Airflow Patterns of Running Speech in Patients With Voice Disorders

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Summary: Objective. Aerodynamic measures of voice have historically been acquired using sustained phonation tasks. This study seeks to determine whether there are differences in airflow during sustained phonation (MFs), in running speech (MFrs), or during phonation in running speech (MFvrs). We also seek to determine whether these patterns are diagnostically significant.

Methods. Data were collected on 40 subjects (15 men, 25 women), ages 20–79, with a mean age of 53 in this prospective study. All participants received a comprehensive videostroboscopic evaluation and were deemed appropriate for voice evaluation and trial therapy. The Phonatory Aerodynamic System 6600 was used for data collection. The *Comfortable Sustained Phonation* and *Running Speech* protocols were used for data acquisition. Patient diagnoses were divided into five subgroups: benign lesions, vocal fold paralysis or paresis, muscle tension dysphonia, edema or laryngitis, and chronic cough. Statistical methods such as analysis of variance and Tukey tests assessed pairwise differences in the airflow rate. Pairwise Tukey multiple comparisons of means testing using a 95% family-wise confidence level were completed to determine the interrelationships of the pairs.

Results. Differences were found among airflow measures (P value = 0.0152), pairwise comparisons of MFs-MFvrs pair (P value = 0.012), and diagnosis. No significance was found in MFs-MFrs (P = 0.051) or MFvrs-MFrs (P = 0.94) pairs. Mean flow rates were higher than the norms in MFs. The overall range of mean airflow was similar to those of published norms.

Conclusion. Assumptions about mean airflow of connected speech should not be made based on sustained phonation tasks alone. No salient diagnostic characteristics were found by diagnosis.

Key Words: Aerodynamic–Voice assessment–Airflow–Running speech–Voice disorders.

INTRODUCTION

Voicing occurs as the result of conversion of aerodynamic energy to acoustic energy. Therefore, it stands to reason that efficient aerodynamic to acoustic energy conversion needs to occur for optimal voicing.[1,2] Granqvist et al[3] posit that a fundamental aspect of sound generation is the relationship between the transglottal airflow and the resulting vibration of the vocal folds. The efficiency of this conversion by means of the pulsating transglottal airflow has been shown to be dependent upon subglottal pressures, the vibratory characteristics of the vocal folds (ie, length, mass, and stiffness pliability, approximation, and impact forces), as well as upstream resonance requirements as well as influences of co-articulation.[4–6]

Considering that airflow is essential for voicing to occur, it is curious that there is a paucity of research in the scientific literature on the nature of airflow as it relates to voicing in general and running speech in particular. Studies of the aerodynamics of vocal production have evaluated the role of the respiratory or chest wall complex[7–12]; comparison of subglottal pressure in normal subjects and those with vocal fold polyps using an airflow interruption method[13,14]; subglottal system consisting of subglottal pressure, oral airflow, and audio signals[15]; subglottal pressure in relation to loudness control[16–20]; aerodynamic properties of phonation postsurgical intervention[21]; and estimated subglottal pressure and mean airflow as a potential marker for specific voice disorders.[22–29]

The studies on the aerodynamics of running speech have focused on breath groups alone[30]; breath groups in conjunction with measures of lung volumes[31]; glottal airflow and lung volume using an imbedded phonatory target[32]; or breath groups in conjunction with measures of duration of the total segment as well as inspiration and exhalation.[28] Stathopoulos[33] measured the effect of consonant type on airflow within a consonant-vowel-consonant target imbedded in a larger short sentence context, that is, "say ___ again" with the neutral *swa* /ʌ/ as the target vowel. Her findings indicate there may be an effect of the manner of the consonant (ie, stop, fricative, affricate, nasal, liquid, or glide) on airflow. In a later study, Sapienza and Stathopoulos questioned whether speech tasks affect acoustic and aerodynamic measures. They ask ". . . is the function of disordered and normal voice during vowel prolongation generalizable to connected speech?"[34(p413)].

Historically our understanding of the acoustic and aerodynamic properties of phonation has been based almost exclusively on sustained vowel samples. This is understandable from an aerodynamic (airflow) perspective because running speech is a constantly moving target. In sustained phonation, a great deal of information can be extracted from a relatively stable segment. This is not possible in running speech. The airflow during connected speech is constantly shifting in response to the nature of the consonants (voiced and voiceless, stop, fricative, nasal, or liquid), as well as the changing shape of the vocal tract by the

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vowels and co-articulation effects. In addition, each phonatory segment will vary depending on the rate, intensity, pitch inflection, and duration of the speech. To date, there have been no published norms for mean airflow during running speech. Existing normative data on mean airflow rate is currently based on sustained phonation tasks.

Several different methodologies have been used to determine mean airflow. Holmberg et al[16] derived mean airflow from the short voiced segment following the /p/ in the repeated /pa-pa-pa/ or /pi-pi-pi/ task commonly used to determine subglottal pressure. Zraick et al[35,36] derived mean airflow using a sustained phonation task. Both methods use a facemask coupled to a pneumotachometer with an integral calibrated microphone placed firmly over the mouth and nose. In the airflow interruption method used by Holmberg, a small diameter airflow tube is inserted into the airflow mask, whereas the sustained phonation protocol used by Zraick measures airflow without the addition of the airflow tube. The mean airflow during sustained phonation determined by Holmberg et al[16] was (0.19 ± 0.07), which is higher than the means determined by Zraick et al[35,36] for comparable age and gender (0.13 ± 0.07). Based on these results, it appears as though the protocol used to determine mean flow rate for sustained phonation is important, especially when comparing mean flow rate on sustained phonation with that of running speech. Clinically then, the question arises whether one can extrapolate information within patient about running speech based on data collected only in the simpler context of sustained phonation.

The current prospective study of the aerodynamics of phonation addresses two questions raised in a previous retrospective study Gilman et al.[29] First, can intrasubject inferences be made about airflow in running speech based on data gathered during sustained phonation? Second, because several of the studies cited above[23–28,34] suggest that measures of mean airflow may be diagnostically significant as a marker for vocal fold pathologies in their specific populations, is it reasonable to ask whether there are in fact diagnosis-specific characteristics of airflow during running speech based on mean airflow of the entire segment or mean airflow during phonation only (eliminating voiceless segments)?

RESEARCH QUESTIONS

Question 1 was divided into two parts to reflect the differences between the mean flow parameters measured as well as the differences, if any, between running speech in general and the voiced segments only.

(1a) Do differences exist between mean airflow of sustained phonation (MFs), of running speech (MFrs), and voiced segments only during running speech (MFvrs)?

(1b) In the context of running speech, do differences exist between measures of mean airflow during running speech in general (ie, with voice and voiceless sounds) (MFrs) compared with the voiced segments only (MFvrs)?

Question 2: The second research question addressed here compares aerodynamic measures in running speech across the patient population to determine whether there are aerodynamic markers related to airflow patterns of respiration (specifically volume of inspiration and exhalation) that are diagnosis-specific.

METHODS

This study was approved by the Emory University Institutional Review Board.

Fifty-three patients were enrolled in this study. All participants had received a comprehensive videostroboscopic evaluation by a laryngologist and were deemed appropriate for referral for acoustic and aerodynamic voice evaluation and trial therapy.

Inclusion criteria included participants 19 years of age or older with a primary diagnosis of dysphonia secondary to benign vocal fold lesions, scar, laryngitis or edema of the vocal folds, paralysis or paresis, muscle tension (primary or secondary), or chronic cough. Exclusionary criteria included patients with significant comorbidities such as autoimmune disorders, malignancies, pulmonary-respiratory, or cardiac disorders.

Of the 53 patients initially enrolled in the study, complete data were collected on 40 subjects, 15 men (age 39–69) and 25 women (ages 20–79). Mean age was 53.

Protocol or procedures

Aerodynamic measures were collected using the Phonatory Aerodynamic System 6600 (PAS6600), (KayPentax, Montvale, NJ), a hardware and software system used clinically for measurement of aerodynamic measures of airflow, inspiratory, and expiratory volume in addition to acoustic and durational measures of phonation. It consists of a facemask coupled to a pneumotachometer with an integral calibrated microphone. Calibration was completed prior to data acquisition for each subject according to manufacturer's guidelines. The intraoral tube used for measuring intraoral pressures was not used for this study as suggested by manufacturer's guidelines for mean airflow in sustained phonation.

Subjects were assessed for aerodynamic measures of mean flow rate on sustained phonation (MFs) and running speech (MFrs). Mean flow rate during running speech was further broken down to mean flow rate during phonation only (MFvrs) to determine whether the voiceless sounds statistically alter mean flow rate during running speech.

All protocols required participants to be seated with the airflow mask placed securely over the nose and mouth to create a complete seal. The airflow mask was capped, as the intraoral tube was not used. To acquaint subjects with the required sustained phonation task, subjects were asked to sustain /s/, /z/, and /a/ as long as comfortable without the airflow mask.

Two protocols were used for this study. The *Comfortable Sustained Phonation Protocol* was used for acquisition of mean airflow during sustained phonation. The subjects were asked to sustain an /a/ at a comfortable pitch and loudness for 5–10 seconds. The *Running Speech Protocol* was used for acquisition of mean airflow during running speech. For this task subjects were asked to describe the *Cookie Theft Picture*.[37]

Data analysis

The PAS6600 algorithm generates measures of mean expiratory airflow, peak expiratory airflow, mean airflow during voicing only, expiratory volume, mean inspiratory airflow, peak inspiratory airflow, and inspiratory volume. Data were derived from the entire sample.

Data were collected and analyzed on mean airflow rates as well as on inspiratory and exhalatory volumes for sustained phonation (MFs) and during running speech (MFrs). The PAS algorithm provides additional data on phonation only during running speech (MFvrs).

Patient diagnoses were divided into five subgroups for data analysis of diagnosis-specific markers during running speech: group 1 (n = 9/40) benign lesions or scar; group 2 (n = 9/40) vocal fold paralysis or paresis; group 3 (n = 8/40) primary muscle tension; group 4 (n = 11/40) edema or laryngitis; and group 5 (n = 3/40) chronic cough.

Statistical analysis

Statistical analysis for the difference in the overall mean airflow rate across MFs, MFrs, and MFvrs, as well as difference across diagnostic groups of mean flow in MFvrs, were assessed by analysis of variance. Tukey tests were conducted subsequently to assess pairwise differences in the airflow rate. Pairwise Tukey multiple comparisons of means testing using a 95% family-wise confidence level were completed to determine the interrelationships of the pairs.

RESULTS

Research questions

(1a) Do statistical differences exist across all subjects between mean airflow of sustained phonation (MFs), running speech (MFrs), and voiced segments during running speech (MFvrs)?

(1b) Do statistical differences exist across all subjects between measures of mean airflow during running speech (MFrs) in general (ie, with voice and voiceless sounds) compared with phonation only (MFvrs)?

Significant difference (*P* value = 0.0152) was found when comparing the overall mean airflow rates of MFs, MFrs, and MFvrs. Significant difference was also noted between the airflow rate of the all voiced MFs and MFvrs (*P* value = 0.021), whereas there was not sufficient evidence to detect significant difference between the airflow rate on MFs-MFrs pair (*P* = 0.051) or MFvrs-MFrs (*P* = 0.94) pair.

As expected, the mean airflow of MFs in our study population is higher than the overall norms published by Zraick et al.[35,36] Manual examination of the results of our study was applied to the differences broken down by age and gender to determine whether or not differences exist in our study population that mirror the overall differences when age and gender are not taken into account. In our study the mean MFs was consistently higher in each group than either of the running speech measures. In running speech, the means and standard deviations were identical in the 40-year-old and above female group and for the 60-year-old and above male group. Only a minor difference was noted in the 40- to 59-year-old male group (MFvrs 0.15, std 0.03) versus MFrs (0.16, std 0.03). The 18- to 39-year-old male group is not considered here, as there was only one subject. Standard deviations were lower across all gender and age groups. The comparative breakdown can be seen in Table 1.

Question 2: Do diagnosis-specific aerodynamic markers exist for mean airflow or mean inspiratory and exhalatory volumes?

There was not sufficient evidence to detect significant differences by diagnosis in aerodynamic measures of mean exhalatory airflow (MFrs and MFvrs) during phonation in running speech. There was no significance when overall volumes of inhalation or exhalation were analyzed by diagnosis.

DISCUSSION

For purpose of comparison with the norms of sustained phonation published for the PAS6600,[35,36] data are presented by age and gender. Of the 41 parameters examined, only a few showed age and gender effects. No age and gender effects were found for mean airflow during sustained phonation. A previous study by Goozee et al[38] found an age effect for sustained /i/ only. In the published norms, Zraick et al emphasize that their findings

TABLE 1.
Comparative Mean (Std) Airflow: Norms and Study Population

Zraick et al Norms: Mean Airflow During Sustained Phonation (MFs)						
	Female			Male		
Age	18–39	40–59	60–89	18–39	40–59	60–89
Norm n	n = 47/157	n = 22/157	n = 20/157	n = 32/157	n = 19/157	n = 18/157
MFs Norm	0.13 (0.08)	0.15 (0.07)	0.10 (0.06)	0.13 (0.08)	0.11 (0.05)	0.15 (0.04)

Study Population: Mean Airflow for All Conditions (MFs, MFvrs, MFrs)						
	Female			Male		
Age	18–39	40–59	60–89	18–39	40–59	60–89
Study population n	n = 4/25	n = 13/25	n = 8/25	n = 1/15	n = 7/15	n = 7/15
MFs	0.16 (0.09)	0.17 (0.11)	0.2 (0.13)	0.02	0.18 (0.05)	0.17 (0.11)
MFvrs	0.08 (0.07	0.12 (0.08)	0.12 (0.03)	0.01	0.15 (0.03)	0.15 (0.07)
MFrs	0.10 (0.07)	0.12 (0.08)	0.12 (0.03)	0.04	0.16 (0.03)	0.15 (0.08)

TABLE 2.
Comparative Range of Airflow: Norms and Study Population Between Female and Male

Zraick et al Norms: Range of Airflow During Sustained Phonation (MFs)						
	Female			Male		
Age	18–39	40–59	60–89	18–39	40–59	60–89
Norm n	n = 47/157	n = 22/157	n = 20/157	n = 32/157	n = 19/157	n = 18/157
MFs norm	0.01–0.30	0.04–0.27	0.03–0.27	0.04–0.22	0.03–0.43	0.04–0.22

Study Population: Range of Airflow for All Conditions						
	Female			Male		
Age	18–39	40–59	60–89	18–39	40–59	60–89
Study population n	n = 4/25	n = 13/25	n = 8/25	n = 1/15	n = 7/15	n = 7/15
MFs	0.05–0.26	0.04–0.39	0.02–0.46	0.04	0.09–0.25	0.05–0.32
MFvrs	0.03–0.19	0.01–0.26	0.06–0.17	0.01	0.09–0.20	0.01–0.29
MFrs	0.04–0.21	0.03–0.23	0.07–0.16	0.04	0.11–0.21	0.01–0.25

are preliminary, but suggest that in general age and gender should be taken into account when using the PAS system until more comprehensive studies can be completed.

The statistical analysis was based on the total N, but our analysis has taken into account the potential effect of age and gender on the parameters investigated. Because only five patients (four women and one man) fell into the 18–39 age range, this age range is not included in our comparative analysis. The N for the other age groups is large enough to suggest trends.

As could reasonably be expected, the mean for MFs (sustained phonation) in the disordered study population was higher than the published norms by age and gender across all groups. In addition, the mean MFs was also higher than either of the running speech measures. When MFs was compared with running speech in the older female group, that is, over 40 years of age, and in the male group, 40–59 years of age, the running speech measures (MFrs and MFvrs) were lower than the mean airflow MFs within the study population and the published norms. The published MFs norms were similar only in the male (60+) group. These findings provide evidence that mean airflow measures derived from sustained phonation tasks may not be an appropriate measure to predict airflow during running speech.

It was interesting that the overall range of airflow during sustained phonation in both the Zraick study as well as the current study was surprisingly wide. The range within the normal population was found to be as little as 0.01 l/s to a high of 0.43 l/s. The ranges were almost identical within the study population (0.01–0.46 l/s). During running speech however, the upper range across all groups did not exceed 0.29 l/s in either MFrs or MFvrs. Ranges two standard deviations below the mean are present in MFs in the normal population and were found in all conditions (MFs, MFrs, MFvrs) in the 18- to 59-year-old female groups and in the 60-year-old and above male group. In the 40- to 59-year-old male group, the range fell only one standard deviation below the mean. This comparison with the normative data suggests that there is a segment of the normal population whose mean airflow is well below the mean, yet the individuals do not complain of any voice problems. The clinical question arises whether these patterns when found in the disordered population are part of the pathology or are simply long-held habituated patterns. Our findings agree with those of Goozee et al[37] who remarked on the wide variance of individual ranges, especially phonatory airflow, making it difficult to determine what constitutes abnormality in these measures (Table 2).

These preliminary results suggest that airflow during sustained phonation is not necessarily the same as mean airflow during running speech whether in the normal or disordered population. Differences have been found when comparing the overall mean airflow across the different speech or phonation tasks. Pairwise comparisons suggest that more nuanced relationships may be in play. No significance was found within the study population in the overall comparison of MFs-MFrs pair (sustained phonation-running speech) or the MFvrs-MFrs pair (running speech with and without voiceless sounds). However, significance was suggested between the MFs-MFvrs pair. Because the common denominator for this pair is voicing, it would seem reasonable to expect no difference. However, it is well known that vocal fold lesions or other pathologies can have a significant impact on running speech depending on phonemic content, coarticulation, or effects of prosody, rate, or other linguistic aspects of speech. Not all pathologies influence airflow dynamics in sustained phonation.

No statistical significance was found with respect to whether airflow measures of mean airflow or expiratory-inspiratory volume have diagnostically significant markers.

At first glance these findings appear to be counterintuitive. One would expect, for example, that individuals with vocal fold paralysis would have increased mean airflow during running speech as well as sustained phonation, and someone with severe muscle tension or vocal fold stiffness might exhibit decreased mean airflow. However, the human body is amazing in its ability to compensate. The presence of laryngeal pathology does not necessarily change innate or habituated patterns of respiratory-phonatory coordination, prosody, or rate of speech. The wide range of airflow by diagnostic groups makes this clear, strongly suggesting that other significant linguistic factors play a role. Additional evidence can be found in close examination of the patterns of airflow. Close examination of individual respiratory

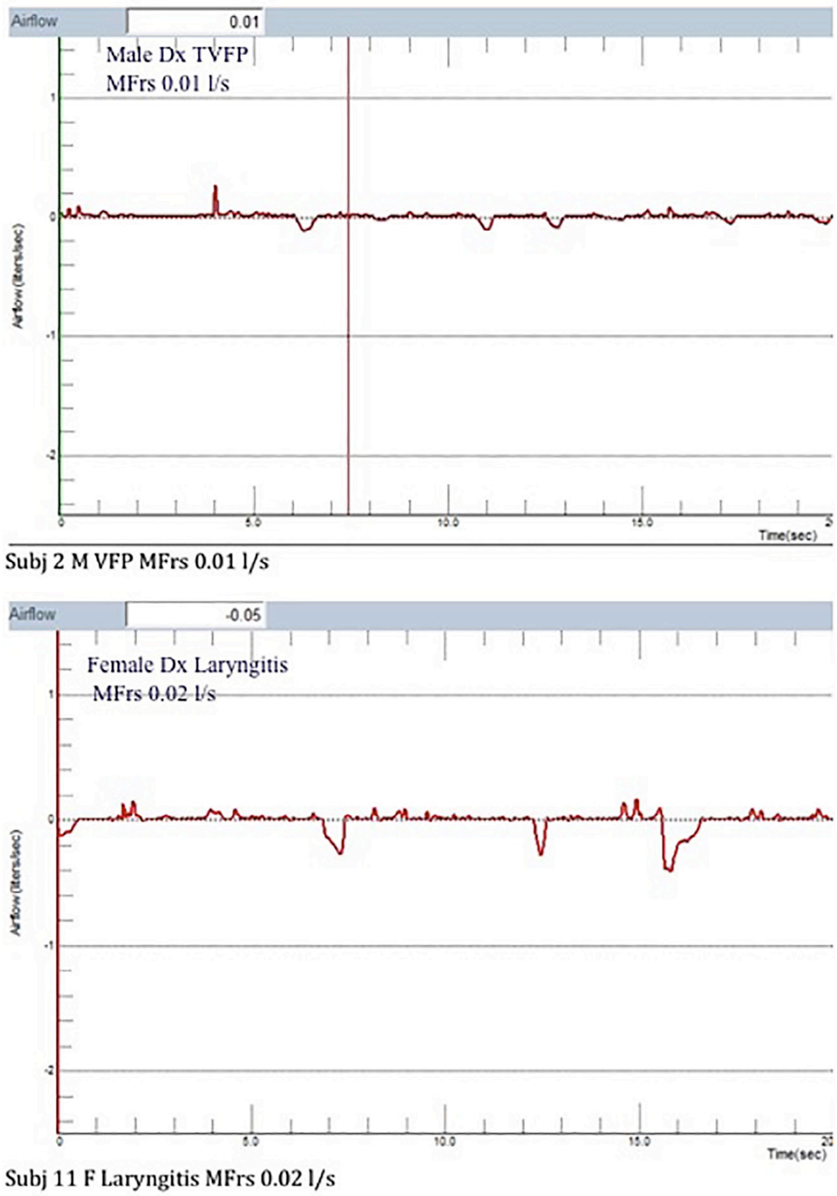

FIGURE 1. Breath holding as seen by minimal exhalatory and inhalatory airflow. TVFP, true vocal fold paralysis; VFP, vocal fold paralysis.

patterns suggests several patterns of respiratory-phonatory coordination. The images below provide visual documentation of some of these patterns. The question arises whether these are pre-morbid habituated patterns or compensatory patterns related to the existing pathology. The apparent overlap of range with those in the normal population also suggests that these may likely be pre-morbid habituated patterns.

Figure 1 and Figure 2 show two examples of common patterns. Figure 1 compares patients with mean running speech flow rates of 0.01 l/s and 0.02 l/s, respectively. The first subject is a man with a diagnosis of paralysis or paresis and the second subject is a woman with a diagnosis of laryngitis. With respect to both expiratory and inspiratory airflow, they appear very similar yet their diagnoses would suggest very different flow patterns.

Figure 2 shows a woman with muscle tension dysphonia with normal airflow during speech followed by a large expiratory spike during a short phonation break in the middle of run-on speech, which was then followed by a large inhalatory pause. Note the high expiratory peak at the arrow that occurs at the moment of cessation of phonation in the absence of inhalation. Additional large expiratory peaks seen throughout the sample are most likely related to high expiratory airflow associated with consonants or retarding the airflow during phonation. The subject's peak expiratory airflow is elevated (1.66 l/s). It is notable that her first breath does not occur until about 14 seconds into speaking at which time she takes a large breath before continuing.

Additional patterns frequently observed in other study subjects include deep inhalation followed by large expiratory peak prior to onset of phonation, inhalation, which was then followed by break holding, that is, no movement of the airflow prior to onset of phonation or breath holding during pauses in phonation among others. Whether or not these respiratory-phonatory

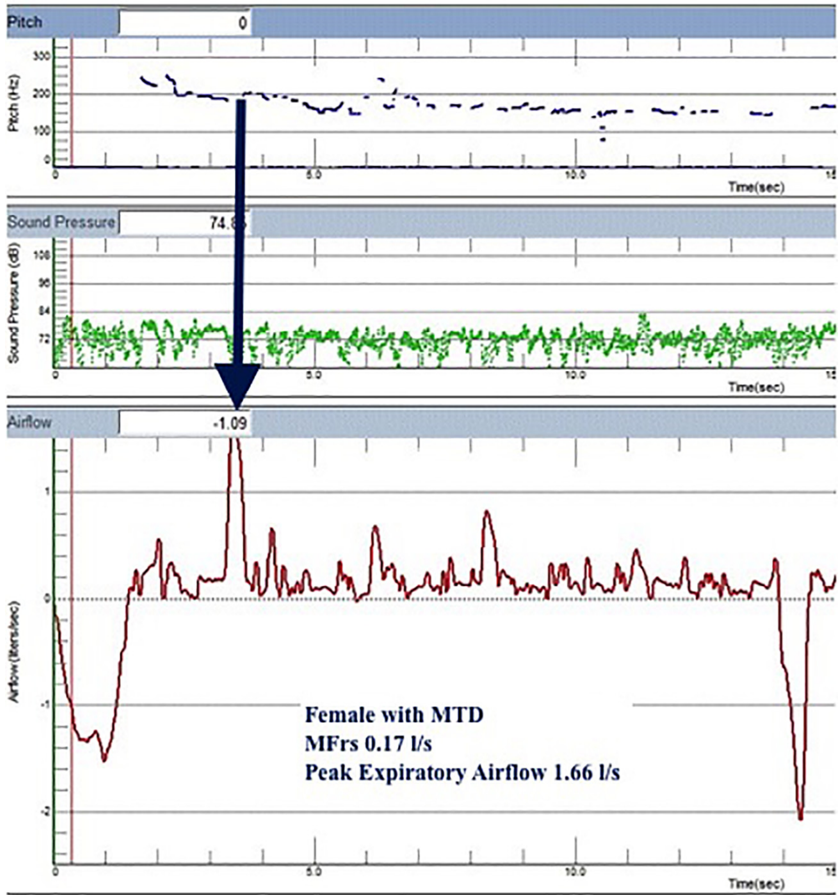

FIGURE 2. Increased peak airflow on exhalation at phonation offset.

patterns are part of compensatory behavior due to patient's current pathology or disorder is impossible to determine. However, many patients report these are familiar patterns, suggesting some potential exacerbation resulting from the voice problem, but not caused by the voice problem.

Our findings that MFs in the study population are higher than the published norms taking into account variations for age and gender are consistent with the results of our previous larger retrospective study of the aerodynamic properties of sustained phonation.[29] A larger study of running speech (MFrs and MFvrs) in patients with voice disorders is needed to be able to confirm the present findings.

Limitations

Forty patients were recruited for this study. In light of the possible statistical importance of gender and age suggested by Goozee et al,[38] statistical analysis of the total group can only suggest trends rather than definitive conclusions. However, the examinations of the age/gender group means are in line with our conclusions.

In addition, it could be argued that the running speech task consisting of a description of the *Cookie Theft* picture[37] resulted in too many variables when comparing MFrs and MFvrs. This task could have used a standard reading passage for greater phonemic consistency. However, it was felt that spontaneous speech would provide a more accurate sample of the patients' speech patterns, including the habituated linguistic characteristics of prosody, rate, intonation, etc.

CONCLUSION

The results of this study suggest that differences between the mean flow rate of sustained phonation tasks and that of running speech should be taken into consideration during clinical evaluations. Although some correlation was present, validated norms for mean flow rate during running speech in structured reading tasks as well as spontaneous speech are needed to address issues of habituated speaking patterns and the true effect of voice disorders on airflow during speech. Preliminary comparisons of the range of mean flow rates among the non–voice-disordered population and those with benign voice disorders suggest there may be little difference in the two groups. However, from a therapeutic perspective, evaluation of the patterns of airflow can be very helpful in optimizing vocal function, whether or not the patterns are due to long-standing habituated patterns or compensatory patterns.

Further research is needed to clarify these points.

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