratory cycle to create an illusion of slow motion. As a result, the examiner is able to see the sequence of vocal fold vibration. The human eye is unable to pick up each vibratory cycle individually because of its high speed, making videostroboscopy a necessary tool in evaluating laryngeal function and helping to diagnose voice disorders. Both endoscopy and videostroboscopy rely on the human eye and ear making subjective ratings of the function of the vocal folds rather than providing objective data.
Electroglottography (EGG)

Electroglottography (EGG) is used as another measure in evaluating laryngeal function. EGG involves placing electrodes on the surface of the skin on each side of the thyroid cartilage. High frequency currents are sent through the electrodes with increasing resistance as the vocal folds are abducted and decreasing resistance as the vocal folds are adducted (Ferrand, 2012). A waveform develops from this pattern of resistance signifying the opening and closing phases of the vocal folds. This assessment can be used to see the cycle of vocal fold movement and thus predict abnormal function. EGG is interpreted by the shape of the waveform as well as through calculation of the opening and closing phases of vocal fold vibration. EGG is a noninvasive assessment tool but because endoscopy is considered the gold standard in assessing function, it is used less often clinically.

Limitations to Current Measurement Options

While endoscopy and EGG are currently used to assess laryngeal function, they lack the ability to predict laryngeal abnormality and weaknesses in their use exist. First, both endoscopy and EGG require equipment that is not readily available to all speech-language pathologists. Additionally, the costs associated with having the equipment and running the tests are high and often require additional professional assistance. Another disadvantage is that endoscopy is an invasive procedure that requires inserting equipment into the oral or nasal cavity, which can be uncomfortable to and unwanted by the patient. Finally, these measures rely primarily on perceptual ratings creating issues with reliability. Speech-language pathologists may interpret functioning during these assessments in different ways, and therefore, reliability
across SLPs is questionable. The shortcomings noted above make these tools less than ideal in clinical settings, and highlight the advantages of measuring L-DDK rates if normative data existed to use as comparison. It is thus necessary to explore the validity and reliability of measuring L-DDK as a possible diagnostic tool.

Validity and Reliability of L-DDK

While L-DDK research does exist, there are notable inconsistencies in the methods used to measure L-DDK which affect the validity of the measures. First, studies have varied in the task that participants are asked to perform. Some previous studies have relied on the adductory /ʌ/ task alone while others have relied on only the abductory /hʌ/ task alone. These inconsistent procedures do not allow for comparisons between studies and it has yet to be established if results on these two tasks differ in participants. The validity of the measures of L-DDK will be improved by collecting both rates on the adductory task /ʌ/ and the abductory task /hʌ/ to fully understand laryngeal function. Collecting normative data on both tasks can provide a better understanding of how the tasks relate to one another and if significant differences in task exist.

Second, there has been variability in the methods used to measure L-DDK regardless of the task and this affects the reliability of the measures. In some L-DDK studies, perceptual ratings were used (i.e. tapping a pencil for each syllable) while others included objective measures (i.e. transferring audio recorded data to a spectrogram for analysis). The inconsistency in measurements can decrease reliability of the results and limits the ability to compare across studies.
While no study exists on the reliability of L-DDK measurements, Gadesmann and Miller (2008) have looked at the reliability of oral DDK measurements. Perceptual versus objective measures were compared during oral DDK tasks. Findings suggested some issues with the reliability of oral DDK measures due to the variability in use. Researchers highlight the importance of addressing measurement accuracy in oral DDK measures because of its potentially useful nature in early detection of articulatory dysfunction. Similar to the results of Gadesmann and Miller’s (2008) study, it will be essential to assess the reliability of L-DDK measures collected using objective graphic data from an oscillogram. Eventually, these objective data can be compared to a perceptual rating scale of L-DDK rate to assess the reliability of perceptual measures.

**Statement of the Problem**

To date, there is limited research on L-DDK as an assessment tool for laryngeal function. The literature that does exist lacks consistency in both the procedures for data collection and the method for measurement of L-DDK. Additionally, research suggests that individuals with neuromotor disorder of the larynx break down on L-DDK tasks compared to matched controls. While these findings indicate that L-DDK can be an important clinical tool, normative data must first be collected for use in comparison for these disordered populations. The current study resulted in a set of normative data for adults between the ages 20 through 40 and establish a consistent framework for implementing L-DDK tasks for use as an assessment tool for speech-language pathologists.
CHAPTER II

PURPOSE

The purpose of the current study was to collect normative data for L-DDK tasks in a sample of 20 to 40 year old males and females. Such normative data are crucial to understanding normal functioning of the mature larynx before the effects of aging begin. Normative data of the larynx in 20 to 40 year olds can be compared to normative data of the aging population to understand age-related effects on L-DDK tasks. Because of the non-invasive and inexpensive nature of L-DDK, normative rates can then be referenced and used for comparison when assessing laryngeal function in disordered populations. While existing research lacks consistency on the performance of L-DDK tasks, participants were asked to perform both the repetition of the adductory and abductory tasks of /ʌ/ and /hʌ/. Additionally, because of sex-related differences in hormone levels and the development of the mature larynx, male and female L-DDK rates were compared. With these gaps in research in mind, the following questions were addressed:

1. What are the normative values for L-DDK rates for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 20 and 40 years?

2. Is there a difference between L-DDK rates for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 20 and 40 years?

3. Is there a difference between the normative values of L-DDK rates for males and females in this age range?
CHAPTER III

METHOD

Design

A differential research design was used to compare the two L-DDK tasks. Differential research design was with two groups, males and females. Sex, then, was the independent variable and the L-DDK tasks were the dependent variables.

Participants

Selection

Participants included in the study were males and females between the ages of 20 and 40 years old. All participants who met inclusion requirements read and signed a consent form in order to participate in the study.

Recruitment

Participants included family members, friends, neighbors, and co-workers of the researches. They were recruited by word of mouth and through IRB approved flyers. Each participant was provided an Informed Consent Form (Appendix A) that explained the premise of the study and identified the risks, benefits, and requirements for participating. After reading this form, each participant signed the Voluntary Consent Form (Appendix B) to indicate a willingness to participate in the study. The Indiana University of Pennsylvania Institutional Review Board reviewed and approved the study protocol, the Informed Consent Form, and the Voluntary Consent Form (Log No. 12-230).
Inclusion and Exclusion Criteria

Inclusion criteria required that participants demonstrate a vocal quality within a typical range as determined by the auditory-perceptual judgment made by a speech-language pathologist with expertise in voice disorders. This judgment was made using the Consensus Auditory-Perceptual Evaluation of Voice (“Consensus Auditory-Perceptual Evaluation of Voice [CAPE-V],” 2006) which was completed for each participant prior to beginning the study. A score of 20 or below on the CAPE-V was the maximum for participants who were included in the study. Individuals with scores above 20 or who exhibited any of the following were excluded from the study: a) vulnerability; b) symptoms of cold or illness on the day of testing; c) history of respiratory, laryngeal, or neurologic disease; d) previous surgeries of the larynx; e) history of structural or dynamic laryngeal abnormalities; f) profound hearing loss; g) lack of comprehension of the task; h) currently pregnant.

Final Sample Size

One participant was excluded from the study due to being below the target age range. The final sample size included 39 participants between the ages of 20 and 40 years old. Of the 39 participants, 17 were males and 22 were females.

Procedures

Data collection began after informed consent was received. Data collection was conducted in a quiet room in either a participant’s home, a place of work, or a community center room. Participants were required to complete four tasks: a) produce L-DDK tasks /ʌ/ and /hʌ/ for 7 seconds three times each; b) sustain the vowels /a/ and
/i/ for 5 seconds three times each; c) read six sentences; d) maintain natural
conversation for 30 seconds. All tasks, with the exception of the L-DDK task, were
derived from the CAPE-V protocol (“Consensus Auditory-Perceptual Evaluation of
Voice [CAPE-V],” 2006). The four tasks were recorded using a Roland CD-2 CF/CD
Recorder and recordings were copied onto a compact disk. Participants were placed
six inches from the Audio-Technica ATR20 Dynamic Cardioid Low Impedance

In order to assess each participant for the inclusion criteria of voice quality
within a typical range, three vocal tasks of the CAPE-V were recorded for the
perceptual voice quality assessment. The first task included producing the lax vowel
/a/ and tense vowel /i/ for five seconds three times. Next, participants read six
sentences aloud to measure various laryngeal behaviors. These sentences included: 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 phonatory task required each participant to maintain a
natural conversation for 30 seconds using the question prompt: “Tell me what you did
yesterday.” A speech-language pathologist with expertise in both voice disorders and
the use of the CAPE-V rated the recordings and made a judgment regarding each
participants’ voice quality. Only participants with voice quality within what is
considered a typical range (i.e., CAPE-V scores of 20 or lower) were included in the
study.
Data collection for the study began when participants were presented with the following verbal instructions modeled from the instructions used in 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, 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 subject 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 7 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 sounds … (/ʌ/ or /hʌ/).”

The above instructions were provided for both the /ʌ/ and /hʌ/ tasks. The investigator demonstrated the task first by producing both syllable sounds as quickly and consistently as possible. Three trials of each task were then completed by each participant. The order of tasks were counterbalanced across participants (Bassich-Zeren, 2004). For example, alternating participants produced the adductory task prior to the abductory task to prevent the possibility of fatigue or practice effects on performance results.
Measurement

Rate was measured after data for L-DDK tasks were collected. Rate was measured objectively by converting the recording track for each L-DDK task into an oscillogram consistent with the measurement used by Shanks (1966), by using the Kay Pentax Multidimensional Voice Program™ digital software (MDVP) rather than analog voice data. Once the recordings were digitized into the oscillogram, the first half second was removed from the beginning of the track to eliminate potential artifacts due to instability at the onset of a new task. The subsequent 5 seconds were used for analysis. Consistent with several other researchers, the number of amplitude peaks was counted, representing one repetition of /ʌ/ or /hʌ/, on the oscillogram for each five second segment (Leeper & Jones, 1991; Ptacek et al. 1966; Renout et al. 1995; Shanks, 1966). The number of peaks was divided by five to calculate repetitions per second. In addition, audio recordings were examined for perceptual verification of the amplitude peaks to assure that the oscillographic peaks represented the intended syllable and were not spurious.

Use of Data

Data from this study were part of a larger collection of normative data across the adult lifespan. The subset of data collected for this study was only used for the purpose of this study and that of the larger study from which it was drawn. All identifying information was seen only by the investigators of this study and of the larger study. Identifying information was not used on digital audio files or paper
documents. All paperwork with identifying information has been securely locked away and will only be available to the investigators of this study. Upon completion of the larger study of which this study was a subset, all documentation with identifying information will be destroyed.

**Statistical Analysis**

Statistical analyses were completed using IBM® SPSS® Statistics Data Editor software (SPSS Statistics Data Editor, 2010). Three separate statistical analyses were completed. A mixed between-within ANOVA, mean, range, and standard deviation of L-DDK tasks were reported to determine normative values in adults between the ages of 20 and 40 years. The two tasks, adductory task /ʌ/ and the abductory task /ʌ/, and the six trials represented the categorical independent variables within-subjects. Laryngeal diadochokinetic trials were analyzed in total repetitions per 5 seconds and repetitions per second. Both sets of results were analyzed due to the chance of repetitions per second masking any trends in the results. It was important, however, to report repetitions per second to compare results with other studies.

The next analysis was completed to answer the question “Is there a difference between L-DDK rates for the adductory task /ʌ/ and the abductory task /ʌ/ in adults between the ages of 20 and 40 years old.” Rates were compared using a mixed between-within subjects analysis of variance (ANOVA; Graziano & Raulin; 2007). Interaction effect, main effect, and between-subjects effect were also analyzed and reported as Wilks’ lambda (Λ) values at the alpha level (0.05 level of confidence) (Silverman, 1998). The interaction effect assessed the change in scores over time for
the two groups and identified whether the null hypothesis could be rejected (Silverman, 1998). The null hypothesis states, “the observed differences or relationships are due to chance, or random fluctuation.”

The effect of sex on L-DDK tasks was analyzed using a mixed between-within ANOVA to answer the question. “Is there a difference between normative values of L-DDK rate for males and females?” Thus, sex represented the categorical independent variable between participants.
CHAPTER IV
RESULTS

The results of the interaction effect of production rate and sex must be analyzed first to determine if the change in rate across the two tasks is the same for both groups (males and females). The interaction effect results answered the question, “Is there a difference between L-DDK rates for the adductory task /ʌ/ and the abductory task /ʌ/ in adults between the ages of 20 and 40 years?” No statistically significant interaction effect was found between L-DDK tasks (Wilks’ Lambda = .84, \( F(5, 33)=.30, p=.16, \eta^2_p = .16 \)). Table 1 highlights the interaction effect results, Multivariate Tests of Production Rates.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
<th>F</th>
<th>Hypothesis df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Rates*SEX Wilks’ Lambda</td>
<td>.84</td>
<td>1.27</td>
<td>5.00</td>
<td>33.00</td>
<td>.30</td>
<td>.16</td>
</tr>
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</table>

The next question addressed in the current study was, “What are the normative values for L-DDK rate for the adductory task /ʌ/ and the abductory task /ʌ/ in adults between the ages of 20 and 40 years?” To answer this question, means and standard deviations of both L-DDK tasks for males and females were calculated. For males, the total normative value (over three trials) for the L-DDK task /ʌ/ was \( M=4.80 \) repetitions per second (range=2.6-7.2; \( SD=0.86 \)). For females, the total...
normative value (over three trials) for the L-DDK task /ʌ/ was $M=5.02$ repetitions per second (range=3.2-7.4; $SD=0.63$). For males, the total normative value (over three trials) for the L-DDK task /ʌ/ was $M=5.01$ repetitions per second (range=3.8-6.4; $SD=0.63$). For females, the total normative value (over three trials) for the L-DDK task /ʌ/ was $M=4.88$ repetitions per second (range=3.6-5.8; $SD=0.50$). Results for total repetitions per 5 seconds is highlighted below in Table 2. Data for the total repetitions across 5 seconds were divided by five to calculate L-DDK rates per second. Rates per second are summarized below in Table 3.
Table 2

*Descriptive Statistics for Total Repetitions per 5 Seconds*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Sex</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>/ʌ/ 1</td>
<td>m</td>
<td>25.18</td>
<td>5.07</td>
<td>15-36</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>26.86</td>
<td>3.78</td>
<td>19-37</td>
<td>22</td>
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<td></td>
<td>Total</td>
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<td>4.41</td>
<td>15-37</td>
<td>39</td>
</tr>
<tr>
<td>/ʌ/ 2</td>
<td>m</td>
<td>23.94</td>
<td>3.67</td>
<td>14-29</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>24.64</td>
<td>2.54</td>
<td>16-28</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Total</td>
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<td>3.06</td>
<td>14-29</td>
<td>39</td>
</tr>
<tr>
<td>/ʌ/ 3</td>
<td>m</td>
<td>22.88</td>
<td>4.09</td>
<td>13-30</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>23.77</td>
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<td>16-28</td>
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<td>17</td>
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*m = male, f = female*
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<td>3.8-5.8</td>
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<tr>
<td></td>
<td>Total</td>
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<td>3.6-6.4</td>
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</tr>
<tr>
<td>/hs/ 2</td>
<td>m</td>
<td>5.04</td>
<td>0.55</td>
<td>4.2-6.0</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>4.81</td>
<td>0.49</td>
<td>3.6-5.8</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4.91</td>
<td>0.52</td>
<td>3.6-6.0</td>
<td>39</td>
</tr>
<tr>
<td>/hs/ 3</td>
<td>m</td>
<td>4.84</td>
<td>0.62</td>
<td>3.8-6.0</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>f</td>
<td>4.71</td>
<td>0.52</td>
<td>3.6-5.4</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4.76</td>
<td>0.56</td>
<td>3.6-6.0</td>
<td>39</td>
</tr>
<tr>
<td>/hs/ Total</td>
<td>m</td>
<td>5.01</td>
<td>0.63</td>
<td>3.8-6.4</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>f</td>
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<td>0.50</td>
<td>3.6-5.8</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4.93</td>
<td>0.56</td>
<td>3.6-6.4</td>
<td>39</td>
</tr>
</tbody>
</table>

*m = male, f = female
The final question asked in the current study was, “Is there a difference between normative values of L-DDK rate for males and females in this age range? A between-subjects test was conducted to determine if there was a significant difference between groups for males versus females on L-DDK tasks. Results concluded that there was no statistically significant difference between males and females (F(1,37) = 3514.26, p = .811, η² < .01). Table 4 below highlights these results.

Table 4

*Tests of Between-Subjects Effects*

<table>
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<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
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<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<td>3514.26</td>
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<td>0.99</td>
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<td>sex</td>
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<td>2.30</td>
<td>.06</td>
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<tr>
<td>Error</td>
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<td>37</td>
<td>39.70</td>
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</tbody>
</table>
CHAPTER V
DISCUSSION

Summary

Limited research exists on L-DDK measures. The research that does exist on the usefulness of L-DDK as a measure of vocal fold function provides no normative data to use as comparison. Furthermore, the L-DDK tasks have been inconsistent across studies and researchers have used subjective rather than objective methods of measurement. The current study sought to fill the gaps and correct the flaws found in previous research. The research team collected data on L-DDK rates for both the adductory /ʌ/ and the abductory task /hʌ/ in adult males and females between the ages of 20 and 40 years. Results revealed no significant differences in L-DDK task for the adductory task /ʌ/ and the abductory task /hʌ/ in adults between the ages of 20 and 40 years. In addition, results revealed no significant differences between normative values for males versus females in this age range.

The purpose of the current study was to provide normative rates for L-DDK tasks. While there have been attempts at collecting normative data for laryngeal function in previous research, methods for collecting and interpreting results have varied and therefore no strong set of normative data exists. Ptacek et al. (1966) attempted to provide evidence of L-DDK rate changes with age. The results of the current study were consistent with their findings on the task of producing /ʌ/.

Specifically, Ptacek et al. reported that for participants between the ages of 18 and 39, the rate per second was 5.1 for males and 5.3 for females. In the current study, the
rate per second was 4.8 for males and 5.0 for females. While the rates across the two studies were similar, the Ptacek et al. study relied on only one trial of the task of producing /ʌ/. The current study was designed to include multiple repetitions of the task, which increases the confidence in the reliability and validity of the results.

The attempt to collect normative L-DDK rates by Shanks (1966) can also be compared to current findings. Rates collected by Shanks for a young adult group (20 to 40 years of age) of women had a mean of 5.46 for the task /hʌ/. When compared to the current mean for L-DDK task /hʌ/ for women of 4.88, results from research by Shanks had a much higher rate. These findings may be due to a difference in methods between Shanks and the current study. Shanks interpreting rate using a 3 second sample of syllable repetitions and calculating repetitions per second. Participants in the current study produced repetitions over 5 seconds and repetitions per second were calculated. The longer time frame for repetitions, then, in the current study as compared to Shanks’, may suggest that rate may decrease over time thus fatigue may be a factor over time of task.

Finally, Renout’s (1995) research on vocal fold function of individuals with ALS examined L-DDK rates for this population over three, 5-second segments. This study separated patients with bulbar and non-bulbar type ALS to find L-DDK rates for the production of /hʌ/. Findings of Renout’s study show mean rates of 3.19, 2.94, and 2.69 over three trials in the bulbar group and mean rates of 5.00, 4.96, and 4.40 over three trials in the non-bulbar group. Similar to Renout’s study, the current study shows a trend of decreased rate over the three trials. Total rates in the current study are based off of an average of the three trials so these decreased rates over trials must
be considered. This finding suggests that laryngeal fatigue and decrease in breath support may result over consecutive trials in both disordered populations as well as normative populations.

Additionally, because of such diversity in terms of task in previous L-DDK research, the current study attempted to understand if a difference existed between the adductory task /ʌ/ and the abductory task /hʌ/. Previous studies have used one of the L-DDK tasks, but no other study has used both or compared tasks. Canter (1965) evaluated laryngeal functioning using the repetition of the syllable /hʌ/ saying that this production “assesses the ability to alternate vocal fold abduction and adduction” (218). Alternately, Ptacek et al. (1966) used the isolated /ʌ/ to assess laryngeal functioning saying that, “when an isolated vowel is produced in rapid succession the vocal folds themselves must act as ‘articulators’ in initiating and terminated the sounds” (359). Since differences exist on task among L-DDK research, the current study compared both tasks to identify if a difference in rate exists. Current findings suggest that no significant difference in rate exists between tasks. These findings validate that both the adductory task /ʌ/ and the abductory task /hʌ/ provide similar information on laryngeal functioning.

Finally, the current study attempts to understand if a difference exists in L-DDK rate for males versus females between the ages of 20 and 40. Interestingly, results suggest that no difference exists between groups of males versus females. This result was surprising especially in the early adult age group of 20 and 40 given the structural and hormonal differences between males and females. However, results of the current research support results found by Ptacek et al. (1966) where mean rates
for males (5.1) and females (5.3) were very similar. These findings suggest that structural and hormonal differences may not play as important of a role in L-DDK rate as originally thought. While sex and L-DDK task have no significant effect on rate for this age group based on the current study, future research can consider the effects of neurological factors on L-DDK rates. It has yet to be determined if sex and L-DDK task differences exist in rate among disordered populations.

**Limitations**

Before L-DDK tasks can be used as a diagnostic tool for assessing laryngeal functioning, normative rates must be collected for comparison. While the current study provides this essential normative data for the 20 to 40 year old age group, there were some limitations to consider. One major limitation to take into consideration is the small sample size. The sample size for the current study was 39. While this sample size is similar to the sample size (N=40) used in research by Shanks (1966), a larger sample size would improve the confidence we can have in the findings.

Previous research has differed in the way L-DDK rates were collected. The current study used an objective measuring system to collect rates through use of an oscillogram and by counting the number of peaks in a 5-second time frame. While this method provides clear objective numbers for rate, it is not the most cost and time-efficient method for use in a clinical setting. Future research is needed to compare this objective measuring system to a more subjective measure as done in previous research by Verdolini & Palmer (1997). Their subjective measure for calculating rate consisted of a clinician dotting with a pen for each production of an L-DDK task. The
current study relies on an objective measure for calculating rate causing a limitation to the ability to generalize the L-DDK measurement to a clinical setting. Future research could compare subjective ratings to the objective measures found in the current study to determine whether those subjective ratings can be equally as reliable.

Additionally, the current study examines only the L-DDK measurement of rate. Previous research suggests that along with rate, strength and consistency may also be important factors to consider when analyzing vocal fold function (Verdolini & Palmer, 1997). Future research may consider additional factors beyond rate to fully understand laryngeal function. It is possible that the variables of task and sex may differ on phonatory measures of strength and consistency.

**Implications**

The current study provides the first step in understanding the usefulness of L-DDK measurements to analyze vocal fold functioning. The normative results provided in this study set the groundwork for the eventual clinical use of L-DDK measures as a diagnostic tool for disordered populations. The current study focuses on the early adult population only and further research is needed to increase sample size for this group as well as target additional age groups. Future research in this area is needed to address the following: a) increased sample size of normative data; b) comparison of subjective against objective measures; c) calculating measures of strength and consistency; and d) ultimately, compare normative data alongside populations with laryngeal abnormalities as a clinical diagnostic tool.
REFERENCES


SPSS Statistics Data Editor (Version 19). (2010). Chicago, IL: IBM.


Appendix A

Informed Consent Form

Project Title: Laryngeal Diadochokinesis: 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’ and ‘huh’ several times, 2) hold out an ‘ah’ and ‘e’ for 5 seconds, 3) read six sentences, and 4) answer a brief question about yourself. You will be seated approximately 6 inches from a microphone.

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: Lori E Lombard, PhD
Professor
Speech-Language Pathology Program
Indiana University of Pennsylvania
203 Davis Hall
Indiana, PA 15705
Phone: 724/357-2450
llombard@iup.edu

This project has been approved by the Indiana University of Pennsylvania Institutional Review Board for the Protection of Human Participants (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