Pediatric Laryngeal Diadochokinetic Rates: Establishing a Normative Database

Steve Maturo, MD¹, Courtney Hill, MD², Glenn Bunting, MS, CCC-SLP³, Cathy Ballif, MA, CCC-SLP³, Rie Maurer, MA⁴,⁵, and Christopher Hartnick, MD²

Abstract
Objective. Laryngeal diadochokinetic (L-DDK) rate is a measure of laryngeal neural integrity. The objectives for this study included the following: (1) establish the first comprehensive pediatric normative database for L-DDK rates (DDK) using the Voice Evaluation Suite, a computerized voice analysis program; and (2) analyze normal L-DDK rates for age and gender differences.

Study Design. Cross-sectional study with planned data collection.

Setting. Outpatient pediatric otolaryngology clinic.

Subjects and Methods. Three hundred seven children aged 4 to 18 with normal voices. L-DDK rates were collected during a 6-month period. Main outcome measures included age, gender, and L-DDK rates.

Results. Three hundred seven children (151 girls and 156 boys) were evaluated. There was no statistically significant difference between the overall mean L-DDK rate of boys (2.69 syllables/s) compared to girls (2.55 syllables/s; \( P > .05 \)). Further analysis of all individual age groups did not reveal any statistical significance between boys and girls. There was a statistically significant difference among children aged 4 to 11 compared to those 12 to 18 years old. Among boys aged 4 to 11, the mean rate was 2.49 syllables per second, whereas among 12- to 18-year-olds, the rate was 2.95 syllables per second (\( P < .01 \)). The mean rate was 2.40 syllables per second among girls aged 4 to 11 and 2.74 syllables per second for those aged 12 to 18 (\( P < .01 \)).

Conclusion. This is the largest normative pediatric L-DDK analysis in the English literature. The findings suggest that neurolaryngeal development approaches adult maturation at the beginning of the teenage years. These data have the potential application for objective measurement of neurolaryngeal coordination in children with neurologic impairment and also in children who have undergone nerve reinnervation procedures.

Keywords
diadochokinetic, DDK, pediatric voice, pediatric speech

Received August 27, 2011; revised September 16, 2011; accepted September 20, 2011.

Objective voice data such as acoustic and aerodynamic measurements are not routinely gathered or studied for the pediatric population. This is likely because of a combination of factors, foremost being a lack of pediatric normative data and perceived difficulty in testing children. Unfortunately, the incidence of pediatric voice complaints is not insignificant, with more than 1 million US children affected by chronic dysphonia.¹² Without normative data, it is difficult to assess objectively treatment effectiveness for most children with voice problems as opposed to adults, where normative values are commonly used to measure both speech and surgical therapy.

Diadochokinetic (DDK) rate is a measurement of how quickly an individual can produce a series of rapid, alternating sounds. Oral DDK rate is one means of assessing oromotor skills, as it provides insight concerning the ability to coordinate and execute rapid articulatory movements.³ Oral diadochokinetic tasks involve consonant-vowel repetitions, such as repetition of the nonsensical phrase “pa-ta-ka,” where laryngeal and oral coordination is necessary. Laryngeal DDK (L-DDK) measures the adduction or abduction rate of the true

¹Department of Otolaryngology Head and Neck Surgery, San Antonio Uniformed Services Health Education Consortium, Lackland AFB, Texas, USA
²Department of Otology and Laryngology, Massachusetts Eye and Ear Infirmary, Harvard Medical School, Boston, Massachusetts, USA
³Voice and Speech Laboratory, Massachusetts Eye and Ear Infirmary, Boston, Massachusetts, USA
⁴Center for Clinical Investigation, Brigham and Women’s Hospital, Boston, Massachusetts, USA
⁵Harvard Catalyst, The Harvard Clinical and Translational Science Center, Boston, Massachusetts, USA

This article was selected as an oral presentation for the annual meeting of the American Academy of Otolaryngology—Head and Neck Surgery in San Francisco, California, September 2011.

Corresponding Author:
Steve Maturo, MD, Department of Otolaryngology Head and Neck Surgery, San Antonio Uniformed Services Health Education Consortium, Wilford Hall Medical Center, Lackland AFB, TX 78236, USA
Email: Stephen.maturo@sbcglobal.net
vocal folds. Laryngeal DDK tasks assess the capability of the vocal folds to either adduct or abduct, such as with the repetition of the phrase “uh,” where no oropharyngeal or labial coordination is necessary. Faster L-DDK rates reflect a higher degree of neuromuscular control. The majority of DDK research has centered on oral DDK rate studies with further investigation into oromotor deficits in areas such as traumatic brain injury and hearing loss.4,5

As within many areas of the speech and voice literature, there are few pediatric studies investigating DDK rates. Normative pediatric oral DDK rate studies, albeit limited, show highly variable intra- and interparticipant rates. This variability is particularly apparent for younger children. Generally, preschool children produce 1 trisyllabic sound per second, and this rate increases, with oromotor maturation occurring between ages 10 and 15 years.6,7 Children with neuromotor and speech disorders such as ataxia, dysarthria, and stuttering have been shown to have slower oral DDK rates in comparison to children without neuromotor and speech disorders.8-10 Individuals with hearing impairments have been shown to have significantly slower oral DDK rates than normal-hearing children, suggesting that exposure to auditory stimulation may be a primary factor for the development of speech coordination.5 Currently, there are no dedicated studies looking solely at L-DDK rates in normally developing children.

The goal of this research was to establish a normative L-DDK database of primary English-speaking children between the ages of 4 and 18 years. By establishing a comprehensive normative database, we hope to provide some insight into when the childhood L-DDK rate changes. From identifying the age ranges when these changes occur, we hope to identify time periods when functional neurolaryngeal maturation occurs in the developing child. This would add to a foundation of knowledge for future neurolaryngeal models, with the hope that this will lead to improvements in the treatment of pediatric voice and speech disorders.

Material and Methods

This study was approved by the Institutional Review Board of the Massachusetts Eye and Ear Infirmary. Patients between the ages of 4 to 18 years were recruited from an outpatient pediatric otolaryngology clinic. All children were free of hearing, neurologic, cognitive, or developmental delays as reported by their parents. If there was a child or parental concern for hearing abnormalities, audiograms were evaluated. Children with voice abnormalities or articulation concerns were excluded from the study. All children who met the screening criteria and were willing to participate were included in the study. Children who were unable to complete the voice protocol were excluded from final data analysis. Informed consent was obtained. Informed assent was obtained in children older than 12 years.

Laryngeal DDK recordings and measurements were made in a quiet room using a Dell (Dell, Inc, Round Rock, Texas) Optiplex 960 personal computer (Microsoft Windows XP Professional Version 2002; Microsoft Corp, Redwood, Washington) with an Intel Core Duo 2 CPU (3.1 GHz, 1.94 GB of RAM). Children were fitted with an adjustable Shure Beta 53 (Shure, Inc, Niles, Illinois) head-worn microphone placed 3 cm from the right oral commissure at approximately a 45-degree angle. The Voice Evaluation Suite ([VES]; Estill Voice International, Pittsburgh, Pennsylvania) was used to measure the laryngeal DDK rate. VES is a Windows computer program for automated collection, analysis, storage, and retrieval of the significant clinical characteristics of a patient’s speaking voice. The program uses an audio digitizer with microphone and preamplifier for collection of quantitative acoustic measures that are stored in a computer database for easy recall and comparison. The system was calibrated daily based on the VES user manual instructions.

Patients were asked to repeat as rapidly and clearly as possible the phrase “uh, uh, uh” in a normal-volume voice during a 7-second period. Timing was carried out by the computer, which detected vocal onset and offset, thus negating the need for a handheld timer. Children were asked to repeat the task if the repetition of “uh” was indistinct or too soft to be picked up by the computer.

Descriptive statistics were performed for gender and age group. Selected data were plotted using bar graphs for visual inspections. Group comparisons were performed using either t tests or Wilcoxon rank sum tests. A simple linear regression graph of L-DDK was created for each gender, but these graphs were not found to be accurate fits over the entire age range. A nonparametric smooth to the data (locally weighted scatterplot smoothing) was applied to determine where the breaks manifested. Based on the comparisons of the model standard error and visual fit, the best-fit piecewise regression model was created. All statistical analysis was conducted using SAS version 9.2 (SAS, Cary, North Carolina).

Results

Three hundred seven children, 151 girls and 156 boys, were evaluated. Each child had a normal voice as reported by the child and parent or guardian. The most common presentations to the clinic were for evaluation of adenotonsillar hypertrophy (29%), ear infections (10%), and nasal obstruction/adenoid hypertrophy (8%). Thirty-one (9%) of the children were siblings of patients being evaluated in the clinic. Table 1 and Figures 1 and 2 demonstrate the results for both girls and boys. Of note, only seven 4-year-olds were tested because of a lack of cooperation in carrying out the task of the protocol.

There was no statistically significant difference between the overall mean rate of boys (2.69 syllables/s) compared to girls (2.55 syllables/s; P > .05). Further analysis of all individual age groups did not reveal any statistical significance between boys and girls. For example, there was no significant difference between 10-year-old boys and 10-year-old girls (P > .10) There was a statistically significant difference among children aged 4 to 11 years compared to those 12 to 18 years. Among boys aged 4 to 11 years, the mean rate was 2.49 syllables per second, whereas among 12-
18-year-olds, the rate was 2.95 syllables per second ($P < .01$). Among girls aged 4 to 11 years, the mean rate was 2.40 syllables per second, whereas it was 2.74 syllables per second among those 12 to 18 years ($P < .01$).

**Discussion**

Laryngeal DDK rate is an indirect measure of the neurophysiological integrity of the larynx. The goals of our study were to identify normative L-DDK rates among 4- to 18-year-old children and to analyze these results for age- or gender-related differences. Our findings suggest that as children age, the neurolaryngeal pathway reaches almost full maturity by the adolescent years. Furthermore, there is no significant gender difference between children of the same age.

Measuring DDK rates is not standardized throughout the language and voice literature. In many published studies, there is not a clear delineation between whether oral DDK rates or laryngeal DDK rates are measured, thus making interpretation even more confusing. Oral DDK rates have
been used as a measure of childhood speech development, yet this is somewhat controversial, especially when used to analyze preschool children. Historically, inter- and intrarater reliability has been questioned when measuring DDK rates because of the widespread variation in carrying out DDK measurements. Varying methods of measurement, along with lack of studies in children, have brought into question the utility of the DDK rate as a measure of speech performance. Our L-DDK study investigates the quantitative aspects of monosyllabic speech, and thus oromotor skill does not contribute to this evaluation. It should be stressed that L-DDK is not a measure of evaluating a child’s speech development. It is strictly an indirect measure of neurolaryngeal function.

There are few studies specifically measuring L-DDK rates, and thus general comparisons to available oral DDK rates may be contextually the most appropriate comparison for our data. From this perspective, our data are in agreement with previous reports showing increasing rates as children age, with no significant intergender differences. The unique aspect encompass, especially the preschool-age children who historically have been underrepresented in DDK studies.

One advantage of the VES system is that it removes the human element of patient timing, which in many previous oral DDK measurements has been done imprecisely with a handheld stopwatch. Also, the VES system measures a monosyllabic, thus alleviating the possible conflict of different consonant segments having differential durational characteristics and pronunciation errors. Although our overall means were lower than the quoted adult normative values for the VES (females, 4.4 syllables/s; males, 4.7 syllables/s), this may be due to differences in patient task instruction. Inherent limitations of the study were related to young age and cooperation. Subjects were encouraged to perform the L-DDK task, but no child was forced to complete against his or her will. In very young children, the DDK task can be quite challenging, as evidenced by our ability to elicit only 7 subjects in the 4-year-old age group. An additional concern when testing children is what defines a “normal pediatric voice.” Testing children in a pediatric otolaryngology clinic may not represent a “generalizable” pediatric population. We attempted to control for this bias by screening for developmental, cognitive, hearing, or voice deficits. Finally, our data should be viewed as the result of using a specific proprietary system. Although various systems are widely used among speech and voice researchers, one must use caution when comparing to historical data. Various proprietary programs have different algorithms that may not provide comparable data to other systems. Also, the normative values quoted by these systems are based on adults only. Caution should be applied when comparing our data with the VES system–defined adult normative data.

Although we have shown the approximate ages when changes of L-DDK occur, there remains the question of what causes these changes. Most likely this is due to the developing neural structures. Previous oral DDK studies have shown decrements in the rate in children with hearing impairment; yet by the inherent nature of the test, it is difficult to ascertain how much of this deficit is due to oral motor incoordination or poorly developed neurolaryngeal control. This suggests the need for additional research comparing normally developing children to those with hearing and neurologic disorders to determine if L-DDK rates can be applied for diagnostic and rehabilitative purposes.

**Conclusion**

We have reported to date the most comprehensive, normative L-DDK rates among English-speaking children. Our data demonstrate that there are no intergender differences of children the same age, but there are discrete ages when increasing rates are seen in both boys and girls. It is hoped that these data can be used as a reference as more speech, voice, and hearing research studies are conducted on children. Furthermore, we hope that they can serve as a functional basis for developmental investigations into the maturing pediatric larynx.

**Author Contributions**

Steve Maturo, conception and design, acquisition of data, analysis and interpretation of data, drafting the article and revising it, and final approval of the version to be published; Courtney Hill, contributions to conception and design, acquisition and interpretation of data, draft revision for important intellectual content, and final approval of the version to be published; Glenn Bunting, contributions to conception and design, analysis and interpretation of data, draft revision for important intellectual content, and final approval of the version to be published; Rie Maurer, design, acquisition of data, analysis and interpretation of data, draft revision, and final approval of the version to be published; Christopher Hartnick, conception and
design, acquisition of data, analysis and interpretation of data, drafting the article and revising it, and final approval of the version to be published.

**Disclosures**

**Competing interests:** None.

**Sponsorships:** None.

**Funding source:** None.

**References**