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Adult Normative Data for Phonatory Aerodynamics in Connected Speech

Ali Lewandowski, MA, CCC-SLP; Amanda I. Gillespie, PhD, CCC-SLP; Samantha Kridgen, BA; Kwonho Jeong, PhD; Lan Yu, PhD; Jackie Gartner-Schmidt, PhD, CCC-SLP

Objectives/Hypothesis: To establish normative values for phonatory aerodynamic measurements in connected speech across adult ages and gender.

Study Design: Prospective data collection across group design.

Methods: One hundred fifty adults aged ≥18 years without voice complaints were stratified into three equal-age groups (group 1 [ages 18–39 years]; group 2 [ages 40–59 years], and group 3 [ages 60 + years]) and two equal-gender groups (male and female) resulting in 25 participants in each category. Participants read the first four sentences of the Rainbow Passage at comfortable pitch and loudness to obtain a connected speech sample. The following dependent variables were analyzed: breath number, reading passage duration, mean phonatory airflow, inspiratory airflow duration, and expiratory airflow duration.

Results: A gender effect was found for mean phonatory airflow, with males showing significantly greater phonatory airflow than females during connected speech (P < .001). Number of breaths was significantly greater for group 3 than group 2 (P < .001) and group 1 (P < .001). Duration, and inspiratory and expiratory airflow durations were all significantly greater for group 3 (P < .001) than group 2 (P < .001) than group 1 (P < .001).

Conclusions: This study provides normative data for phonatory aerodynamics in adult connected speech. Significant age and gender effects were observed.

Key Words: Voice laboratory, aerodynamics, normative values, connected speech, phonatory.

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INTRODUCTION

Phonatory aerodynamic measurements are a standard part of the voice laboratory evaluation.1,2 These measurements have been shown to distinguish normal from disordered voices, determine stimulability for behavioral treatment, and track response to intervention.3-7 Despite the proven significance of aerodynamic measurements, use of these measures in clinical settings is rare. A recent systematic review of aerodynamic measurements revealed that only 10% of the articles utilized aerodynamic measurements for clinical purposes.8

Phonatory aerodynamic measurements can be collected during sustained vowels, consonant-vowel syllables, and connected speech.9-11 Compared to traditional non-speech tasks (e.g., sustained vowels or consonant-vowel combinations), connected speech can reveal treatment change across a variety of voice disorders.1,12 Dastolfo and colleagues found that phonatory aerodynamic outcomes in connected speech demonstrated greater treatment response than phonatory aerodynamics in sustained vowels and repeated consonant vowel stimuli.1 However, data on phonatory aerodynamic values in people without voice disorders are lacking in the literature, which makes judgments about the normalcy of findings in disordered populations difficult. The purpose of this study was to establish phonatory aerodynamic normative values in connected speech.

Normative phonatory aerodynamic values have been established for nonconnected speech tasks. Zraick and colleagues provided normative data across three age groups for 41 phonatory aerodynamic measures of consonant-vowel tasks using the KayPENTAX Phonatory Aerodynamic System (model 6600; Pentax Medical, Montvale, NJ) for 157 vocally healthy adults.12 Statistically significant main effects of age were found for 17% of the measures and main effects of gender for 12% of the measures. Similar work by Weinrich and colleagues provided normative values for 45 aerodynamic measures for pediatric populations resulting in 29% of the measures showing differences that were statistically significant.14 Although these two studies provide an important foundation for normative aerodynamic values, they do not include connected speech.

Gartner-Schmidt and colleagues reported normative data for 20 healthy speakers for a selection of phonatory...
aerodynamic measurements of connected speech in comparison to aerodynamic measurements of patients with treated and untreated unilateral vocal fold paralysis (UVFP). All phonatory aerodynamic measures were significantly increased in patients with preoperative UVFP than the healthy speakers. Specifically, the significant differences between the healthy age and gender-matched controls and those with preoperative UVFP were found in number of breaths, mean airflow rate during voicing, passage duration, inspiratory airflow duration, and expiratory airflow duration. Although this study introduced a small dataset (n = 20) of phonatory aerodynamic values in healthy speakers, a large normative dataset is lacking in the literature.

The current study aimed to provide normative values for phonatory aerodynamics in connected speech in adults. A second aim of this study was to determine differences in phonatory aerodynamics in connected speech among three age groups and between genders.

MATERIALS AND METHODS

Participants

Participants were recruited from the community by self-responding to posted recruitment flyers. Eligible caretakers and family members of patients at the University of Pittsburgh Voice Center who expressed interest in response to recruitment flyers within the clinic were also included.

Inclusion criteria were normal voice as perceptually determined by a speech-language pathologist (SLP) who specialized in voice disorders; a Voice Handicap Index-10 (VHI-10) score of < 11, which indicates absence of a voice handicap, monolingual; English speaker; and no history of any voice problem lasting longer than 2 weeks. Exclusion criteria were history of smoking (for at least 15 years) or pulmonary disease (by patient self-report).

Instrumentation

The KayPENTAX Phonatory Aerodynamic System (PAS) model 6600 was used to collect aerodynamic data from each participant (Pentax Medical). The PAS simultaneously captures the sound waveform and displays the calculated fundamental frequency, sound pressure level in decibels, and airflow signals in real time. The PAS software is equipped with multiple protocols based on typical phonatory and aerodynamic tasks to be performed by participants. A customized protocol created by Ryoji Hirai, MD, for previous work by two of the authors (J.G.-S. and A.I.G.), was also used for the current study (Fig. 1). The window shows three separate measurements; airflow, sound pressure level in decibels, and fundamental frequency. The x-axis for each measurement displays time in seconds, from 0 to 60. The y-axis for airflow is set from -2 to 2 L/s to allow for visual display of breaths taken. The sound pressure level y-axis ranges from 0 to 108 dB, and the fundamental frequency y-axis ranges from 0 to 300 Hz.

The PAS external module consisted of the PAS handheld device, microphone assembly, airflow head, airflow tubes, coupler, and a mask. The participant firmly held the mask to the front of the face. This device conducted airflow directly from the mouth to the airflow head. The air in the flow head crossed a stainless steel mesh screen that provided a resistance value to the airflow. Pressure difference between the two sides of the mesh screen was determined by pressure transducers located on both sides of the screen. Airflow rate was then established by the calculation of pressure divided by the resistance.

Fig. 1. Cursor placement for data measurement using the KayPENTAX Phonatory Aerodynamic System screen shot. Arrows represent number of breaths; thick vertical lines mark the beginning and ending of sound pressure level in decibels, which represents the duration of the reading passage. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]
Procedures

After obtaining informed consent, a screening was performed by an SLP to determine eligibility, which consisted of judging if the participant had normal voice and speech production, followed by participant completion of the VHI-10 and a demographic screening questionnaire.

Equipment calibration. Calibration of the KayPENTAX PAS model 6600 was performed daily using a calibration syringe to inject 1 L of air through a disposable cardboard flow tube into the airflow head in both sound-treated voice laboratories.

Experimental task. Participants were seated at a table directly across from the SLP and instructed to place the PAS mask tightly over the nose and the mouth. Next, participants read the first four sentences of the Rainbow Passage using a comfortable vocal pitch and loudness level. The recording was then deidentified and saved.

Data reduction. All recordings were analyzed by a research assistant. The assistant listened to each passage to screen for any interruptions in the reading task (i.e., repeated words, throat clears, coughing, or sneezing). Any discovered interruptions were extracted from the recordings and the edited versions were then saved. A range threshold was then manually applied by means of cursor placement at the beginning and the end of the passage, which was determined by the beginning and ending sound pressure level in decibels tracing on the top line of the display window. The screen view was then edited to only allow the measurable information. The number of breaths was counted manually by adding each occurrence of negative airflow tracing below the line indicating 0 mL/s of phonatory airflow. The duration of the passage in seconds was also calculated. The following measurements were obtained from the PAS protocol: number of breaths taken during the oral reading of the passage, total duration of the passage, mean airflow during voicing, and inspiratory and expiratory airflow duration (Table I). These measures reflect the same measures from a previous study reporting phonatory aerodynamics in connected speech. Averages were computed and sorted based on age groups and gender.

### TABLE I.

**Descriptions of Aerodynamic Measurements in Connected Speech.**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breath number</td>
<td>Ordinal</td>
<td>Total number of breaths during reading passage; calculated via addition of each occurrence of negative airflow tracing</td>
</tr>
<tr>
<td>Duration</td>
<td>Seconds</td>
<td>Total time to read the passage</td>
</tr>
<tr>
<td>Inspiratory airflow duration</td>
<td>Seconds</td>
<td>Total time of inhalation (negative airflow time)</td>
</tr>
<tr>
<td>Expiratory airflow duration</td>
<td>Seconds</td>
<td>Total time of exhalation (positive airflow time)</td>
</tr>
<tr>
<td>Mean phonatory airflow</td>
<td>Liters per second</td>
<td>Total volume of expiratory airflow accompanied by voicing (determined via pitch tracing) divided by the total time during which voicing occurred.</td>
</tr>
</tbody>
</table>

Definitions adapted from KayPENTAX Phonatory Aerodynamic System instruction manual.

### TABLE II.

**Demographic Information for Healthy Controls.**

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>47.92</td>
<td>28.28</td>
<td>47.73</td>
<td>65.84</td>
</tr>
<tr>
<td>Males</td>
<td>50.45</td>
<td>29.88</td>
<td>51.24</td>
<td>70.24</td>
</tr>
<tr>
<td>Totals</td>
<td>29.3</td>
<td>50.44</td>
<td>68.04</td>
<td></td>
</tr>
</tbody>
</table>

Results

One hundred fifty adults (75 males and 75 females) between the ages of 19 years and 84 years were recruited. The mean age of all participants was 49.19 years. The mean age of the male participants was 50.45 years (range, 20–84 years), and the mean age of the female participants was 47.92 years (range, 19–80 years). The participants were then stratified into the three age groups (18–39, 40–59, and 60+ years) used in prior research on aerodynamic normative values. Group 1 had a mean age of 29.2 years, with 25 males (mean age = 29.88 years) and 25 females (mean age = 28.28 years). Group 2 had a mean age of 50.44 years, with 25 males (mean age = 51.24 years) and 25 females (mean age = 47.73 years). Group 3 had a mean age of 68.04 years, with 25 males (mean age = 70.24 years) and 25 females (mean age = 65.84 years) (Table II).

Dividing healthy controls into age groups, the following means were found in the aerodynamic measures.

**Group 1 (ages 18 to 39 years).** During reading, group 1 participants took an average of 4.4 breaths and demonstrated an average airflow during voicing of 142 mL/s. Average reading passage duration was 20.8 seconds. Mean expiratory airflow duration was 17.39 seconds, and mean inspiratory airflow duration was 3.13 seconds.

**Group 2 (ages 40 to 59 years).** During reading, group 2 participants took an average of 4.82 breaths and demonstrated an average airflow during voicing of 153 mL/s. Average reading passage duration was 23.39 seconds. Mean expiratory airflow duration was 19.1 seconds, and mean inspiratory airflow duration was 3.72 seconds.

**Group 3 (ages 60+ years).** During reading, group 3 participants took an average of 5.37 breaths and demonstrated an average airflow during voicing of 125 mL/s.
Mean airflow 
Inspiratory airflow
Expiratory airflow 
Duration 23.42

Values for phonatory aerodynamics in connected speech

**DISCUSSION**

The aim of this study was to 1) provide normative values for phonatory aerodynamics in connected speech in adults and 2) determine differences in phonatory aerodynamics in connected speech among three age groups and between genders.

**Age Effects**

There were statistically significant increases across the three established age groups for number of breaths, duration, expiratory airflow duration, and inspiratory airflow duration. These results align with findings in the literature that describe the effects of age-related changes within the respiratory and laryngeal mechanisms on airflow measurements. Pulmonary elastic recoil and respiratory muscle strength are reduced with increased age. To achieve the amount of subglottal pressure needed for connected speech, older adults could subconsciously adapt to these age-related changes. Presumably, increased number of breaths as well as increased inspiratory duration may be two of these adaptations used to maintain stable subglottal pressures for voicing. In addition to changes observed in the respiratory system, laryngeal changes including calcification and ossification of laryngeal cartilages and vocal fold atrophy also occur. Although considered a normal part of the aging process, these changes often result in reduced glottal closure during phonation. Based on these factors, it could be hypothesized that mean airflow during voicing would also increase with age. Perhaps the task

<table>
<thead>
<tr>
<th>Outcomes Summary (Two-Way ANOVA).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outcomes</strong></td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>No. of Breaths</td>
</tr>
<tr>
<td>Duration</td>
</tr>
<tr>
<td>Expiratory airflow duration</td>
</tr>
<tr>
<td>Inspiratory airflow duration</td>
</tr>
<tr>
<td>Mean airflow during voicing</td>
</tr>
</tbody>
</table>

Group 1 = ages 18–39 years, Group 2 = ages 40–59 years, and Group 3 = ages 60 + years. ANOVA = analysis of variance.
of connected speech is not taxing enough to reflect higher airflow rates that would otherwise be observed in a task that respiratory and laryngeal adaptations cannot overcome. The individuals in the current study did not undergo laryngeal examination to confirm or deny the presence of pathology, including vocal fold atrophy. However, the existence of vocal fold atrophy may not render a self-perceived voice disorder due to the body’s ability to compensate.

**Gender Effects**

The only significant difference between males and females occurred with mean airflow during voicing. Based on the findings of the current study, males demonstrate significantly greater phonatory airflow during phonation than females. This finding agrees with current literature.\(^\text{13,14,25,26}\) When compared to normative aerodynamic values in nonspeech tasks in the pediatric population, similar findings were observed in measurements of expiratory volume and peak expiratory airflow rates during vital capacity, which measured the maximum amount of air available for respiration or phonation.\(^\text{14}\) Namely, males demonstrated higher values than females. Previous studies have also reported such differences in laryngeal airflow rates due to larger airway diameters in males, even at the prepubescent stage.\(^\text{27,28}\)

Overall, results of the current study align with adult trends found by Zraick and colleagues\(^\text{13}\) with respect to greater airflow values (i.e., mean expiratory airflow and peak expiratory airflow) observed in males compared to females during voicing tasks. Mean airflow during voicing during connected speech was not a measurement reported by Zraick and colleagues,\(^\text{13}\) so a direct comparison cannot be made with this parameter.

Results from the current study corroborate those of the phonatory aerodynamic normative values reported in a previous study comparing healthy controls to individuals with UVFP.\(^\text{10}\) Although age and gender were not stratified in the comparison study, the 20 healthy control participants demonstrated similar age and aerodynamic measures to age group 2 (ages 40–59 years) in the current study. For example, the mean age of the healthy control participants was 49, producing an average mean airflow during voicing of 160 mL/s, which mirrors the average mean airflow during voicing reported for group 2.

**TABLE V.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>ICC</th>
<th>% of Reliability</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of breaths</td>
<td>1.00</td>
<td>100</td>
<td>1.00-1.00</td>
</tr>
<tr>
<td>Duration of passage</td>
<td>0.998</td>
<td>99.8</td>
<td>.990-.999</td>
</tr>
<tr>
<td>Inspiratory airflow duration</td>
<td>0.979</td>
<td>97.9</td>
<td>.940-.993</td>
</tr>
<tr>
<td>Mean airflow during voice</td>
<td>1.00</td>
<td>100</td>
<td>1.00-1.00</td>
</tr>
<tr>
<td>Expiratory airflow duration</td>
<td>1.00</td>
<td>100</td>
<td>1.00-1.00</td>
</tr>
</tbody>
</table>

CI = confidence interval; ICC = intraclass correlation coefficient.

**CONCLUSION**

This study represents the first set of normative values for phonatory aerodynamics in connected speech in adults between male and female genders, and across three age groups. The authors aimed to extend the normative aerodynamic profiles previously established by Zraick et al.\(^\text{13}\) from nonspeech tasks to connected speech tasks. Given the growing popularity of the use of aerodynamic measurements in clinical voice assessments, as well as the increased use of connected speech as an outcome variable, the need for normative measurements is high. Differences were detected in various parameters across both age and gender. Of interest is that age affected all parameters except for mean airflow during voicing. This highlights the potential respiratory–laryngeal compensations made to maintain stable airflow rates during voicing throughout the process of aging. These findings could further enhance the assessment process by helping clinicians to identify and specify abnormal phonatory aerodynamic findings.

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**BIBLIOGRAPHY**


