Effects of a Vocally Fatiguing Task and Systemic Hydration on Men's Voices

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Summary: Voice disorders, specifically vocal fatigue, are more commonly reported by women than by men. Previously, 4 women with normal untrained voices read loudly for 2 hours in an attempt to fatigue the voice. Vocal function deteriorated, as indicated by increases in phonation threshold pressure (PTP) and self-perceived phonatory effort. The increase in PTP was delayed or attenuated to some degree in 3 of the women when they drank ample amounts of water before the experiment. The current study examined the same vocal-loading task and water-drinking condition in 4 vocally normal men. PTP increased after the loud-reading task. Although 2 of the men appeared to benefit from increased systemic hydration (PTP increased more when they were underhydrated than well-hydrated), the other 2 men's data changed in the opposite direction. Phonatory effort correlated well with PTP; this varied across subject and pitch. Laryngeal endoscopy revealed an anterior glottal gap in two men after the loud-reading task. Amplitude of vocal fold vibration was judged to be reduced after the loud-reading task in three subjects when underhydrated and one subject when well hydrated. The high between-subject variability prohibits a conclusion that drinking water is beneficial to vocal function in men, but all subjects studied to date demonstrated detrimental vocal effects of prolonged loud talking.

Key Words: Vocal fatigue—Phonation threshold pressure—Systemic hydration—Gender differences—Laryngeal appearance—Effort.

INTRODUCTION

Vocal fatigue, long recognized as a clinical entity, has received increased attention in recent research literature. This has resulted in part from interest in occupational voice hazards.[1,2] Vocal fatigue is well documented among teachers, primarily a profession selected by women, but also occurs among more gender-balanced or men-dominated occupations such as telemarketers, clergy, and military personnel.[2] Another driving force behind this surge in research is the development of methods and procedures that detect important changes in vocal function after vocally fatiguing tasks. These have included

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questionnaires,[1] acoustic measures,[3,4] laryngeal videostroboscopy,[4–6] and aerodynamic measures.[3,6] An aerodynamic measure that appears to be particularly useful for the purpose of assessing vocal function after prolonged voice use is phonation threshold pressure (PTP).

PTP is defined as the lowest lung pressure required to initiate phonation.[7,8] Titze[8] theorized that PTP increases by increasing the translaryngeal pressure coefficient (*k*, a constant directly related to the lung pressure delivered to the vocal folds), tissue damping (*B*, indicating vocal fold viscosity) mucosal wave velocity (*c*, inversely related to the compliance of the vocal fold cover), and prephonatory glottal half-width (*w*/2, half the distance between the vocal processes of the arytenoid cartilages). Furthermore, PTP increases with decreased vocal fold thickness *T*.

Based on these relationships, predictions can be made regarding the effects of static (ie, *T*, *w*), vibratory (*c*), and viscous (*B*) properties of the vocal folds on PTP. In particular, increased vocal fundamental frequency is associated with decreased *T* and increased *c*, resulting in increased PTP.[8,9] Additionally, increased environmental and/or systemic hydration, presumably associated with decreased *B*, results in decreased PTP especially at high pitches.[9–11] As previously hypothesized, vocal loading via prolonged and excessive vocal fold vibration could result in increased stiffness of the vocal fold tissues (related to increased *c*) and increased viscosity (*B*), both of which should lead to increased PTP.[6] The predictions made in this line of research are based on biomechanic properties of the vocal folds during phonation. The physiologic events that lead to such properties cannot be isolated using these methods, but are presumed to include heat dissipation, neuromuscular aspects of fatigue, and possibly formation of edema.

Because the perception of effort is associated with lung pressure,[12] PTP has been purported to correspond with the "ease" of phonation.[10] Perception of vocal effort is directly related to lung pressure and varies with SPL and F_0 in nonsingers[13] and singers.[14] However, studies that have examined the correlation between PTP and self-perceived phonatory effort have produced equivocal results. Correlations have ranged from strong[15] to weak,[10,16,17] but the interpretation of these data is complicated because of varying methodology. An important inconsistency is the choice of tasks during which the effort data are collected. To directly compare PTP to phonatory effort, the measures should be collected during the same task. However, several studies that have attempted this comparison have used different tasks.[6,10,15] In the current study, effort is rated at each pitch during the PTP task in an attempt to validly assess the relationship between the measures.

Previously, Solomon and DiMattia[6] studied the effects of vocal loading on PTP in four vocally untrained young women. Women were selected for this initial study because they are more likely than men to have voice disorders.[1] Results indicated that PTP increased after 2 hours of loud reading in all of the women, especially at the highest pitch tested (80% of the pitch range). This result indicated that the prolonged speaking task caused changes in phonatory function, and that these changes were detected aerodynamically at very low loudness and high pitch levels.

Clinically, persons with voice disorders often are advised to drink water. Several studies have provided data that indicate decreased vocal function when people are underhydrated.[9–11] Solomon and DiMattia[6] investigated whether water consumption affected phonation before and after the vocally fatiguing task in the four women described previously. Subjects drank 0.5 L of water per day and no other liquids for two days before one fatiguing session (low-hydration condition), and at least 2.5 L of water for two days before a separate session (high-hydration condition). Before the vocal-loading task, only 1 of the 4 women's PTP data revealed the expected benefit of being well hydrated (ie, reduced PTP). However, 3 of the 4 women demonstrated a greater and/or earlier increase in PTP with prolonged loud talking when they were underhydrated. This indirectly implies that laryngeal tissue viscosity may decrease by drinking water and supports the hypothesis that systemic hydration affects PTP.

Results obtained for women cannot necessarily be extended to men. Recent histochemical evidence suggests fundamental differences between human vocal fold microstructure in women and men. Hormone receptors (androgen and progesterone) are more densely distributed in male than female vocal folds.[18] The lamina propria is larger and contains three times more hyaluronic acid in male versus female specimens.[19] Hammond et al[19] speculated that this difference might explain why women, with less shock-absorbing fluid in their vocal folds, may be more prone to certain voice disorders. The mechanism by which fluid infiltrates the vocal tissue is unknown, but may be related to overall body hydration.

The purpose of this study was to generally replicate the previous experiment in 4 vocally untrained men. Minor changes in protocol were implemented to improve and simplify the experimental design (eg, adding multiple baseline measures, rating effort for each PTP trial at each pitch, improving laryngoscopic recording and analysis). At this preliminary stage of investigation, the study was designed to compare each subject's data to his own baseline performance rather than to analyze group performance. Four major findings were predicted: (a) that PTP would elevate after the vocally fatiguing task but to a lesser degree than that reported previously for women,[6] (b) that men's voices would be less susceptible to the effects of altered hydration, (c) that PTP and self-perceived phonatory effort would be positively correlated, and (d) that changes in laryngeal appearance would be less likely in men than in women.

METHODS

Subjects

Four men, ages 19–29 years, participated in this 9–10 hour protocol and subsequently received $100. They were untrained voice users, nonsmokers, and reported no history of neurologic, respiratory, hearing, speech, or voice disorders. All subjects provided informed consent.

Power analyses to determine adequate sample size for the use of inferential statistics, based on previous data (2-hr fatigue effect at 80%ile of the pitch range in women[6]), indicated that 8 subjects at $\alpha = 0.05$ or 6 subjects at $\alpha = 0.10$ would yield power of 0.80. Of 22 men who inquired about the study, 17 passed a telephone screening, 14 participated in the laboratory screening, 7 passed the laboratory screening, and only 4 completed the study. Reasons for failing the laboratory screening included abnormal laryngeal appearance, failed pulmonary function screening, and inability to match pitches. Reasons for starting but not completing the study included scheduling difficulties and missed appointments. Because of limited resources and logistical constraints, the study was terminated after completing data collection for 4 men.

Instrumentation

Measures of oral pressure and airway-opening flow were obtained with the Glottal Enterprises (Syracuse, NY) aerodynamic measurement system (MS100-A2 filters and MCU-4 pneumotachograph calibration unit) and accompanying pressure transducers (PTL-1, PTW-1). Signals were digitized (DI-220, DATAQ Instruments, Akron, OH) onto a desktop computer (Gateway P5-133; sampling rate = 100 Hz for pressure, 1 kHz for flow). A Casio Tone Bank (CT-638) portable electric piano was used to establish and cue pitch levels. A Rhino-Laryngeal Stroboscope System (Kay Elemetrics, Lincoln Park, NJ) with a 70° rigid endoscope was used for laryngeal videostroboscopic imaging.

Procedures

Each subject participated in five sessions: the first for screening and training, the second and fourth while subjects were typically hydrated, and the third and fifth with altered systemic hydration (low and high; order alternated between subjects). The initial session included screenings for hearing (20 dB at 0.5, 1, 2, and 4 kHz in one ear), pulmonary function ($FEV_1/FVC > 0.80$), pitch-matching ability, and laryngeal appearance (via stroboscopic endoscopy). Pitch range including falsetto and excluding pulse register was determined and found to be 35 to 38 semitones for these subjects. Habitual speaking pitch, determined while the subjects read aloud at a comfortable level, was at the 8th–10th percentile of the pitch range for 3 subjects and near the 20th percentile of the pitch range for 1 subject (M2). [Speaking pitch during the loud-reading task used during the experimental sessions approximated the 20th percentile of the pitch range for all subjects.] Tenth, 50th, and 80th percentiles of the semitone pitch range were calculated and rounded to the nearest semitone. These pitches were used consistently throughout the remaining sessions.

The final portion of the initial session involved training and practicing the PTP task and effort ratings (see below). Subjects were then scheduled for their first typical-hydration session and were instructed to keep a log of the amount and type of liquid they drank for each of the two days preceding the session.

All four remaining sessions began with the following general protocol: 10 minutes of reading aloud at a comfortable level (to "warm-up" the voice), collection of 3–5 sets of baseline PTP and effort data, and laryngeal imaging. The two altered-hydration sessions then continued with the collection of 1 set of PTP and effort data ("data collection"), 1 hour of loud reading, data collection, 1 additional hour of loud reading, data collection, 15 minutes of vocal silence, and final data collection. Details and additional information about the protocol follow.

Sessions were scheduled in the morning before subjects engaged in their daily talking activities. They were instructed to consume a dry breakfast and a prescribed amount of liquid depending on the particular session. For two days before the typical hydration sessions, subjects were instructed to drink a typical amount of water or other noncaffeinated beverages. This amount was free to vary between subjects, but was kept consistent with the amount consumed for each subject's first session as indicated by his nutrition/hydration log. Low-hydration sessions were preceded by two days during which subjects were told to drink 25% of their typical amount. High-hydration sessions were preceded by two days when subjects were told to drink 75% more than typical amounts of water and other noncaffeinated beverages. Table 1 lists the actual amounts of liquids consumed by the subjects according to daily logs. Differences from target levels were caused by subject compliance; because of these differences, caution should be exercised when interpreting hydration-related results.

TABLE 1. *Daily Water Consumption (in liters) for Two Days Prior to Sessions*

	Hydration Condition		
Subject	**Typical**	**Low**	**High**
M1	2.5	1.0	3.5
M2	2.5	1.5	4.0
M3	4.0	1.0	7.0
M4	2.5	0.5	4.5

Sessions were scheduled with a minimum of 2 days after typical-hydration sessions and at least 3 days after the first altered-hydration session. The two sessions involving altered hydration included the 2-hour loud-reading task. PTP data collected after 1 and 2 hours of loud reading were lost for the high-hydration condition for Subject M1 because of a data-recording error. Therefore, this session was rescheduled and repeated with the exception of laryngeal imaging 7 months after the original session; laryngeal imaging data were used from the original session.

The reading material used in this study was J.K. Rowling's *Harry Potter: The Sorcerer's Stone*, chosen for its expressive and entertaining text. At the beginning of each session, subjects read aloud at a comfortable loudness level for 10 minutes. This mild "warm-up" task was expected to result in stable phonatory performance. PTP and effort data were collected; this was followed by an additional minute of comfortable reading. This cycle continued until the experimenter estimated from an online display that the PTP data at each of the three pitches yielded a relatively stable baseline (within approximately 0.5 cm H_2O). No more than five sets of baseline data were recorded for each session. Laryngeal imaging followed baseline-data recording and concluded the typical-hydration sessions.

Altered-hydration sessions continued with subjects reading loudly (75–80 dB at 45 cm) for one hour, stopping to collect PTP and effort data, and then resuming the loud-reading task for an additional hour. Every 5 minutes, subjects paused briefly to drink a minimum of 30 ml of water during the high-hydration session and to perform a dry swallow during the low-hydration session. The second hour of loud reading and the collection of PTP and effort data were followed immediately by laryngeal imaging. Subjects then were silent for 15 minutes after which a final set of PTP and effort data was collected.

The order of pitch presentation varied by counterbalancing across and within subjects during the typical-hydration sessions and before the loud-reading task during the altered-hydration sessions. After 1 hour and again after 2 hours of loud reading, each subject provided one trial of PTP and effort data at each pitch. Pitch order remained constant within each subject to allow for comparable data interpretation. Only one set of data could be collected at each 1-hour interval to avoid potential recovery effects. Therefore, the collection of multiple trials and counterbalancing data was prohibited. One set of PTP and effort data also was collected after 15-minutes of vocal silence that followed the post-loud-reading laryngoscopic examination.

Phonation threshold pressure task and effort ratings

For the PTP task, participants held the handle of the circumferentially vented pneumotachographic mask firmly so that the mask formed a seal around the mouth and nose and one end of the pressure tube was in the mouth just behind the lips. Following the method for estimating tracheal (subglottal) pressure by Smitheran and Hixon[20] and replicating the method used by Solomon and DiMattia[6] for obtaining PTP, subjects produced seven legato repetitions of the syllable /pi/ at a rate of 1.5/s (trained with a metronome) at each pitch. The task was repeated several times at a threshold level of phonation until the investigators were satisfied with 3 productions. To train the threshold level, the subject produced the syllable string at a suprathreshold loudness level, then in a whisper, and finally at minimal loudness while maintaining phonation. Once trained, PTP data were collected at the threshold level only. The investigators examined the data signals online for the clear presence of acceptable pressure peaks, airflow cessation during the closed phase of /p/, and continuous airflow modulation (indicating phonation) between adjacent consonants. On occasion, nose clips were used to prevent nasal airflow thus ensuring that oral pressure was a good estimate of tracheal pressure.

Immediately following the PTP task at each pitch, subjects rated how effortful it was to perform that task on a visual-analog scale. They marked an undifferentiated 20-cm line with the extremes labeled "no effort" and "extreme effort."

Laryngeal imaging

Laryngeal imaging without topical anesthesia was conducted once during each typical-hydration session (after collection of the PTP and effort data) and twice during each altered-hydration session (following the collection of the PTP and effort data both before and after the 2-hour loud-reading task). During the examination, subjects sustained /i/ at habitual pitch and loudness, high and low pitch, and soft and loud phonation. To obtain comparable images across sessions, laryngeal landmarks were aligned according to a template drawn on a transparency during the first typical-hydration session.

Data reduction and analysis

Phonation threshold pressure

Oral-pressure peaks during /p/ in the strings of syllable repetitions were analyzed according to standard procedures.[6,20] Three pressure peaks were examined from the midportion (excluding the first and last 2 peaks) of the last three 7-syllable strings produced at each pitch. They were selected for inclusion if they met measurement criteria, including the cessation of airflow during the closed phase of /p/, continuous voicing during the /i/, and acceptable morphology of the pressure waveform. If one or more datum did not meet inclusion criteria, additional pressure peaks were selected from the same strings (unless they were the first or last peak) or from additional strings recorded until a total of nine valid peaks were identified. A peak-picking feature of the data-analysis software (Windaq, DATAQ Instruments, Akron, OH) selected the maxima of each pressure peak selected. PTP estimates for each pitch were derived by averaging the nine pressure peaks selected. For comparing subsequent trials to baseline performance, the last three sets of baseline data recorded at each pitch during each session were used; additional sets (from 0 to 2) were discarded. After determining average PTP for each of these sets, the median baseline value at each pitch was used.

To determine changes in PTP from baseline that extend beyond performance variability, the following conservative criterion was established. Standard deviations (SD) for each subject and each pitch were calculated from the six baseline values collected during the typical-hydration sessions (three each). Table 2 lists the SD for each subject and pitch. Differences in PTP were considered reliable and meaningful if they exceeded 2 SDs and changed in the predicted direction for each comparison. Predicted directions of change are listed under each table of results. Inferential statistical analyses were

TABLE 2. *One Standard Deviation Across the Six Baseline Measures of PTP (Three From Each of the Typical-Hydration Sessions, in cm H_2O) for Each Subject at Each Pitch*

	Pitch		
Subject	**10%**	**50%**	**80%**
M1	0.38	0.30	0.79
M2	0.46	0.26	0.54
M3	0.21	0.47	0.94
M4	0.53	0.52	0.66

Note: For data analysis purpose, differences exceeding 2 SD were considered reliable and meaningful.

deemed inappropriate because of the small sample size and multiple conditions, which yielded low statistical power.

Effort ratings

The visual-analog scales were expressed as a proportion of the line marked by the subject. Pearson product-moment correlation coefficients were calculated to examine correlations between PTP and effort ratings.

Laryngeal imaging

The videotaped samples of laryngeal endoscopy were dubbed in random order within each of the four subjects. Care was taken to ensure that the dubbed sample contained approximately 90 seconds of visible vocal fold. This was not possible for one sample because of excessive supraglottic activity (M2, session T1). The master viewing tape contained 27 images (7 each for M1, M3, and M4; 6 for M2); the last sample in each subjects' series was a randomly selected sample repeated for reliability.

Visual-perceptual ratings

Three ASHA certified speech-language pathologists (not the authors) with a minimum of ten years' experience in voice disorders and over five years' experience using stroboscopy served as judges. They gathered to view the images simultaneously on a large color monitor. Before making the experimental ratings, the judges viewed and discussed a training tape of videostroboscopic images to clarify the perceptual definitions of each of the experimental parameters. The tape contained a variety of laryngeal images selected to illustrate typical, mildly impaired, and severely impaired examples of each parameter.

For the experimental ratings, the judges were informed that they would rate a series of normal male laryngeal videostroboscopic recordings. Each judge rated seven separate parameters from the video image (without audio signal): vibratory closure pattern, supraglottic activity, presence of mucus, color, mucosal wave, amplitude, and symmetry. Categorical choices for vibratory closure pattern included: complete, anterior gap, posterior gap, irregular gap, spindle-shaped gap, hourglass gap, or incomplete closure. The other six parameters were rated on a 100-mm visual-analog scale from normal to abnormal. The judges were encouraged to use the entire scale and to compare the experimental images to other normal laryngeal images they have seen.

After the judges completed their individual ratings, they viewed the 27 images again to discuss and confer on their decisions. Consensus among raters was extremely high; only 9 of the 189 (4%) independent visual-analog ratings and none of the vibratory closure pattern decisions were modified by any judge following the group discussion. Test-retest reliability of four repeated samples also was high. Intrajudge agreement was 100% for vibratory closure pattern and 87.5% within 10 mm (or 10% of the scale) for the additional parameters.

The judges agreed on the vibratory closure patterns; thus, these were entered by consensus. Individual data were averaged across the three judges for the parameters that were rated by visual-analog scale. (Means and medians for these ratings were essentially identical because of the consensus procedure used.) Differences were considered meaningful if they exceeded the difference between the two typical-hydration sessions or 10%, whichever was greater.

RESULTS

Phonation threshold pressure

Phonation threshold pressure (PTP) data for each subject are illustrated in Figures 1–4. Sessions are displayed in the same order for comparative purposes, although M1 and M2 underwent the low-hydration condition before the high-hydration condition.

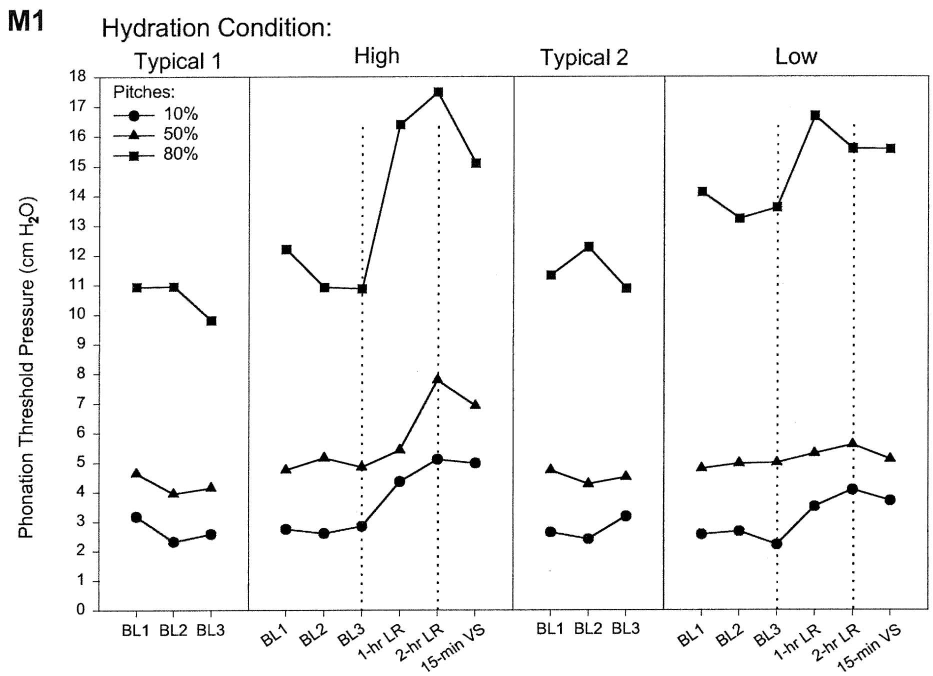

FIGURE 1. Phonation threshold pressure (PTP) across the four sessions for M1. The sessions differed by hydration condition, indicated at the top of chart. Baseline data (BL 1–3) are displayed first for each session, followed by data collected after 1 hour and 2 hours of loud reading (LR) and 15 minutes of vocal silence (VS) for the two altered-hydration sessions (High, Low). The task was performed at the 10th (circle), 50th (triangle), and 80th (square) percentiles of the pitch range. The interval during which subjects read loudly is indicated by the vertical dotted lines.

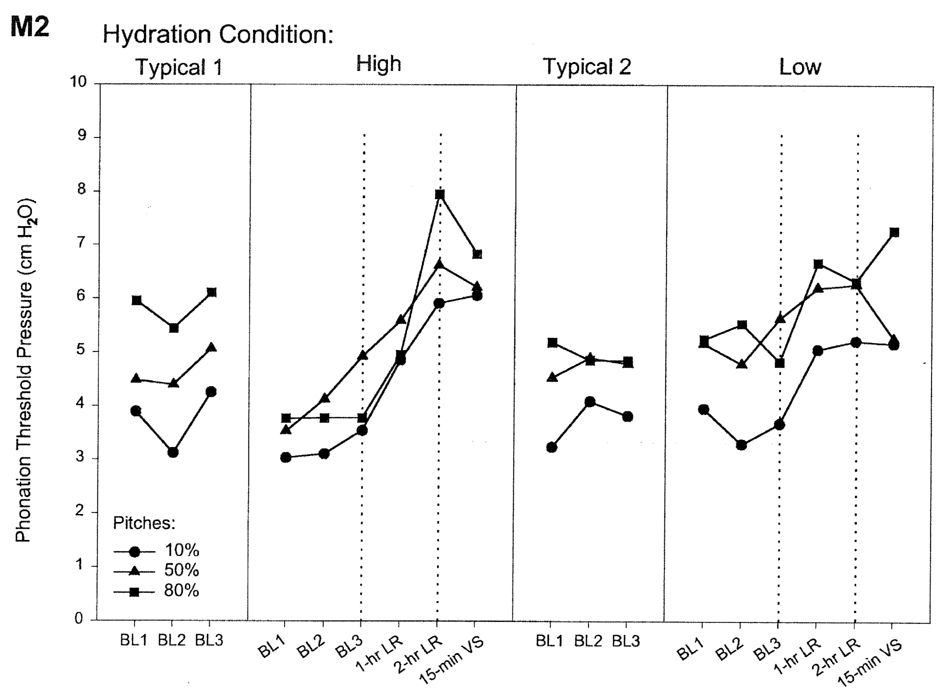

FIGURE 2. PTP results for M2. See legend to Figure 1 for details.

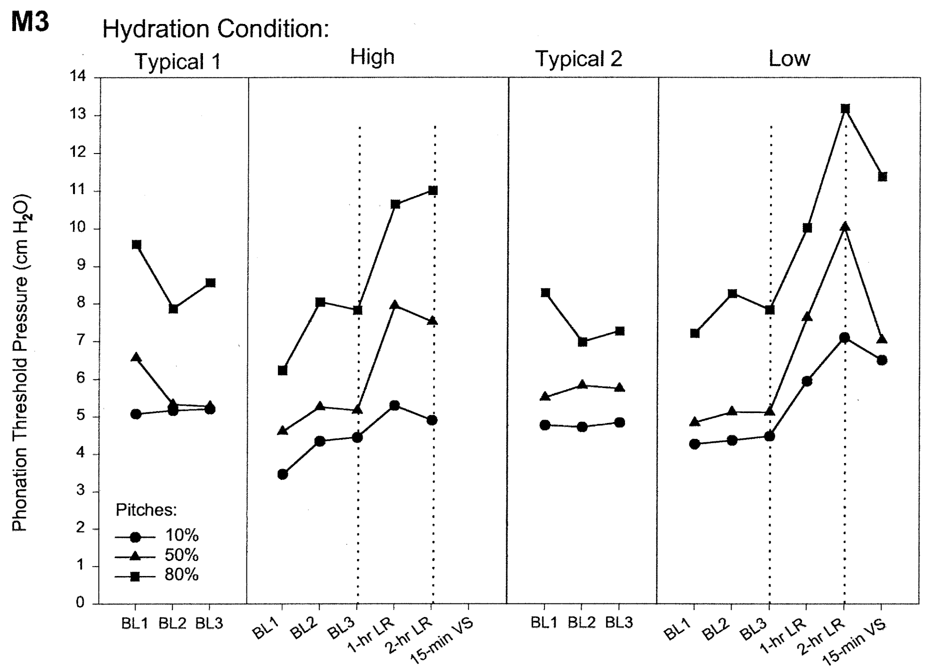

FIGURE 3. PTP results for M3. See legend to Figure 1 for details.

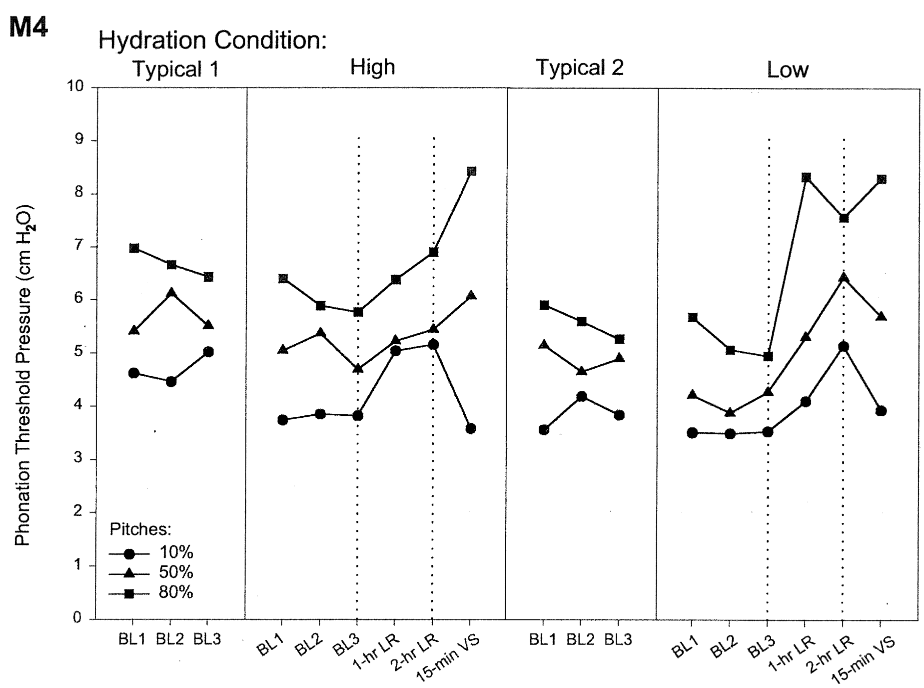

FIGURE 4. PTP results for M4. See legend to Figure 1 for details.

TABLE 3. *Differences in Baseline (median) PTP Values (in cm H_2O) with Systemic Hydration (Low Hydration – High Hydration) for Each Subject at Each Pitch*

Subject	Pitch 10%	Pitch 50%	Pitch 80%
M1	−0.19	0.12	2.67*
M2	0.57	1.04*	1.47*
M3	0.03	−0.05	0.01
M4	−0.31	−0.84	−0.81

Note: * = reliable difference (>2 SD) in the predicted direction (positive).

Hydration effect

To examine for a hydration effect alone, the median baseline PTP values from each altered-hydration session were compared. These differences are listed in Table 3. Baseline PTP values were reliably lower during high- than the low-hydration sessions at 50% and 80% of the pitch range for M2, and at 80% for M1.

Effect of prolonged loud reading

Table 4a lists differences in PTP measured before and after one hour of loud reading, and Table 4b lists differences before and after two hours of loud reading for each experimental session, pitch, and subject. PTP increased reliably after 1 hour of loud reading for 19 out of 24 (79%) trials (Table 4a). At 10% and 80% of the pitch range, PTP increased for 7 out of 8 trials. Averaged data across the four subjects reveal similar degrees of change at each pitch between the two hydration conditions.

TABLE 4A. *Differences in PTP (in cm H_2O) Before (median baseline values) and After 1 Hours of Loud Reading*

	High-Hydration Session			Low-Hydration Session		
	Pitch			Pitch		
Subject	10%	50%	80%	10%	50%	80%
M1	1.61*	0.58	5.46*	0.94*	0.33	3.08*
M2	1.75*	1.47*	1.18*	1.39*	1.05*	1.42*
M3	0.96*	2.78*	2.81*	1.58*	2.52*	2.18*
M4	1.22*	0.18	0.49	0.59	1.10*	3.25*
Mean	1.38	1.25	2.49	1.12	1.25	2.48

After two hours of loud reading, PTP increased reliably for 21 of 24 (88%) of the trials (Table 4b). On average, the increases in PTP were similar across the two hydration conditions, although a substantial increase for M1's 80% pitch during the HH session inflated the average change. Two subjects (M3, M4) demonstrated the expected differences in PTP across hydration sessions such that the change was greater for the low-hydration condition. However, two subjects (M1, M2) demonstrated changes in the opposite direction.

Effect of vocal silence

Compared to data collected after 2 hours of loud reading, PTP decreased after 15 minutes of vocal silence for 9 of 21 (43%) trials for which data were available (Table 5). These differences were distributed across pitches, subjects, and hydration condition.

Effort ratings

Effort ratings averaged across the 4 subjects for each pitch are illustrated in Figure 5. Averaged perceived effort was greatest at the highest pitch, and generally was greater at the 50th than the 10th percentile of the pitch range. Effort and PTP were significantly correlated when examined across all pitches, subjects, and sessions (Table 6). When examined for each pitch, the correlation was strongest at the highest pitch. When examined by subject, M1's ratings of effort and measures of PTP correlated more strongly than those of the other subjects, and M2's effort and PTP data were uncorrelated.

TABLE 4B. *Differences in PTP (in cm H_2O) Before (median baseline value) and After 2 Hours of Loud Reading*

	High-Hydration Session			Low-Hydration Session		
	Pitch			Pitch		
Subject	10%	50%	80%	10%	50%	80%
M1	2.35*	2.95*	6.56*	1.51*	0.63*	1.98*
M2	2.81*	2.50*	4.18*	1.54*	1.10*	1.07
M3	0.56*	2.36*	3.19*	2.74*	4.92*	5.34*
M4	1.33*	0.39	1.01	1.63*	2.22*	2.49*
Mean	1.77	2.05	3.73	1.86	2.22	2.72

Note: * = reliable difference (>2 SD) in the predicted direction (positive).

TABLE 5. *Differences in PTP (in cm H_2O) After 15 Minutes of Vocal Silence Following 2 Hours of Loud Reading*

	High-Hydration Session			Low-Hydration Session		
	Pitch			Pitch		
Subject	10%	50%	80%	10%	50%	80%
M1	−0.13	−0.86*	−2.38*	−0.37	−0.49	−0.01
M2	0.15	−0.41	−1.12*	−0.05	−1.01*	0.95
M3				−0.60*	−3.00*	−1.80
M4	−1.58*	0.63	1.53	−1.21*	−0.74*	0.74
Mean	−0.52	−0.22	−0.66	−0.56	−1.31	−0.0372

Notes: * = reliable difference (>2 SD) in the predicted direction (negative).

Laryngeal imaging

Table 7a lists the categorical results for judgments of vibratory closure pattern based on the videostroboscopic images. Three subjects consistently demonstrated complete closure and one subject (M3) demonstrated either complete closure or a posterior glottal gap when the voice was rested (typical-hydration sessions and prefatigue during altered-hydration sessions). After the vocal-loading task, two subjects (M1, M2) displayed an anterior glottal gap and/or spindle-shaped vibratory closure pattern. This result did not differ with hydration condition. The remaining two subjects demonstrated complete closure after prolonged loud reading.

Additional laryngeal characteristics (Table 7b) varied inconsistently across hydration and fatigue conditions. Differences in ratings were considered substantial if they differed more than the difference between the typical-hydration sessions, provided that this difference was at least 10% of the scale (differences bolded in Table 7b). According to this criterion, Subjects M2 and M3 displayed substantial changes in 3 of the 6 parameters reflecting laryngeal appearance during the low-hydration session, and M4 displayed changes in 4 of the parameters during the high-hydration session. Of the six parameters, the one that most often indicated a change after the fatiguing task was amplitude of vocal-fold vibration (4 of the 8 comparisons indicated a substantial change; 3 occurred during the low-hydration condition). In this case, a "more abnormal" change indicated decreased amplitude of vibration.

TABLE 6. *Pearson Product-Moment Correlation Coefficients (r) Between Phonation Threshold Pressure and Perceived Phonatory Effort*

Subject/s	Pitch/es	*N*	*r*	*P*
all	all	213	0.748	<0.0001
all	10%	71	0.452	<0.0001
all	50%	71	0.447	<0.0001
all	80%	71	0.843	<0.0001
M1	all	54	0.895	<0.0001
M2	all	54	0.094	0.4990
M3	all	54	0.595	<0.0001
M4	all	54	0.347	0.0102

DISCUSSION

Four young men with no vocal complaints or training demonstrated increased phonation threshold pressure at several pitches after talking loudly. The changes in PTP averaged 1 to 2.5 cm H_2O after 1 hour and 1.8 to 3.7 cm H_2O after 2 hours of the vocally fatiguing task; the greatest changes occurred on the highest pitch. The magnitude of these average changes was similar to those reported previously for women. A primary hypothesis of this experiment was that changes in PTP would be less extensive in men than in women. This supposition followed from clinical evidence[1] as well as the presumed protective influence of hyaluronic acid in the extracellular matrix of male vocal folds.[19] The hypothesis was not supported by these results nor by another recent study with a similar design in which 5 men and 5 women were examined.[15] Although the reasons for this inconsistency between clinical observations and

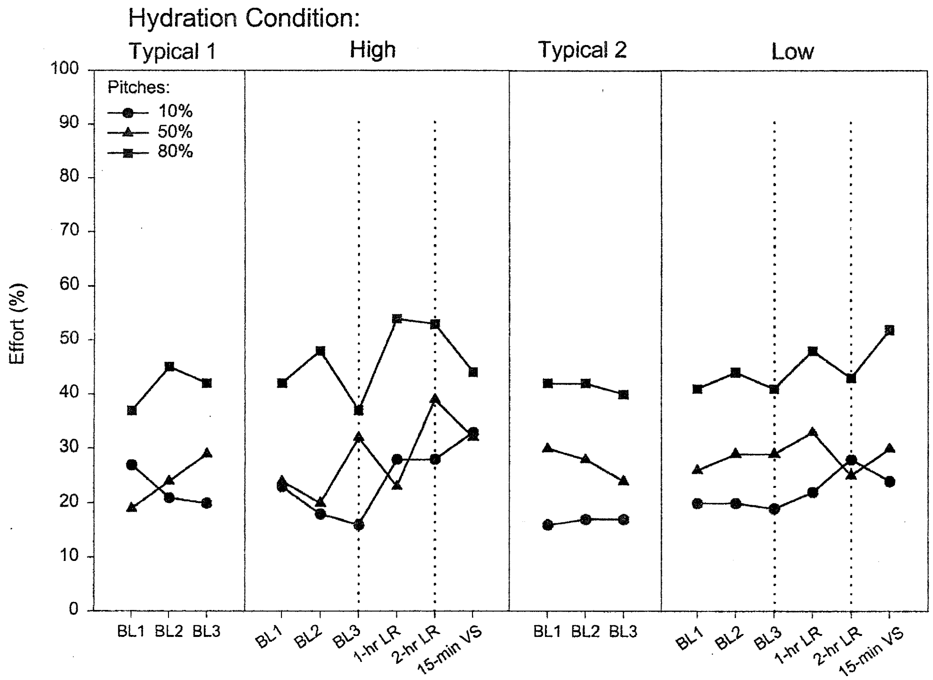

FIGURE 5. Self-perceived phonatory effort during the PTP task at each of three pitches (10th, 50th, and 80th percentiles of the pitch range). Data were averaged across the four subjects.

experimental results are not clear, one probable explanation involves the inclusion only of subjects without vocal complaints in recent experimental research. Persons who present with chronic vocal fatigue may use the vocal mechanism differently and may engage in more phonotraumatic behaviors than speakers without vocal complaints. Another explanation involves the experimental tasks used. By attempting to induce vocal fatigue within a reasonable time period, the task selected in this and other vocal-loading experiments may not reflect typical behavior.

The amount of water the subjects drank for two days before and during each session in this study did not consistently affect the results. When hydration alone was considered, that is, before the loud-reading task began, two of the subjects (M1, M2) demonstrated the expected change in PTP at the highest pitch tested. Interestingly, these two subjects' daily water consumption differed less between the two sessions (2.5 L each, see Table 1) than that for the other two subjects who did not demonstrate an apparent hydration effect. A confounding issue is that M1's HH data were collected 7 months after the LH session. His PTP results could have been affected by lifestyle and climate changes associated with the time of year. Thus, this result can not confidently be attributed to the benefits of systemic hydration. Previously, only 1 of 4 women demonstrated an apparent benefit of drinking water alone.[6] These lower-than-chance findings indicate that simply drinking extra water should not be expected to lower PTP. As discussed in the earlier paper, studies that have reported systematic differences in PTP with hydration manipulated it more globally (room humidity, water consumption, mucolytic or dehydrating medication)[9,10] or more extremely.[11]

One conclusion from the earlier study was that drinking water appeared to delay or attenuate the detrimental effects of the strenuous phonation task in three of the four women.[6] The present results indicated a similar finding for two of the men (M3, M4), but the remaining two demonstrated the opposite effect (greater increases in PTP after loud reading during the high-hydration session when compared to the low-hydration session). Based on this extreme variability and chance-level result, this study did not support the prediction that drinking water would be

TABLE 7A. *Results of Visual-Perceptual Judgments from Laryngeal Stroboscopy: Vibratory Closure Pattern (choice of 7 categories)*

	Hydration Condition					
	Typical		High		Low	
Subject	1	2	Pre	Post	Pre	Post
M1	complete	complete	complete	ant. gap	complete	ant/spindle
M2		complete	complete	ant. gap	complete	ant. gap
M3	post. gap	complete	post. gap	complete	complete	complete
M4	complete	complete	complete	complete	complete	complete

Note: Image from M2's first typical-hydration session was obscured by supraglottic activity.

TABLE 7B. *Results of Visual–Perceptual Judgments from Laryngeal Stroboscopy: Additional Characteristics (percentage of a visual analog scale from "normal" to "abnormal" where higher numbers are more abnormal)*

		Hydration Condition					
		Typical		High		Low	
Subject	Parameter	1	2	Pre	Post	Pre	Post
M1	supraglottic activity	0	6	12	**38**	15	1
	mucus	30	8	16	17	7	16
	color	12	6	9	14	7	12
	mucosal wave	15	2	**12**	20	18	16
	amplitude	7	4	8	3	**1**	**12**
	symmetry	10	3	**8**	**19**	7	2
M2	supraglottic activity		50	**15**	**67**	73	83
	mucus		2	10	12	10	17
	color		1	4	1	9	3
	mucosal wave		7	10	12	**13**	**31**
	amplitude		8	6	10	**6**	**28**
	symmetry		1	7	7	**9**	**23**
M3	supraglottic activity	58	54	59	45	71	71
	mucus	17	12	27	12	**12**	**40**
	color	5	5	5	11	**14**	**27**
	mucosal wave	22	22	19	24	28	22
	amplitude	9	9	15	20	**10**	**29**
	symmetry	20	7	18	4	5	13
M4	supraglottic activity	18	7	**10**	**43**	22	21
	mucus	30	19	20	25	49	53
	color	7	2	**3**	**14**	8	14
	mucosal wave	4	4	9	17	6	15
	amplitude	10	3	**9**	**27**	10	19
	symmetry	10	11	**14**	**26**	9	14

Note: Bolded values represent substantial differences after 2 hours of loud reading in the predicted (more abnormal). A substantial difference was defined as exceeding the difference between the two typical-hydration sessions or 10%, whichever was greater.

beneficial for these men. This equivocal result should be interpreted with caution because of the small sample size in this study. Perhaps a larger subject group would have revealed systematic differences; aggressive recruitment of subjects should be a major goal of future research in this area.

To illustrate the results across genders, Figure 6 plots differences in PTP at 80% of the pitch range

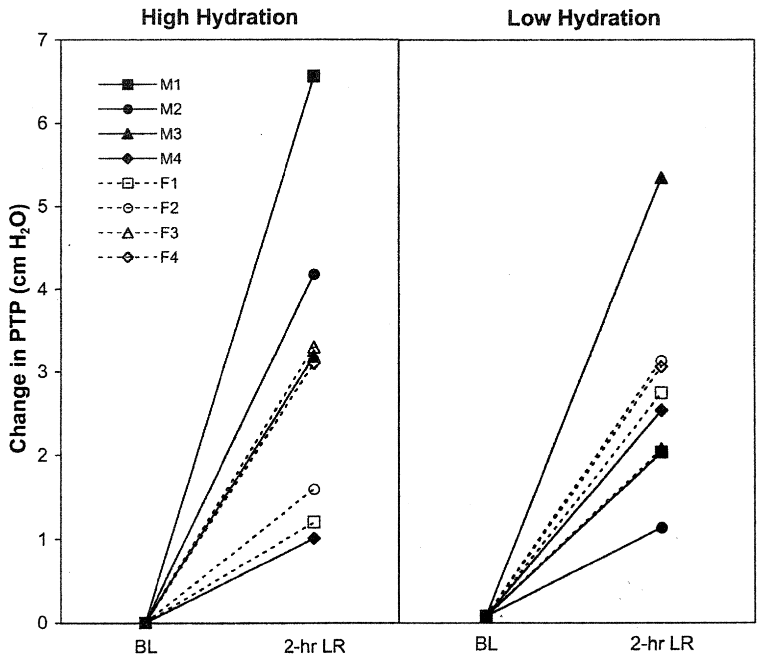

FIGURE 6. Change in PTP at 80% of pitch range before and after 2 hours of loud reading (LR) by the four men in the present study (M1–4) and four women published previously (F1–4).[6] Data are plotted for the two altered-hydration conditions (High, Low).

before and after the 2-hour loud reading task for the four men reported here and the four women reported previously.[6] The median baseline value was used for the men, and the single pre-loud-reading value was used for the women. It is clear from this figure that PTP increased for both men and women after the vocally fatiguing task and that the range of these differences was greater for the men than the women. The reason for this variability is not certain, but subjects' records revealed that some men complied less consistently than the women with the guidelines for food and beverage consumption (eg, skipping breakfast, drinking different amounts or types of beverages than prescribed).

Overall ratings of effort to perform the PTP task at each pitch correlated well with the PTP data. This relationship could not be examined in the previous study[6] because effort ratings were collected during the reading tasks. Other studies have explored this relationship and some have reported a close association between effort and PTP at least for some of the subjects.[11,15,16] Other studies, however, have not demonstrated close associations between these variables.[10,17] In the present study, subjects differed in their ability to "match" their sense of effort to their PTP productions.

The internal sense of lung volume and pressure is probably related to peripheral (eg, pulmonary stretch receptors and muscle receptors) and central (eg, awareness of descending motor signals) mechanisms. Sense of effort has been demonstrated to increase with expiratory[21] and inspiratory[22,23] muscle loading. These findings from the respiratory physiology literature indicate that a prolonged, strenuous breathing task (in this case, loud speaking) is expected to result in increased sense of effort for breathing. The specific mechanisms that account for a correspondence between the sense of *phonatory* effort and lung pressure have not been detailed, but likely include respiratory, phonatory, and even articulatory characteristics.[14] Clearly, this and previous studies reveal that some people seem to have a better internal sense of their own vocal performance than others. This is borne out by clinical experience, and could relate to the variable success of behavioral therapy with voice patients.

One aspect of this study that was not expected to differ between men and women was the return of

PTP values during a vocal-rest period. Surprisingly, PTP values for the men often did not recover after 15 minutes as they usually did for the women. In contrast, Chang and Karnell[15] did not report a difference in recovery patterns for the men and women in their study.

The videostroboscopic images of the larynx during phonation revealed normally configured vocal folds before the vocally fatiguing task. Three of the men in this study displayed a complete vibratory closure pattern and one (M3) inconsistently demonstrated a posterior glottal gap. Both of these patterns have been reported in men with normal voices.[24,25] After the loud-reading task, two men's (M1, M2) patterns changed to reveal an anterior gap (and in one case an inconsistent spindle shape). This observation of an anterior gap and/or spindle-shaped glottis has been documented previously for patients who presented with vocal fatigue[26] and after a vocal-loading task in persons with normal voices.[4–6] Both of these patterns involve an unusual gapping of the mid-to-anterior glottis. Vocal fold bowing, which appears similar to a spindle-shaped pattern, has been associated with modification of thyroarytenoid muscle activity.[27] The strenuous phonation task used in this study could have fatigued this muscle and resulted in the change in vibratory closure pattern observed in two subjects (M1, M2). Localized edema in the midsection of the vocal folds may also give the appearance of an anterior gap. This explanation is consistent with a report of laryngeal edema after prolonged loud talking.[28]

Other parameters describing laryngeal appearance and phonatory behavior changed inconsistently with the vocally fatiguing task and hydration condition. Three or four of the six parameters appeared more abnormal in two subjects (M2, M3) in the low-hydration condition, and in one subject (M4) in the high-hydration condition. This inconsistency across hydration conditions again suggests that the men's larynges did not react systematically to the difference in water consumption.

Of the six laryngeal characteristics judged numerically, the one that most often revealed changes after prolonged loud talking was the amplitude of vibration. This change was perceived in either the high- or low-hydration conditions, but not both, for all four men. Three men demonstrated this change when underhydrated, and the fourth subject's data tended in this direction as well (M4, a change of 9% rather than the 10% required to be considered substantial; see Table 7b). This observation suggests an increase in vocal fold stiffness, which theoretically would contribute to an increase in PTP.[8] The additional contribution of increased viscosity that is hypothesized with reduced hydration would cause PTP to increase as well. The findings of decreased amplitude of vibration and the inferred increase in viscosity for the low-hydration condition lead to the hypothesis that PTP should increase more for the low-hydration session that for the high-hydration session. Only half of the subjects' data supported this prediction, and one of these subjects' PTP and laryngoscopic data were collected during high-hydration sessions that were separated by 7 months. In short, the changes observed in laryngeal and phonatory appearance after a vocally fatiguing task suggest potential mechanisms for changes in PTP but are not entirely adequate to explain the results between the hydration conditions.

Two aspects of laryngeal appearance that do not contribute to current theoretical models of PTP are the presence of mucus and supraglottic activity. Mucus is thought to form on the vocal folds as a protective reaction to phonotraumatic behavior. However, in this study, substantially increased mucus was only noted for one subject in one condition (M3, low-hydration). Increased supraglottic activity was observed after the loud-reading task in three of the men in this study during the high-hydration sessions. Supraglottic activity can contribute to vocal fold stiffness, as documented during whispering,[29] and could have contributed to increased PTP in these subjects. Interestingly, two subjects (M2, M3) generally demonstrated abnormally high supraglottic activity during all endoscopic procedures. In one case (M2, typical hydration session 1), this was so marked that observations of laryngeal appearance were precluded. For both of these subjects, other ratings might have been affected by the distracting presence of supraglottic constriction. Presumably, this activity resulted from "scope defensiveness" that makes comparison of these laryngeal imaging data to the PTP data suspect.

Visual perceptual judgments of laryngeal images are commonly used to support clinical decision-making in patients with voice disorders. This study examined whether laryngeal and phonatory appearance varied systematically after a vocally fatiguing task in two markedly different states of systemic hydration. Findings from these four subjects mirror clinical impressions that some individuals display obvious visible laryngeal effects of strenuous voice use, while others do not.

CONCLUSION

This and a previous experiment[6] provided evidence that phonation threshold pressure and self-perceived phonatory effort increase after prolonged loud phonation. However, data collected from men were markedly more variable than those from women. Water consumption appeared to benefit the women somewhat more than the men, but at least one man's PTP data reflected positive changes, and at least one woman's PTP data did not reflect changes with increased systemic hydration. Clearly, more subjects need to be studied to determine if such an effect is based on sex differences, individual aspects of phonatory function, or other individual differences. Future studies also could include groups of subjects with a variety of vocal complaints and disorders, address the effects of a training regimen on vocal loading, and examine the optimal period and amount of hydration manipulation.

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