Effect of three semi-occluded vocal tract therapy programs on the phonation of patients with dysphonia: lip trill, water-resistance therapy and straw phonation

Iris Meerschman†, Kristiane Van Lierde†‡, Julie Ketels†, Charlotte Coppieters†, Sofie Claeys§ and Evelien D'haeseleer†

†Ghent University, Department of Rehabilitation Sciences, Research group: Speech, Language and Hearing Sciences, Ghent, Belgium
‡University of Pretoria, Department of Speech-Language Pathology and Audiology, Pretoria, South Africa
§Ghent University, Department of Otorhinolaryngology, Ghent, Belgium

ABSTRACT

Aim. The aim of this study was to investigate the effect of three SOVT therapy programs: lip trill, water-resistance therapy (WRT) and straw phonation, on the vocal quality, vocal capacities, psychosocial impact and vocal tract discomfort of patients with dysphonia.

Methods & Procedures. A blocked-randomized sham-controlled trial was used. Thirty-five patients with dysphonia (mean age = 21 years; 33 women, two men) were assigned to either a lip trill group, a WRT group, a straw phonation group, or a control group using blocked randomization. The lip trill, WRT and straw phonation groups practiced their respective SOVT exercise across three weeks, whereas the control group received a sham treatment across the same time span. A multidimensional voice assessment consisting of both objective (multiparametric indices: Dysphonia Severity Index (DSI), Acoustic Voice Quality Index (AVQI)) and subjective (subject's self-report, auditory-perceptual evaluation) vocal outcomes was performed by a blinded assessor pre- and post-therapy.

Outcomes & Results. Lip trill and straw phonation therapy led to a significant improvement in DSI. Auditory-perceptual grade and roughness significantly decreased after straw phonation. Lip trill and WRT both led to a significant decrease in Voice Handicap Index. Subjects reported a better self-perceived vocal quality and a more comfortable voice production after WRT. No changes were found after the sham treatment in the control group.

Conclusions. Results suggest that SOVT therapy programs including lip trill or straw phonation can improve the objective vocal quality in patients with dysphonia. Auditory-perceptual improvements were found after straw phonation therapy, whereas psychosocial improvements were found after lip trill and WRT. Patients seem to experience more comfort and a better self-perceived vocal quality after WRT. This study supports the use of the three SOVT therapy programs in clinical practice. They all had a positive impact on one or more outcomes of the multidimensional voice assessment. Strikingly, vocal quality outcomes were not in line with the subject's opinion. Larger-scale investigation is needed to support these preliminary findings.

INTRODUCTION

Obtaining an economic and efficient voice production is the main aim of voice therapy. The intent is to produce a normal vocal intensity and power with less mechanical stress to laryngeal tissues, less muscular effort and less energy loss. These factors will decrease the risk of laryngeal hyperfunction, vocal fatigue and vocal injury (Titze 2006, Titze and Verdolini Abbott 2012, Gaskill and Quinney 2012, Croake *et al.* 2017, Mills *et al.* 2017). A promising way to obtain vocal economy and efficiency is by semi-occluding the vocal tract while phonating (Titze 2006, Gaskill and Quinney 2012, Croake *et al.* 2017, Mills *et al.* 2017). A semi-occluded vocal tract (SOVT) creates a heightened supraglottal pressure and inertive reactance, which enhances the vocal fold vibration and assists its production of acoustic energy via a non-linear feedback mechanism (Titze 2006, Titze and Verdolini Abbott 2012, Conroy *et al.* 2014, Kapsner-Smith *et al.* 2015, Guzman *et al.* 2017a). In general, SOVT exercises elicit a voice production that relies more heavily on that non-linear source-filter interaction than on adductory stress to give the voice acoustic power (Maxfield *et al.* 2015).

Several subgroups of SOVT exercises can be distinguished. First, semi-occlusions of the vocal tract can be formed either by the articulators (lips and/or tongue) or by the use of an assistive device (Titze 2006, Andrade *et al.* 2014, Dargin and Searl 2015, Maxfield *et al.* 2015, Fantini *et al.* 2017). Lip trill is an example of an SOVT exercise solely formed by the articulators, whereas water-resistance therapy (WRT) and straw phonation use a tube or straw inserted between the lips. In the latter cases, an artificial lengthening of the vocal tract is achieved (Conroy *et al.* 2014). This lengthening creates an additional increase in supraglottal pressure and inertive reactance, especially if small-diameter tubes or straws are used (Titze 2006, Titze and Verdolini Abbott 2012, Gaskill and Quinney 2012, Maxfield *et al.* 2015). A second subdivision depends on whether the free end of the tube or straw is placed into air (straw phonation) or water (WRT). For WRT, both flexible soft-walled tubes, glass tubes or straws can be used (Sovijärvi 1969, Sihvo 2006, Simberg and Laine 2007, Kapsner-Smith *et al.* 2015, Guzman *et al.* 2017a, Mailänder *et al.* 2017, Tyrmi *et al.* 2017). A last subdivision depends on the number of vibratory sources (Andrade *et al.* 2014, Guzman *et al.* 2017b). Straw phonation has a single source of vibration (i.e., vocal folds only), whereas lip trill and WRT have a secondary source of vibration (i.e., lip trilling and water bubbling). A secondary vibratory source at the distal part of the vocal tract produces a fluctuating intraoral pressure that is hypothesized to create a 'massage-like' effect on the vocal folds and the vocal tract with a reduction of discomfort and muscle tension (Andrade *et al.* 2014, Guzman *et al.* 2017b).

To date, most authors have been interested in the immediate, often physical or physiological, effects of a single SOVT performance. Whether a therapy program (i.e., longer than one session) using SOVT exercises leads to an enhanced phonation and improved vocal quality on the short or long term is not yet sufficiently confirmed (Gaskill and Quinney 2012, Kapsner-Smith *et al.* 2015). To our knowledge, only three studies investigated the isolated effect of a lip trill, water-resistance and/or straw phonation therapy program (i.e., longer than one session) in a dysphonic population (Kapsner-Smith *et al*. 2015, Guzman *et al.* 2017a, 2017b). Kapsner-Smith *et al.* (2015) found that straw phonation using stirring straws led to a decrease (improvement) in the psychosocial impact of dysphonia (Voice Handicap Index—VHI) and the auditory– perceptual parameter roughness (six weekly sessions of 30–60 min, n=10).Guzman *et al.* (2017a) also showed a decrease in VHI in patients with hyperfunctional dysphonia after both phonation through a drinking straw in air and water (i.e., WRT) (eight weekly sessions of 30 min, n = 10 per group). Furthermore, a better self-perceived resonant voice quality was found after therapy in both groups. In the straw phonation group, this improvement was also rated by the clinician during the auditory–perceptual evaluation. In a later study, Guzman *et al.* (2017b) showed that one session (30 min) of lip trills or WRT (drinking straw), followed by a 1-week home-practice program, led to improvements in self-perceived muscle relaxation, vocal tract discomfort and resonant voice quality (n=21 per group).None of the above studies included objective multiparametric vocal quality indices or control groups receiving sham (placebo) treatment.

The purpose of this study was to investigate the effect of three SOVT therapy programs: lip trill, WRT and straw phonation, on the vocal quality, vocal capacities, psychosocial impact and vocal tract discomfort of patients with dysphonia, using a blocked-randomized sham-controlled trial and a multidimensional voice assessment performed by an assessor blinded to group allocation. Based on the promising physics of a SOVT, objective vocal quality improvements were expected for the three SOVT therapy programs. Lip trill and WRT might specifically decrease vocal tract discomfort due to the double source of vibration which possibly creates a 'massage-like' effect on the vocal tract with reduction of muscle tension (Andrade *et al.* 2014, Guzman *et al.* 2017b). Changes in psychosocial impact and auditory–perceptual vocal quality were not yet expected after 3 weeks of practice.

MATERIAL AND METHODS

Participants

Participants were recruited at the departments of Speech, Language, and Hearing Sciences and Otorhinolaryngology of Ghent University and Ghent University Hospital in September–October 2017. Inclusion criteria were patients diagnosed with dysphonia and referred for voice therapy. Diagnosis was based on the results of a multidimensional voice assessment, performed by a speech–language pathologist (SLP) experienced in voice diagnostics (I.M.). Smoking, pregnancy, current participation in voice training or therapy, mental health conditions, and physically limiting diseases that might interfere with study completion were selected as exclusion criteria. A total of 35 patients (33 women and two men), with a mean age of 21 years (SD = 5.3 years; range = 17–44 years) participated in the study. Three subjects left the study before termination (one subject of the lip trill group, one subject of the WRT group and one subject of the control group).

Design

A blocked-randomized sham-controlled trial was used. Participants were assigned to either a lip trill group (n = 9), a WRT group (n = 9), a straw phonation group (n = 9) or a control group (n = 8) using blocked randomization, stratified by age, gender and being a student versus an employee. There were no significant differences among the four groups in gender (chi-square test; p = 0.572) and age (Kruskall–Wallis test; p = 0.759). For an overview of the professions and areas of study per group, see table 1.

Table 1. Professions and areas of study of the participants in the lip trill group, the water-resistance therapy (WRT) group, the straw phonation group and the control groups

	Lip trill (*n* = 9)	WRT (*n* = 9)	Straw phonation (*n* = 9)	Control (*n* = 8)
Professions				
Teacher	1	1	0	0
Entertainer nursing home	0	0	1	0
Occupational therapist	0	0	1	0
Areas of study				
Speech-language pathology	4	6	7	6
Communication management	1	0	0	1
Podology	0	0	0	1
Educational sciences	0	1	0	0
Pharmaceutical sciences	1	0	0	0
Social work and welfare	1	0	0	0
Dental care	1	0	0	0
High school (human sciences)	0	1	0	0

Voice therapy

The lip trill, WRT and straw phonation groups practiced their respective SOVT exercise across 3 weeks with a frequency of two 30-min sessions a week. For a detailed overview of the three therapy programs, see table 2. Besides these guided group sessions, participants were encouraged to practice their respective SOVT exercise at home for at least 5 min a day. This home-practice program consisted of the basic exercise followed by a short repetition of what was learnt in the last session (e.g., pitch and loudness exercises after the second session). The content and structure of both the therapy and home practice programs were similar for every SOVT group. Subjects of the control group received a sham (placebo) treatment across the same time span with a frequency of one 1-h session a week. They learnt how to perform an auditory–perceptual evaluation of voice samples using the GRBASI scale (Hirano 1981; completed with an 'I' parameter by Dejonckere *et al.* 1996) and a visual analogue scale. They did not evaluate their own voices, nor receive any active vocal techniques. Participants of the control group were not encouraged to practice at home.

The voice therapy programs were guided by two therapists (J.K. and C.C.). The content and structure of the programs were discussed and described in detail before the study started. Most therapy sessions were guided by both therapists, whereas some were guided by one of them. Therapist bias was avoided by equally distributing these sessions between the two therapists.

Voice assessment

A multidimensional voice assessment, including both objective and subjective vocal measures, was used to evaluate the patients' voices pre- and post-therapy. Assessments were performed in a sound-treated room at Ghent University Hospital by an SLP experienced in voice diagnostics and blinded to group allocation (I.M.).

<u>Multiparametric indices</u>

Dysphonia Severity Index (DSI). The DSI is a multiparametric approach designed to establish an objective and quantitative correlate of the perceived vocal quality (Wuyts *et al.* 2000). It is based on a weighted combination of the following parameters: maximum phonation time (MPT, s), highest frequency (F-high, Hz), lowest intensity (I-low, dB) and jitter (%). The DSI is constructed as 0.13 MPT + 0.0053 F-high − 0.26 I-low − 1.18 jitter + 12.4. The index ranges from –5 to +5 for severely dysphonic to normal voices. A more negative index indicates a worse vocal quality. Values > +5 are possible in subjects with excellent vocal capacities. A DSI = +1.6 is the threshold separating normophonic from dysphonic persons (Raes *et al.* 2002).

MPT was determined by asking the participants to sustain the vowel /a:/ at their habitual pitch and loudness after a maximal inspiration, in free field while seated. The production was modelled by the experimenter and the participants received visual and verbal encouragements to produce the longest possible sample. The length of the sustained vowel was measured with a chronometer and the best trials of three attempts was retained for further analysis.

F-high and I-low were obtained by the Voice Range Profile of the Computerized Speech Lab (CSL, model 4500, KayPENTAX, Montvale, NY, USA) and a Shure SM-48microphone (located at a distance of 15 cm from the mouth, angled at 45°). Subjects were instructed to produce the vowel /a:/ for at least 2 s using respectively a habitual pitch and loudness, a minimal pitch,

Table 2 Content of the lip trill, WRT and straw phonation therapy programs

Session	Lip trill	WRT	Straw phonation
1	Lip trills without phonation ○ Correct and eutonic posture in sitting and standing position ○ Costo-abdominal breathing ○ Moistening of the lips and/or light push on the cheeks with thumb and index finger to facilitate lip trill production (if necessary) Lip trills with phonation ○ Habitual and comfortable pitch/loudness ○ Sensory feedback and forward focus: vibrations in midfacial region ○ Avoidance of hyperfunction (feedback by the experimenters)	Introduction to the material ○ Flexible, soft-walled tube ○ Diameter 10mm; length 35cm Water bottle, water depth: 2 cm Blowing through the tube ○ Correct and eutonic posture in sitting and standing position ○ Costo-abdominal breathing ○ Breathing in through the nose, blowing out through the mouth ○ Relaxed cheeks Phonation through the tube ○ [o] or [ɔ] sound ○ Use of soft voice onset [hɔ], [ho] ○ Habitual and comfortable pitch/loudness ○ Mild and constant water bubbling ○ Sensory feedback and forward focus: vibrations in midfacial region, cheeks ○ Avoidance of hyperfunction (feedback by the experimenters)	Introduction to the material ○ Drinking straw ○ Diameter 5mm; length 21cm Blowing through the straw ○ Correct and eutonic posture in sitting and standing position ○ Costo-abdominal breathing ○ Breathing in through the nose, blowing out through the mouth ○ Relaxed cheeks Phonation through the straw ○ [o] or [ɔ] sound ○ Use of soft voice onset [hɔ], [ho] ○ Habitual and comfortable pitch/loudness ○ Sensory feedback and forward focus: vibrations in midfacial region ○ Avoidance of hyperfunction (feedback by the experimenters)
2	Lip trills without phonation Lip trills with phonation ○ Habitual pitch Lip trills with pitch variations (supported by visual feedback: hand) ○ Pitch glides: ascending, descending ○ Pitch inflections ○ High pitch, low pitch Lip trills with loudness variations (supported by visual feedback: hand) ○ Crescendo, decrescendo ○ Loud sound, soft sound	Blowing through the tube WRT with phonation ○ Habitual pitch WRT with pitch variations (supported by visual feedback: hand) ○ Pitch glides: ascending, descending ○ Pitch inflections ○ High pitch, low pitch WRT with loudness variations (supported by visual feedback: hand) ○ Crescendo, decrescendo ○ Loud sound, soft sound	Blowing through the straw Straw phonation ○ Habitual pitch Straw phonation with pitch variations (supported by visual feedback: hand) ○ Pitch glides: ascending, descending ○ Pitch inflections ○ High pitch, low pitch Straw phonation with loudness variations (supported by visual feedback: hand) ○ Crescendo, decrescendo ○ Loud sound, soft sound

Table 2 *(Continued)*

Session	Lip trill	WRT	Straw phonation
3	Lip trills with pitch and loudness variations Lip trills when "reading" words and sentences ○ Using prosodic patterns ○ Alternating between lip trill "reading" and normal open-mouth reading	WRT with pitch and loudness variations WRT when "reading" words and sentences ○ Using prosodic patterns ○ Alternating between WRT "reading" and normal open-mouth reading	Straw phonation with pitch and loudness variations Straw phonation when "reading" words and sentences ○ Using prosodic patterns ○ Alternating between straw phonation "reading" and normal open-mouth reading
4	Lip trills with pitch and loudness variations Lip trills when "reading" words and sentences ○ Alternating between lip trill "reading" and normal open-mouth reading	WRT with pitch and loudness variations WRT when "reading" words and sentences ○ Alternating between WRT "reading" and normal open-mouth reading	Straw phonation with pitch and loudness variations Straw phonation when "reading" words and sentences ○ Alternating between straw phonation "reading" and normal open-mouth reading
5	Lip trills when "reading" words and sentences Lip trills when "reading" texts ○ Alternating between lip trill "reading" and normal open-mouth reading	WRT when "reading" words and sentences WRT when "reading" texts ○ Alternating between WRT "reading" and normal open-mouth reading	Straw phonation when "reading" words and sentences Straw phonation when "reading" texts ○ Alternating between straw phonation "reading" and normal open-mouth reading
6	Lip trills when "reading" words and sentences Lip trills when "reading" texts Lip trills when spontaneous "speaking" ○ Alternating between lip trill "speaking" and normal-open mouth speaking	WRT when "reading" words and sentences WRT when "reading" texts WRT when spontaneous "speaking" ○ Alternating between WRT "speaking" and normal-open mouth speaking	Straw phonation when "reading" words and sentences Straw phonation when "reading" texts Straw phonation when spontaneous "speaking" ○ Alternating between straw phonation "speaking" and normal-open mouth speaking

a minimal intensity (at a habitual pitch), a maximal pitch, and a maximal intensity (at a habitual pitch) (Heylen *et al.* 1998). Each production was modelled by the experimenter and the subjects received visual and verbal encouragement.

Jitter (%) was obtained by the Multi Dimensional Voice Program of the CSL and a Shure SM-48 microphone (located at a distance of 15 cm from the mouth, angled at 45°). Participants produced the vowel /a:/ at their habitual pitch and loudness, following an automatic series (counting to 2). A mid-vowel segment of 3 s registered with a sampling rate of 50 kHz was used for the analysis.

Acoustic Voice Quality Index (AVQI). The AVQI is a recently developed objective multiparametric approach to quantify dysphonia severity based on both a sustained vowel and continuous speech (Maryn *et al.* 2010a). It consists of a weighted combination of six acoustic measures: three time-domain measures (i.e., shimmer local (SL), shimmer local dB (SLdB) and harmonics-to-noise ratio (HNR)), two frequency-domain measures (i.e., general slope of the spectrum (Slope) and tilt of the regression line through the spectrum (Tilt)), and one frequency-domain measure (i.e., smoothed cepstral peak prominence (CPPs)) (Maryn *et al.* 2010b). The formula of the index is 2.571 [3.295 – 0.111 CPPs – 0.073 HNR – 0.213 SL + 2.789 SLdB – 0.032 Slope + 0.077 Tilt] and ranges from 0 to 10. A higher index indicates a worse vocal quality. The threshold score separating normophonic from dysphonic persons in Dutch is 2.95 (Maryn *et al.* 2010a). AVQI (v.02.03) was calculated on an audio recording of a sustained /a:/ vowel and the first two sentences of the Dutch phonetically balanced text 'Papa en Marloes' (Van de Weijer and Slis 1991), using the software program PRAAT version 6.0.14 (Boersma and Weenink).

<u>Subject's self-report</u>

Baseline voice questionnaire. A questionnaire based on the checklists of Russell *et al.* (2000), De Bodt *et al.* (2008) and Van Lierde *et al.* (2010a, 2010b) was presented at baseline to explore the occurrence of voice-related symptoms, risk factors, vocal abuse, vocal load and lifestyle habits.

Voice Handicap Index (VHI). Subjects filled in the Dutch version of the VHI to evaluate the psychosocial impact of the voice disorder (Jacobson *et al.* 1997, De Bodt *et al.* 2000). The VHI is a self-rating questionnaire consisting of 30 statements, evaluating functional (10 statements, F-scale), physical (10 statements, P-scale), and emotional (10 statements, E-scale) restrictions. Every statement is scored on a five-point Likert scale (0: never, 1: almost never, 2: sometimes; 3: almost always; 4: always). The total VHI score ranges from 0 to 120, with higher scores indicating greater impacts.

Vocal Tract Discomfort Scale (VTDS). Participants also completed the Dutch version of the VTDS (Mathieson *et al.* 2009, Luyten *et al.* 2016). It consists of eight sensations that can be felt in or around the throat: burning, tight, dry, aching, tickling, sore, irritable and globus. Each item should be scored on frequency (never, seldom, sometimes, more than sometimes, often, very often, always) and severity (no, almost no, limited, more than limited, moderate, more than moderate, severe perception) using a seven-point Likert scale. The total VTDS score (sum of frequency and severity) can range from 0 to 96, with higher scores indicating more discomfort.

Frequency of home practice and the subject's opinion regarding the received therapy program. At the posttest, subjects filled in a last questionnaire to check their frequency of home practice and their opinion regarding the received therapy program. Subjects completed this questionnaire before they received any information about their vocal progress.

Auditory–perceptual evaluation

For the auditory–perceptual evaluation of the subjects' voices, the GRBASI scale was used (Hirano 1981; completed with an 'I' parameter by Dejonckere *et al.* 1996). The six parameters 'overall grade of hoarseness' (G), 'roughness' (R), 'breathiness' (B), 'asthenia' (A), 'strain' (S) and 'instability' (I) were scored using a four-point grading scale (0: absent, 1: mild, 2: moderate, 3: severe). Evaluations were based on a sustained /a:/ vowel and reading aloud the Dutch phonetically balanced text 'Papa en Marloes' (Van de Weijer and Slis 1991).

Statistical analysis

Data were analyzed statistically using SPSS version 25 (SPSS Corporation, Chicago, IL, USA).

Fisher's Exact tests were used to compare the groups regarding self-reported voice-related symptoms, risk factors, vocal abuse and lifestyle habits (baseline), the frequency of home practice, and the subject's opinion regarding the received therapy program (post-therapy).

Linear mixed-model analyses were used to compare groups over time on each continuous outcome measure using the restricted maximum likelihood estimation and scaled identity covariance structure. Time (pre and post), group (lip trill, WRT, straw phonation or control group) and time-by-group interaction were specified as fixed factors. A random intercept for subjects was included. Model assumptions were checked by inspecting whether residuals were normally distributed. Generalized linear mixed models were used for the categorical outcome measures. A significant time-by-group interaction indicates a significantly different evolution over time between the groups. Within-group effects of time were determined using post-hoc pairwise comparisons.

All analyses were conducted at $\alpha = 0.05$. No adjustments for multiple outcomes were made because a minimum set of sensitive multidimensional voice measures was selected. Furthermore, the reduced risk of type-I errors associated with these adjustments might not balance the substantially increased risk of type-II errors (Feise 2002).

RESULTS

Baseline voice-related symptoms, risk factors, vocal load, and lifestyle habits

Table 3 presents the results of the questionnaire on voice-related symptoms, risk factors, vocal load and lifestyle habits in the lip trill group, the WRT group, the straw phonation group and the control group. Fischer's Exact tests showed no significant differences in baseline occurrence between the four groups.

Table 3. Baseline voice-related symptoms, risk factors, vocal load and lifestyle habits

	Lip trill (n = 9)	WRT (n = 9)	Straw phonation (n = 9)	Control (n = 8)	Fischer's Exact test p-value
Voice-related symptoms					
Hoarseness	7	6	5	3	0.420
Vocal fatigue	4	3	3	0	0.207
Sore throat	3	4	2	2	0.746
Risk factors					
Vocal abuse	7	6	5	5	0.871
Reflux	2	1	2	0	0.722
Allergies	2	4	1	5	0.138
Upper respiratory tract infections	3	8	5	5	0.128
Asthma	0	2	0	0	0.229
Stress	5	4	2	6	0.190
Tension in shoulders and/or neck	3	3	5	3	0.799
Vocal load					
Speaking in noisy environments	1	2	1	0	0.889
Hobbies with high vocal load	4	4	3	5	0.745
Professional voice use	2	2	2	0	0.576
Lifestyle habits					
Alcohol use	8	7	5	5	0.421
Smoking	0	0	0	0	-
Sleep deprivation	5	6	3	4	0.599

Pre- to post-therapy evolution

The results of the multidimensional voice assessment performed pre- and post-therapy are shown in table 4 (multiparametric indices), table 5 (subject's self-report) and table 6 (auditory–perceptual evaluation). A significant time-by-group interaction was found for VHI, which indicates a significantly different evolution between the four groups. VHI significantly decreased (improved) in the lip trill (estimated mean (EM) difference = –8, p = 0.002) and WRT (EM difference = –9, p = 0.001) groups, but not in the straw phonation and control groups. The other outcome parameters showed no significant time-by-group interaction, which indicates no significant differences in evolution between the four groups.

Within-group analyses showed that both lip trill therapy and straw phonation therapy led to a significantly increased (improved) DSI (lip trill: EM difference = +2.0, p = 0.031; straw phonation: EM difference = +1.8, p = 0.042), and straw phonation therapy led to a significantly decreased (improved) auditory–perceptual dysphonia grade and roughness (p = 0.046). No significant changes were found for the control group.

Table 4. Pre- to post-therapy evolution of the multiparametric indices

		Pre		Post		Evolution pre-post		Time*group	Comparison time within groups
Parameters	Group	EM	95% CI	EM	95% CI	EM diff	95% CI	*p*-value	*p*-value
DSI	LT	0.0	[-1.7, +1.6]	+2.0	[+0.2, +3.7]	+2.0	[+0.2, +3.7]		0.031*
	SP	-0.5	[-2.1, +1.2]	+1.3	[-0.4, +3.0]	+1.8	[+0.1, +3.4]		0.042*
	WRT	+0.1	[-1.5, +1.8]	+0.9	[-0.8, +2.7]	+0.8	[-1.0, +2.6]		0.359
	C	+1.3	[-0.4,+3.1]	+1.9	[+0.1, +3.8]	+0.6	[-1.3, +2.4]	0.623	0.513
AVQI	LT	4.53	[3.89, 5.17]	4.30	[3.64, 4.98]	-0.23	[-0.98, +0.52]		0.543
	SP	4.02	[3.38, 4.66]	4.33	[3.69, 4.97]	+0.31	[-0.41, +1.03]		0.384
	WRT	4.53	[3.89, 5.17]	5.01	[4.34, 5.68]	+0.48	[-0.27, +1.23]		0.205
	C	4.08	[3.37, 4.80]	3.91	[3.19, 4.63]	-0.17	[-1.01, +0.66]	0.465	0.677

Note: EM, estimated mean; CI, confidence interval; DSI, Dysphonia Severity Index; AVQI, Acoustic Voice Quality Index; LT, lip trill group; SP, straw phonation group; WRT, water-resistance therapy group; C, control group. * indicates a significant effect.

Table 5. Pre- to post-therapy evolution of the subject's self-report

		Pre		Post		Evolution pre-post		Time*group	Comparison time within groups
Parameters	Group	EM	95% CI	EM	95% CI	EM diff	95% CI	*p*-value	*p*-value
VHI	LT	34	[20, 48]	26	[12, 40]	-8	[-13, -3]		0.002*
	SP	23	[8, 36]	24	[10, 38]	+1	[-3, +6]		0.482
	WRT	32	[18, 46]	23	[9, 37]	-9	[-14, -4]		0.001*
	C	15	[0, 30]	12	[0, 26]	-3	[-8, +2]	0.011*	0.171
VTDS	LT	29	[20, 37]	28	[19, 36]	-1	[-2, +2]		0.091
	SP	20	[11, 28]	20	[11, 28]	0	[-1, +1]		0.691
	WRT	33	[25, 42]	32	[24,41]	-1	[-2, +2]		0.089
	C	16	[7, 25]	16	[6; 25]	0	[-2, +1]	0.346	0.649

Note: EM, estimated mean; CI, confidence interval; VHI, Voice Handicap Index; VTDS, Vocal Tract Discomfort Scale; LT, lip trill group; SP, straw phonation group; WRT, water-resistance therapy group; C, control group. * indicates a significant effect.

Table 6. Pre- to post-therapy evolution of the auditory-perceptual evaluation

		Pre				Post				Time*group	Comparison time within groups
Parameters	Group	Median	IQR	Mean	SD	Median	IQR	Mean	SD	*p*-value	*p*-value
G	LT	2	[1.5, 2]	1.9	0.6	1	[1, 2]	1.6	0.8		0.180
	SP	1	[1, 2]	1.6	0.7	1	[0.5, 2]	1.1	0.8		0.046*
	WRT	1	[1, 2.5]	1.7	0.9	1	[1, 1.75]	1.3	0.9		0.414
	C	1	[1, 1]	0.9	0.4	1	[0, 2]	1.0	0.8	0.569	>0.999
R	LT	2	[1, 2]	1.6	0.7	1	[0, 2]	1.1	1.1		0.408
	SP	1	[0.5, 2]	1.2	1.0	1	[0, 1.5]	0.8	0.8		0.046*
	WRT	1	[0.5, 2]	1.2	0.8	0.5	[0, 1]	0.7	1.0		0.317
	C	1	[1, 1]	1.0	0.5	1	[0, 2]	0.7	0.8	0.987	0.414
B	LT	1	[0.5, 2]	1.2	1.0	1	[0, 2]	1.0	0.8		0.083
	SP	1	[0, 2]	1.0	1.1	1	[0, 1]	0.7	0.5		0.257
	WRT	1	[1, 2]	1.3	0.9	0.5	[0, 1]	0.6	0.7		0.157
	C	1	[1, 1.75]	1.1	0.6	1	[0, 1]	0.7	0.8	0.834	0.102
A	LT	1	[0.5, 2]	1.2	0.8	1	[0, 1]	0.6	0.5		0.096
	SP	1	[0, 1]	0.9	0.9	0	[0, 1]	0.6	0.7		0.083
	WRT	1	[0, 1]	0.8	0.7	0	[0, 1.75]	0.8	1.2		>0.999
	C	0.5	[0, 1]	0.5	0.5	0	[0, 1]	0.4	0.5	0.403	0.564
S	LT	1	[0.5, 2]	1.2	0.8	1	[0, 2]	1.0	0.8		0.257
	SP	1	[0.5, 1.5]	1.1	0.9	1	[0, 2]	0.9	0.9		0.317
	WRT	1	[0.5, 2]	1.3	1.0	0.5	[0, 1.75	0.9	1.1		0.516
	C	0	[0, 0.75]	0.3	0.5	0	[0, 0]	0.2	0.4	0.915	>0.999
I	LT	0	[0, 1]	0.4	0.5	0	[0, 1]	0.3	0.5		0.564
	SP	0	[0, 1]	0.6	1.0	0	[0, 0.5]	0.3	0.7		0.157
	WRT	0	[0, 1]	0.3	0.5	0	[0, 0]	0.2	0.7		>0.999
	C	0	[0, 0]	0.2	0.4	0	[0, 0]	0.2	0.4	0.916	>0.999

Note: IQR, interquartile range; G, grade; R, roughness; B, breathiness; A, asthenia; S, strain; I, instability; LT, lip trill group; SP, straw phonation group; WRT, water-resistance therapy group; C, control group. * indicates a significant effect.

Frequency of home practice

Daily home practice was reported by two subjects of the lip trill group, one subject of the WRT group and one subject of the straw phonation group. Five subjects of the lip trill group, five subjects of the WRT group and eight subjects of the straw phonation group practised several days a week. Two subjects of the WRT group practiced 1 day a week, and one subject of the lip trill group did not practice at home. There was no significant difference in frequency of home practice among the three SOVT groups (Fischer's Exact test, $p = 0.448$). Subjects in the control group did not practice at home.

Subjects' opinion regarding the received therapy program

The subjects' opinion regarding the received therapy program is shown in table 7. Fischer's Exact tests showed a significant difference among the three SOVT groups for the questions 'Did you experience a more comfortable voice production after a session?' ($p = 0.018$), 'How did you evaluate your vocal quality after a session?' ($p = 0.001$) and 'Do you experience improvements in your vocal capacities after the complete therapy program?' ($p = 0.041$). Answers to the first two questions were in benefit of the WRT group (standardized residuals 2.0 and 3.2, respectively).

Table 7. Subjects' opinion regarding the received therapy program

	Lip trill (*n* = 8)	WRT (*n* = 8)	Straw phonation (*n* = 9)	Control (*n* = 7)	Fischer's Exact test *p*-value
Do you think the therapy program was effective?	4	6	5	3	0.678
Did you become more aware of your voice use?	7	6	8	3	0.213
Did you experience a more comfortable voice production after a session?	3	6	2	0	0.018*
How did you evaluate your vocal quality after a session?					0.001*
Better	0	6	1	0	
Similar	6	2	7	7	
Worse	2	0	1	0	
How do you evaluate your vocal quality after the complete therapy program?					0.243
Better	1	3	1	0	
Similar	7	4	6	7	
Worse	0	1	2	0	
Do you experience improvements in your vocal capacities after the complete therapy program?	4	5	3	0	0.041*
Did people in your environment notice changes in your voice production or vocal quality?	0	2	2	0	0.293

DISCUSSION

The purpose of this study was to investigate the effect of three SOVT therapy programs: lip trill, WRT and straw phonation, on the vocal quality, vocal capacities, psychosocial impact and vocal tract discomfort of patients with dysphonia. Based on the promising physics of a SOVT, objective vocal quality improvements were expected for the three SOVT therapy programs. Lip trill and WRT were expected to decrease vocal tract discomfort due to the 'massage-like' effect achieved by the double source of vibration (Andrade *et al.* 2014, Guzman *et al.* 2017b). Changes in psychosocial impact and auditory–perceptual vocal quality were not yet expected after 3 weeks of practice.

First, no significant time-by-group interactions were found for the vocal quality outcomes (DSI, AVQI, GRBASI), indicating no significantly different evolution between the four groups. This lack of interaction effect might be due to the small sample size or the relatively short treatment period. Within-group analyses, however, showed a significant improvement in DSI in the lip trill and straw phonation groups. Furthermore, straw phonation led to a significant decrease in auditory–perceptual grade and roughness. A positive impact of straw phonation therapy on auditory–perceptual parameters has also been found in earlier studies (Kapsner-Smith *et al.* 2015, Guzman *et al.* 2017a). The reason why straw phonation led to pronounced improvements in vocal quality probably relates to the high supraglottal pressure associated with the combination of a narrow and elongated vocal tract. This configuration might create the best match between source and filter, and consequently lead to vocal economy and efficiency (Titze 2006, Titze and Verdolini Abbott 2012, Gaskill and Quinney 2012, Maxfield *et al.* 2015). Despite the promising progress in vocal quality, straw phonation was the only treatment that did not lead to improvements in self-report. Neither the VHI nor the VTDS decreased. Moreover, most of the subjects (6/9) reported no improved vocal quality and two of them even reported a worse vocal quality after the 3 weeks. Several hypotheses for this lack of progress are possible: (1) 3 weeks of practice might be too short to experience a change by the patients; (2) the subjects' standards regarding a 'good' or 'bad' vocal quality might have shifted due to the treatment; or (3) the high resistance to airflow associated with straw phonation might feel unnatural or uncomfortable for the subjects (Titze 2006, Gaskill and Quinney 2012). Lip trill and WRT, on the contrary, did show an effect on self-report measures. The psychosocial impact, determined with the VHI, significantly decreased in the two groups. For this outcome, a significant time-by-group interaction was found, which clearly demonstrate the benefit compared with the control group. Furthermore, WRT was rated best by the participants as most of them (6/8) reported a better self-perceived vocal quality immediately after the sessions, and three of them still experienced that improvement at the post-test. A possible reason for this self-report progress might be the 'massage-like' effect of the double vibratory source (Andrade *et al.* 2014, Guzman *et al.* 2017b). This effect might balance the potential uncomfortable feeling associated with the increased supraglottal pressure. The hypothesis that lip trill and WRT might actually decrease the level of discomfort in the vocal tract has not been supported by the VTDS results in the current study. Guzman *et al.* (2017b), on the other hand, did find a decreased VTDS after both lip trill and WRT. These contradictory finding may be due to differences in inclusion criteria. Self-reported vocal complaints, including vocal fatigue and muscle tension perception, were specified as inclusion criteria in the study of Guzman *et al.* (2017b) but not in the current study. Despite the lack of VTDS improvements found in the current study, other self-report findings did support the hypothesis for WRT. Almost all (6/8) subjects actually reported a more comfortable voice production after the WRT sessions.

Surprisingly, WRT showed no improved objective or auditory–perceptual outcomes. A possible explanation for the lack of progress is the relatively limited water depth used in the current study. Guidelines for WRT with a flexible soft-walled tube (also called Lax Vox® tube) describe an initial 2 cm water depth which can gradually evolve to a maximum of 7 cm (Sihvo 2006, Tyrmi *et al.* 2017). In this study, water depth was restricted to 2 cm to keep treatment conditions as strict as possible for every subject and every session. It can be hypothesized that an increase in water depth might lead to better results due to higher flow resistance (Andrade *et al.* 2016). Besides, the diameter of tubes and straws also plays a crucial role in modifying flow resistance. It might be assumed that a combination of smaller diameters with more water depth provides the best cumulative outcome. However, results of recent studies do not support this hypothesis. Guzman *et al.* (2017a, 2017b) also found no acoustic or auditory–perceptual improvements after WRT that combined a 5 mm diameter with a 5 cm water depth. The authors hypothesized that water bubbling could disturb auditory feedback and therefore impair the improvement of vocal quality.

Glass tubes absorb less sound and might possibly be more suitable (Simberg and Laine 2007). In general, WRT shows contradictory results. There is need for further research to find the best matched materials, diameters and water depths for individual vocalists who all have unique glottal resistances (Titze 2002a, Titze 2002b, Maxfield *et al.* 2015).

Unique for this study, is the inclusion of a control group that received a sham treatment. Unlike drug trials and some medical interventions, voice therapy trials cannot easily blind participants to the treatment they receive or trigger placebo effects (Bos-Clark and Carding 2011). For the current sham treatment, we specifically chose an activity related to voice but without active vocal practice. Because of ethical reasons, the received therapy programs were kept relatively short (3 weeks) and subjects had the opportunity to follow a therapy program including all three SOVT exercises immediately after the post-test. Therefore, long-term follow-up outcomes could not be included in this study.

To our knowledge, this is the first study that investigated the isolated effect of SOVT therapy programs in patients with dysphonia using both a multidimensional voice assessment, an assessor blinded to group allocation and a sham-controlled trial. Despite these methodological strengths, results should be interpreted with caution. Owing to the small sample size and the lack of adjustments for multiple outcome measures, the study might be underpowered. Other limitations are differences in treatment frequency and home practice assignment between the SOVT groups and the control group, and the lack of laryngostroboscopic data. Future studies should include larger and more heterogeneous study populations, auditory–perceptual evaluation scales that are more sensitive to change (e.g., consensus auditory–perceptual evaluation of voice—CAPE-V; Kempster *et al.* 2009), and long-term follow-up results.

CONCLUSIONS

Results suggest that SOVT therapy programs including lip trill or straw phonation can improve the objective vocal quality in patients with dysphonia. Auditory–perceptual improvements were found after straw phonation therapy. Lip trill and WRT both led to a decrease in the psychosocial impact associated with dysphonia. Patients seem to experience more comfort and a better self-perceived vocal quality after WRT.

This study supports the use of the three SOVT therapy programs in clinical practice. They all had a positive impact on one or more outcomes of the multidimensional voice assessment. Strikingly, vocal quality outcomes were not in line with the subject's opinion. Larger-scale investigation is needed to support these preliminary findings.

REFERENCES

Andrade, A. P., Wistbacka, G., Larsson, H., Södersten, M., Hammerberg, B., Simberg, S., Svec, J. G. and Granqvist, S., 2016, The flow and pressure relationships in different tubes commonly used for semi-occluded vocal tract exercises. *Journal of Voice*, 30(1), 36–41.

Andrade, A. P., Wood, G., Ratcliffe, P., Epstein, R., Pijper, A. and Svec, J. G., 2014, 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. *Journal of Voice,* 28(5), 589-595.

Bos-Clark, M. and Carding, P., 2011, Effectiveness of voice therapy in functional dysphonia: where are we now? *Current Opinion Otolaryngology-Head and Neck Surgery,* 19(3), 160-164.

Conroy, E. R., Henninck, T. M., Awan, S. N., Hoffman, M. R., Smith, B. L. and Jiang, J. J., 2014, Effect of variations to a simulated system of straw phonation therapy on aerodynamic parameters using excises canine larynges. *Journal of Voice,* 28(1), 1-6.

Croake, D. J., Andreatte, R. D. and Stemple, J. C., 2017, Immediate effects of the vocal function exercises semi-occluded mouth postures on glottal airflow parameters: A preliminary study. *Journal of Voice,* 31, 245.e9–245.e14.

Dargin, T. C. and Searl, J., 2015, Semi-occluded vocal tract exercises: aerodynamic and electroglottographic measurements in singers. *Journal of Voice,* 29(2), 155-164.

De Bodt, M. S., Jacobson, B. H., Musschoot, S., Zaman, S., Heylen, L. and Mertens, F., 2000, De Voice Handicap Index. Een instrument voor het kwantificeren van de psychosociale consequenties van stemstoornissen. *Logopedie,* 13, 29-33.

De Bodt, M., Mertens, D. and Heylen, L., 2008, *Werken aan stem* (Antwerpen: Garant).

Dejonckere, P. H., Remacle, M., Fresnal-Elbaz, M.,Woisard, V., Crevier-Buchman, L. and Millet, B., 1996, Differential perceptual evaluation of pathological voice quality: reliability and correlations with acoustic measurements. *Revue De Laryngologie - Otologie Rhinologie*, 117(3), 219–224.

Fantini, M., Succo, G., Crosetti, E., Borragán Torre, A., Demo, R. and Fussi, F., 2017, Voice quality after a semi-occluded vocal tract exercise with a ventilation mask in contemporary commercial singers: acoustic analysis and self-assessments. *Journal of Voice,* 31(3), 336-341.

Feise, R. J., 2002, Do multiple outcome measures require p-value adjustment? *BMC Medical Research Methodology,* 2, 8.

Gaskill, C. S. and Quinney, D. M., 2012, The effect of resonance tubes on glottal contact quotient with and without task instruction: a comparison of trained and untrained voices. *Journal of Voice,* 26(3), e79-e93.

Guzman, M., Jara, R., Olavarria, C. Caceres, P., Escuti, G., Medina, F., Medina, L., Madrid, S., Muñoz, D. and Laukkanen, A. M, 2017a, Efficacy of water resistance therapy in subjects diagnosed with behavioral dysphonia: a randomized controlled trial. *Journal of Voice,* 31(3), 385.e1-385.e10.

Guzman, M., Acuña, G., Pacheco, F., Peralta, F, Romero, C., Vergara, C. and Quezada, C., 2017b, The impact of double source of vibration semioccluded voice exercises on objective and subjective outcomes in subjects with voice complaints. *Journal of Voice,* doi: 10.1016/j.jvoice.2017.08.021.

Heylen, L., Wuyts, F., Mertens, F., De Bodt, M., Pattyn, J., Croux, C. and Van de Heyning, P. H., 1998, Evaluation of the vocal performance of children using a voice range profile index. *Journal of Speech, Language, and Hearing Research,* 41, 232–238.

Hirano, M., 1981, *Clinical Examination of Voice.* New York: Springer Verslag.

Jacobson, B. H., Johnson, A., Grywalski, C., Sirbergleit, A., Jacobson, G. and Benninger, M. S., 1997, The Voice Handicap Index (VHI): development and validation. *American Journal of Speech-Language Pathology*, 6, 66-70.

Kapsner-Smith, M. R., Hunter, E. J., Kirkham, K., Cox, K. and Titze, I. R., 2015, A randomized controlled trial of two semi-occluded vocal tract voice therapy protocols. *Journal of Speech, Language, and Hearing Research,* 58, 535-549.

Kempster, G. B., Gerratt, B. R., Verdolini Abbott, K., Barkmeier-Kraemer, J. & Hillman, R. E., 2009, Consensus auditory-perceptual evaluation of voice: development of a standardized clinical protocol. *American Journal of Speech-Language Pathology,* 18(2), 124-132.

Luyten, A., Bruneel, L., Meerschman, I., D'haeseleer, E., Behlau, M., Coffé, C. and Van Lierde, K., 2016, Prevalence of vocal tract discomfort in the Flemish population without self-perceived voice disorders. Journal of Voice, 30(3), 308–314.

Mailänder, E., Mühre, L. and Barsties, B, 2017, Lax Vox as a voice training program for teachers: a pilot study. *Journal of Voice,* 31(2), 262.e13-262.e22.

Maryn, Y., Corthals, P., Van Cauwenberge, P., Roy, N. and De Bodt, M., 2010a, Toward Improved Ecological Validity in the Acoustic Measurement of Overall Voice Quality: Combining Continuous Speech and Sustained Vowels. *Journal of Voice,* 24(5), 540-555.

Maryn, Y., De Bodt, M., and Roy, N., 2010b, The Acoustic Voice Quality Index: Toward improved treatment outcomes assessment in voice disorders. *Journal of Communication Disorders,* 43, 161-174.

Mathieson, L., Hirani, S. P., Epstein, R., Baken, R., J., Wood, G. and Ruben, J. S., 2009, Laryngeal manual therapy: a preliminary study to examine its treatment effects in the management of muscle tension dysphonia. *Journal of Voice*, 23, 353–366.

Maxfield, L., Titze, I., Hunter, E. and Kapsner-Smith, M., 2015, Intraoral pressures produced by thirteen semi-occluded vocal tract gestures. *Logopedics Phonatrics Vocology,* 40(2), 86-92.

Mills, R., Hays, C., Al-Ramahi, J. and Jiang, J. J., 2017, Validation and evaluation of the effects of semi-occluded face mask straw phonation therapy methods on aerodynamic parameters in comparison to traditional methods. *Journal of Voice*, 31, 323–328.

Raes, J., Wuyts, F. L., De Bodt, M. and Clement, P., 2002, The Dysphonia Severity Index used with a percentage scale. *Stem-, Spraak- en Taalpathologie,* 11(1), 30-37.

Russell, A., Oates, J. and Pemberton, C., 2000, *Voice care for teachers* (Flinders University).

Sihvo, M. (2006). *Terve Ääni, Äänen Hoidon A B C (Healthy Voice. The A B C for Voice Care).* Helsinki: Kirjapaja.

Simberg, S. and Laine, A., 2007, The resonance tube method in voice therapy: description and practical implementations. *Logopedics Phoniatrics Vocology,* 32, 165-170.

Sovijärvi, A., 1969, Nya metoder vid behandlingen av röstrubbningar. *Nordisk Tidskrift for Tale og Stemme*, 3, 121-131.

Titze, I. R., 2002a, How to use the flow-resistant straws. *Journal of Singing*, 58(5), 429–430.

Titze, I. R., 2002b, Regulating glottal airflow in phonation: Application of the maximum power transfer theorem to a low dimensional phonation model. *Journal of the Acoustical Society of America*, 111(1), 367–376.

Titze I. R., 2006, Voice training and therapy with a semi-occluded vocal tract: rationale and scientific underpinnings. *Journal of Speech, Language, and Hearing Research*, 49, 448-459.

Titze, I. R. and Verdolini Abbott, K., 2012, *Vocology: The Science and Practice of Voice Habilitation.* Salt Lake City, UT: National Center for Voice and Speech.

Tyrmi, J., Radolf, V., Horáček, J. and Laukkanen, A. M., 2017, Resonance tube or Lax Vox? *Journal of Voice,* 31(4), 430-437.

Van Lierde, K. M., D'haeseleer, E., Wuyts, F. L., De Ley, S., Geldof, R., De Vuyst, J. and Claeys, S., 2010a, The objective vocal quality, vocal risk factors, vocal complaints, and corporal pain in Dutch female students training to be speech-language pathologists during the 4 years of study. *Journal of Voice*, 24(5), 592–598.

Van Lierde, K. M., Claeys, S., D'haeseleer, E., Deley, S., Derde, K., Herregods, I., Strybol, I. and Wuyts, F., 2010b, The vocal quality in female student teachers during the 3 years of study. *Journal of Voice*, 24(5), 599–605.

Van De Weijer, J. and Sliss, I., 1991, Nasaliteitsmeting met de nasometer. *Logopedie en Foniatrie*, 63, 97–101.

Wuyts, F. L., De Bodt, M. S., Molenberghs, G., Remacle, M., Heylen, L., Millet, B., Van Lierde, K., Raes, J. and Van de Heyning, P. H., 2000, The Dysphonia Severity Index: an objective measure of vocal quality based on a multi-parameter approach. *Journal of Speech, Language, and Hearing Research,* 43, 796–809.