ABSTRACT

Background. A promising way to obtain vocal economy and efficiency is by semi-occluding the vocal tract while phonating. Current knowledge about the immediate effects of semi-occluded vocal tract (SOVT) phonation on the laryngeal function and configuration is based mainly on computer modeling or excised larynges studies. In in vivo SOVT studies, electroglottography has been the most commonly used laryngeal outcome, showing contradictory results between studies. Therefore, exploring these aspects by direct visualization of the human larynx during SOVT phonation using strobovideolaryngoscopy is needed.

Aims. The aim of this study was to investigate and compare the immediate effects of straw phonation (SP) in air, SP in 2cm water, and SP in 5cm water (with stirring straws), on the laryngeal function and configuration of a homogeneous group of vocally healthy female speech-language pathology students, visualized with flexible strobovideolaryngoscopy (SVL).

Methods & Procedure. A randomized controlled trial was used. Fifty-two female speech-language pathology students (mean age: 18.7 years, SD: 0.6) were assigned randomly to one of three experimental groups or a control group: (1) SP in air (2) SP in 2cm water (3) SP in 5cm water, or (4) [u] phonation with similar soft onset and slightly pursed lips as in SP but without a straw (control group). The participants underwent flexible SVL during habitual [u] phonation, followed by the specific SOVT exercise of their group assignment. All video samples were evaluated randomly and blindly by two experienced investigators using the Voice-Vibratory Assessment with Laryngeal Imaging (VALI) rating form, first independently and then by consensus.

Outcome & Results. Compared to habitual phonation, the vibrational amplitude decreased during SP in 5cm water and SP in 2cm water, being more prominent in the first, more flow-resistant exercise. The mucosal wave also decreased during SP in 5cm water. The anteroposterior (AP) supraglottic compression similarly increased during SP in air, SP in 2cm and SP in 5cm water. Further, a rise in mediolateral compression and a decrease in phase symmetry and regularity were found during SP in 2cm water. A similar decrease in regularity was observed during SP in 5cm water.

Conclusions & Implications. Both SP in air and SP in water cause positive immediate laryngeal effects for voice training opportunities. More AP supraglottic activity found during each exercise might indicate epilarynx narrowing, an economic phenomenon associated with SOVT. Immersing the straw in water additionally diminished the vibrational amplitude, lowering vocal fold impact stress and risk for phonotrauma during the exercise. The decreased regularity of the vibrational cycles during SP in water might be due to the varying back pressure created by the water bubbling. The impact of SP in water on ML supraglottic compression needs further investigation.

WHAT THIS PAPER ADDS

What is already known on the subject?

A promising way to obtain vocal economy and efficiency is by semi-occluding the vocal tract while phonating. Current knowledge about the immediate effects of semi-occluded vocal tract (SOVT) phonation on the laryngeal function and configuration is based mainly on computer modeling or excised larynges studies. In in vivo SOVT studies, electroglottography has been the most commonly used laryngeal outcome, showing contradictory results between studies. Therefore, exploring these aspects by direct visualization of the human larynx during SOVT phonation using strobovideolaryngoscopy is needed.

What this study adds?

Group results of the current study generally support earlier computer modeling and in vivo studies, strengthening the current SOVT knowledge. Both SP in air and SP in water cause positive immediate laryngeal effects for voice training opportunities. More anteroposterior supraglottic activity found during each exercise might indicate epilarynx narrowing, an economic phenomenon associated with SOVT. Immersing the straw in water additionally diminished the vibrational amplitude, lowering vocal fold impact stress and risk for phonotrauma during the exercise. The decreased regularity of the vibrational cycles during SP in water might be due to the varying back pressure created by the water bubbling. The impact of SP in water on ML supraglottic compression needs further investigation.

Clinical implications of the study.

Current results support that both SP in air and SP in water can be useful exercises in voice training. SP in water has shown the additional gain of lowering the vibrational amplitude during the exercise, hence supporting its appropriacy for vocal warm-ups by minimizing vocal fold impact stress and the risk of phonotrauma. In the future, large-scale randomized controlled trials in other subgroups of voice users, including dysphonic patients, are needed to support evidence-based practice. Strobovideolaryngoscopy can facilitate the search for individualized training and therapy approaches.

INTRODUCTION

Voice training and therapy frequently rely on a semi-occluded vocal tract (SOVT) to obtain economic and efficient voice use (Titze, 2006). Semi-occluding the vocal tract during phonation tries to achieve a resonant and powerful voice with limited energy loss and vocal fold impact stress by optimizing the source-filter interaction (Titze, 2006; Maxfield et al., 2015; Titze et al., 2021). The increased supraglottic pressure and inertive reactance induce favorable laryngeal function and configuration, in which vocal fold vibration and subglottic pressure are balanced, vibrational amplitude is relatively low, and the vocal folds are barely abducted/adducted (Titze & Verdolini Abbott, 2012; Gaskill & Quinney, 2012; Laukkanen et al., 2012; Guzman, Laukkanen et al., 2013; Smith & Titze, 2017). SOVT exercises, if correctly performed and sufficiently controlled, are expected to occur with some epilarynx (i.e. the ventricle + the ventricular space between the false folds + the laryngeal vestibule) narrowing in the anteroposterior (AP) dimension (Titze, 2006; Titze & Verdolini Abbott, 2012; Guzman, Castro et al., 2013; Dargin et al., 2016; Titze et al., 2021). This AP epilarynx narrowing has been shown to correlate with larynx lowering and pharynx widening in trained voice users (Guzman, Castro et al., 2013). Furthermore, an increased pharyngeal to epilaryngeal tube ratio (megaphone shape) contributes to the singer's and speaker's formant, or in other words, amplifies the vocal output without increasing the input, leading to more vocal economy (Sundberg, 1974; Titze & Story, 1997; Laukkanen et al., 2012; Guzman, Castro et al., 2013; Dargin et al., 2016).

Current knowledge about the immediate effects of SOVT phonation on the laryngeal function and configuration is based mainly on in silico (computer simulations) (Titze, 2006; Titze & Laukkanen, 2007; Lã et al, 2017; Titze et al., 2020; Titze et al., 2021) or excised larynges studies (Conroy et al., 2014; Mills et al., 2017; Kang et al., 2019; Tangney et al., 2021). In in vivo SOVT studies, electroglottography (EGG) has been the most commonly used laryngeal outcome, showing contradictory results between studies (Meerschman et al., SR in preparation (CRD42021274203)). Therefore, authors have been interested in exploring these aspects by direct visualization of the human larynx during SOVT phonation using (strobo)videolaryngoscopy (Menezes et al., 2005; Guzman, Castro et al., 2013; Ogawa et al., 2013; Dargin et al., 2016; Meerschman et al., 2021).

With strobovideolaryngoscopy (SVL), Meerschman et al. (2021) found a small non-significant decrease in vibrational amplitude during straw phonation (SP) with a drinking straw in water in dysphonic patients. These results were consistent with those found by high-speed videolaryngoscopy during tube phonation in water in vocally healthy untrained subjects (Guzman et al., 2017) and a vocally healthy trained male singer (Laukkanen et al., 2020). Surprisingly, opposite results were found during SP with a drinking straw in air, showing an increase in vibrational amplitude during the exercise (Meerschman et al., 2021). It was hypothesized by the authors that a drinking straw in air might not create sufficient supraglottic pressure to lower the vibrational amplitude, based on intraoral pressure measurements by Maxfield et al. (2015). For vocal fold closure, no changes were detected during lip trill, tongue trill or SP in air by Dargin et al. (2016) and during SP in air or water by Meerschman et al. (2021) in vocally healthy singers and dysphonic patients, respectively, although more sensitive continuous ratings might be needed to detect subtle changes (instead of categories of glottal closure).

Guzman, Castro et al. (2013) and Meerschman et al. (2021) reported higher AP supraglottic compression during SOVT phonation (lip/tongue trill, SP in air/water) in patients with dysphonia, being more prominent for higher-resistant exercises (stirring straw in air or straws in water). Ogawa et al. (2013) found decreased mediolateral (ML) supraglottic compression during humming in both vocally healthy untrained participants and patients with muscle tension dysphonia. However, Menezes et al. (2005) did not find any changes in supraglottic compression during tongue trills in vocally healthy speech therapy students, and Dargin et al. (2016) noted strong inter- and intraindividual variation during lip trill, tongue trill and SP in air in vocally healthy singers.

Limitations of the above studies are the relatively low sample sizes (*n* range = 4 – 30), lack of control groups and randomization (Menezes et al., 2005; Ogawa et al., 2013; Guzman et al., 2013; Dargin et al., 2016), lack of blinded visual-perceptual ratings and inter/intrarater reliability results (Menezes et al., 2015; Dargin et al., 2016), and heterogenous samples in terms of age, gender, vocal pathology or training (Menezes et al., 2005; Ogawa et al., 2013; Meerschman et al., 2021).

Therefore, the purpose of this study was to investigate and compare the immediate effects of SP in air, SP in 2cm water, and SP in 5cm water (with stirring straws), on the laryngeal function and configuration of a homogeneous group of vocally healthy female speech-language pathology students, visualized with flexible SVL, using a randomized controlled trial. Based on previous studies, reduced vibrational amplitude (Guzman et al., 2017, Laukkanen et al., 2020; Meerschman et al., 2021) and more AP supraglottic activity (Guzman et al., 2013; Meerschman et al., 2021) were hypothesized during SP compared to habitual phonation. Effects were expected to be more prominent in higher flow-resistant exercises, i.e. SP in 5cm water > SP in 2cm water > SP in air (Guzman et al., 2013; Meerschman et al., 2021).

METHODS

This study was approved by the Ethics Committee of Ghent University Hospital (BC-09807).

Participants

Fifty-eight female students in the first year of study toward a bachelor degree in Logopaedic and Audiological Sciences at Ghent University (academic year 2021-2022), were recruited for this study by convenience sampling. They all provided written informed consent. Exclusion criteria were an organic vocal fold pathology diagnosed by a specialized otorhinolaryngologist, smoking, pregnancy and hearing problems. Three participants were excluded due to an organic vocal fold pathology (vocal fold nodules or edema), and one participant was excluded due to smoking. Further, the data of two participants were not analyzed because of technical errors while saving videos. Finally, the study sample consisted of fifty-two female students with a mean age of 18.7 years (range: 17-20, SD: 0.6).

Design

A randomized controlled trial was used. Participants were assigned randomly to one of three experimental groups or a control group: (1) SP in air (n = 14), (2) SP in 2cm water (n = 13), (3) SP in 5cm water (n = 13), or (4) /u/ phonation with similar soft onset and slightly pursed lips as in straw phonation but without a straw (control group, n = 12). An online random number generator was used for this procedure. There were no significant differences in age between the four groups (Kruskal Wallis Test, p = 0.094).

Material and methods

Straw phonation material

Ecologic compostable wheat stirring straws with a diameter of 3mm and a length of 20cm were selected for all experimental groups. SP in water was performed in reusable cups, and the water depth (2cm or 5cm) was set by drawing a line on the straw.

Preparatory phase

Before the experiment, in the second week of the academic year, all students received one group SP workshop of 20 min guided by an experienced voice therapist (I.M.). The aim of this session was to strive for a correct and comfortable SOVT production prior to the actual experiment. First, focus was on an eutonic posture in sitting position and costo-abdominal breathing. Participants were instructed to breath in through the nose and blow out through the mouth without phonation. Second, they were asked to repeat this but now adding phonation on a [ɔ] vowel with soft onset [hhhɔɔɔ] during exhalation, at habitual comfortable pitch and loudness. Afterwards, both step one (without phonation) and step two (with phonation) were repeated with the straw. Attention was drawn to sensory feedback, forward focus, and avoidance of hyperfunction. At the preparatory phase, students were unaware of their group assignment and were specifically instructed to not practice the exercises at home.

Flexible strobovideolaryngoscopy and phonatory tasks

In the third and fourth week of the academic year, all students underwent flexible SVL by a specialized otorhinolaryngologist (P.T. or F.D.) using an EndoFLEX Spectar laryngoscope (Xion Medical). The participants were examined in seated position with the head upright and without administration of topical anesthesia. During the examination, they were asked to phonate an [u] vowel at habitual pitch and loudness (baseline), followed by the specific SOVT exercise of their group assignment. For the SOVT phonation, they were instructed to produce an [u] vowel at habitual pitch and loudness with soft onset and slightly pursed lips through the stirring straw (either in air, 2cm water or 5cm water) or without a straw (control group). The

[u] vowel was selected for all phonatory tasks (baseline and SOVT, both in the experimental group and the control group) so that potential differences are more certainly attributable to SP and not to differences in vowel production. The same voice therapist (I.M.) guided them through these phonatory tasks, together with a master's student (K.P.) for practical support.

Visual-perceptual ratings

After data collection, all video samples were evaluated randomly and blindly by an otorhinolaryngology resident (C.D.V.) and a speech-language pathologist specialized in voice (I.K.). Evaluations were standardized by use of the Voice-Vibratory Assessment with Laryngeal Imaging (VALI) rating form for stroboscopy (Poburka et al., 2017). In advance, a half hour training session was provided in which each parameter was clarified with the definition, a high-quality graphic, and two video examples.

After the training, the assessors first independently evaluated each video sample on a self-paced basis, after which a consensus evaluation was reached. Ten percent of the samples were randomly repeated to assess intrarater reliability. The video samples were presented without audio to prevent bias of the participant's voice quality on the judges' ratings.

The evaluated parameters were glottal closure (complete, anterior gap, posterior gap, hourglass, spindle gap, irregular, or incomplete), amplitude (magnitude of lateral movement of the vocal folds, in %), mucosal wave (magnitude of lateral movement of the mucous membrane in %), vertical level (on-plane, off-plane left lower, or off-plane right lower), nonvibratory portion (adynamic segments of tissue that appear stiff, in %), anteroposterior (AP) and mediolateral (ML) supraglottic activity (constriction of the supraglottic structures, rated $0 - 5$ with the aid of concentric circles), free edge contour (normal, convex, concave, irregular, or rough), phase closure (open phase predominates, nearly equal, or closed phase predominates), phase symmetry (the degree of symmetry between the left and the right vocal folds in terms of opening and closing, in %), and regularity (consistency of averaged stroboscopic cycles, in %) (Poburka et al., 2017).

Statistical analysis

The data were analyzed statistically by SPSS version 28 (SPSS Corporation, Chicago, IL, USA) at $\alpha = 0.05$.

To determine the interrater reliability of the visual-perceptual ratings, a two-way mixed, consistency, average-measures intraclass correlation coefficient (ICC) was calculated for the continuous variables, and a Cohen's kappa (K) was used for the nominal variables (Hallgren, 2012; Koo & Li, 2016). Intrarater reliability was determined using a two-way mixed, absolute agreement, single-measures ICC for the continuous variables, and a Cohen's K was used for the nominal variables (Hallgren, 2012; Koo & Li, 2016).

Linear mixed model analyses were used to compare the groups over phonatory condition (habitual [u] phonation vs SOVT phonation) on each continuous variable using the restricted maximum likelihood estimation and scaled identity covariance structure. Group, Phonatory Condition and Phonatory Condition * Group interaction were determined as fixed factors. A random intercept for subjects was included. Model assumptions were checked by inspecting whether residuals were distributed normally. Within-group effects of Phonatory Condition were determined by posthoc pairwise comparisons. Marginal homogeneity tests were used to compare nominal variables between habitual /u/ phonation and SOVT phonation within groups.

RESULTS

Inter and intrarater reliability

Excellent interrater reliability was found for all parameters with ICC's or K's ranging from 0.86 – 0.99 (Cicchetti, 1994; Landis & Koch, 1977).

The intrarater reliability for rater 1 was good to excellent for most parameters (ICC or K = 0.63-1.00), fair for mucosal wave (0.58), and poor for ML supraglottic activity (ICC = 0.29). Rater 2 showed good to excellent intrarater reliability for most parameters (ICC or K = 0.63-0.92), except for the parameters mucosal wave (ICC = 0.29) and ML supraglottic activity (ICC = 0.22) (Cicchetti, 1994; Landis & Koch, 1977).

The parameters non-vibratory portion and vertical level were not retained for further analysis as they were scored '0' and 'on plane', respectively, for all video samples.

Habitual [u] phonation (baseline)

Habitual [u] phonation at baseline showed no differences for any outcome parameter between the four groups, suggesting that randomization was successful.

Immediate effects SOVT phonation

Results of the linear mixed model analyses for the continuous outcome parameters can be found in Table 1. A significant Phonatory Condition * Group interaction was found for the parameters amplitude right ($p < 0.001$), amplitude left ($p = 0.037$), AP supraglottic activity ($p = 0.002$), and phase symmetry ($p = 0.039$), indicating significant different SOVT effects on these parameters between the four groups.

Posthoc pairwise comparisons showed that amplitude right and left decreased significantly compared to baseline (habitual phonation) during SP in 5cm water (R: -11.2%, $p < 0.001$; L: -8.9%, $p = 0.004$), whereas no change was detected in the SP in air or control group. During SP in 2cm water, amplitude right also decreased significantly (-7.1%, $p = 0.008$) and amplitude left showed a non-significant decrease (-5.5%, $p = 0.084$). A graphical representation of the amplitude evolution can be seen in Figures 1 (amplitude right) and 2 (amplitude left).

Mucosal wave also decreased compared to baseline (habitual phonation) during SP in 5cm water (R: - 6.5%, $p = 0.003$; L: - 6.5%, $p = 0.005$). A trend of decreased mucosal wave also was observed during SP in 2cm water but did not reach significance (R: -3.3%, $p = 0.134$, L: -4,6%, $p = 0.054$). No changes were found in the SP in air or control group.

Posthoc tests further revealed significantly increased AP supraglottic activity compared to baseline (habitual phonation) during SP in air (+1.4, $p < 0.001$), SP in 2cm water (+1.3, $p = 0.001$) and SP in 5cm water (+1.5, $p < 0.001$), whereas no change was found in the control group. A graphical representation of the evolution in AP supraglottic activity can be found in Figure 3.

Although no significant interaction effect was found, posthoc tests showed that the ML supraglottic activity significantly increased during SP in 2cm water (+ 0.6, $p = 0.043$) compared to baseline (habitual phonation), whereas no differences were found in the other three groups.

Furthermore, the phase symmetry decreased significantly during SP in 2cm water (-12.9%, $p = 0.009$), and the regularity decreased significantly during both SP in 2cm water (-13.1%, $p = 0.028$) and SP in 5cm water (-12.5%, $p = 0.026$).

The results of the nominal outcome parameters for both habitual phonation and SOVT phonation in each group can be found in Table 2. Marginal homogeneity tests showed no significant immediate SOVT effects for these parameters.

DISCUSSION

The purpose of this study was to investigate and compare the immediate effects of SP in air, SP in 2cm water, and SP in 5cm water (with stirring straws), on the laryngeal function and configuration of a homogeneous group of vocally healthy female speech-language pathology students, visualized with flexible SVL.

As hypothesized (Guzman et al., 2017, Laukkanen et al., 2020; Meerschman et al., 2021), reduced vibrational amplitude was found during SP in 5cm water and SP in 2cm water, being more prominent in the first, more flow-resistant SOVT exercise. The increased supraglottic pressure achieved by the semi-occlusion and the water results in reduced transglottic pressure (difference between sub- and supraglottic pressure) which consequently lowers the vibrational amplitude (Titze, 2006; Guzman, Laukkanen et al., 2013; Dargin et al., 2016; Smith & Titze, 2017). This phenomenon makes the exercises ideal for warm-up and voice training due to the lower vocal fold impact stress. Phonation with high subglottic pressure and high frequency is then possible with minimal risk of injury to the vocal fold mucosa (Titze, 2006; Guzman, Laukkanen et al., 2013; Dargin et al., 2016; Smith & Titze, 2017). In previous high-speed laryngeal imaging studies investigating tube phonation in water, Guzman et al. (2017) also found a lower amplitude-to-length ratio in most of the vocally healthy untrained participants, and Laukkanen et al. (2020) reported diminished maximum glottal width and decreased glottal amplitude in a vocally healthy trained male singer. Meerschman et al. (2021) also found a trend of a lower vibrational amplitude during SP with a drinking straw in water in dysphonic patients. SP in air, however, did not lower the vibrational amplitude in the current study or in our previous work (Meerschman et al., 2021). In that study, the amplitude even increased during SP with a drinking straw in air. There is growing evidence that small diameter stirring straws (± 3mm diameter) are needed to create sufficient supraglottic pressure and optimal laryngeal effects, especially in females whose mean glottal openings are smaller than those of males creating higher glottal resistance (Maxfield et al., 2015; Titze et al., 2021). Based on the current results, it can be hypothesized that both a small straw diameter and sufficient water submersion are needed to achieve amplitude reduction in vocally healthy female subjects. Further research is needed to investigate this hypothesis, and determine whether this is the case for each voice user, all differing in glottal resistance (females/males, vocally healthy/dysphonic, trained/untrained etc.).

The second hypothesis, i.e. more AP supraglottic activity during SP compared to habitual phonation, also was supported by the current results with a similar increase in the three experimental groups. This observation could be due to AP epilarynx narrowing, an economic phenomenon associated with SOVT (Titze, 2006; Titze & Verdolini Abbott, 2012; Guzman, Castro et al., 2013; Dargin et al., 2016). Previous studies with dysphonic subjects revealed that AP supraglottic compression increases further with higher-resistant exercises (Guzman, Castro et al., 2013; Meerschman et al., 2021). In the current study, such differences could not be detected. This could be due to a different study population (vocally healthy vs dysphonic), or it might indicate that a stirring straw by itself induces sufficient flow resistance to create substantial AP supraglottic compression and that no extra water is needed for that purpose. It is important to discuss the possible risk of compensatory laryngeal tension elicited by the flexible laryngoscopic examination itself, creating bias and potentially incorrect conclusions regarding the SP effects (Van Lierde, Claeys et al., 2004; De Bodt et al., 2012). However, the fact that this randomized controlled trial did not detect changes in AP supraglottic activity in the control group undergoing the exact same examination significantly diminishes this risk of bias (Porzsolt et al., 2015).

Compared to AP supraglottic activity, which can be considered economic in particular contexts and voice users, ML supraglottic compression is seen mostly as harmful and a sign of hyperfunction (Stager et al., 2000; Van Lierde, De Ley et al., 2004; Dargin et al., 2016). No changes in ML supraglottic compression were found in the SP in air, SP in 5cm water or control group. However, an increase was noticed during SP in 2cm water. Meerschman et al. (2021) also reported a small, non-significant increase in ML supraglottic compression during SP with a drinking straw in 2cm water in dysphonic subjects. It could be that, compared to SP in air and [u] phonation, the extra resistance of the water induces some compensatory ventricular fold adduction, especially in untrained subjects. However, a similar observation would then be expected during SP in 5cm water, which was not the case. It should be noted that ML supraglottic compression was the only parameter that showed low intrarater reliability in both raters. Therefore, interpretation should be made with caution, and further research is needed to investigate the effects of SP in water on ML supraglottic compression.

Results of the study further suggest that the regularity of the vocal fold vibration (consistency of cycles) diminishes if the straw is submerged in water. This observation may be explained by the fluctuating intraoral pressure and back pressure to the vocal folds caused by the water bubbling (Andrade et al., 2014; Granqvist et al., 2015). Earlier EGG research by Andrade et al. (2014) showed a higher relative contact quotient range and fundamental frequency range in SOVT exercises with a secondary vibratory source (such as water bubbling) compared with single source exercises, indicating less regular vocal fold vibration. Granqvist et al. (2015) also reported that the varying back pressure of the bubbles modulates the vocal fold vibration, observed with high-speed imaging and EGG. The fluctuating intraoral pressure has been hypothesized to create a 'massage-like' effect on the vocal apparatus, leading to muscle relaxation, improved blood circulation and more laryngeal comfort, again making SP in water a promising voice training and rehabilitation tool (Andrade et al., 2014; Granqvist et al., 2015; Guzman et al., 2018; Meerschman et al., 2019; Laukkanen et al., 2020). During SP in 2cm water, a decrease in phase symmetry was also noted, which might be explained by the same hypothesis (Andrade et al., 2014; Granqvist et al., 2015). However, a decrease could not be detected during SP in 5cm water. Therefore, further research is needed to explore SOVT effects on phase symmetry, comparing influencing factors such as water depth and straw or tube diameter.

SOVT exercises are expected to cause vocal folds to be slightly abducted (Titze & Verdolini Abbott, 2012; Gaskill & Quinney, 2012). Although no statistically significant differences could be detected in glottal closure between habitual and SOVT phonation, some trends were noticeable. During SP in air, SP in 2cm water and [u] phonation (with similar soft onset and slightly pursed lips as in SP but without a straw), glottal closure was incomplete in approximately 25% of the subjects, which was not the case in any of the subjects during habitual phonation. In the SP in 5cm water group, there was a 15.4% increase in spindle gap. Consequently, SOVT phonation induced some vocal fold abduction in specific subjects, indicating less vocal fold impact stress and more economic phonation (Titze, 2006; Titze & Verdolini Abbott, 2012; Guzman, Laukkanen, et al., 2013; Dargin et al., 2016). Further, each SOVT exercise seemed to eliminate some posterior gaps, and two participants achieved a complete glottal closure in the SP in 2cm water group. In the future, high-speed imaging with more sensitive continuous ratings is needed to make clear conclusions regarding glottal closure.

This is the first randomized controlled trial investigating the immediate laryngeal effects of SOVT phonation visualized with SVL that focused on a relatively large homogeneous group of voice users, i.e. vocally healthy female speech-language pathology students. A limitation of the study is the low intrarater reliability found for ML supraglottic activity in both raters. Since the interrater reliability was excellent, a learning effect occurred during the experiment. More training opportunities beforehand might solve this problem in further research. The authors of the VALI form (Poburka et al., 2017) also reported higher reliability with high-speed videoendoscopy. In future, other subgroups of voice users and carry over effects from SOVT phonation to habitual phonation should be explored.

CONCLUSIONS

SP in air, SP in 2cm water and SP in 5cm water all showed favorable immediate laryngeal effects for voice training opportunities in a homogeneous group of vocally healthy female speech-language pathology students. More AP supraglottic activity was found during each exercise, which may indicate epilarynx narrowing, an economic phenomenon associated with SOVT. Immersing the straw in water additionally lowered the vibrational amplitude, minimizing vocal fold impact stress and the risk of phonotrauma during the exercise. The decreased regularity of the vibrational cycles during SP in water might be due to the varying back pressure created by the water bubbling. The impact of SP in water on ML supraglottic activity needs further investigation. In the future, large-scale randomized controlled trials in other subgroups of voice users, including dysphonic patients, are needed to support evidence-based practice. Furthermore, potential retention effects of SOVT phonation on the laryngeal function and configuration should be explored.

Table 1: Immediate effects of SOVT phonation on the continuous outcome parameters

Parameter	Group	Phonatory Condition				Linear Mixed Model			
		habitual phonation		**SOVT phonation**		**Phonatory Condition**	**Group**	**Phonatory Condition * Group**	**Posthoc comparison Phonatory Condition within Groups**
		EM	**95%CI**	**EM**	**95%CI**	***p*-value**	***p*-value**	***p*-value**	***p*-value**
Amplitude R (%)	SP air	36.7	[32.6,40.7]	37.7	[33.6,41.7]	.004*	.747	< .001*	.662
	SP 2cm water	39.6	[35.1,44.1]	32.5	[28.0,37.0]				.008*
	SP 5cm water	40.0	[35.6,44.4]	28.8	[24.5,33.2]				< .001*
	control [u]	34.6	[30.1,39.1]	37.1	[32.6,41.6]				.330
Amplitude L (%)	SP air	36.0	[32.0,40.0]	36.3	[32.3,40.4]	.060	.536	.037*	.904
	SP 2cm water	36.3	[31.7,40.8]	30.8	[26.3,35.4]				.084
	SP 5cm water	37.7	[33.3,42.0]	28.8	[24.5,33.2]				.004*
	control [u]	33.8	[29.2,38.3]	36.3	[31.7,40.8]				.419
Mucosal wave R (%)	SP air	36.0	[32.9,39.1]	35.0	[31.9,38.1]	.027*	.979	.074	.611
	SP 2cm water	37.9	[34.5,41.4]	34.6	[31.1,38.0]				.134
	SP 5cm water	39.2	[35.9,42.5]	32.7	[29.4,36.0]				.003*
	control [u]	35.4	[32.0,38.9]	36.7	[33.2,40.1]				.570
Mucosal wave L (%)	SP air	36.0	[32.7,39.3]	35.7	[32.4,38.9]	.022*	.991	.079	.873
	SP 2cm water	37.9	[34.3,41.6]	33.3	[29.7,37.0]				.054
	SP 5cm water	39.2	[35.7,42.7]	32.7	[29.2,36.2]				.005*
	control [u]	35.8	[32.2,39.5]	36.7	[33.0,40.3]				.721

AP supraglottic activity	SP air	1.2	[0.5,1.9]	2.6	[1.9,3.3]	< .001*	.425	.002*	< .001*
	SP 2cm water	1.0	[0.2,1.8]	2.3	[1.4,3.1]				.001*
	SP 5cm water	1.4	[0.7,2.2]	2.9	[2.1,3.7]				< .001*
	control [u]	1.4	[0.7,2.3]	1.3	[0.4,2.1]				.468
ML supraglottic activity	SP air	0.7	[0.3,1.0]	0.9	[0.5,1.2]	.200	.914	.192	.357
	SP 2cm water	0.6	[0.2,1.0]	1.1	[0.7,1.5]				.043*
	SP 5cm water	0.8	[0.4,1.1]	0.9	[0.5,1.3]				.509
	control [u]	0.8	[0.4,1.2]	0.6	[0.2,1.0]				.304
phase symmetry (%)	SP air	89.3	[77.7,100.9]	84.0	[72.4,95.6]	.210	.598	.039*	.215
	SP 2cm water	92.9	[79.9,105.9]	80.0	[67.0,93.0]				.009*
	SP 5cm water	93.1	[80.6,105.5]	98.8	[86.4,111.3]				.212
	control [u]	91.7	[78.7,104.6]	92.5	[79.5,105.5]				.861
regularity (%)	SP air	80.0	[69.7,90.3]	72.3	[62.0,82.6]	.001*	.916	.752	.165
	SP 2cm water	85.0	[73.9,96.1]	71.9	[60.9,83.0]				.028*
	SP 5cm water	85.7	[75.1,96.4]	73.2	[62.6,83.9]				.026*
	control [u]	83.1	[72.0,94.1]	77.7	[66.6,88.7]				.278

Note. SP: straw phonation, SOVT: semi-occluded vocal tract, EM: estimated mean, CI: confidence interval, R: right, L: left, AP: anteroposterior, ML: mediolateral
* indicates a significant effect ($p < 0.05$)

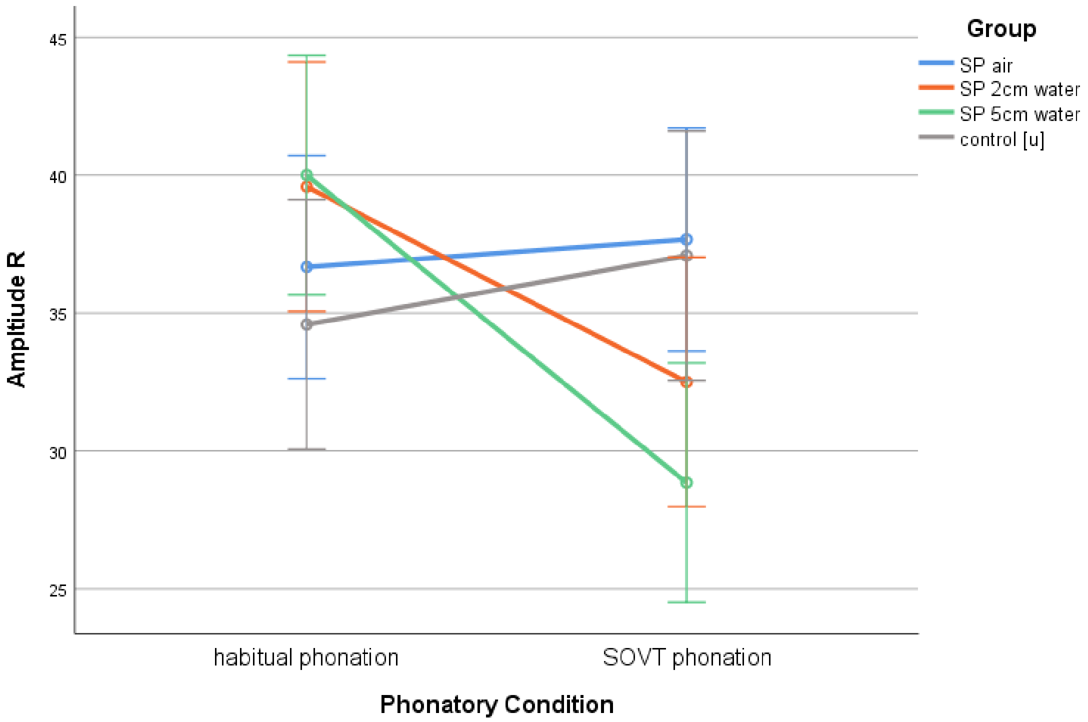

Figure 1: Amplitude right (R) during habitual phonation and SOVT phonation

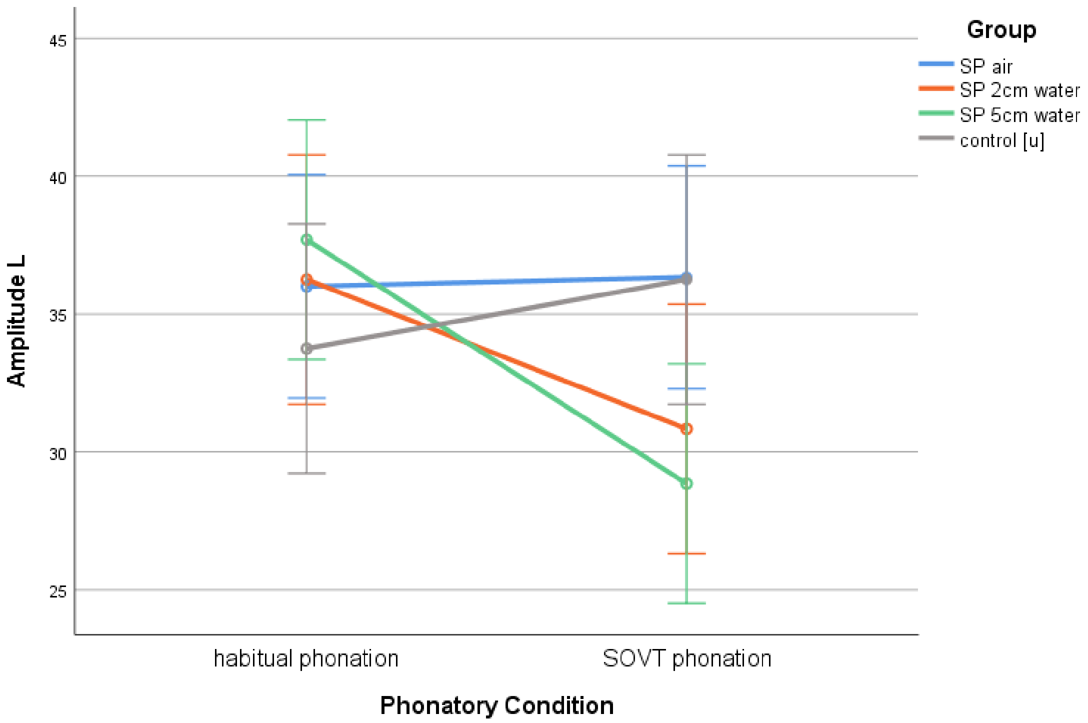

Figure 2: Amplitude left (L) during habitual phonation and SOVT phonation

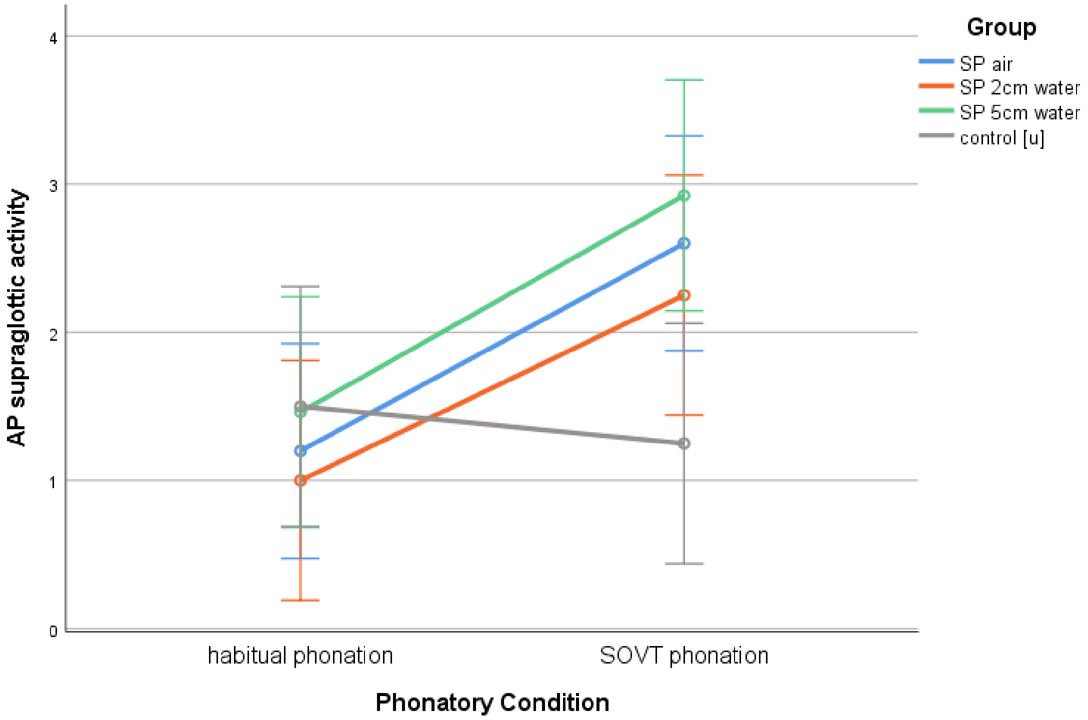

Figure 3: Anteroposterior (AP) supraglottic activity during habitual phonation and SOVT phonation

Table 2: Immediate effects of SOVT phonation on the nominal outcome parameters

Parameter	Phonatory Condition per Group							
	SP air (*n* = 14)		SP 2cm water (*n* = 13)		SP 5cm water (*n* = 13)		control [u] (*n* = 12)	
	Habitual phonation *n (%)*	SOVT phonation *n (%)*	Habitual phonation *n (%)*	SOVT phonation *n (%)*	Habitual phonation *n (%)*	SOVT phonation *n (%)*	Habitual phonation *n (%)*	SOVT phonation *n (%)*
Glottal closure								
complete	4 (28.6)	4 (28.6)	2 (15.4)	4 (30.8)	4 (30.8)	4 (30.8)	5 (41.7)	5 (41.7)
anterior gap	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
posterior gap	8 (57.1)	6 (42.9)	9 (69.2)	4 (30.8)	7 (53.8)	5 (38.5)	7 (58.3)	4 (33.3)
hourglass	2 (14.3)	1 (7.1)	1 (7.7)	1 (7.7)	1 (7.7)	1 (7.7)	0 (0)	0 (0)
spindle gap	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (15.4)	0 (0)	0 (0)
irregular	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
incomplete	0 (0)	3 (21.4)	1 (7.7)	4 (30.8)	1 (7.7)	1 (7.7)	0 (0)	3 (25.0)
Marginal homogeneity test, p-value	*.140*		*.439*		*.564*		*.157*	
free edge contour right								
normal	12 (85.7)	13 (92.9)	13 (100)	11 (85.6)	12 (92.3)	11 (84.6)	11 (91.7)	10 (83.3)
convex	1 (7.1)	0 (0)	0 (0)	1 (7.7)	1 (7.7)	2 (15.4)	0 (0)	1 (8.3)
concave	0 (0)	1 (7.1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (8.3)
irregular	1 (7.1)	0 (0)	0 (0)	1 (7.7)	0 (0)	0 (0)	1 (8.3)	0 (0)
rough	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Marginal homogeneity test, p-value	*.439*		*.206*		*.317*		*>0.999*	
free edge contour left								
normal	11 (78.6)	12 (85.7)	13 (100)	11 (85.6)	11 (84.6)	11 (84.6)	11 (91.7)	10 (83.3)
convex	1 (7.1)	0 (0)	0 (0)	1 (7.7)	1 (7.7)	2 (15.4)	1 (8.3)	1 (8.3)
concave	1 (7.1)	1 (7.1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (8.3)
irregular	1 (7.1)	1 (7.1)	0 (0)	1 (7.7)	1 (7.7)	0 (0)	0 (0)	0 (0
rough	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Marginal homogeneity test, p-value	*.739*		*.206*		*.527*		*.414*	
phase closure								
open phase predominates	0 (0)	2 (14.3)	1 (7.7)	1 (7.7)	2 (15.4)	0 (0)	0 (0)	0 (0)
nearly equal	12 (85.7)	12 (85.7)	11 (85.6)	8 (61.5)	9 (69.2)	9 (69.2)	11 (91.7)	10 (83.3)
closed phase predominates	2 (14.3)	0 (0)	1 (7.7)	4 (30.8)	2 (15.4)	4 (30.8)	1 (8.3)	2 (16.7)
Marginal homogeneity test, p-value	*.527*		*.109*		*.637*		*.564*	

Note. SP: straw phonation, SOVT: semi-occluded vocal tract

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