Spatiotemporal Quantification of Vocal Fold Vibration After Exposure to Superficial Laryngeal Dehydration: A Preliminary Study

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Summary: Objectives. The aim of the study was to evaluate the effects of a superficial laryngeal dehydration challenge on vocal fold vibration in young healthy adults using high-speed video imaging.

Subjects and Methods. In this prospective study, the effects of a 60-minute superficial laryngeal dehydration challenge on spatial (speed quotient, amplitude quotient) and temporal measures (jitter percentage, vibratory onset time) of vocal fold vibration and phonation threshold pressure (PTP) were evaluated in 10 (male = 4, female = 6) vocally normal adults (21–29 years). All measures except the vibratory onset time were measured at the 10 (low) and 80 (high) percent level of their pitch range. The vibratory onset time was obtained at habitual pitch and loudness level. Superficial laryngeal dehydration was induced by oral breathing in low ambient humidity. Prechallenge and postchallenge differences were statistically investigated using *t* tests with Bonferroni correction.

Results. The speed quotient at low-pitch phonation significantly decreased after oral breathing of low ambient humidity. Other spatiotemporal measures and PTP at low and high pitch were not significant after challenge.

Conclusions. Results from this initial study have implications for the use of high-speed video imaging to detect and quantify the subtle changes in vocal fold vibrations after superficial dehydration in healthy individuals. Preliminary findings indicate that superficial dehydration in healthy individuals results in spatial deviations at low pitch. However, further studies are warranted to identify additional spatiotemporal changes in vocal fold vibration after superficial dehydration in normal and disordered populations.

Key Words: Dehydration–Oral breathing–Vocal fold vibrations–High-speed videoendoscopy–Phonation threshold pressure.

INTRODUCTION

Individuals with voice disorders are often recommended vocal hygiene measures such as increased water intake, humidification of ambient air, and limited intake of drying agents such as caffeine, alcohol, and so forth. These recommendations are based on research findings that systemic and superficial dehydration are detrimental to voice production. Systemic and superficial dehydration challenges have been shown to negatively influence phonation threshold pressure (PTP; an aerodynamic measure), jitter and shimmer (acoustic measures), and perceived phonatory effort (a subjective measure of vocal effort), in individuals with normal[1–3] and disordered voice.[4,5] However, there are limited studies investigating dehydration using direct assessment of vocal fold vibrations through laryngeal imaging.[6,7] The goal of this study was a first step to fill this gap in research by quantifying the effects of oral breathing of low-humidity ambient air (hereafter referred as superficial dehydration), on vibratory motion using laryngeal high-speed videoendoscopy.

Previous studies in vocally healthy individuals have largely investigated the effects of challenges involving systemic,[7–9] superficial,[2,10] or combined systemic and superficial[11,12] dehydration on PTP and perceived phonatory effort. PTP and phonatory effort generally were reported to increase with exposure to "dry" conditions (eg, no water consumption, low ambient humidity, mouth breathing, and/or drying medication) when compared to "wet" conditions (eg, heavy water consumption, high humidity, and/or administration of mucolytics). Similarly, acoustic perturbation measures were reported to increase in healthy individuals after mouth breathing of dry air[1] and in amateur karaoke singers after reduced water intake and lack of voice rest.[13] At the kinematic level, the physiological correlates of these phenomena remain speculative, as measures from acoustic and aerodynamic assessments provide only indirect inferences regarding vocal fold vibrations.

Clinically, direct assessments of vocal fold motion using techniques of laryngeal imaging are critical for assessment of vibratory motion. However, limited investigations exist using such techniques to study the influence of exposure to dehydration challenges on direct measures of vocal fold vibrations. Solomon et al (2003)[7] performed visual judgments of videostroboscopic data for glottal closure pattern, supraglottic activity, presence of mucus, color, mucosal wave, amplitude, and symmetry, to evaluate the effects of vocal loading and "systemic" hydration in four adult men. They found reduced vibratory amplitude after dehydration in three of four men on visual judgments of videostroboscopic recordings.[7] However, the effects of superficial dehydration on vibratory motion remain unknown.

Induced dehydration in excised canine larynx setup revealed increased vocal fold stiffness and viscosity,[14,15] PTP,[16] phonation threshold flow,[17] and subglottal pressure for sustained oscillation,[18] as well as decreased voicing efficiency.[16] Dehydrated

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canine larynges also exhibited decreased liquid-to-solid volume and mass ratios.[19] The observed biomechanical changes in vocal fold stiffness and viscosity from superficial dehydration challenges should be observed in spatiotemporal aspects of vocal fold vibration. More specifically, increased stiffness resulting from vocal fold surface dehydration is generally regarded to coincide with increased phonatory effort[10,20] and could result in an increase in the onset time of vocal fold vibrations and a reduction in the amplitude quotient.[21,22] Amplitude quotient is a glottal area waveform derivative measure which has been reported to indirectly reflect vocal fold stiffness. Additionally, it can be safely hypothesized that increased stiffness from superficial dehydration challenges would result in alteration of the opening and closing dynamics of a glottal cycle. These changes in the glottal cycle can be quantified using measures of the glottal area waveform, such as the speed quotient, open quotient, and so forth.

Quantification of cycle-to-cycle spatiotemporal measures and rapid, transient events like vibratory onset time requires the use of laryngeal imaging modalities that capture vocal fold vibrations at high temporal resolution of at least 4000 Hz.[23,24] Additionally, each vocal fold vibratory motion can be quantified separately with high-speed imaging, which can be especially useful to investigate the effects of superficial dehydration in individuals with voice disorders. The aim of this initial study was to identify whether superficial laryngeal dehydration, induced by oral breathing in low humidity, results in changes to the spatial (speed quotient, amplitude quotient) and temporal measures (jitter percentage, vibratory onset time) of vocal fold vibrations based on laryngeal high-speed videoendoscopy, in young healthy individuals without voice disorders.

MATERIALS AND METHODS

Participants

Thirteen vocally normal adults (male = 5, female = 8), age range 21–29 years (mean = 22.85 years), were recruited at the Indiana University, Vocal Physiology and Imaging Laboratory after signing of institutional review board–approved informed consent forms. Participants were included in the study if they had negative histories of vocal pathology, smoking, or respiratory disease. Additionally, all participants were perceptually judged to have normal voice by a certified speech pathologist specializing in voice disorders, using the CAPE-V scale.[25] None of the participants were on any medications, except birth control.

Data from two female participants could not be obtained because of heightened gag reflex. One male subject could not be included in the study because of the severe compression of the glottis during phonation, thereby preventing clear views of the vocal fold margins, necessary for accurate image processing. Hence, the study included data from 10 adults (male = 4, female = 6).

Data collection

Data were collected in a double-walled sound-treated booth before and after the dehydration challenge. The room (12 × 8 × 8 feet) humidity was maintained between 3% and 11% (mean = 5%, Traceable Memory Hygrometer, VWR, Radnor, PA), for the dehydration challenge, using two commercially available dehumidifiers (Goldstar DH404E, 40-pint; LG Goldstar, Englewood Cliffs, New Jersey). The humidity level was kept constant for pretrial and posttrial within subject. This humidity level is lower than the humidity level reported in prior studies on oral breathing, where the humidity was maintained at 20%[10,26] or <30%.[3] Participants breathed ambient room air for 1 hour through their mouth while their nostrils were occluded. Studies investigating the effects of oral breathing of low-humidity air typically report exposure time of 15 minutes,[3,10,27] with one study of 2 hours.[28] One hour was chosen as a reasonable compromise between 15 minutes and 2 hours and to counteract any effects of physiological instability after short-duration exposure.[29]

It is well-known that vocal fold vibrations[30,31] and PTPs[32,33] vary with pitch and loudness of the voice. Hence, before recording the vocal fold vibrations and PTP, each participant's pitch range was obtained using the pitch range program on the real-time pitch module of the *Computerized Speech Lab* (model 4500, PENTAX Medical, Montvale, NJ). The mouth-to-microphone distance was held constant at 6 inches with an angle of 45°. The participants were instructed to glide from the lowest note to the highest note on the vowel /i/, sustaining the lowest and the highest notes for 3 seconds; at habitual loudness. Subsequently, the participants' 10% and 80% pitch levels were calculated from the voice range in semitones because PTP is frequently measured at these pitch levels.[4,27,33] Additionally, previous literature on superficial dehydration has somewhat consistently shown an increase in PTP at high-[2,8] and low-pitch[3] levels; however, there are fewer studies investigating low-pitch levels. For this initial study, high-speed videoendoscopic and aerodynamic recordings were obtained at participants' 10% and 80% pitch levels to evaluate changes in vibratory function at extremes of the vocal range.

For laryngeal imaging, the participants' task was to produce sustained steady-state phonation of the vowel /i/ at 10% and 80% pitch levels and typical loudness. In addition to the sustained phonation task, a laryngeal diadochokinetic task of repeated /i.i.i/ at habitual pitch and loudness with a syllable rate of 1.5 syllables/s was recorded to obtain vibratory onset time. A visual metronome (Seiko DM15 Clip-On Metronome; Seiko Instruments Inc., Japan) was used to elicit the specific syllable rate production. Participants were trained to perform the sustained phonation task and the laryngeal diadochokinetic task before the actual recordings. The laryngeal imaging recordings were acquired with a digital gray-scale high-speed videoendoscopic (PENTAX digital model 9710; Montvale, NJ) system with a sampling rate of 4000 frames/s and a spatial resolution of 512 × 256 pixels for a maximum duration of 4.094 seconds.

The *Phonatory Aerodynamic System* (model 6600; PENTAX Medical, Montvale, NJ) was used to obtain the PTP after appropriate calibration of the equipment. The 10% and 80% pitch levels were used to obtain the PTP. Participants were instructed to produce seven repetitions of the syllable /pi/ as soft as possible, just above a whisper, after training. These productions