

Aerodynamic Characteristics of Syllable and Sentence Productions in Normal Speakers

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Summary: Background. Aerodynamic measures of subglottic air pressure (Ps) and airflow rate (AFR) are used to select behavioral voice therapy *versus* surgical treatment for voice disorders. However, these measures are usually taken during a series of syllables, which differs from conversational speech. Repeated syllables do not share the variation found in even simple sentences, and patients may use their best rather than typical voice unless specifically instructed otherwise. This study examined the potential differences in estimated Ps and AFR in syllable and sentence production and their effects on a measure of vocal efficiency in normal speakers.

Methods. Prospective study. Measures of estimated Ps, AFR, and aerodynamic vocal efficiency (AVE) were obtained from 19 female and four male speakers ages 22–44 years with no history of voice disorders. Subjects repeated a series of /pa/ syllables and a sentence at comfortable effort level into a face mask with a pressure-sensing tube between the lips.

Results. AVE varies as a function of the speech material in normal subjects. Ps measures were significantly higher for the sentence-production samples than for the syllable-production samples. AFR was higher during sentence production than syllable production, but the difference was not statistically significant. AVE values were significantly higher for syllable *versus* sentence productions.

Conclusions. The results suggest that subjects increase Ps and AFR in sentence compared with syllable production. Speaking task is a critical factor when considering measures of AVE, and this preliminary study provides a basis for further aerodynamic studies of patient populations.

Key Words: Subglottic pressure–Airflow rate–Vocal efficiency–Syllable production–Sentence production.

INTRODUCTION

To characterize the nature of a voice problem, patients are tested to measure airflow and pressure generated during their speech. These tests typically consist of repeating certain syllables to represent specific speech sounds. However, these tests are not recreations of actual speech, and may not accurately measure a patient's voicing ability during real-world speech. It is important to use appropriate speech tasks during clinical voice measurement so that data accurately reflect patients' everyday functioning. Measures that characterize a representative sample of a patient's voice enable accurate decisions about which treatment option is best for a given voice disorder. Aerodynamic measurement of vocal output provides an indication of the workload of the voice, and such measures have also been used to track changes in voice production.¹ The work of Smitheran and Hixon demonstrated intraoral pressure measurements taken with a seal around the nose and mouth to be a valid method of estimating subglottic pressure with high accuracy.² They used a series of /pa/ syllables repeated into a mask with a pressure-sensing tube between the lips to obtain an aerodynamic profile of speech production, and this method continues to be used in voice

assessment.³ These measures are used to acquire an aerodynamic profile of the patient. Subsequently, they may be used when deciding whether a patient is a candidate for surgery or behavioral therapy. The aerodynamic profile may also be used to measure progress after such interventions.^{3,4} The development of new instruments has allowed noninvasive and reliable measurement of aerodynamic data.^{5,6} We are not the first to identify the effects of the speaking task, such as sustained single-phoneme production *versus* connected speech, on voice measurements.⁷ However, real-world conversational speech is not the same as repeated syllable production, and patients have complained of vocal fatigue and high effort needed to produce a string of syllables even when aerodynamic measures during syllable production are within normal limits.^{8–10} We hypothesize that aerodynamic measures taken during syllable production differ from those obtained during a sentence. This preliminary investigation explores aerodynamic measures in 23 young, healthy subjects with no voice complaints who provided voice samples via syllable production and a simple sentence to determine if the two sampling methods differ.

METHODS

Following institutional review board approval, 23 young, healthy adult subjects were recruited to provide voice samples. All subjects denied any current or previous voice complaints. The subjects ranged in age from 22 to 44 years old with a mean age of 26.5 years and a median age of 24 years. Females comprised the majority of the group (19 subjects).

Aerodynamic data were collected with the *Phonatory Aerodynamic System (PAS)* model 6600 (Pentax Medical, Montvale, NJ). Calibration of the airflow channel was done according to the

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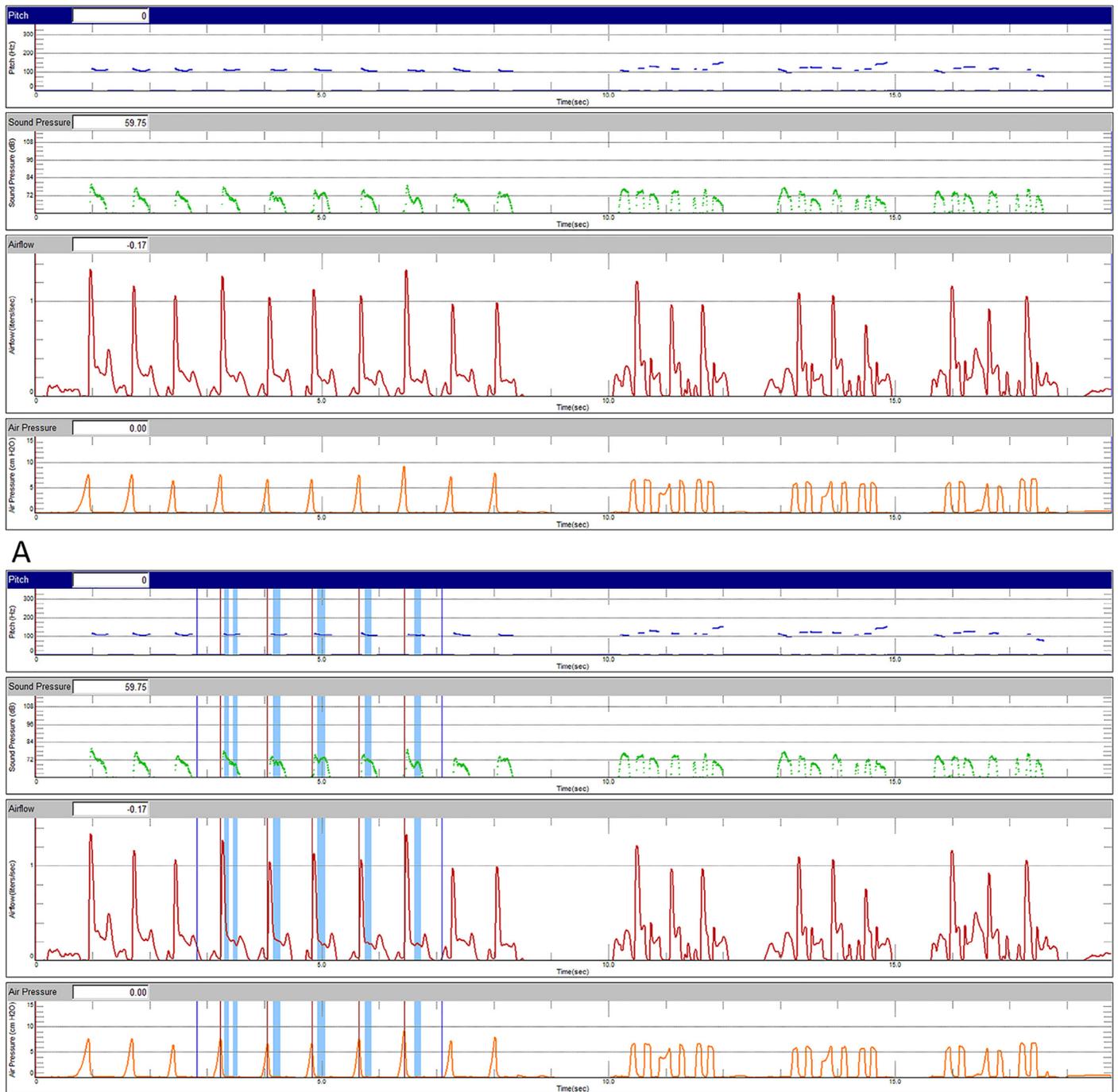


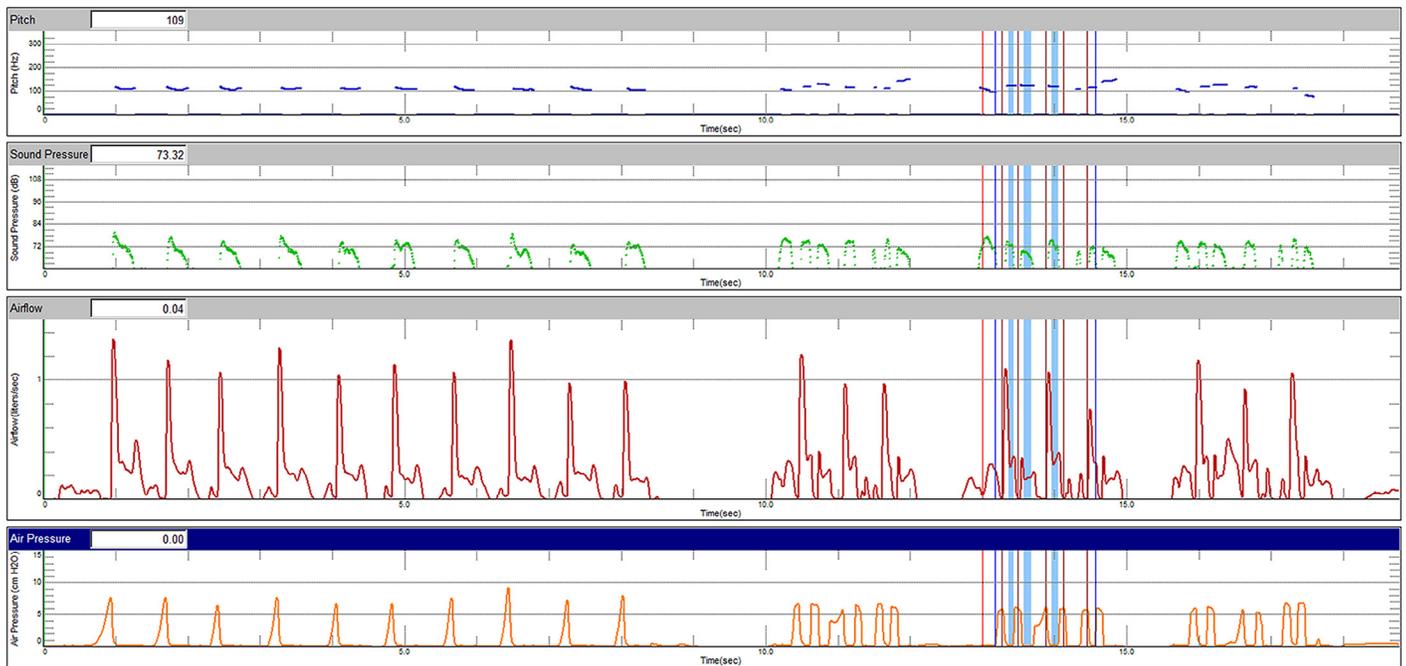
FIGURE 1. (A–C) Representative voice data demonstrating collection techniques. The first line displays pitch curve, the second line displays sound pressure amplitude, the third line displays airflow rate, and the fourth line displays subglottic pressure. Voicing tasks are seen (left to right) as a series of 10 /pa/ syllables, then three repetitions of “my papa popped a pepper.” (A) Image shows tracings after data capture. (B) Image shows analysis for /pa/ syllable repetition. (C) Image shows analysis for “my papa popped a pepper” sentence repetition. Tracings are representative of voice data for both male and female subjects.

manufacturer’s protocol before recording the data.¹¹ Subjects were instructed to speak at their most comfortable effort level into a face mask with a pressure-sensing tube between their lips.

For syllable production measurements, subjects repeated a series of 10 /pa/ syllables into the face mask at a rate of approximately 1.5 syllables per second. Representative data are

shown in Figure 1A. Five sequential syllable repeats were chosen for analysis (Figure 1B).

For the sentence production, subjects repeated the phrase “my papa popped a pepper” three times, with a 1- to 2-second pause between each repetition. This sentence was chosen to obtain pressure tracings in syllables similar to the syllable string (namely



C

Figure 1. (Continued)

papa, popped, pepper). The middle production was chosen for analysis to avoid artifacts from initiating or ending speech (Figure 1C).

Measures of estimated subglottic air pressure (Ps) and mean airflow rate (AFR) were calculated using the PAS software. Aerodynamic vocal efficiency (AVE), a measure obtained by dividing acoustic power (mean sound pressure level multiplied by a constant) by aerodynamic power (mean peak air pressure multiplied by target airflow and a constant), was derived by the PAS software from the two measures.¹¹

Paired *t* tests were calculated to determine the differences between syllable and sentence Ps, AFR, and AVE. Data were then log transformed, and a linear regression analysis was run comparing Ps and AVE as well as AFR and AVE. All variables were transformed on the log scale because of non-normality and skewness of the data. For AFR and AVE, degrees of freedom were $n = 22$.

RESULTS

Table 1 summarizes group aerodynamic measures obtained for Ps, AFR, and AVE for the syllable and sentence productions.

Subglottic pressure (Ps) measures during syllable production had a mean of 5.59 ± 1.63 cm H₂O. Ps measures during sentence production had a mean of 6.60 ± 1.69 cm H₂O. Paired *t* tests showed Ps was significantly higher during sentence production ($P = 0.0029$). AFR measures during syllable production had a mean of 127.83 ± 61.57 mL/s. AFR measures during sentence production had a mean of 147.39 ± 61.44 mL/s. AFR was significantly higher during sentence production ($P = 0.0209$). AVE measures during syllable production had a mean of 34.68 ± 25.31 ppm. AVE measures during sentence production had a mean of 22.30 ± 16.29 ppm. AVE was significantly higher during syllable than sentence production ($P = 0.0094$, Table 1).

Linear regression analysis showed positive association between airflow and efficiency, which was statistically significant in both syllable and sentence production. Based on the current data, during syllable production a 10% increase in AFR resulted in a 13% decrease in AVE when Ps is held constant during sampling ($\beta = -1.465$; 95% CI = $-2.088, -0.842$; $P < 0.0001$, Figure 2). During sentence production, a 10% decrease in AFR resulted in an 8% decrease in AVE when Ps is held constant ($\beta = -0.879$; 95% CI = $-1.585, -0.174$; $P = 0.0171$, Figure 3). A positive

TABLE 1.
Acoustic Measurements of Subjects During Syllable and Sentence Production

	Syllable Production	Sentence Production	<i>P</i> Value
Subglottic pressure (cm H ₂ O)	5.59 ± 1.63	6.60 ± 1.69	0.0029*
Airflow rate (mL/s)	127.83 ± 61.57	147.39 ± 61.44	0.0209*
Efficiency (ppm)	34.68 ± 25.31	22.30 ± 16.29	0.0094*

Values were compared using paired *t* tests.

* $P < 0.05$.

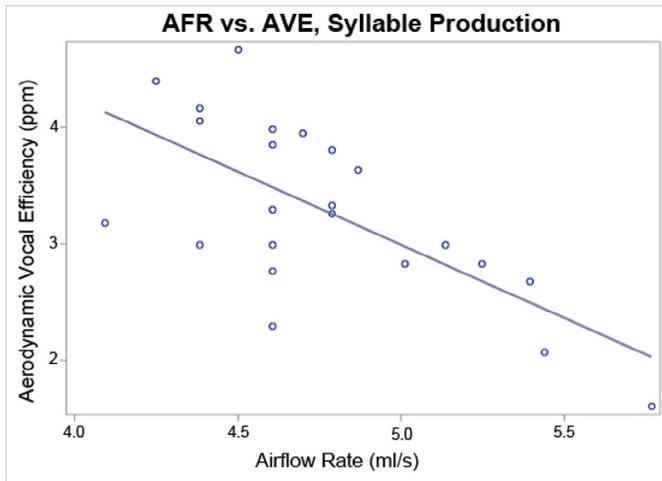


FIGURE 2. Linear regression analysis of log-transformed data comparing airflow and efficiency during syllable production. Results were statistically significant, showing that a 10% increase in airflow resulted in a 13% decrease in efficiency with pressure held constant ($\beta = -1.465$; 95% CI = $-2.088, -0.842$; $P < 0.0001$).

association (that was not statistically significant) was present between Ps and AVE in both syllable and sentence production ($P = 0.0583$ and $P = 0.5264$, respectively). During syllable production, a 10% increase in Ps results in a 7.7% increase in AVE when AFR is held constant ($\beta = 0.780$; 95% CI = $-0.030, 1.591$; $P = 0.0583$). During sentence production, a 10% increase in Ps results in a 3.3% increase in AVE when AFR is held constant ($\beta = 0.340$; 95% CI = $-0.760, 1.441$; $P = 0.5264$). No statistically significant interaction effects between Ps and AFR were seen on linear regression analysis.

For syllable production, an increase of 1 cm H₂O in Ps increases AVE by 12 ppm ($P = 0.1745$), and an increase of 1 mL/s in AFR increases AVE by 0.22 ppm ($P = 0.5854$). For sentence

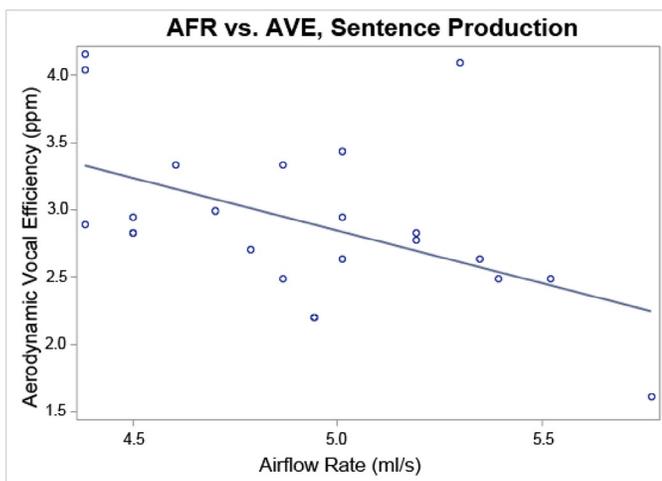


FIGURE 3. Linear regression analysis of log-transformed data comparing airflow and efficiency during sentence production. Results were statistically significant, showing that a 10% increase in airflow resulted in an 8% decrease in efficiency with pressure held constant ($\beta = -0.879$; 95% CI = $-1.585, -0.174$; $P = 0.0171$).

production, an increase of 1 cm H₂O in Ps decreases AVE by 6 ppm ($P = 0.3050$), and an increase of 1 mL/s in AFR decreases AVE by 0.38 ppm ($P = 0.1104$).

DISCUSSION

The purpose of this study was to determine if aerodynamic measures of Ps, AFR, and AVE differ when normal speakers are repeating a series of syllables or a short sentence when speaking at a comfortable effort level. Having the subject speak at a comfortable effort level is important to most closely reproduce real-world speech. The results indicated a significantly higher AVE during syllable production and significantly higher Ps and AFR during sentence production. Previous studies using auditory-perceptual measures have not provided a clear consensus as to whether repeated syllables or running speech offers a gold standard for judging vocal efficiency.¹²⁻¹⁴ Some studies have compared syllable and sentence production, but analyses were performed subjectively.⁷ This study applied objective aerodynamic analysis to the evaluation of syllable and sentence production, giving it the advantage of quantitative measurement.

The values for Ps and AFR seen in sentence production are larger than those in syllable production. One explanation for this finding could be that subjects are taking a larger breath before beginning the voice task, as this study did not control for the subjects' breath sizes. In the present study, subjects were simply instructed to speak at a comfortable effort. The increase in Ps and AFR could also account for the decreased AVE seen in sentence production, as there is an inverse relationship between Ps/AFR and AVE.

The need for more careful enunciation in producing a sentence *versus* repeating syllables may affect the aerodynamics of voice production. That is, it could be that subjects' comfortable speaking effort when producing a sentence is higher than that for producing syllables. Based on linear regression, if one holds Ps constant, the higher AFR during sentence production appears to be responsible for the decreased AVE seen during sentence production. Other factors, such as vocal effort or familiarity with the task, may have contributed to AVE.

Several factors may contribute to the higher AVE observed in syllable production compared with sentence production. First, syllable production represents invariant effort in phonation, whereas sentence production involves rapid and frequent changes in phoneme structure. Second, syllable production may be easier to standardize, whereas sentence production may be heavily influenced by factors such as dialect, cognition, and region.⁷

The data collected in this study tended to have equal or slightly lower means for Ps and AFR than those measured in previous studies of healthy subjects measuring syllable production at subjects' most comfortable speaking level.^{10,15} However, these studies were limited to syllable production alone and do not have data on subjects' sentence production measures.

The standard deviations for syllable and sentence productions were similar for Ps and AFR, showing similar variability between subjects for both tasks. The values for Ps and AFR are in agreement with previous studies done on normative data obtained via syllable production using the PAS system. Zraick et al reported higher values of AVE than those of the current study.

However, both studies show large standard deviations for AVE. Additionally, the differences in AVE may be related to a relatively large number of females in the present study *versus* a more equal distribution of males and females in the Zraick et al study.¹⁶

This study does have its limitations. It must be kept in mind that these AFRs were true for the subjects in this study only, who were healthy and without voice complaints, and may not hold true for subjects with voice disorders. Further studies of older and voice-disordered patients may provide further evidence about the aerodynamics of vocal efficiency. Results from healthy voices may not always be applicable to pathologic voices as they may represent profiles from two significantly different populations. A study using cepstral peak prominence and smoothed cepstral peak prominence analyses found significant difference in normal and pathologic voice qualities in Iranian adults.¹⁷ The need to establish the range of aerodynamic variations remains for both normal and pathologic voices.

Other potentially confounding factors include subjects' effort levels and laryngeal structure. Subjects were asked to speak at their normal, comfortable effort level, but it is difficult to rigorously control for this variable. It could also be that alternate mechanisms, such as laryngeal architecture outside of the true vocal folds, could be playing a role in the discrepancy between perceived and measured voicing efforts, which were not measured in this study.^{18,19}

In this study, no attempt was made to have speakers control for lung volume, as has been seen in other studies.²⁰ Further, because of the limited number of male participants in our population, it was not possible to address differences between male and female subjects statistically. However, previous work has found there to be no significant differences in AVE between male and female subjects repeating a /pa/ syllable task.²¹

CONCLUSION

The decision of whether to use syllable or sentence production to measure voice aerodynamics is key to accurately evaluating appropriate treatment methodologies. When healthy adult subjects speak at their usual, comfortable effort level, Ps and AFRs were higher when producing sentences *versus* syllables. These differences between syllable and sentence production could be a sign of truly differing efforts, indicating that simulated speech (through sentence production) may be a more reliable method of assessing real-world performance. These data suggest careful interpretation of syllable-elicited data is needed, as they may underestimate the effort being used by normal speakers and possibly also those with voice problems. This preliminary study of voice efficiency in normal speakers provides a basis for further aerodynamic studies of patient populations.

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