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Reducing the Negative Vocal Effects of Superficial Laryngeal Dehydration With Humidification

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Abstract

Objectives—Environmental humidification is a simple, cost-effective method believed to reduce superficial laryngeal drying. This study sought to validate this belief by investigating whether humidification treatment would reduce the negative effects of superficial laryngeal dehydration on phonation threshold pressure (PTP). Phonation threshold pressure data analysis may be vulnerable to bias because of lack of investigator blinding. Consequently, this study investigated the extent of PTP analysis reliability between unblinded and blinded investigators.

Methods—Healthy male and female adults were assigned to a vocal fatigue (n = 20) or control group (n = 20) based on their responses to a questionnaire. PTP was assessed after 2 hours of mouth breathing in low humidity (dehydration challenge), following a 5-minute break in ambient humidity, and after 2 hours of mouth breathing in high humidity (humidification).

Results—PTP significantly increased following the laryngeal dehydration challenge. After humidification, PTP returned toward baseline. These effects were observed in both subject groups. PTP measurements were highly correlated between the unblinded and blinded investigator.

Conclusions—Humidification may be an effective approach to decrease the detrimental voice effects of superficial laryngeal dehydration. These data lay the foundation for future investigations aimed at preventing and treating the negative voice changes associated with chronic, surface laryngeal drying.

Keywords

laryngeal dehydration; humidification; voice production; phonation threshold pressure; vocal fatigue

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Superficial laryngeal dehydration causes vocal changes.^{1–5} Superficial dehydration of the larynx can be induced by mouth breathing and exposure to low humidity.^{1–3,5} As it is often difficult to avoid mouth breathing and low humidity environments in everyday life, identifying methods for reducing the detrimental voice effects associated with these events is necessary. However, to date, few such studies exist in human subjects.^{2,6,7} The objective of the current study was to provide support for humidification in decreasing the negative voice effects of superficial laryngeal dehydration. The effectiveness of humidification treatment to reduce superficial laryngeal drying was tested in individuals with a history of vocal fatigue and a control group. Individuals with vocal fatigue are believed to be at higher risk for the development of voice problems^{8,9} as well as potentially more susceptible to the adverse phonatory effects of dehydration.^{1,10} Consequently, humidification treatment may be particularly useful for individuals who experience vocal fatigue.

Subjects were exposed to a dehydration challenge followed by a humidification treatment. This order of challenges was necessary because we investigated whether humidification would reduce the negative vocal effects of laryngeal dehydration. Laryngeal dehydration was induced by 2 hours of mouth breathing in low humidity. Mouth breathing in a low humidity environment, for even short durations, has been shown to adversely affect voice.¹ However, adverse voice changes following 15–20 minutes of mouth breathing in low humidity have not been observed consistently.^{11,12} Individuals may regularly spend longer periods of time breathing in dry environments.⁶ It is possible that more consistent voice changes will be observed following longer challenge durations. Therefore, longer, more realistic 2-hour challenge durations were chosen for the current investigation. Vocal changes were measured using phonation threshold pressure (PTP). This measure reflects the minimum lung pressure that is required to initiate and sustain phonation.¹³ Phonation threshold pressure has been used previously in laryngeal dehydration studies of reduced water intake,^{14,15} diuretics,¹⁶ dialysis,¹⁷ mouth breathing,^{1,18} desiccated air,^{2,6,7} and accelerated breathing.³

PTP is used extensively in voice research,¹⁹ but PTP data analysis is challenging. Investigators may be vulnerable to biases that can result from knowledge of experimental group, conditions, or directions of predicted change.^{2,20} Blinding, or the purposeful withholding of information from individuals who play a role in a study, is a research strategy endorsed as a method to reduce bias during data analysis.²¹ Several researchers have used investigator blinding in PTP studies;^{6,16} however, blinding in PTP analysis is not a universal hallmark of research studies.²² To the best of our knowledge, no studies have been published that report whether differences in PTP measurements occur as a result of investigator blinding. This is an important issue because knowledge of experimental conditions could affect investigator decisions during data analysis and lead to potentially biased conclusions regarding treatment effects. Consequently, we further sought to investigate the extent of analysis reliability between a trained unblinded and a trained blinded investigator. PTP data needed to be highly reliable between the unblinded and blinded investigator to examine whether humidification treatment could reverse the adverse voice effects induced by a laryngeal dehydration challenge.

Methods

Subjects

Forty healthy, nonsmoking adults participated in this investigation following procedures approved by the Purdue University Institutional Review Board. Participants denied a history of laryngeal, respiratory disease, or hearing problems. All subjects presented with perceptually normal speech and voice, normal laryngeal appearance (9100 Videostroboscope, Pentax Medical, Montvale, New Jersey, USA), and normal respiratory function (Discovery Spirometer, Futuremed America, Inc, Granada Hills, California, USA). At the time of the study, subjects were free of any respiratory illness and nasal congestion and were not taking any over-the-counter or prescription medications except oral contraceptives. Subjects were assigned to a vocal fatigue or control group¹ based on responses to a voice history questionnaire (Table 1). Vocal fatigue was defined as tiring of the voice after prolonged vocal activity. The questionnaire asked if subjects experienced vocal fatigue, and the duration, and chronicity of vocal fatigue. The vocal fatigue group included 20 subjects (mean age = 21 years, equal numbers of males and females). All subjects reported vocal fatigue following loud or heavy voice use at least 1 time per month for 1 or more years, but were asymptomatic at the time of testing. The control group included 20 subjects (mean age = 24 years, equal numbers of males and females). All control subjects denied experiencing vocal fatigue following prolonged vocal activity. See Table 2 for a detailed description of subject characteristics.

Design

Participation in the study involved a single experimental session. All subjects were asked to maintain habitual eating and drinking habits on the day of participation to simulate their daily hydration levels.^{15,16} The humidity was controlled at 2 levels (low humidity and moderate-high humidity) with commercially available dehumidifiers and humidifiers and monitored continuously throughout the session (Traceable Memory Hygrometer, VWR, Radnor, Pennsylvania, USA). During the session, each subject first completed a dehydration challenge that included 2-hours of mouth breathing in low humidity (16–27%). To ensure compulsory mouth breathing, the nostrils were occluded with foam plugs secured with medical tape. Next, subjects were provided a 5-minute break in ambient humidity. After the break, subjects completed 2 hours of mouth breathing in moderate-high humidity (62–80%). Subjects were instructed to refrain from eating, drinking, and speaking for the duration of the study session; however, limited speaking was permitted during the 5-minute break. The dehumidifiers and humidifiers used to control ambient humidity were turned off during data collection because of the increased noise level in the laboratory. Voice changes were assessed at 4 time points (baseline, post-dehydration, post-break, post-humidification) using PTP as described below.

Data Collection

PTP varies with vocal fundamental frequency.^{15,23} Consequently, at the start of the session, each subjects' maximum vocal frequency range was determined.²⁴ A laryngeal microphone was placed around the subject's neck on either side of the thyroid notch. Subjects were instructed to glide on the /ee/ sound to their highest and lowest frequencies using a soft

voice. The highest and lowest frequencies were recorded in Hertz and converted to semitones on a keyboard. The 10th and 80th percentile pitches were calculated from the semitone range. The 10th (PTP₁₀) and 80th (PTP₈₀) percentile pitches are commonly used in dehydration studies as they appear most sensitive to the hydration state of the vocal folds.^{14,20}

Data collection instruments were calibrated at the start of each session (MCU-4 Calibration System, Glottal Enterprises, Syracuse, New York, USA). The primary instrumentation included a circumferentially vented pneumotachograph face mask fitted with PTL-1 and PTW-1 differential pressure transducers for the collection of oral pressure and oral flow respectively (Glottal Enterprises). Prior to collection of baseline measures, subjects were trained to perform the PTP task at each pitch.^{25,26} During training, the investigator firmly held the mask around the subject's mouth and nose. Individuals were cued to the pitch and then asked to repeat the /pee/ syllable about 7 times on a single breath, as softly and smoothly as possible, at a rate of 1.5 syllables/second. The production of 7 /pee/ syllables at minimal vocal loudness constituted 1 syllable string. Subjects practiced until they were deemed trained. Trained was defined as the consistent soft production of syllable strings of equal peak height with oral flows reaching 0 ml/s during the /p/ production. Upon the completion of training, a minimum of 5 syllable strings were collected at PTP₁₀ and the PTP₈₀. PTP₁₀ and PTP₈₀ were each collected at baseline, post-dehydration, post-break, and post-humidification. PTP₁₀ and PTP₈₀ syllable strings not meeting the "trained" criteria during data collection were marked and excluded from data analysis.

Data Analysis

Two investigators (E.E.L. and A.S.) who were trained in PTP methodology analyzed the data from all subjects. One investigator (A.S.) was blinded to which PTP data corresponded to the subject group and time points (baseline, post-dehydration, post-break, and post-humidification), while the other investigator (E.E.L.) was unblinded to the identity of the subject groups and time points. During analysis, each investigator manually selected 3 middle /p/ peaks from each /pee/ syllable string. The peak pressures were averaged across 3 to 5 strings at both 10th and 80th percentile pitches for estimating PTP₁₀ and PTP₈₀. This protocol was used at the 4 time points.

Statistical Analysis

SPSS software (Version 19, IBM, Armonk, New York, USA) was used for the analysis. Interrater reliability between the blinded and unblinded investigator was first assessed using a 2-way mixed, absolute, single-measures intraclass correlation coefficient (ICC). Separate ICCs were performed for PTP₁₀ and PTP₈₀. Measurements of PTP were highly correlated between the blinded and unblinded investigator (see the results section). Therefore measurements of PTP were averaged across the investigators to determine the effectiveness of humidification for reducing the negative voice effects induced by superficial vocal fold dehydration. PTP data were then subjected to Kolmogorov–Smirnov normality tests. Data for PTP₈₀ were not normally distributed; therefore, these data were log transformed prior to conducting further statistical analyses. A mixed, repeated measures ANOVA was performed with group (vocal fatigue, control) as the between factor and time (baseline, post-

dehydration, post-break, post-humidification) as the within factor. Separate ANOVAs were performed for PTP₁₀ and PTP₈₀. Paired *t* tests were used for post hoc analyses. The alpha level was Bonferroni corrected to .025 to account for the multiple analyses.

Results

Values for ICC were in the excellent range for PTP₁₀ (ICC = .97) and PTP₈₀ (ICC = .99), indicating that PTP was measured similarly across the blinded and unblinded investigator. The high ICC suggests that a minimal amount of measurement error was introduced by the independent, trained investigators during data analysis, and therefore statistical power for subsequent analyses is not substantially reduced. Phonation threshold pressure measures were therefore deemed to be suitable to examine whether humidification treatment could reduce the adverse voice effects induced by a laryngeal dehydration challenge. We also questioned whether there would be differential effects of dehydration and humidification in a group who reported vocal fatigue as compared to a control group.

Phonation threshold pressure means and standard deviations are listed in Table 3. A significant main effect for time was observed for both PTP₁₀, $F(3, 114) = 1.92, P = .003$ (Figure 1A), and PTP₈₀, $F(3, 114) = 7.30, P < .001$ (Figure 1B). Post hoc testing revealed that PTP₁₀ significantly increased following the dehydration challenge by an average of 0.43 cm H₂O ($P < .001$). PTP₁₀ remained significantly greater than baseline after the 5-minute break ($P = .018$). PTP₁₀ decreased following humidification, and was similar to baseline values ($P = .263$); PTP₈₀ also significantly increased following the dehydration challenge by an average of 0.56 cm H₂O ($P = .002$). Post-break, PTP₈₀ was not significantly different from baseline ($P = .144$). Following humidification, PTP₈₀ values reverted toward baseline. Specifically, PTP₈₀ post-humidification was significantly lower than PTP₈₀ at both post-dehydration ($P < .001$) and post-break ($P = .001$) and similar to baseline ($P = .327$). Laryngeal dehydration and humidification had similar effects on vocal fatigue and control groups at PTP₁₀, $F(3, 114) = 1.71, P = .17$, and PTP₈₀, $F(3, 114) = 0.44, P = .73$.

Discussion

Dehydration of the laryngeal surface is detrimental to voice production.^{1,2} This documented finding necessitates an understanding of how the adverse voice effects associated with dehydration may be reversed. To date, there have been limited investigations that explore the effectiveness of methods to reverse the negative vocal effects of dehydration challenges. There is evidence that rehydration of superficially dehydrated excised canine larynges by immersion in saline restores phonatory function as measured by PTP.⁵ However, to date, in investigations utilizing human subjects, results have been more variable. In vocally untrained females, nebulized lubricant treatments did not improve PTP or self-perceived vocal effort following superficial vocal fold drying.² However, when participating in a similar study design, trained female singers did report improvements in self-perceived vocal effort following nebulized treatments.⁶ Nebulized treatments reduced superficial dehydration-induced increases in PTP in patients with Sjögren's syndrome; however, these improvements were not significant.⁷ Humidification is a superficial hydration technique frequently recommended to patients by voice professionals.² Humidification alone¹ or in combination

with other hydration treatments¹⁵ lowers PTP. However, the utility of this simple method to reduce dehydration-induced vocal decrement has not been systematically investigated in human subjects.

The current study demonstrates that PTP₁₀ and PTP₈₀ significantly increase following a vocal fold dehydration challenge and that these increases begin reverting toward baseline with humidification. Reductions toward baseline were significant only for PTP₈₀. This is not surprising as past research suggests that PTP produced at high pitches may be most useful for detecting biomechanical changes to the vocal folds as a result of hydration interventions.^{16,27} The beneficial effect of increased humidification in countering the PTP increase was observed in subjects with a history of vocal fatigue and controls, providing preliminary evidence that humidification may be a useful approach to reverse the detrimental effects of superficial laryngeal dehydration in different subject populations.

To induce superficial vocal fold dehydration, subjects were required to mouth breathe in low humidity. The effects of mouth breathing in low humidity on PTP have been investigated previously. However, these investigations have typically used short mouth breathing durations. Fifteen minutes of inhaling through the mouth, in low humidity or desiccated air increased PTP by 0.50 cm H₂O on average.^{1,2} In this study, 2 hours of mouth breathing in low humidity increased PTP₁₀ by 0.43 cm H₂O and PTP₈₀ by 0.56 cm H₂O. These magnitudes of PTP increases are similar to those observed with shorter challenges and support a hypothesis that during longer dehydration challenges, speakers may begin to compensate for the effects of superficial vocal fold dehydration. Although the current study cannot elucidate the exact nature of compensation, possible mechanisms may include increasing hydration to the vocal folds through systemic mechanisms such as increased laryngeal blood flow or local thermal changes. The water content in the exhaled airstream may also provide the means to rehydrate the vocal folds following superficial dehydration. In the current investigation, we exposed subjects to 2 hours of humidification to match the duration of the dehydration challenge. However, it is possible that much shorter duration of humidification treatment could reverse the negative voice effects of superficial vocal fold drying. Fifteen minutes of humidification alone lowers PTP.¹ Consequently, it would be beneficial for future investigations to investigate the utility of shorter humidification intervals in reducing dehydration-induced vocal decrement.

The effectiveness of humidification in reducing the negative voice effects of superficial vocal fold drying were examined in subjects with a history of vocal fatigue and controls. Vocal fatigue is a common clinical condition that is thought to be associated with the development of voice problems.⁹ Previously, it had been shown that mouth breathing in low humidity for 15 minutes increases PTP to a greater extent in females who report vocal fatigue as compared to controls.¹ Inspection of mean data reveals that the increase in PTP following 2 hours of mouth breathing at low humidity is greater in subjects that report vocal fatigue as compared to controls, but this was not a significant change. We can speculate on some reasons for these differences. Subjects were recruited into the vocal fold fatigue group through a questionnaire and brief interview as described previously.¹ However, previous studies have recruited subjects with a 2-year history of vocal fatigue, while the current study utilized 1 year as an inclusionary criterion. In addition, the current study included both

female and male participants, while past studies have solely investigated females.^{1,10} The effects of vocal fatigue history and sex on dehydration-induced changes in PTP await detailed investigation. Overall, our findings support the effectiveness of increased environmental humidification to reverse the detrimental voice effects of a dehydration challenge in both groups of subjects.

In the current study, we specifically sought to investigate whether humidification would restore dehydration-induced increases in PTP to pre-dehydration levels. This study design necessitated that participants were exposed first to a dehydration challenge and then humidification. As discussed, PTP₁₀ and PTP₈₀ significantly increased following a vocal fold dehydration challenge. Increases in PTP₈₀ then reverted toward baseline with increased environmental humidification. However, we recognize that PTP₈₀ also began to decrease toward baseline following the 5-minute break. It is therefore difficult to determine whether the PTP decreases observed following humidification are a function of the environment as opposed to time-elapsing postdehydration challenge or to voice rest. Consequently, future studies should include controls for time, voice rest, and training. Despite the reduction in PTP₈₀ following the break, it was not until humidification treatment that PTP₈₀ decreased to values lower than post-dehydration. To further test the utility of this preliminary finding, further studies should also include a no-treatment control. Overall, the current results provide justification for future studies that seek to systematically investigate the effectiveness of humidification as a technique to treat or prevent the adverse voice effects of superficial vocal fold drying. Comparing the effectiveness of different types of humidification methods such as increasing ambient humidity or spraying topical treatments is also an important future clinical goal.

Analysis of PTP data by blinded and unblinded investigators was a critical component of this study. Blinding is a widely used approach to reduce research bias. Research biases may result from an investigator's awareness of experimental groups, challenges, or treatments. A double-blind research protocol, where both subjects and investigators are blinded, is ideal and has been used in studies investigating the effectiveness of hydration treatments.^{2,6,7} However, complete blinding of investigators may sometimes be difficult due to facility and personnel limitations. Investigators analyzing data, on the other hand, can most always be blinded. During PTP data analysis, researchers make semisubjective decision regarding issues such as the selection of oral pressure peaks for analysis. Such decisions should ideally be made without knowledge of experimental group or condition. However, such blinding in PTP studies occurs rarely, or researchers fail to report that they did so.²² Furthermore, we do not know the impact of investigator blinding on PTP data analysis. Consequently, in the current study, we also sought to investigate role of blinding in PTP data analysis. We report using an ICC that PTP ratings were highly correlated between a blinded and unblinded investigator. This may be suggestive of the robustness of the current data and provide further preliminary support that humidification may be useful for reducing the detrimental voice effects of a superficial laryngeal dehydration challenge. However, our findings do not negate the need for investigator blinding during PTP data analysis and instead argue for its inclusion in all PTP studies. PTP data collection is subject to many of the same biases as outlined for data analysis. Therefore, blinding during data collection should be employed when possible. The absence of blinding during both data collection and analysis may lead to

exaggerated treatment effects.²¹ Consequently, blinding should be a necessary component of all studies that use PTP, particularly those that seek to analyze the effect of treatments, such as humidification, in reducing the adverse effects of superficial vocal fold dehydration. The use of blinding during PTP collection and analysis should further extend into the clinic where voice therapists routinely use this measure to examine the effectiveness of surgical, medical, and behavioral treatments in treating a wide range of vocal fold pathologies. We would further benefit from future studies that seek to systematically investigate a variety of blinding paradigms and how those paradigms impact PTP data collection and analysis in both research and clinical work.

Conclusions

This study sought to quantify the effectiveness of humidification in reducing dehydration induced-voice decrement in individuals with a history of vocal fatigue and controls. In both participant groups, PTP significantly increased at low and high pitches following 2-hours of mouth breathing in low humidity. The increases in PTP at high pitch reverted toward baseline following exposure to a humidified environment. There are some limitations of the current study that should be addressed. Although the temperature of the laboratory was not recorded, subjectively, ambient temperature increased during experimental sessions. It has been suggested that environmental temperature may influence vocal function.¹¹ Twenty minutes of mouth breathing in hot, dry air does not increase PTP in vocally healthy participants. However, the effect of temperature on PTP during longer durations of mouth breathing has yet to be investigated and should be considered in the future. In the current study, we purposefully chose to limit voice use during the experimental session to focus on the effect of a laryngeal dehydration challenge and humidification on PTP. However, additional studies should combine manipulations of environmental humidity with intervals of voice use to investigate more naturalistic conditions. Participants were asked to refrain from eating and drinking throughout the duration of the experimental session. Consequently, it cannot be ascertained that systemic dehydration did not contribute to the voice changes observed in this investigation. Previous studies have used drug treatments, such as diuretics, to investigate the effect of systemic dehydration on PTP.¹⁶ However, to the best of our knowledge, the effect of a short, 4-hour period without food and liquid on PTP has yet to be investigated. In studies seeking to investigate the effect of systemic dehydration on other voice parameters, subjects were asked to refrain from food and liquid consumption for at least 12 hours to induce a systemically dehydrated body state.^{28,29} It would be beneficial for future investigations of this type to include measurements of total body mass to better define the influence of systemic dehydration/hydration on PTP. Finally, in the current experimental paradigm, we cannot ascertain whether superficial laryngeal dehydration was induced. However, the increase in PTP observed here is consistent with changes to biomechanical properties of vocal fold tissue. To the best of our knowledge, this is the first study to demonstrate the potential usefulness of environmental humidification to reverse the detrimental voice effects of dehydration in subjects successively exposed to a dehydration challenge and humidification. These preliminary findings pave the way for future treatment studies that seek to systematically investigate humidification as an intervention for laryngeal drying.

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References

1. Sivasankar M, Erickson E, Schneider S, Hawes A. Phonatory effects of airway dehydration: preliminary evidence for impaired compensation to oral breathing in individuals with vocal fatigue. *J Speech Lang Hear Res.* 2008; 51:1494–1506. [PubMed: 18664688]
2. Tanner K, Roy N, Merrill R, Elstad M. The effects of three nebulized osmotic agents in the dry larynx. *J Speech Lang Hear Res.* 2007; 50:635–646. [PubMed: 17538106]
3. Sivasankar M, Erickson E. Short-duration accelerated breathing challenges affect phonation. *Laryngoscope.* 2009; 119:1658–1663. [PubMed: 19522007]
4. Hemler R, Wieneke G, Dejonckere P. The effect of relative humidity of inhaled air on acoustic parameters of voice in normal subjects. *J Voice.* 1997; 11:295–300. [PubMed: 9297673]
5. Jiang J, Ng J, Hanson D. The effects of rehydration on phonation in excised canine larynges. *J Voice.* 1999; 13:51–59. [PubMed: 10223675]
6. Tanner K, Roy N, Merrill R, et al. Nebulized isotonic saline versus water following a laryngeal desiccation challenge in classically trained sopranos. *J Speech Lang Hear Res.* 2010; 53:1555–1566. [PubMed: 20699338]
7. Tanner K, Roy N, Merrill RM, et al. Comparing nebulized water versus saline after laryngeal desiccation challenge in Sjogren's syndrome. *Laryngoscope.* 2013; 123:2787–2792. [PubMed: 23674107]
8. Chang A, Karnell M. Perceived phonatory effort and phonation threshold pressure across a prolonged voice loading task: a study of vocal fatigue. *J Voice.* 2004; 18:454–466. [PubMed: 15567047]
9. Kostyk B, Rochet A. Laryngeal airway resistance in teachers with vocal fatigue: a preliminary study. *J Voice.* 1998; 12:287–299. [PubMed: 9763179]
10. Sivasankar M, Fisher K. Oral breathing challenge in participants with vocal attrition. *J Speech Lang Hear Res.* 2003; 46:1416–1427. [PubMed: 14700365]
11. Sandage MJ, Connor NP, Pascoe DD. Vocal function and upper airway thermoregulation in five different environmental conditions [published online ahead of print July 30, 2013]. *J Speech Lang Hear Res.*
12. Sundararajan, A., Erickson-Levendoski, E., Sivasankar, M. Investigating the effects of moderate humidity in reducing dehydration. Poster presented at: American Speech-Language-Hearing Association; November 15–17, 2012; Atlanta, GA.
13. Titze I. The physics of small-amplitude oscillation of the vocal folds. *J Acoust Soc Am.* 1988; 83:1536–1552. [PubMed: 3372869]
14. Verdolini K, Titze I, Druker D. Changes in phonation threshold pressure with induced conditions of hydration. *J Voice.* 1990; 4:142–151.
15. Verdolini K, Titze I, Fennel A. Dependence of phonatory effort on hydration level. *J Speech Lang Hear Res.* 1994; 37:1001–1007.
16. Verdolini K, Min Y, Titze I, et al. Biological mechanisms underlying voice changes due to dehydration. *J Speech Lang Hear Res.* 2002; 45:268–281. [PubMed: 12003510]
17. Fisher K, Ligon J, Sobecks J, Roxe D. Phonatory effects of body fluid removal. *J Speech Lang Hear Res.* 2001; 44:354–367. [PubMed: 11324657]
18. Sivasankar M, Fisher K. Oral breathing increases Pth and vocal effort by superficial drying of the vocal fold mucosa. *J Voice.* 2002; 16:172–181. [PubMed: 12150370]

19. Plexico L, Sandage M, Faver K. Assessment of phonation threshold pressure: a critical review and clinical implications. *Am J Speech Lang Pathol*. 2011; 20:348–366. [PubMed: 21856967]
20. Roy N, Tanner K, Gray S, Blomgren M, Fisher K. An evaluation of the effects of three laryngeal lubricants on phonation threshold pressure. *J Voice*. 2003; 17:331–342. [PubMed: 14513956]
21. Polit DF. Blinding during the analysis of research data. *Int J Nurs Stud*. 2011; 48:636–641. [PubMed: 21367415]
22. Leydon C, Wroblewski M, Eichorn N, Sivasankar M. A meta-analysis of outcomes of hydration intervention on phonation threshold pressure. *J Voice*. 2010; 24:637–643. [PubMed: 20359862]
23. Solomon N, Ramanathan P, Makashay M. Phonation threshold pressure across the pitch range: preliminary test of a model. *J Voice*. 2007; 21(5):541–550. [PubMed: 16753281]
24. Erickson-Levendoski E, Sivasankar M. Investigating the effects of caffeine on phonation. *J Voice*. 2011; 25:e215–e219. [PubMed: 21704493]
25. Fisher K, Swank P. Estimating phonation threshold pressure. *J Speech Lang Hear Res*. 1997; 40:1122–1129. [PubMed: 9328883]
26. Erickson E, Sivasankar M. Evidence for adverse phonatory change following an inhaled combination treatments. *J Speech Lang Hear Res*. 2010; 53:75–83. [PubMed: 19696437]
27. Solomon N, Glaze L, Arnold R, Van Mersbergen M. Effects of a vocally fatiguing task and systemic hydration on men's voices. *J Voice*. 2003; 17:31–46. [PubMed: 12705817]
28. Hamdan AL, Sibai A, Rameh C. Effect of fasting on voice in women. *J Voice*. 2007; 21:495–501. [PubMed: 16630706]
29. Hamdan AL, Ashkar J, Sibai A, Oubari D, Hussein ST. Effect of fasting on voice in males. *Am J Otolaryngol*. 2011; 32:124–129. [PubMed: 20392525]

Figure 1.

Mean $\pm$ standard error of the mean for the effects of laryngeal dehydration and humidification on PTP₁₀ (A) and PTP₈₀ (B) in control and vocal fatigue subject groups. The dehydration challenge and humidification treatment were each 2 hours in duration.

Table 1

Vocal Fatigue History Questionnaire.

Do you experience vocal fatigue or worsening of voice with prolonged vocal activity?
If yes, how often?
If yes, for how long have you been experiencing this symptom?
If yes, when was the last time you experienced vocal fatigue?
Does vocal fatigue typically follow loud or heavy voice use?
Are you currently experiencing vocal fatigue?

Table 2

Subject Characteristics.

Vocal Fatigue Group				Control Group			
Subject Number	Sex	Age, y	Vocal Fatigue	Subject Number	Sex	Age, y	Vocal Fatigue
1	Male	22	Yes: 3×/month, 4 years	1	Male	23	No
2	Male	22	Yes: 2×/month, 2 years	2	Male	24	No
3	Male	19	Yes: 4×/month, 4 years	3	Male	24	No
4	Male	22	Yes: 8×/month, 1 year	4	Male	21	No
5	Male	27	Yes: 8×/month, 5 years	5	Male	27	No
6	Male	19	Yes: 2×/month, 1 year	6	Male	20	No
7	Male	21	Yes: 1×/month, 4 years	7	Male	19	No
8	Male	21	Yes: 2×/month, 2 years	8	Male	20	No
9	Male	22	Yes: 4×/month, 4 years	9	Male	31	No
10	Male	21	Yes: 12×/month, 3 years	10	Male	23	No
11	Female	20	Yes: 1×/month, 4 years	11	Female	23	No
12	Female	21	Yes: 4×/month, 3 years	12	Female	23	No
13	Female	19	Yes: 4×/month, 1 year	13	Female	23	No
14	Female	22	Yes: 1×/month, 8 years	14	Female	30	No
15	Female	19	Yes: 1×/month, 3 years	15	Female	20	No
16	Female	20	Yes: 1×/month, 7 years	16	Female	19	No
17	Female	22	Yes: 2×/month, 2 years	17	Female	20	No
18	Female	25	Yes: 1×/month, 3 years	18	Female	22	No
19	Female	19	Yes: 12×/month, 6 years	19	Female	25	No
20	Female	19	Yes: 4×/month, 2 years	20	Female	37	No

Table 3Phonation Threshold Pressure (PTP) Means and Standard Deviations.^a

	Baseline	Post-dehydration	Post-break	Post-humidification
Control				
PTP10	4.36 (0.96)	4.57 (1.25)	4.65 (1.24)	4.44 (1.24)
PTP80	5.81 (2.15)	6.21 (2.23)	6.01 (2.15)	5.57 (2.20)
Vocal fatigue				
PTP10	4.71 (1.01)	5.37 (1.11)	5.00 (1.11)	4.97 (1.47)
PTP80	6.79 (2.36)	7.50 (2.35)	7.05 (1.49)	6.74 (2.01)

^aPTP = cm H₂O, mean (standard deviation).