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


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. Stemple3 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.” Examples of physiological voice therapy programs include resonant voice therapy (RVT),1 the accent method of voice therapy (AM),2 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,5–8 others on vocal tract configuration,22,25–29 and also an important number of investigations have explored aerodynamic variables.20–33 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 iner-1tance.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 (CQEGG).10–19 Andrade et al18 as well as Guzman et al19 compared the CQEGG 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
the lowest CQ\textsubscript{EGG} values, whereas straw submerged 10 cm below water presented the greatest CQ\textsubscript{EGG}.\textsuperscript{28} Low CQ\textsubscript{EGG} values during tongue and lip trills have also been reported by Andrade et al\textsuperscript{19} and Gaskill and Erickson.\textsuperscript{20}

The impact of SOVTE on vocal fold vibration and glottal area variables has also been observed by high speed digital imaging during tube phonation.\textsuperscript{\textendash 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.\textsuperscript{23} Muscle activity has also been assessed using electromyography.\textsuperscript{24} Findings from electromyography showed that the ratio of thyroarytenoid muscle activity versus cricothyroid muscle activity increased during phonation into a tube.\textsuperscript{24}

Vocal tract shape changes during SOVTE have been investigated through CT,\textsuperscript{17,25,29} magnetic resonance imaging,\textsuperscript{26} and with flexible laryngeal endoscopy as it comes to hypopharyngeal and laryngeal changes.\textsuperscript{27} In a single case CT study with a vocally normal subject, Vampola et al\textsuperscript{15} 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.\textsuperscript{28} Similar results have been demonstrated by Laukkonen et al\textsuperscript{26} and Guzman et al\textsuperscript{27} 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. Westbacka et al\textsuperscript{30} 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 end tube 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 postexercices.\textsuperscript{29}

Various earlier studies have addressed the effect of different SOVTEs on air pressure measures.\textsuperscript{15,30\textendash 33,37} Maxfield et al\textsuperscript{12} measured the intraoral pressure (P\textsubscript{oral}) 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\textsuperscript{10} showed that compared with vowel phonation, the P\textsubscript{oral} increased in phonation into a resonance tube and stirring straw, most when the resonance tube was 10 cm in water. Subglottic pressure (P\textsubscript{sub}) also tended to increase relatively more than P\textsubscript{oral}, and thus transglottic pressure (P\textsubscript{trans}) 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 P\textsubscript{sub}, P\textsubscript{oral}, and P\textsubscript{trans}.\textsuperscript{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 P\textsubscript{sub} and P\textsubscript{oral} 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).\textsuperscript{37}

**Evidence about efficacy of physiological approach of voice therapy**

Multiple earlier studies have demonstrated the efficacy of physiological approach of voice rehabilitation programs.\textsuperscript{36,62} VFEs have been examined with both normal and voice disordered populations,\textsuperscript{38\textendash 46} as well as RVT\textsuperscript{57,59} and AM.\textsuperscript{60\textendash 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 /b:/ 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.\textsuperscript{64} In a recent randomized controlled trial, Kapsner-Smith et al\textsuperscript{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 (notreatment group).\textsuperscript{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.\textsuperscript{66,67} In a controlled study conducted by Simberg et al,\textsuperscript{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.\textsuperscript{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\textsuperscript{37} showed that when tubes are submerged into water, back pressure (analogous to P\textsubscript{oral}) needs to overcome the pressure generated by the water depth before flow can start.\textsuperscript{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\textendash 40 Hz,\textsuperscript{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 videostrobscopy (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 CO_{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_{2}O), glottal resistance (cm H_{2}O/L/s), and PTP (cm H_{2}O)

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.\textsuperscript{68} Alpha ratio is a measure that represents overall spectral slope.\textsuperscript{69} This spectral variable has been found to depend on phonation type (degree of vocal fold adduction), being higher in hyperfunctional voices.\textsuperscript{70}
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. This self-administered 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. 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).

**Self-assessment of voice quality**

Before aerodynamic, electroglottographic, and acoustic 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 administered 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
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

| 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          |

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

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

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

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pre</th>
<th>Post</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glottal airflow (L/s)</td>
<td>0.15 (0.10–0.20)</td>
<td>0.15 (0.11–0.17)</td>
<td>0.7213</td>
</tr>
<tr>
<td>EGG CQ (%)</td>
<td>57.38 (48.36–62.19)</td>
<td>56.80 (52.80–61.23)</td>
<td>0.7713</td>
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<td>Subglottic pressure (cm H2O)</td>
<td>8.81 (7.83–9.87)</td>
<td>8.41 (6.61–8.73)</td>
<td>0.0218</td>
</tr>
<tr>
<td>Glottal resistance (cm H2O/L/s)</td>
<td>55.44 (47.60–132.70)</td>
<td>53.86 (39.22–96.13)</td>
<td>0.1141</td>
</tr>
<tr>
<td>PTP (cm H2O)</td>
<td>5.76 (5.33–6.16)</td>
<td>4.40 (4.29–5.34)</td>
<td>0.0051</td>
</tr>
</tbody>
</table>

**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
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. A recent investigation conducted by Chen et al reported 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. A positive effect of VFE on VHI has also been observed, in various other studies, eg, in patients with aging voice, teachers with voice complaints, and subjects diagnosed with behavioral dysphonia. Additionally, two studies have reported positive outcomes for VHI after voice treatment with RVT, Roy et al 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 in a group of female teachers with voice disorders. Other studies exploring the effectiveness of physiological voice therapy programs (VFE, RVT, AM) have also demonstrated some self-reported improvements using different scales than VHI. Gillivan-Murphy et al 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. 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 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 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), 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 inerance. In a modeling study with excised larynges, PTP was assessed by Conroy et al 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. 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. Chen et al 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 and Motel et al found a significant increase of PTP after vocal warm-up, whereas other studies have reported a high variability among participants or no effect. Only one study, conducted by McHenry and Johnson, 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.

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. Kotby and Fex 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 Bassioumy. Only one previous study has shown opposite results (increment of Psub); however, they are expected taking into account the population included (elderly men). The authors suggested that this increase was a result of improved glottal closure.
Several studies have demonstrated an increase in Psob or Poral during semi-occluded exercises, especially when the tube is submerged in different depths of water. Results suggest that the increased Psob 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, and the depth of immersion when the tube is placed into water. Considering that an increment in Psob is commonly observed during SOVTe, it seems paradoxical that after a long-term voice therapy Psob has been found to be lower compared with pretreatment condition. Nevertheless, it is feasible that a moderate increment of Psob 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. 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. in a study performed with a group of singers treated with VFe and by Kotby et al. after therapy with AM. An increased maximum phonation time reported after VFe and AM 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 or after RVT. 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 CQEGG during practicing and in some cases immediately after it, no significant changes were evidenced in CQEGG after 8-week voice therapy period in the present study. Previous studies have revealed that CQEGG 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 CQEGG compared with that with lower airflow resistance (eg, Finnish glass tube with the distal end in air). No previous studies assessing the effect of tube phonation either in air or into water (as long-term therapy programs) on CQEGG 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 CQEGG, 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 CQEGG). The absence of change in glottal resistance was also reported after 20 sessions of therapy with AM. A decreasing trend in glottal resistance has in turn been reported after short-term exercising with SOVTE. Laukkonen et al. showed a decrease in this variable (due to increased flow and decreased Psob) after phonation with [β:]. In another study, where three different semi-occlusions were tested ([β:], [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. 

Acoustic findings from the present investigation are concordant with CQEGG 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). More negative values are indicative of a less tight vocal fold adduction. Therefore, taking into account CQEGG, 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 abovementioned 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. 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.

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


