Whisper and Phonation: Aerodynamic Comparisons Across Adduction and Loudness

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Summary: Introduction. Whisper is known to be produced by different speakers differently, especially with respect to glottal configuration that influences glottal aerodynamics. Differences in whisper production and phonation types imply important linguistic information in many languages, are identified in vocal pathologies, are used to communicate mood and emotion, and are used in vocal performance.

Objective. The present study focused on investigating the aerodynamic differences between whisper and phonation at different loudness and adduction levels.

Methods. Three men and five women between 20 and 40 years of age participated in the study. Smooth syllable strings of the syllable /baep:/ were whispered and phonated at three different loudness levels (soft, medium, and loud) and three voice qualities (breathy, normal, and pressed).

The voice qualities are associated with different adduction levels. This resulted in 18 treatment combinations (three adduction levels × three loudness levels × two sexes).

Results. A regression analysis was performed using a PROC MIXED procedure with *SAS* statistical software. Under similar production conditions, subglottal pressure was significantly lower in whisper than in phonation in 10 of 18 combinations, mean glottal airflow was significantly higher in whisper than in phonation in 13 of 18 combinations, and flow resistance was significantly lower in whisper than in phonation in 14 of 18 combinations, with the female subjects demonstrating these trends more frequently than the male subjects do. Of importance, in general, compared with phonation under similar production conditions, whisper is not always accompanied by lower subglottal pressure and higher airflows.

Conclusion. Results from this study suggest that the typical finding of lower subglottal pressure, higher glottal airflow, and decreased flow resistance in whisper compared with phonation cannot be generalized to all individuals and depends on the "whisper type." The nine basic production conditions (three loudness levels and three adduction levels) resulted in data that may help explain the wide range of variation of whisper production reported in earlier studies.

Key Words: Whisper–Phonation–Aerodynamics–Loudness–Adduction.

INTRODUCTION

Whispering is a socially significant form of communication. Cirillo[1] surveyed 350 people to find out when and why people whispered and found that 38% of the subjects indicated that they whisper in private, often quite frequently. People whisper to (1) avoid disturbing someone (eg, in "silence zones" of libraries and hospitals), (2) communicate a secret message to a specific person and confirm affiliation with the person, (3) initiate a playful encounter or for fun, and (4) attract the attention or induce curiosity in members of an audience.[1] Actors and singers use "stage whisper" for special effects,[2] and children whisper during play. Patients with aphonia communicate by whispering.[3] Furthermore, "soft whisper" is therapeutically prescribed for some patients with vocal pathologies.[4] The study of this unique physiological action of the larynx (whispering) is important to the understanding of certain pathologic vocal phenomena, such as aphonia and vocal fold paralysis.

Whisper especially is known to be produced by different speakers differently. Some researchers suggest that there is high inter- and intra-subject variation during whisper production, especially with respect to glottal configuration that influences glottal aerodynamics.[5–8] At the level of the glottis, individuals demonstrate various configurations such as no vocal fold contact, various degrees of closeness of the two vocal folds, and compression of the anterior and middle thirds or the entire length of the membranous vocal folds. At the level of the supraglottis, there may be various degrees of false vocal fold gap or anterior-posterior displacement of the epiglottis and arytenoid cartilages. The high variability in whisper production data may be related to how the individual whispers, that is, with what loudness and adduction levels. In general, whisper may be thought of as "soft," but "loud whisper" or "stage whisper" may be used during performance and by individuals with voice disorders. When one whispers loudly along with vocal strain as in severe muscle tension dysphonia, glottal adduction may be increased as well. The loudness and adduction variations in whisper production should affect the acoustic and aerodynamic characteristics of whisper. Thus, understanding the effects of intentionally varying loudness and adduction on acoustic and aerodynamic measures may help to explain the variability of these measures in the clinic and in earlier whisper studies.

To our knowledge, only two studies have attempted to report the aerodynamic variability in whisper production. Monoson and Zemlin compared two types of whisper (quiet and loud or forced

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whisper) with breathy and normal phonation in five female young adults.[9] In their study, mean flow was the greatest for forced whisper (0.328 L/s) followed by breathy phonation (0.258 L/s), quiet whisper (0.203 L/s), and normal phonation (0.120 L/s). These mean airflow values for whisper are lower than the mean airflow values (0.90–1.71 L/s) for whisper found by Sundberg et al.[10] This difference could be due to the nature of the subjects used in the studies. Monoson and Zemlin investigated young adult female subjects, whereas Sundberg et al investigated one subject, a 69-year-old man who was 6 foot 7 inches tall, thus suggesting that the size of the larynx may make a large difference in subsequent airflow values. In addition, gender effects have been found for mean glottal airflow, with male subjects demonstrating significantly greater airflow rates than female subjects do.[11–16]

In their study, Sundberg et al[10] examined aerodynamic and glottal measures for different levels of loudness and adduction in whisper. Their subject produced four types of whisper: hyperfunctional (more compressed), neutral, hypofunctional (more abducted), and post-phonatory, at three loudness levels (soft, medium, and loud). Measurements were made of the glottal area, glottal flow, and subglottal pressure (Ps) (via tracheal puncture). For this subject, whisper was produced with a wide range of numerous measures, namely, Ps, 1.3–17 cm H_2O; glottal flow, 0.9–1.71 L/s; glottal area, 0.065–1.76 cm^2; and glottal perimeter, 1.09–1.76 cm. Relatively highly adducted glottal configurations resulted in whisper that tended to have higher Ps and lower glottal areas and flows than for relatively highly abducted glottal configurations during whisper, with neutral and post-phonation whisper values in between. In more adducted and abducted whisper, the glottis assumed a rectangular or elliptical shape for this subject. Prior investigations of glottal configuration during whisper revealed vocal folds with straight medial edges or a glottis with a toed-in configuration.[6] Sundberg et al[10] found that glottal flow changed more for small changes of area when the area was already small than when it was already large (see also Scherer et al[17]). The authors derived an equation for whisper aerodynamics (relating glottal flow, Ps, and glottal area), as well as an equation involving nondimensional terms (pressure coefficient and Reynolds number). Although the study by Sundberg et al[10] is the first of its kind to offer generalized expressions for whisper aeromechanics because of the wide range of whisper conditions, the subject sampling (one subject) limits broader issues of individual differences.

According to Luchsinger and Arnold,[3] whisper differs from phonation in a number of ways: (1) The glottis shows the shape of an inverted Y and the vocal folds are incompletely touching over their anterior-posterior length. (2) The vocal fold tension is much lower than in phonation, and the folds do not vibrate; as a result, the escaping air is set into non-periodic frictional turbulence so that a noise is produced instead of a tone with periodic vibrations. (3) The expiratory air volume is greatly increased; whispering is therefore "much more strenuous" than speaking in a normal voice. (4) The subglottal air pressure is much lower than it is during phonation.[3] The current study challenges the latter two assertions.

Netsell et al[15] recorded estimates of subglottal air pressure and mean volume velocity of airflow during phonation from 30 normal adults during repetition of consonant-vowel syllables. Results suggested no gender differences in subglottal air pressure, but men used significantly higher flows than women did in all speaking tasks. Women had greater laryngeal airway resistances than men did for the [i] vowel. Women also had greater resistances during the [i] vowel than during the [*a*] vowel, and the men did not. Thus, it is important to include both male and female subjects in the attempt to explain variability of aerodynamic measures across gender.

The present study is an attempt to obtain the variability of whisper aerodynamics when individuals whisper over a wide range of loudness and adduction levels, and to compare the aerodynamics of whisper productions with phonation also produced over a wide range of loudness and adduction.

METHODS

Subjects

Eight subjects (three men and five women) with an age range of 20–27 years (mean age of 23 years) participated in the study. All subjects were nonsmokers and native speakers of English with no history of voice or speech problems, hearing loss, or professional voice training.

Equipment

A Glottal Enterprises aerodynamic flow mask system (MSIF-2 S/N 2049S; Syracuse, NY) was used to obtain oral air pressure and airflow. Calibrations for pressure and flow were completed for a wide range of flows and pressures, using a calibrated pneumotachograph for calibrating flow and a U-tube manometer for calibrating the oral pressure transducer. A headband microphone system (AKG C-420, AKG Acoustics, Vienna, Austria) with preamplifier (APHEX 107, Aphex Systems, Sun Valley, CA) was used to record the audio signal simultaneously with the aerodynamic recordings. The mouth-to-microphone distance was held constant at 6 cm for all subjects. All signals were simultaneously recorded into a 16-bit DATAQ A/D system (model DI-720 Series, DATAQ Instruments, Akron, OH) and analyzed using custom-written "*Sigplot*" software written in MATLAB code.

Syllables for analysis

Subjects were instructed to produce at least five trials of the five-syllable series of /bæp:/, that is, /bæp:bæp:bæp:bæp:bæp:/, smoothly on one breath for each condition of whisper and phonation. Typically, Ps is estimated from intraoral pressure measured during the production of syllables with voiceless plosives such as /pæp/. Although this is a widely used method for obtaining estimates of Ps, a common source of error in this measurement can occur if the intrasyllable Ps is not constant.[18] Rothenberg[19] described ways to reduce this error, including the use of repeated "/baep/" syllables instead of the more classically used "/pa/." Frazer[20] studied the differences in intraoral pressure for smoothly produced strings of /bi:p:/ and /pi:p:/ and found similar estimates of Ps between them, suggesting that smoothly produced "beep" sequences may be just as useful, or more so, than "peep" sequences for studies estimating Ps, especially in cases where