Efficacy of Water Resistance Therapy in Subjects Diagnosed With Behavioral Dysphonia: A Randomized Controlled Trial

*,†,*Marco Guzman, *,†Rodrigo Jara, ‡Christian Olavarria, *Paloma Caceres, *Geordette Escuti, *Fernanda Medina, *Laura Medina, *Sofia Madrid, §Daniel Muñoz, and ‖Anne-Maria Laukkanen, *†‡§Santiago, Chile, and ‖Tampere, Finland

Summary: Purpose. The purpose of the present study was to determine the efficacy of water resistance therapy (WRT) in a long-term period of voice treatment in subjects diagnosed with voice disorders.

Methods. Twenty participants, with behavioral dysphonia, were randomly assigned to one of two treatment groups: (1) voice treatment with WRT, and (2) voice treatment with tube phonation with the distal end in air (TPA). Before and after voice therapy, participants underwent aerodynamic, electroglottographic, acoustic, and auditory-perceptual assessments. The Voice Handicap Index and self-assessment of resonant voice quality were also performed. The treatment included eight voice therapy sessions. For the WRT group, the exercises consisted of a sequence of five phonatory tasks performed with a drinking straw submerged 5 cm into water. For the TPA, the exercises consisted of the same phonatory tasks, and all of them were performed into the same straw but the distal end was in air.

Results. Wilcoxon test showed significant improvements for both groups for Voice Handicap Index (decrease), subglottic pressure (decrease), phonation threshold pressure (decrease), and self-perception of resonant voice quality (increase). Improvement in auditory-perceptual assessment was found only for the TPA group. No significant differences were found for any acoustic or electroglottographic variables. No significant differences were found between WRT and TPA groups for any variable.

Conclusions. WRT and TPA may improve voice function and self-perceived voice quality in individuals with behavioral dysphonia. No differences between these therapy protocols should be expected.

Key Words: Tube phonation–Semi-occluded vocal tract–Voice therapy–Subglottic pressure–Phonation threshold pressure.

INTRODUCTION

Physiological approach of voice therapy is commonly used by speech-language pathologists in treating patients with a wide variety of voice disorders. Stemple[1] defined this approach of voice therapy as "programs aimed to modify the physiology of the vocal mechanism." According to Stemple, this approach involves three main components: "1) to improve the balance between the primary voice production sub-systems (respiration, phonation, and resonance), simultaneously, as opposed to working on each component individually (as symptomatic approach does), 2) to improve the strength, balance, tone, and stamina of laryngeal muscles, and 3) to develop a healthy mucosal covering of vocal folds."[2] Examples of physiological voice therapy programs include resonant voice therapy (RVT),[3] the accent method of voice therapy (AM),[4] and vocal function exercises (VFE).[1]

Semi-occluded vocal tract exercises

A common aspect in physiological voice therapy programs mentioned above is that all of them take advantage of semi-occluded vocal tract exercises (SOVTE). This group of exercises includes phonation on voiced fricatives, nasals, lip and tongue trills, hand over mouth, and phonation into different tubes with the distal end either freely in the air or submerged into a recipient filled with water.

Several studies have been carried out to investigate the physiological aspects of SOVTE. Some of them have focused on the glottal source,[5–24] others on vocal tract configuration,[22,25–29] and also an important number of investigations have explored aerodynamic variables.[29–33] Some effects regarding the glottal source, related to the increased inertive reactance in the vocal tract, have been reported in modeling studies.[9,34,35] Specifically, earlier modeling investigations support the idea that this increment positively affects the vocal fold vibration,[5,8,34,35] changing the glottal flow amplitude and pulse shape.[6,7,35,36] According to Titze, strengthening of the higher harmonics and an increase in the overall sound pressure level are caused by an increased skewing of the glottal flow waveform (faster cessation of the flow) when inertive reactance is increased.[5–8] Additionally, the phonation threshold pressure (PTP) (the minimum subglottal pressure required to initiate and sustain phonation) is reduced by increased vocal tract inertance.[8,35,36] Low values of this variable suggest an easy phonation (low phonatory effort).

A considerable number of studies have explored the possible effect of SOVTE on vocal fold adduction through electroglottographic contact quotient (CQ_{EGG}).[10–19] Andrade et al[18] as well as Guzman et al[19] compared the CQ_{EGG} among different SOVTEs. The latter found that different SOVTEs differentially affect vocal fold adduction in both subjects with dysphonia and subjects with normal voice. Lip and tongue trills produced

Accepted for publication September 8, 2016.

From the *Department of Communication Sciences, University of Chile, Santiago, Chile; †Department of Otolaryngology, Las Condes Clinic, Santiago, Chile; ‡University of Chile Hospital, Santiago, Chile; §Department of Otolaryngology, University of Chile, Santiago, Chile; and the ‖School of Education, Speech and Voice Research Laboratory, University of Tampere, Tampere, Finland.

Address correspondence and reprint requests to Marco Guzman, Department of Communication Sciences, University of Chile, Santiago, Chile; Department of Otolaryngology, Las Condes Clinic, Santiago, Chile. E-mail: guzmann.marcoa@gmail.com, mguzman@med.uchile.cl

Journal of Voice, Vol. 31, No. 3, pp. 385.e1–385.e10
0892-1997

http://dx.doi.org/10.1016/j.jvoice.2016.09.005

the lowest CQ_{EGG} values, whereas straw submerged 10 cm below water presented the greatest CQ_{EGG}.[19] Low CQ_{EGG} values during tongue and lip trills have also been reported by Andrade et al[18] and Gaskill and Erickson.[10]

The impact of SOVTE on vocal fold vibration and glottal area variables has also been observed by high speed digital imaging during tube phonation.[20–22] Additionally, an investigation (a double-case study) using computerized tomography (CT) was carried out to observe whether there are systematic changes in the vocal fold adjustment during and after tube phonation.[23] Muscle activity has also been assessed using electromyography.[24] Findings from electromyography showed that the ratio of thyroarytenoid muscle activity versus cricothyroid muscle activity increased during phonation into a tube.[24]

Vocal tract shape changes during SOVTE have been investigated through CT,[17,25,29] magnetic resonance imaging,[26] and with flexible laryngeal endoscopy as it comes to hypopharyngeal and laryngeal changes.[27] In a single case CT study with a vocally normal subject, Vampola et al[25] found that the most dominant modification during tube phonation was the expansion of the cross-sectional area of the oropharynx and oral cavity. A higher velum position was also reported. When comparing the pre- and posttube phonation, the authors showed that the total volume of the vocal tract was considerably larger after phonation into the tube. The volume of the valleculae and piriform sinuses also increased.[25] Similar results have been demonstrated by Laukkanen et al[26] and Guzman et al[17] in vocally normal subjects. The latter also showed that the vertical laryngeal position was lower during phonation into a tube compared with vowel phonation, and that the changes were more prominent during phonation into a narrow straw (stirring straw) compared with phonation into the traditional Finnish glass tube. Wistbacka et al[28] showed in a recent investigation with a dual-channel electroglottograph that phonation into a tube submerged into water caused a lower vertical laryngeal position, whereas it rose during phonation with the distal tube end in air. Moreover, in a recent investigation with CT on voice patients, the total volume of the vocal tract increased during tube phonation compared with the conditions pre- and postexercises.[29]

Various earlier studies have addressed the effect of different SOVTEs on air pressure measures.[17,30–33,37] Maxfield et al[32] measured the intraoral pressure (Poral) produced by 13 semi-occlusions. The highest values of oral pressure were evidenced for a straw submerged in water, for lip trills, and for a stirring straw with the free end in air. Radolf et al[30] showed that compared with vowel phonation, the Poral increased in phonation into a resonance tube and stirring straw, most when the resonance tube was 10 cm in water. Subglottic pressure (Psub) also tended to increase relatively more than Poral, and thus transglottic pressure (Ptrans) was higher during tube and straw phonation compared with vowel phonation. In a recent investigation, it was found that all exercises with phonation into tubes in air and submerged in water had a significant effect on Psub, Poral, and Ptrans.[37] Phonation into a flexible silicon tube (LaxVox-like tube) submerged 10 cm in water and phonation into a stirring straw in air resulted in the highest values of Psub and Poral compared with baseline. Moreover, most variables behaved in a similar way regardless of the vocal status of the participants (functional dysphonia, normal without voice training, normal with voice training, and vocal fold paralysis).[37]

Evidence about efficacy of physiological approach of voice therapy

Multiple earlier studies have demonstrated the efficacy of physiological approach of voice rehabilitation programs.[38–63] VFEs have been examined with both normal and voice disordered populations,[38–56] as well as RVT[57–59] and AM.[60–63] However, there are few studies exploring the efficacy of alternative voice rehabilitation programs based on SOVTE, such as phonation into different tubes with the distal end either freely in the air or submerged into a recipient with water. An investigation on the effect of drinking straw phonation in air plus bilabial consonant /ß:/ in a group of acting students diagnosed with muscle tension dysphonia showed that after a 6-week therapeutic period, significant positive changes were observed by spectral analysis and laryngoscopic assessment.[64] In a recent randomized controlled trial, Kapsner-Smith et al[65] demonstrated that a 6-week therapeutic program, based on flow-resistant tube exercises (stirring straw phonation), caused significantly more improvement in Voice Handicap Index (VHI) scores than in the scores of the control condition (no-treatment group).[65] Furthermore, flow-resistant tube therapy resulted in significant decrease in roughness (from the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) scale) relative to the control group. To the best of our knowledge, only two longitudinal studies have been carried out using phonation into tubes submerged in water (water resistance therapy [WRT]) in subjects with behavioral dysphonia.[66,67] In a controlled study conducted by Simberg et al,[66] participants from experimental group underwent a 7-week therapy period with WRT. Perceptual assessment and results from a questionnaire of the occurrence of vocal symptoms revealed significant positive changes in the treatment group compared with the control group.[67]

Tube in air versus tube into water

From the physical point of view, one of the main differences between tube phonation with the free end in air and tube submerged into water is the degree of resistance that they offer to the airflow, being greater when tube is placed in water. Andrade et al[33] showed that when tubes are submerged into water, back pressure (analogous to Poral) needs to overcome the pressure generated by the water depth before flow can start.[33] Another difference between tube phonation in air and into water is due to the water bubbles produced during the latter (WRT). Therefore, tube phonation in water generates a pulsating oral pressure at the frequency of 15–40 Hz,[30,31] which may cause a massage-like effect on the laryngeal and pharyngeal tissues.

Although the two physical differences between tube in air and tube in water are well supported by evidence, there is no evidence on the possible long-term effects of these two therapeutic approaches and the possible differences in the effects. It seems important to investigate whether these approaches would result in different therapeutic outcomes. The investigation is motivated by the fact that these two approaches are practical and easy to use in voice therapy, and therefore they have become increasingly popular worldwide. Therefore, the present study aimed to determine the efficacy of WRT and tube phonation in air during a long-term period of voice treatment in subjects diagnosed with behavioral dysphonia.

METHODS

Participants

Twenty-eight participants were initially enrolled in this study. All participants were randomly assigned to one of two treatment groups before starting voice therapy procedures: (1) voice treatment with WRT, and (2) voice treatment with tube phonation with the distal end in air (TPA). Subjects were distributed equally among groups (n = 14 for each group). The mean age in the WRT group was 28 years, with a range of 20–35. The mean age in the TPA group was 27 years, with a range of 18–33. The inclusion criteria for all participants were (1) age within the range of 18–50 years, (2) laryngoscopic diagnosis of hyperfunctional dysphonia (with the absence of organic lesions), and (3) no current or previous voice therapy. Laryngeal evidence for hyperfunction was the presence of compression of the glottis or supraglottic structures during phonation. Moreover, all subjects reported sensation of muscle tension and effort during phonation. Even though 28 participants were initially enrolled, only 20 participants completed the entire therapeutic procedure (10 participants in each group).

Participants from all groups were native speakers of Spanish. This study was reviewed and approved by the University of Chile, Faculty of Medicine Review Board. Informed consent was obtained from all the participants. Assessment and therapy sessions were carried out in the voice research laboratory at the University of Chile.

Laryngoscopic assessment

Before voice therapy, all participants underwent laryngoscopic, aerodynamic, electroglottographic, acoustic, and perceptual assessments of voice. First, they were asked to undergo rigid videostroboscopy (Digital Videostroboscopy System RLS 9100-B; KayPENTAX, Lincoln Park, NJ) to confirm medical diagnosis. Laryngoscopic examinations were performed by one experienced laryngologist at the University of Chile Hospital and who is a coauthor of the present study (C.O.). No topical anesthesia was used during endoscopic procedure.

Aerodynamic and electroglottographic assessments

Aerodynamic and electroglottographic (EGG) signals were captured simultaneously during all phonatory tasks. Aerodynamic data were collected with the Phonatory Aerodynamic System (PAS; KayPENTAX, Model 4500). EGG data were obtained with an electroglottograph (KayPENTAX, Model 6103). Both aerodynamic and EGG systems were connected to an interface (*Computerized Speech Lab*, Model 4500, KayPENTAX), which in turn was connected to a desktop computer running a real-time aerodynamic and EGG analysis software (KayPENTAX, Model 6600, version 3.4). All samples were digitally recorded at a sampling rate of 22.1 KHz with 16 bits/sample quantization. Calibration of the airflow rate and pressure was performed before every recording session according to the manufacturer's instructions.

Participants performed different phonatory tasks according to the protocol used in PAS for aerodynamic and electroglottographic assessments. In the present study, only two protocols were used: "comfortable sustained phonation with EGG" and "voice efficiency." During "comfortable sustained phonation protocol," subjects were required to produce a sustained vowel [a:]. During "voice efficiency protocol," an estimate of the Psub was recorded from the Poral during the occlusion of the voiceless consonant [p:] during the repetition of the syllable [pa:]. A thin plastic and flexible tube inserted into the mouth was used to capture Poral. During "voice efficiency protocol," PTP was also obtained. For that purpose, participants were asked to produce repetition of the syllable [pa:] as softly as possible but without entering into whisper. All phonatory tasks were demonstrated by researchers, and a brief practice was conducted before obtaining voice recordings that best represented the target productions. For PTP, a longer practice was performed. Three repetitions were made for all phonatory tasks.

All samples were analyzed with real-time aerodynamic and EGG analysis software. A criterion level of 25% from the peak-to-peak amplitude of the EGG signal was used for CQ_{EGG} analysis. Only the most stable sections from the middle part of the samples were included in the EGG and aerodynamic analyses. Once the stable sections were selected, the following variables were obtained:

(1) comfortable sustained phonation protocol: mean EGG contact quotient (CQ) (%) and mean glottal airflow (L/s)
(2) voice efficiency protocol: mean Psub (cm H_2O), glottal resistance (cm H_2O/L/s), and PTP (cm H_2O)

Audio recordings and acoustical analysis

After aerodynamic and EGG assessments, participants were recorded when reading a 242-word phonetically balanced text, which took approximately 90 seconds. A Focusrite Scarlett 8i-6 USB audio interface (Focusrite Audio Engineering, High Wycombe, UK) and a Rode condenser-omnidirectional microphone, Model NT2-A (Rode, Long Beach, CA) were used to capture the audio signals. The microphone was positioned 30 cm from the mouth of the participants, who remained standing. Recordings took place in an acoustically treated room, and the samples were recorded digitally at a sampling rate of 44.1 kHz and with 16 bits. The recording of voice signals was made using the software *Pro Tools 9.0* (Avid Corporation, Burbank, CA).

Acoustical analysis with long-term average spectrum (LTAS) was performed. The acoustical variables in this study were (1) the sound level difference between the F1 and F0 regions (L1–L0), that is, the level difference between 300–800 Hz and 50–300 Hz; and 2) the alpha ratio, which is the sound level difference between 50–1000 Hz and 1000–5000 Hz. L1–L0 has been associated with the degree of vocal fold adduction. Hypoadducted vocal folds present a strong L0 (sound level of F0) and low L1 (sound level of F1), whereas a weak L0 and strong L1 are present in voices with higher vocal fold adduction.[68] Alpha ratio is a measure that represents overall spectral slope.[69] This spectral variable has been found to depend on phonation type (degree of vocal fold adduction), being higher in hyperfunctional voices.[70] The

LTAS spectra for each subject were obtained by the *Praat* software, version 5.3.60 (Institute of Phonetic Sciences of the University of Amsterdam, The Netherlands). For each sample, a bandwidth of 100 Hz and Hanning window were used. Before performing LTAS analysis, unvoiced sounds and pauses were eliminated from the samples by the *Praat* software using the pitch-corrected LTAS version with standard settings.

Auditory-perceptual evaluation

All recorded audio samples from the phonetically balanced text were perceptually assessed by three blinded judges (speech-language pathologists with at least 10 years of experience in voice clinic). Additionally, 20% of samples were randomly repeated in order to determine whether judges were consistent in their perceptions (intra-rater reliability analysis). They were not aware of these repetitions. Perceptual assessment was performed on a 100-mm visual analog scale. Only one perceptual variable was assessed, resonant voice quality. This variable was defined as a voice that sounds as being produced easily and with forward placement (0 = not resonant at all, 100 = very resonant). Forward placement is an auditory perception of well projected and bright voice. Raters could replay each sample as many times as they wanted before making their decision and moving on to the next sample. The evaluation was performed in a quiet room at the voice research laboratory using high-quality headphones (Bose AE2, Bose Corporation Framingham, MA). None of the listeners reported any hearing problems.

Questionnaire application

All participants were asked to complete the Spanish adaptation and validation of the VHI-30.[71,72] This self-administrated questionnaire is a health status instrument designed to assess the voice handicap resulting from voice problems. The VHI has important psychometric properties of reliability and validity.[71] It contains 30 items chosen to address the functional, physical, and emotional impact of voice problems. Each item is individually scored on a 5-point Likert scale anchored by "never" (score of 0) and "always" (score of 4).[71]

Self-assessment of voice quality

Before aerodynamic, electroglottographic, and acoustics recordings, all participants were required to self-assess their voice quality. Perceptual assessment was performed on a 100-mm visual analog scale. Only one perceptual variable was assessed (resonant voice quality), defined as a voice that feels easy and with sensation of vibration on the front part of face and mouth (0 = not resonant at all, 100 = very resonant).

Voice therapy procedures

The treatment period included eight voice therapy sessions within 8 weeks, with a frequency of one therapy session per week. Each session lasted for 30 minutes. Therapy sessions were administrated by four trained speech-language pathologists. To standardize the therapeutic performance, all clinicians participated in a 20-hour training period (conducted by the first author of the present study) prior to performing the therapy. This training period included aspects related to sensory-motor learning principles applied to voice rehabilitation and use of SOVTE.

All therapy sessions included three sections: (1) introduction (3 minutes), where the clinician asked about home practice and any voice issue that happened during the previous week; (2) core (24 minutes), where the participants demonstrated exercises that had been practiced during the previous week and rehearsed new phonatory tasks planned for the session; and (3) end of practice (3 minutes), where the clinician instructed the home practice that the patient should perform every day until the next therapy session. The first therapy session also included instruction about vocal hygiene habits (hydration, avoidance of high loudness speech, and avoidance of laryngeal irritants) for both groups.

For the WRT group, the exercises consisted of a sequence of five phonatory tasks performed into a commercial plastic drinking straw (5 mm in inner diameter and 25.8 cm in length) submerged 5 cm into water. The main reason for choosing this type of tubes is the fact that they are easily available and affordable for clinicians and patients in several countries. Phonatory tasks included (1) sustained vowel-like sound, (2) ascending and descending *glissandos* throughout a comfortable vocal range, (3) intensity and pitch accents, (4) *messa di voce*, and (5) singing the melody of the song "happy birthday" into the straw. These phonatory tasks were sequentially included in the treatment period during the eight sessions. Participants were asked to feel vibratory sensations on the alveolar ridge, and face and head areas, and to feel ease of phonation. Participants from this group were also encouraged to feel a massage-like sensation produced by water bubbling during all phonatory tasks with WRT. Before and during practice, the clinicians provided individual demonstrations and verbal descriptions of each phonatory task.

For the TPA group, the exercises consisted of the same five phonatory tasks performed into the same kind of a plastic drinking straw as was used in the exercise group, but in the control group the distal end of the straw was held in air. Moreover, lip buzz ([ß:]) was also included in the first session for the control group to help the subjects recognize vibratory sensations.

For a home exercise program, the subjects from both groups were required to complete 6–8 times daily, during 5–10 minutes each time. At the end of each session, the subjects were given on a paper sheet detailed instructions for the home exercise program. The instructions included all phonatory tasks learned during the session.

Posttherapy assessment

Once the eight-session voice therapy period was accomplished, each participant underwent the same assessment procedure as had been performed for the pretherapy assessment. The procedure included aerodynamic, EGG, acoustic, auditory-perceptual assessment, and self-assessment of voice. Posttesting was performed exactly 1 week after completion of voice therapy.

Statistical analysis

All statistical analyses were made using Stata 13.1 (StataCorp LP, College Station, TX). A P value <0.05 was considered

TABLE 1.
Results (Median and Interquartile Range) From Experimental Group for VHI, Auditory-Perceptual Assessment, and Self-Perceived Voice Quality (Wilcoxon Test)

Variable	Pre	Post	*P* Value
Total VHI	33.00 (25.00–47.00)	20.50 (14.00–25.00)	0.0018
VHI functional	9.00 (5.00–16.00)	6.00 (4.00–6.00)	0.0101
VHI physical	15.50 (10.00–19.00)	11.50 (5.00–15.00)	0.0056
VHI emotional	9.50 (5.00–13.00)	3.00 (2.00–6.00)	0.0128
Self-assessment	43.00 (38.00–74.00)	75.50 (72.00–89.00)	0.0002
Auditory-perceptual assessment	61.25 (49.00–66.50)	58.25 (51.50–68.00)	0.0602

Abbreviation: VHI, Voice Handicap Index.

statistically significant, and all P values were two-sided. Descriptive statistics were calculated for the variables, including median and interquartile range. Variables were compared between control group and experimental group and before-after treatment using the Wilcoxon test. Spearman's rank correlation coefficient with Bonferroni-adjusted significance level was used to assess correlation between variables. Intraclass correlation coefficient (ICC) was also used to assess reliability of the listening evaluation.

RESULTS

Reliability analysis

Intra-rater reliability analysis for auditory-perceptual evaluation demonstrated good agreement for each judge (Judge 1: 0.75, $P = 0.031$; Judge 2: 0.65, $P = 0.049$; Judge 3: 0.84, $P = 0.001$). Initially, poor agreement was obtained between judges (inter-rater analysis). This was due to dissimilar evaluation by one of the judges, so with this outlying judge removed from the analysis we obtained adequate and significant ($P < 0.05$) final consistency for auditory-perceptual assessment. The ICC prevoice therapy was 0.68 ($P = 0.038$), and the ICC postvoice therapy was 0.87 ($P = 0.008$).

Wilcoxon test results

Tables 1 and 2 show results from the WRT and TPA groups, respectively, for VHI, auditory-perceptual assessment, and self-perceived voice quality. Significant improvements ($P < 0.05$) were observed for both groups when pre- and postvoice therapy conditions were compared for the total score of VHI (decrease) and self-perception of resonant voice quality (increase). Improvement in auditory-perceptual assessment was found only for the TPA group. No significant differences were found when comparing the WRT and TPA groups.

Tables 3 and 4 display the results for the WRT and TPA groups, respectively, for aerodynamic and EGG variables. Significant changes ($P < 0.05$) were observed in both groups when pre- and

TABLE 2.
Results (Median and Interquartile Range) From Control Group for VHI, Auditory-Perceptual Assessment, and Self-Perceived Voice Quality (Wilcoxon Test)

Variable	Pre	Post	*P* Value
Total VHI	33.50 (18.00–44.00)	22.50 (9.00–37.00)	0.0463
VHI functional	7.00 (4.00–10.00)	6.50 (2.00–9.00)	0.1811
VHI physical	17.00 (10.00–24.00)	11.00 (5.00–17.00)	0.0217
VHI emotional	4.50 (3.00–13.00)	4.50 (2.00–7.00)	0.5731
Self-assessment	44.00 (29.00–58.00)	70.00 (61.00–79.00)	0.0093
Auditory-perceptual assessment	37.75 (20.50–53.00)	53.50 (33.00–60.00)	0.0125

Abbreviation: VHI, Voice Handicap Index.

TABLE 3.
Results (Median and Interquartile Range) From Experimental Group for Aerodynamic and EGG Variables (Wilcoxon Test)

Variables	Pre	Post	*P* Value
Glottal airflow (L/s)	0.15 (0.10–0.20)	0.15 (0.11–0.17)	0.7213
EGG CQ (%)	57.38 (48.36–62.19)	56.80 (52.80–61.23)	0.7713
Subglottic pressure (cm H_2O)	8.81 (7.83–9.87)	8.41 (6.61–8.73)	0.0218
Glottal resistance (cm H_2O/L/s)	55.44 (47.60–132.70)	53.86 (39.22–96.13)	0.1141
PTP (cm H_2O)	5.76 (5.33–6.16)	4.40 (4.29–5.34)	0.0051

Abbreviations: CQ, contact quotient; EGG, electroglottographic; PTP, phonation threshold pressure.

TABLE 4.
Results (Median and Interquartile Range) From Control Group for Aerodynamic and EGG Variables (Wilcoxon Test)

Variables	Pre	Post	*P* Value
Glottal airflow (L/s)	0.18 (0.15–0.30)	0.17 (0.12–0.25)	0.1394
EGG CQ (%)	55.30 (52.66–56.82)	53.75 (49.20–56.74)	0.5751
Subglottic pressure (cm H_2O)	10.23 (9.62–11.42)	8.58 (7.84–9.41)	0.0218
Glottal resistance (cm H_2O/L/s)	55.76 (46.17–66.75)	44.62 (36.83–52.59)	0.0926
PTP (cm H_2O)	6.10 (5.77–6.82)	4.83 (4.15–5.44)	0.0051

Abbreviations: CQ, contact quotient; EGG, electroglottographic; PTP, phonation threshold pressure.

postvoice therapy conditions were compared for Psub (decrease) and PTP (decrease). No significant differences were found between the WRT and TPA groups.

The results from the acoustical analysis are shown in Tables 5 and 6. No significant changes were found when comparing pre- and postvoice therapy conditions for both groups.

Correlation analysis

Correlation analysis revealed some results of clinical relevance. A strong linear negative correlation was found between VHI total score and self-perceived voice quality for the TPA group both before therapy (rho = –0.765; P = 0.009) and after therapy (rho = –0.666; P = 0.035). The VHI emotional subscale and self-perceived voice quality (rho = –0.689; P = 0.027) also correlated negatively both before (rho = –0.802; P = 0.005) and after therapy for the TPA group. Furthermore, there was a negative correlation between the VHI functional subscale and self-perceived voice quality (rho = –0.754; P = 0.011) for the TPA group before therapy. These three correlations suggest that the more voice problems the subjects reported, the less ease and less vibratory sensations they experienced during voice production. Moreover, PTP also showed a strong negative correlation with self-perceived voice quality (rho = –0.754; P = 0.041) for the TPA group before therapy, suggesting that the less Psub was needed to barely initiate phonation the less effort and more vibratory sensations were perceived during phonation. Additionally, and contrary to what could be expected, PTP correlated negatively with the VHI total score (rho = –0.840; P = 0.002), VHI functional subscale (rho = –0.650; P = 0.028), and VHI organic subscale (rho = –0.856; P = 0.001) for the TPA group before therapy. These results suggest that the more Psub was needed to initiate phonation the less voice problems the subjects reported. This paradoxical negative correlation is likely due to the small sample size. It may also reflect a difficulty to find the softest possible tone in the first recording.

DISCUSSION

The present study assessed the effects of an 8-week voice therapy period with WRT as a primary treatment for patients diagnosed with behavioral dysphonia. The results appear to support the role of WRT (one representative of physiological approach in voice treatment) as a potentially effective treatment for subjects with functional voice disorders. Effectiveness of WRT was compared to voice therapy with phonation into a tube with the distal end in air. Data showed significant improvements for both treatment protocols when pre- and postvoice therapy conditions were compared for VHI (decrease), Psub (decrease), PTP (decrease), and self-perception of resonant voice quality (increase). No significant differences were found for any acoustic, electroglottographic, or auditory-perceptual variable. Additionally, no significant differences were found when comparing the WRT and TPA groups for any variable.

A significant reduction of the total VHI score was observed for both groups after voice therapy. Moreover, the scores of each individual subscale (functional, physical, and emotional) significantly improved (decrease) after therapy for the WRT group. No improvements were observed for the functional and emotional subscales for the TPA group. From our data, it seems that

TABLE 5.
Results (Median and Interquartile Range) From Experimental Group for Acoustic Variables (Wilcoxon Test)

Variable	Pre	Post	*P* Value
Alpha ratio	−12.52 (−16.13–11.20)	−13.71 (−15.64–12.46)	0.5751
L1–L0	−0.08 (−3.53 2.97)	−1.19 (−4.22 3.89)	0.6012

TABLE 6.
Results (Median and Interquartile Range) From Control Group for Acoustic Variables (Wilcoxon Test)

Variable	Pre	Post	*P* Value
Alpha ratio	−14.83 (−16.57–9.78)	−16.01 (−17.87–13.45)	0.0745
L1–L0	−2.65 (−4.38 0.23)	−2.74 (−4.58 3.46)	0.7213

WRT had a wider positive impact than therapy with tube in air, regarding the areas that could be affected by voice disorders (functional, physical, and emotional). Several earlier studies using physiological programs for voice rehabilitation have used VHI as an outcome.[39,47,55,58,59,65] A recent investigation conducted by Kapsner-Smith et al demonstrated a significant reduction of the VHI total score after voice therapy for both treatment groups (VFE and phonation into a thin straw with the free end in air) compared with the non-treatment group.[65] A positive effect of VFE on VHI has also been observed, in various other studies, eg, in patients with aging voice,[47,55] teachers with voice complaints,[39] and subjects diagnosed with behavioral dysphonia.[56] Additionally, two studies have reported positive outcomes for VHI after voice treatment with RVT.[58,59] Roy et al[58] observed that following a 6-week period, both the RVT and the use of electric voice amplification resulted in a significant reduction of the mean VHI scores. Similar results of RVT were shown by Chen et al[59] in a group of female teachers with voice disorders. Other studies exploring the effectiveness of physiological voice therapy programs (VFE,[40,47] RVT,[57,58,73] and AM[63]) have also demonstrated some self-reported improvements using different scales than VHI. Gillivan-Murphy et al[40] in a study performed with primary and secondary school teachers reported improvements in the Voice Symptom Severity Scale in subjects from the experimental group treated with VFE. The Voice Symptom Severity Scale is a 30-item patient-derived inventory of voice symptoms with three content domains and a total score.[74] Evidence supports the idea that physiological voice therapy programs such as VFE, RVT, AM, and tube phonation protocols positively affect self-assessment outcomes.

In the present study, visual analog scale assessing the self-perceived resonant voice quality also showed a significant improvement (increment) for both groups after 8 weeks of voice therapy. Patients felt their voice production easier (less effort) and involving more vibratory sensations in the front part of face and mouth. No significant differences were found when comparing both groups. Interestingly, correlation analysis from our data showed a strong negative correlation between self-perceived voice quality and VHI total score, and some of the subscales for the TPA group. Perceived phonatory effort has also been assessed in earlier works where subjects have been treated with physiological voice therapy programs. Sauder et al[47] reported less self-perceived phonatory effort after a 6-week treatment period in a group of subjects with aging voice. Furthermore, in an investigation where RVT was administered to patients diagnosed with vocal nodules, Verdolini-Marston et al[57] found a decrease in self-perceived phonatory effort after 2 weeks of voice treatment. Likely the patients of the present investigation and those from the above-mentioned earlier studies learned to produce a more resonant voice after the treatment period. Nevertheless, it is also possible that they just learned to pay attention to some sensations associated with voice production. That as such may also be seen as a positive outcome.

As perceived phonatory effort has been associated with the PTP (the Psub required to barely initiate and sustain phonation),[34,35] this parameter would be expected to decrease after voice therapy. Our data showed a significant decrease in PTP for both groups. Furthermore, correlation analysis from our data interestingly demonstrated associations between PTP and the VHI total score, VHI functional subscale, and VHI physical subscale. The greatest value was found in the latter. Because VHI physical subscale is related to the degree of physical vocal discomfort (eg, "I use a great deal of effort to speak," "I feel as though I have to strain to produce voice," "my voice sounds creaky and dry," my voice "gives out" on me in the middle of speaking"), it is reasonable to find an association between these variables.

PTP is expected to decrease during SOVTE, as it has been found to decrease due to the increased vocal tract inertance.[8,35] In a modeling study with excised larynges, PTP was assessed by Conroy et al[75] during nine conditions: control, two tube diameters, three tube lengths, and three levels of flow input. A significant decrease in PTP was detected for the longest tube and the narrower tubes. Similarly, PTP was found to decrease for a glass resonance tube in a study applying a physical model of human voice production.[31] To the best of our knowledge, no studies have been conducted to assess PTP after a long-term period of voice therapy with tube phonation. Only one investigation has used PTP as an outcome to observe changes after a physiological voice therapy program.[59] Chen et al[59] reported a significant reduction of PTP after an 8-week period of voice treatment with RVT in teachers with voice disorders. Additionally, some investigations have been carried out to observe PTP after voice exercises as vocal warm-up. Theoretically, vocal warm-up should increase blood flow to the vocal fold muscles, thus decreasing muscle viscosity, and this in turn should decrease the PTP. Nevertheless, no consistent results have been found. In some cases, findings are even contrary to what is expected from the theoretical point of view. Vintturi et al[76] and Motel et al[77] found a significant increase of PTP after vocal warm-up, whereas other studies have reported a high variability among participants or no effect.[78,79] Only one study, conducted by McHenry and Johnson,[80] reported a decrease of PTP after vocal warm-up. During SOVTE, a decreased PTP could be explained as a result of increased vocal tract reactance. After SOVTE, ie, after the semi-occlusion has been removed from the vocal tract, the effect is supposed to remain due to a better phonation balance (neither breathy nor pressed phonation) or an improved impedance match between the larynx and the vocal tract, eg, in terms of a slightly narrowed epilarynx.[9]

Another aerodynamic measure that exhibited changes when comparing pre- and postvoice therapy conditions in the present study was Psub. It decreased in both groups significantly. Likely, this reduction also reflects (as PTP did) the lower phonatory effort perceived by subjects in their voice production. Two previous therapeutic investigations performed using physiological approaches (AM) reported changes in Psub after a long-term treatment period.[61,63] Kotby and Fex[61] observed a decrease in Psub after a 20-week period of voice treatment with AM in a group of subjects diagnosed with a wide variety of voice disorders. Similar findings were reported by Bassiouny.[63] Only one previous study has shown opposite results (increment of Psub); however, they are expected taking into account the population included (elderly men).[43] The authors suggested that this increase was a result of improved glottal closure.[43]

Several studies have demonstrated an increase in Psub or Poral during semi-occluded exercises[17,28–33] (especially when the tube is submerged in different depths of water). Results suggest that the increased Psub is a compensation due to the increased Poral, which in turn is caused by the high degree of airflow resistance offered by these semi-occlusions. The main variables that affect the airflow resistance during tube phonation are the diameter and length of the tube in air,[21,29,30,32,81] and the depth of immersion when the tube is placed into water.[29,30,32] Considering that an increment in Psub is commonly observed during SOVTE, it seems paradoxical that after a long-term voice therapy Psub has been found to be lower compared with pretreatment condition. Nevertheless, it is feasible that a moderate increment of Psub during SOVTE helps train breathing function during a long-term period of voice therapy, resulting in a decreased phonatory effort. Further studies should be performed on this topic.

Glottal airflow rate has been found to change after voice therapy with some physiological programs. Stemple et al[38] reported a significant decrease in airflow rate after VFE. Authors suggested that this reduction may be due to improved balance between glottal adduction and subglottic pressure. Similar results were provided by Sabol et al[45] in a study performed with a group of singers treated with VFE and by Kotby et al after therapy with AM.[60] An increased maximum phonation time reported after VFE[38,44,46] and after AM[60] could also be a consequence of reduction in airflow rate. Findings from the present study did not show significant differences in glottal airflow rate for neither group. Possibly, this variable was not sensitive enough to the improvement in voice function observed in both the experimental and control groups. Earlier studies did not find any reduction in glottal airflow rate either after VFE[56] or after RVT.[59] The lack of pre-post differences in glottal airflow rate in our data could be associated with the absence of pre-post differences in auditory-perceptual analysis for the WRT group.

Even though SOVTEs have been found to affect CQ_{EGG} during practicing and in some cases immediately after it,[10–19] no significant changes were evidenced in CQ_{EGG} after 8-week voice therapy period in the present study. Previous studies have revealed that CQ_{EGG} could be dependent on the degree of airflow resistance that SOVTEs offer during exercise. Normally, SOVTEs with high resistance (eg, tube submerged into water) cause a higher CQ_{EGG} compared with that with lower airflow resistance (eg, Finnish glass tube with the distal end in air).[19,33] No previous studies assessing the effect of tube phonation either in air or into water (as long-term therapy programs) on CQ_{EGG} have been carried out, thus no direct comparison can be done. Glottal resistance was another variable included in the present study, which could be associated with CQ_{EGG}, as both tell about the resistance that vocal folds offer to the airflow. No significant pre post differences were observed in glottal resistance for either group. However, it tended to decrease in both groups (same trend was seen in CQ_{EGG}). The absence of change in glottal resistance was also reported after 20 sessions of therapy with AM.[60] A decreasing trend in glottal resistance has in turn been reported after short-term exercising with SOVTE.[81–83] Laukkanen et al[82] showed a decrease in this variable (due to increased flow and decreased Psub) after phonation with [ß:]. In another study, where three different semi-occlusions were tested ([ß:], [m:], and phonation into a glass tube in air), most subjects showed a decrease in glottal resistance, mainly due to increased airflow. The authors suggested that these types of exercises immediately affect the control of glottal width.[83]

Acoustic findings from the present investigation are concordant with CQ_{EGG} and glottal resistance results. Neither L0–L1 nor alpha ratio showed significant differences in pre-post comparison. However, there was a small decrease (more negative values) in both parameters after voice therapy in both groups. Recall that both L1–L0 and alpha ratio have been found to depend on phonation type (degree of vocal fold adduction).[68,69] More negative values are indicative of a less tight vocal fold adduction. Therefore, taking into account CQ_{EGG}, glottal resistance, L1–L0, and alpha ratio, it would be possible to state that both groups tended to decrease vocal fold adduction, even though no significant pre-post differences were found. Because subjects from the present study were diagnosed with hyperfunctional dysphonia, it is reasonable to expect a decreasing trend for all the above-mentioned variables.

In the present study, the auditory-perceptual assessment demonstrated pre-post improvements only for the TPA group. The patients treated with WRT did not show significant differences when comparing pre and post conditions. It is possible to speculate that water bubbling could disturb the auditory monitoring and thus impair the improvement of voice quality. Further studies are needed on this topic. Other studies on physiological approach of voice therapy have also showed only partially positive results in perceptual assessment. In a recent work investigating the therapeutic effect of VFE and stirring straw phonation (compared with a non-treatment group), the auditory-perceptual results using CAPE-V were not totally satisfactory.[65] A statistically significant improvement was found only for roughness (decrease) in the stirring straw phonation group. Neither VFE nor stirring straw groups showed changes in overall severity of perceptual voice problem, in strain or in breathiness.[65]

CONCLUSION

WRT and TPA may improve voice function and self-perceived voice quality in individuals with behavioral dysphonia. No differences between these therapy protocols should be expected. It seems that the main positive effect of both rehabilitation protocols is related to the decrease of phonatory effort, which could be evidenced by subjective and objective measures.

REFERENCES

1. Stemple JC. *Voice Therapy: Clinical Studies*. San Diego, CA: Singular Publishing Group; 2000.
2. Thomas L, Stemple J. Voice therapy: does science support the art? *Commun Disord Rev*. 2007;1:49–77.
3. Verdolini K. Resonant voice therapy. In: Verdolini K, ed. *National Center for Voice and Speech's Guide to Vocology*. Iowa City, IA: National Center for Voice and Speech; 1998.
4. Kotby N. *The Accent Method of Voice Therapy*. San Diego, CA: Singular Publishing; 1995.
5. Rothenberg M. Acoustic interaction between the glottal source and the vocal tract. In: Stevens KN, Hirano M, eds. *Vocal Fold Physiology*. Tokyo: University of Tokyo Press; 1981:305–328.

6. Rothenberg M. Source-tract acoustic interaction and voice quality. In: Lawrence VL, ed. *Transcripts of the 12th Symposium Care of Professional Voice, Part I*. New York: The Voice Foundation; 1983:25–31.
7. Fant G, Lin Q. Glottal source-vocal tract acoustic interaction. *Speech Transmission Lab Quart Prog Status Rep Royal Inst Technol Sthlm Sweden*. 1987;1:13–27.
8. Titze I, Story B. Acoustic interactions of the voice source with the lower vocal tract. *J Acoust Soc Am*. 1997;101:2234–2243.
9. Titze I. Voice training and therapy with a semi-occluded vocal tract: rationale and scientific underpinnings. *J Speech Lang Hear Res*. 2006;49:448–459.
10. Gaskill C, Erickson M. The effect of a voiced lip trill on estimated glottal closed quotient. *J Voice*. 2008;22:634–643.
11. Laukkanen A-M. About the so called "resonance tubes" used in Finnish voice training practice. *Scand J Logop Phoniatr*. 1992;17:151–161.
12. Gaskill CS, Erickson ML. The effect of an artificially lengthened vocal tract on estimated glottal contact quotient in untrained male voices. *J Voice*. 2010;24:57–71.
13. Gaskill C, Quinney D. The effect of resonance tubes on glottal contact quotient with and without task instruction: a comparison of trained and untrained voices. *J Voice*. 2012;26:e79–e93.
14. Cordeiro GF, Montagnoli AN, Nemr NK, et al. Comparative analysis of the closed quotient for lip and tongue trills in relation to the sustained vowel /ɛ/. *J Voice*. 2012;26:17–22.
15. Hamdan AL, Nassar J, Al Zaghal Z, et al. Glottal contact quotient in Mediterranean tongue trill. *J Voice*. 2012;26:669, e11–e15.
16. Guzman M, Rubin A, Muñoz D, et al. Changes in glottal contact quotient during resonance tube phonation and phonation with vibrato. *J Voice*. 2013;27:305–311.
17. Guzman M, Laukkanen A-M, Krupa P, et al. Vocal tract and glottal function during and after vocal exercising with resonance tube and straw. *J Voice*. 2013;27:305–311.
18. Andrade PA, Wood G, Ratcliffe P, et al. Electroglottographic study of seven semi-occluded exercises: LaxVox, straw, lip-trill, tongue-trill, humming, hand-over-mouth, and tongue-trill combined with hand-over-mouth. *J Voice*. 2014;28:589–595.
19. Guzman M, Calvache C, Romero L, et al. Do different semi-occluded voice exercises affect vocal fold adduction differently in subjects diagnosed with hyperfunctional dysphonia? *Folia Phoniatr Logop*. 2015;67:68–75.
20. Granqvist S, Simberg S, Hertegård S, et al. Resonance tube phonation in water: high-speed imaging, electroglottographic and oral pressure observations of vocal fold vibrations—a pilot study. *Logoped Phoniatr Vocol*. 2014;28:1–9.
21. Laukkanen A-M, Pulakka H, Alku P, et al. High-speed registration of phonation-related glottal area variation during artificial lengthening of the vocal tract. *Logoped Phoniatr Vocol*. 2007;32:157–164.
22. Guzman M, Laukkanen A-M, Traser L, et al. Effect of water resistance therapy on vocal fold vibration: a high speed registration study. The Voice Foundation's 42nd Annual Symposium: Care of the Professional Voice, Philadelphia, 2014.
23. Hampala V, Laukkanen AM, Guzman MA, et al. Vocal fold adjustment caused by phonation into a tube: a double-case study using computed tomography. *J Voice*. 2015;29:733–742.
24. Laukkanen A-M, Titze IR, Hoffman H, et al. Effects of a semioccluded vocal tract on laryngeal muscle activity and glottal adduction in a single female subject. *Folia Phoniatr Logop*. 2008;60:298–311.
25. Vampola T, Laukkanen A-M, Horacek J, et al. Vocal tract changes caused by phonation into a tube: a case study using computer tomography and finite-element modeling. *J Acoust Soc Am*. 2011;129:310–315.
26. Laukkanen A-M, Horacek J, Krupa P, et al. The effect of phonation into a straw on the vocal tract adjustments and formant frequencies. A preliminary MRI study on a single subject completed with acoustic results. *Biomed Signal Process Control*. 2010;7:50–57.
27. Guzman M, Castro C, Testart A, et al. Laryngeal and pharyngeal activity during semioccluded vocal tract postures in subjects diagnosed with hyperfunctional dysphonia. *J Voice*. 2013;27:709–716.
28. Wistbacka G, Sundberg J, Simberg S. Vertical laryngeal position and oral pressure variations during resonance tube phonation in water and in air. A pilot study. *Logoped Phoniatr Vocol*. 2016;41:117–123.
29. Guzman M, Miranda G, Olavarria C, et al. Computerized tomography measures during and after artificial lengthening of the vocal tract in subjects with voice disorders. *J Voice*. 2016;doi:10.1016/j.jvoice.2016.01.003; in press.
30. Radolf V, Laukkanen A-M, Horáček J, et al. Air-pressure, vocal fold vibration and acoustic characteristics of phonation during vocal exercising. Part 1: measurement in vivo. *Eng Mech*. 2014;21:53–59.
31. Horáček J, Radolf V, Bula V, et al. Air-pressure, vocal folds vibration and acoustic characteristics of phonation during vocal exercising. Part 2: measurement on a physical model. *Eng Mech*. 2014;21:193–200.
32. Maxfield L, Titze I, Hunter E, et al. Intraoral pressures produced by thirteen semi-occluded vocal tract gestures. *Logoped Phoniatr Vocol*. 2015;40:84–90.
33. Andrade P, Wistbacka G, Larsson H, et al. The flow and pressure relationships in different tubes commonly used for semi-occluded vocal tract exercises. *J Voice*. 2016;30:36–41.
34. Story B, Laukkanen A-M, Titze I. Acoustic impedance of an artificially lengthened and constricted vocal tract. *J Voice*. 2000;14:455–469.
35. Titze I. The physics of small-amplitude oscillation of the vocal folds. *J Acoust Soc Am*. 1988;83:1536–1552.
36. Rothenberg M. Cosí fan tutte and what it means or nonlinear source-tract acoustic interaction in the soprano voice and some implications for the definition of vocal efficiency. In: Baer T, Sasaki C, Harris KS, eds. *Vocal Fold Physiology: Laryngeal Function in Phonation and Respiration*. San Diego, CA: College-Hill Press; 1986:254–263.
37. Guzmán M, Castro C, Madrid S, et al. Air pressure and contact quotient measures during different semioccluded postures in subjects with different voice conditions. *J Voice*. 2016;doi:10.1016/j.jvoice.2015.09.010; in press.
38. Stemple J, Lee L, D'Amico B, et al. Efficacy of vocal function exercises as a method of improving voice production. *J Voice*. 1994;8:271–278.
39. Roy N, Gray S, Simon M, et al. An evaluation of the effects of two treatment approaches for teachers with voice disorders: a prospective randomized clinical trial. *J Speech Lang Hear Res*. 2001;44:286–296.
40. Gillivan-Murphy P, Drinnan M, O'Dwyer T, et al. The effectiveness of a voice treatment approach for teacher with self-reported voice problems. *J Voice*. 2006;20:423–431.
41. Pasa G, Oates J, Dacakis G. The relative effectiveness of vocal hygiene training and vocal function exercises in preventing voice disorders in primary school teachers. *Logoped Phoniatr Vocol*. 2007;32:128–140.
42. Ensslen A, Croake D, Stemple J. Does a systematic vocal exercise program enhance the physiologic range of voice production in graduate-level opera singers. 38th Annual Symposium: Care of the Professional voice, Philadelphia, PA, 2007.
43. Gorman S, Weinrich B, Lee L, et al. Aerodynamic changes as a result of vocal function exercises in elderly men. *Laryngoscope*. 2008;118:1900–1903.
44. Tanner K, Sauder C, Thibeault S, et al. Vocal fold bowing in elderly male monozygotic twins: a case study. *J Voice*. 2010;24:470–476.
45. Sabol JW, Lee L, Stemple JC. The value of vocal function exercises in the practice regimen of singers. *J Voice*. 1995;9:27–36.
46. Nguyen DD, Kenny DT. Randomized controlled trial of vocal function exercises on muscle tension dysphonia in Vietnamese female teachers. *J Otolaryngol Head Neck Surg*. 2009;38:261–278.
47. Sauder C, Roy N, Tanner K, et al. Vocal function exercises for presbylaryngis: a multidimensional assessment of treatment outcomes. *Ann Otol Rhinol Laryngol*. 2010;119:460–467.
48. Tay EY, Phyland DJ, Oates J. The effect of vocal function exercises on the voices of aging community choral singers. *J Voice*. 2012;26:672, e19–e27.
49. Ziegler A, Verdolini Abbott K, Johns M, et al. Preliminary data on two voice therapy interventions in the treatment of presbyphonia. *Laryngoscope*. 2013;124:1869–1876.
50. Berg EE, Hapner E, Klein A, et al. Voice therapy improves quality of life in age-related dysphonia: a case-control study. *J Voice*. 2008;22:70–74.
51. Sharma N, De M, Martin T, et al. Laryngeal reconstruction following shrapnel injury in a British soldier: case report. *J Laryngol Otol*. 2009;123:253–256.
52. Ellis LW, Beltyukova SA. Effects of compliance monitoring of vocal function exercises on voice outcome measures for normal voice. *Percept Mot Skills*. 2011;112:729–736.

53. Patel RR, Pickering J, Stemple J, et al. A case report in changes in phonatory physiology following voice therapy: application of high-speed imaging. *J Voice*. 2012;26:734–741.
54. Guzman M, Angulo M, Munoz D, et al. Effect on long-term average spectrum of pop singers' vocal warm-up with vocal function exercises. *Int J Speech Lang Pathol*. 2013;15:127–135.
55. Kaneko M, Hirano S, Tateya I, et al. Multidimensional analysis on the effect of vocal function exercises on aged vocal fold atrophy. *J Voice*. 2015;29:638–644.
56. Pedrosa V, Pontes A, Pontes P, et al. The effectiveness of the comprehensive voice rehabilitation program compared with the vocal function exercises method in behavioral dysphonia: a randomized clinical trial. *J Voice*. 2016;30:377, e11–e19.
57. Verdolini-Marston K, Burke MK, Lassac A, et al. A preliminary study of two methods of treatment for laryngeal nodules. *J Voice*. 1995;9:74–85.
58. Roy N, Weinrich B, Gray SD, et al. Three treatments for teachers with voice disorders: a randomized clinical trial. *J Speech Lang Hear Res*. 2003;46:670–688.
59. Chen SH, Hsiao TY, Hsiao LC, et al. Outcome of resonant voice therapy for female teachers with voice disorders: perceptual, physiological, acoustic, aerodynamic, and functional measurements. *J Voice*. 2007;21:415–425.
60. Kotby MN, El-Sady SR, Basiouny SE, et al. Efficacy of the accent method of voice therapy. *J Voice*. 1991;5:316–320.
61. Kotby MN, Fex B. The accent method: behavior readjustment voice therapy. *Logoped Phonatr Vocol*. 1998;23:39–43.
62. Fex B, Fex S, Shiromoto O, et al. Acoustic analysis of functional dysphonia: before and after voice therapy (accent method). *J Voice*. 1994;8:163–167.
63. Bassiouny S. Efficacy of the accent method of voice therapy. *Folia Phoniatr Logop*. 1998;50:146–164.
64. Guzman M, Callejas C, Castro C, et al. Therapeutic effect of semi-occluded vocal tract exercises in patients with type I muscle tension dysphonia. *Revista Logop Foniatr Audiol*. 2012;32:139–146.
65. Kapsner-Smith MR, Hunter EJ, Kirkham K, et al. A randomized controlled trial of two semi-occluded vocal tract voice therapy protocols. *J Speech Lang Hear Res*. 2015;58:535–549.
66. Simberg S, Sala E, Tuomainen J, et al. The effectiveness of group therapy for students with mild voice disorders: a controlled clinical trial. *J Voice*. 2006;20:97–109.
67. Tapani M. Resonaattoriputki toiminnallisen ääihäirion hoitmenetelmänä. Seitsemän naispotilaan Seurantatutukimus [Resonance tube as a therapy method for a functional voice disorder. A follow-up study of seven female patients] (in Finnish). Helsinki, Finland: University of Helsinki; 1992.
68. Kitzing P. LTAS criteria pertinent to the measurement of voice quality. *J Phon*. 1986;14:477–482.
69. FrØkjaer-Jensen B, Prytz S. Registration of voice quality. Bruel-Kjaer technology review. *Brüel Kjaer Tech Rev*. 1976;3:3–17.
70. Laukkanen AM, Ilomäki I, Leppänen K, et al. Acoustic measures and self-reports of vocal fatigue by female teachers. *J Voice*. 2008;22:283–289.
71. Jacobson B, Johnson A, Grywalski C, et al. The Voice Handicap Index (VHI): development and validation. *Am J Speech Lang Pathol*. 1997;6:66–70.
72. Núñez-Batalla F, Corte-Santos P, Señaris-González B, et al. Adaptation and validation to the Spanish of the Voice Handicap Index (VHI-30) and its shortened version (VHI-10). *Acta Otorrinolaringol Esp*. 2007;58:386–392.
73. Law T, Lee KY, Ho FN, et al. The effectiveness of group voice therapy: a group climate perspective. *J Voice*. 2012;26:e41–e48.
74. Deary IJ, Wilson JA, Carding PN, et al. VoiSS: a patient-derived voice symptom scale. *J Psychosom Res*. 2003;54:483–489.
75. Conroy ER, Hennick TM, Awan SN, et al. Effect of variations to a simulated system of straw phonation therapy on aerodynamic parameters using excised canine larynges. *J Voice*. 2014;28:1–6.
76. Vintturi J, Alku P, Lauri ER, et al. Objective analysis of vocal warm-up with special reference to ergonomic factors. *J Voice*. 2001;15:36–53.
77. Motel T, Fisher K, Leydon C. Vocal warm-up increases phonation threshold pressure in soprano singers at high pitch. *J Voice*. 2003;17:160–167.
78. Elliot N, Sundberg J, Gramming P. What happens during vocal warmup? *J Voice*. 1995;9:37–44.
79. Milbrath RL, Solomon NP. Do vocal warm-up exercises alleviate vocal fatigue? *J Speech Lang Hear Res*. 2003;46:422–436.
80. McHenry M, Johnson J, Foshea B. The effect of specific versus combined warm-up strategies on the voice. *J Voice*. 2009;23:572–576.
81. Smith SL, Titze IR. Characterization of flow-resistant tubes used for semi-occluded vocal tract voice training and therapy. *J Voice*. 2016;doi:10.1016/j.jvoice.2016.04.001; in press.
82. Laukkanen A-M, Päivi L, Vilkman E. Vocal exercising and speaking related changes in glottal resistance. *Logoped Phoniatr Vocol*. 1998;23:85–92.
83. Laukkanen A-M, Lindholm P, Vilkman E. On the effects of various vocal training methods on glottal resistance and efficiency. A preliminary report. *Folia Phoniatr Logop*. 1995;47:324–330.