Published in final edited form as:

J Voice. 2017 May ; 31(3): 323–328. doi:10.1016/j.jvoice.2016.04.009.

Validation and evaluation of the effects of semi-occluded face mask straw phonation therapy methods on aerodynamic parameters in comparison to traditional methods

Randal Mills¹, Cameron Hays¹, Jehad Al-Ramahi¹, and Jack J. Jiang, M.D., Ph.D.¹

¹University of Wisconsin-Madison School of Medicine and Public Health, Department of Surgery, Division of Otolaryngology – Head and Neck Surgery, Madison, WI

Abstract

Objectives/Hypothesis—Traditional semi-occluded vocal tract (SOVT) therapies have the benefit of improving vocal economy but, do not allow for connected speech during rehabilitation. In this study, we introduce a semi-occluded face mask (SOFM) as an improvement upon current methods. This novel technique allows for normal speech production, and will make the transition to everyday speech more natural. We hypothesize that use of a SOFM will lead to the same gains in vocal economy seen in traditional methods.

Study Design—Repeated measures excised canine larynx bench experiment with each larynx subject to controls and a randomized series of experimental conditions.

Methods—Aerodynamic data were collected for 30 excised canine larynges. The larynges were subjected to conditions including a control, two tube extensions (15 and 30 cm), and two tube diameters (6.5 and 17 mm) both with and without the SOFM. Results were compared between groups and between conditions within each group.

Results—No significant differences were found between the phonation threshold pressure (PTP) and phonation threshold flow (PTF) measurements obtained with or without the SOFM throughout all extension and constriction levels. Significant differences in PTP and PTF were observed when varying the tube diameter while the same comparison for varying the tube length at least trended towards significance.

Conclusions—This study suggests that a SOFM can be used to elicit the same gains in vocal economy as what has been seen with traditional SOVT methods. Future studies should test this novel technique in human subjects to validate its use in a clinical setting.

Corresponding author: Jack J. Jiang, M.D., Ph.D., 1300 University Avenue, 2745 Medical Sciences Center, Madison, WI 53706, Phone: (608) 265-9854, Fax: (608) 265-2139, jjjiang@wisc.edu. Please direct reprint requests to Dr. Jack Jiang

Presenting at Meeting: The Voice Foundation's 45th Annual Symposium: Care of the Professional Voice; Philadelphia, PA; June 1 – June 5, 2016

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Keywords

Resonance tube; Face mask; Straw phonation therapy; Phonation threshold flow; Phonation threshold pressure; Excised larynx

Introduction

Voice disorders are common in the US, with approximately 25 million workers suffering from some form of vocal pathology.¹ These disorders ultimately lead to a diminished quality of life and can have a significant negative impact on one's social, psychological, professional, and financial well-being.² Research that contributes to a better understanding of the mechanics of voice production could help reduce this impact by allowing for the development of more effective therapeutic interventions.

The vocal folds, which function as a resonator, periodically open and close during phonation. The vocal tract interacts with the vocal folds by acting as a filter for the sound produced.³ This source-filter interaction attenuates partials of the source spectrum and influences the conversion rate of aerodynamic energy into acoustic energy.^{1, 3, 4} These effects work to maintain vocal economy, which is the ratio of vocal output to effort.⁴ A decrease in the source-filter interaction, and thus a decrease in vocal economy, increases the amount of effort needed to produce a similar vocal output.⁴ A greater phonatory effort raises the intraglottal pressure and collision stress of the vocal folds, which can elicit trauma in these tissues.^{1, 4, 5, 6} A common intervention to improve vocal economy, and reduce the probability of sustaining a vocal fold injury, is the use of semi-occluded vocal tract (SOVT) exercises.^{1, 2} These exercises include phonating through a straw or a Finnish tube and have been used for decades as a means to help teachers, singers, and other voice-dependent professionals prevent re-injury after vocal surgery or to correct bad vocal habits.^{7, 8} SOVT therapies are most commonly performed in the oral cavity, but can also be implemented at any point along the supraglottal vocal tract.^{1, 2, 7}

A key factor in the function of voice is the impedance of the upper airway, which alters the acoustic-aerodynamic interaction and changes the phonation threshold pressure (PTP), or the minimum subglottal pressure (SGP) necessary to induce phonation.^{9, 10, 11} Impedance consists of resistance and reactance. Resistance is responsible for removing energy in the airway while reactance stores energy for vocal fold oscillation. Reactance can be further divided into a positive component, inertance, and a negative component, compliance.⁹ Inertance, which eases the initiation and maintenance of vocal fold vibration, releases a buildup of stored supraglottal pressure to create a suction that assists in the opening and closing of the vocal folds. Inertance (I) is quantitatively defined by the equation:

$$I = \frac{\rho \cdot \ell}{A} \quad (1)$$

where ρ is the density of the air column, ℓ is the length, and A is the cross-sectional area.⁹ An increase in inertance is thought to contribute to improved vocal economy, and is thus a

focus in selecting SOVT configurations. On the contrary, compliance, which inhibits self-sustained phonation, results in a decrease in vocal economy. The equation for compliance (C) also depends on the configuration of the SOVT and is defined as:

$$C = \frac{LA}{\rho c^2} \quad (2)$$

where L is the length, A is the cross-sectional area, ρ is the density of the air column, and c is the speed of sound in air.⁹ High inertance and low reactance are needed to achieve maximum vocal economy.^{9, 10, 12, 13} However, as both of these components depend on SOVT parameters, the configurations used in SOVT therapy must be carefully evaluated through testing with vocal tracts of varying diameters and lengths.^{6, 11}

Conroy et al. introduced a novel approach of using oppositional airflow to further influence supraglottal pressure and impedance beyond the configuration of the vocal tract.¹⁴ This constant airflow was applied to the vocal tract superior to the larynx, and was tested at varying levels. It was found that applying a constant oppositional airflow during SOVT exercises has a significant effect on lowering PTP and PTF, and is therefore ideal for low impact vocal fold oscillation.

While SOVT exercises have been shown to enhance the quality of voice, there is still limited research in this area and a need for improved methodologies. Currently, there is insufficient data to identify the ideal laryngeal adjustments and the optimal ratio of compliance to inertance that could augment the effects of voice therapies. As a result, it has been of recent interest to gain a better understanding of the mechanisms behind SOVT therapies and select the optimal configuration to maximize vocal improvements. Optimizing this treatment would have the effect of increasing gains in vocal economy and providing more effective treatment for those suffering from voice disorders.^{15, 16}

One major limitation of traditional SOVT methods is that subjects are restricted from producing continuous speech. These methods typically place the occlusion at the mouth, rendering full articulation impossible and limiting exercises to single phoneme tasks. A semi-occluded face mask (SOFM), which was first introduced by Borragán et al., could overcome this limitation by placing the occlusion distal to the mouth.¹⁷ This allows for connected speech during therapy and can provide an easier transition from voice therapy to everyday speech production. The mask could be used with different levels of vowel and speech production to observe the overall effect the mask has on phonation. Additionally, changes in multiple upper airway measurements, such as PTP, phonation threshold flow (PTF), and supraglottal pressure, could be recorded with this method to track the progress of different treatments.^{8, 12} Although there is limited research regarding the effectiveness of SOFM therapies, early studies have shown promise.^{18, 19, 20} For example, Fouquet et al. used a hands-over-mouth technique to evaluate vocal quality and found that this semi-occlusion strategy could be used to promote vocal fold adduction and reduce phonatory effort.¹⁹ Also, Rosenberg used a cup phonation method, in which a small occlusion was made at the bottom of a cup, which allowed for continuous phonation tasks to be performed

through the open side.²⁰ Although these studies are promising, these methods did not allow for the simple attachment of various resonance tubes and also for the addition of oppositional airflow.

In this study, we explore a modification of adding a SOFM to a previously verified setup of using excised canine larynges to study SOVT therapies. We believe that a SOFM can improve upon current methods of SOVT therapies to provide an easier transition from vocal rehabilitation to natural speech production. However, before testing this idea, we must ensure that a SOFM is as effective as currently available methods. Thus, we hypothesize that performance of exercises using a SOFM will fail to show statistically significant changes in aerodynamic measures from the same exercises using only the resonance tube of a SOVT. At the same time, we hypothesize that this therapy will not hinder the positive effects on vocal economy seen with the traditional procedure.

Methods

Excised Canine Larynges

A total of 30 canine larynges were used in this study. The larynges were excised and dissected using the method described by Jiang and Titze from animals sacrificed for unrelated research purposes.²¹ The larynges were then frozen in 0.9% saline solution and thawed individually upon use. Prior to data collection, a careful and thorough inspection was conducted on each larynx to ensure that no vocal fold irregularities or trauma were present. Any larynx found to have damage was discarded and replaced with a healthy specimen.

Semi Occluded Vocal Tract and Mask

The SOVT shown in Figure 1 allows for the attachment of PVC pipes with varying dimensions, thereby producing several different test conditions. The laryngeal insert is a small tube with an inner diameter of 6 mm and a length of 25 mm. A conical section with a length of 25 mm transitions from an inner diameter of 6 mm to a larger inner diameter of 25 mm. After this transition, there is an inlet port in the vertical plane for supraglottal pressure measurements and another for oppositional airflow input. Distal to the larynx and the inlet port for oppositional airflow, a final outlet port with an inner diameter of 25 mm is present in the horizontal plane. Extensions, constrictions, and the SOFM can all be attached to this outlet port. The conical portion and the laryngeal insert are comprised of acrylonitrile butadiene styrene plastic, while the remaining portion was constructed using a polyvinylchloride pipe.

The face mask fits onto the outlet of the vocal tract model so that no additional constriction is added. The inner diameter of the mask outlet is 31 mm when attachments are not present. An elastic rubber plug with a flexible inlet is inserted into the outlet of the mask. Both constrictions and extensions could be inserted into the flexible inlet creating a tight seal. When the SOFM is attached, the oppositional airflow is introduced through an inlet on the mask and the airflow input on the vocal tract is sealed with a plug.

Apparatus

The excised larynx apparatus shown in Figure 2 is used to simulate the human respiratory system. To initiate phonation, air is passed through a system of two humidifiers (Concha Therm III; Fisher and Paykel Healthcare, Inc., Laguna Hills, CA) before reaching the larynx. Airflow is manually increased using a needle valve until sustained vocal fold vibration is achieved and is measured by an Omega airflow meter (model FMA-1610 A; Omega Engineering, Inc., Stamford, CT). Subglottal pressure measurements are obtained by a digital pressure meter (PX Series; Omega Engineering, Inc., Stamford, CT), while supraglottal pressure measurements are obtained by a pressure transducer (Part No. SSCSNBN005NDAA5; Honeywell, Morristown, NJ). All aerodynamic measurements are recorded using a data acquisition board (model AT-MIO-16; National Instruments Corp., Austin, TX) and a customized LabVIEW 15.0 program (National Instruments Corp., Austin, TX). Oppositional airflow was supplied by a continuous positive airway pressure (CPAP) machine (REMstar Plus CPAP Machine, Model No. 1009586I; Respironics Inc., Murrysville, PA). To ensure constant flow from the CPAP, a flow resistor (Model No. 7100R20; Hans Rudolph Inc., Shawnee, KS) and a one-way flow valve (1810 Series; Hans Rudolph Inc., Shawnee, KS) were connected in series between the outlet of the CPAP and the inlet on the vocal tract. The apparatus is housed in a sound-attenuated room to reduce the ambient noise present throughout the data collection process.

Mounting

Each larynx was mounted on the apparatus as specified by Jiang and Titze.¹⁵ To prevent the leakage of air, a metal clamp was used to secure the trachea to the outlet of the pseudo-lung. The vocal tract was inserted superior to the vocal folds to prevent any excess tissue from obstructing phonatory vibrations. Bilateral three-pronged micrometers were used to manipulate the arytenoids to adduct the vocal folds. A suture was placed through the thyroid cartilage so that the elongation of the vocal folds could be held constant. The epiglottis was then adhered (Loctite 401 Instant Adhesive, Part No. 40104; Henkel Corporation, Düsseldorf, Germany) to the vertical portion of the SOVT, while the rest of the tissue was adhered around the remainder of the laryngeal insert. This was done to prevent air from leaking as it passed over the vocal folds and entered the artificial vocal tract. Throughout the duration of the testing procedure, 0.9% saline solution was applied to the vocal folds to limit potential tissue dehydration.

Experimental conditions

The same conditions were applied to each larynx both with and without the SOFM. For all trials, oppositional airflow of 200 mL/s was supplied by a CPAP machine. Four experimental conditions and a control were tested for each larynx both with and without the SOFM. The control was tested before the other experimental conditions to allow for the collection of baseline data. Of the four experimental conditions, two were constrictions and two were extensions of the vocal tract. The constrictions consisted of decreasing the inner diameter of the outlet port from 25 mm to 17 mm and 6.5 mm, while the extensions consisted of increasing the length by 15 cm and 30 cm. These configurations and the level of airflow were chosen due to their use in a preliminary study conducted by Conroy et al. that

validated the use of the excised canine model for SOVT straw phonation studies.¹² The tubes used to extend the vocal tract also had an inner diameter of 17 mm, which was necessary to create an air-tight seal. The order in which these conditions were tested was randomized to control for the effect of fatigue. To further control for fatigue, half of the larynges started by performing trials with a SOFM while the other half started without a SOFM. In each control and experimental condition tested, five trials consisting of five seconds of sustained phonation at PTP were completed with a three second break between trials. The vocal folds were hydrated with 0.9% saline solution between each condition.

Statistical analysis

Measurements of PTP and PTF were obtained by first averaging over the five seconds of sustained phonation and then averaging these values across all five trials within a condition. PTP and PTF were then compared across groups using a two-way repeated measures analysis of variance (ANOVA) in SigmaPlot 11.0 (Systat Software, Inc., Chicago, IL). In this model, the presence of the tube and mask were the two factors for which an interaction effect was checked. Post hoc t-tests with the Bonferroni correction were completed to determine pairwise comparisons between constriction and extension conditions. Normality was evaluated using the Shapiro-Wilk test, and tests for equal variance were also performed.

Results

Average PTP and PTF data are displayed in Table 1. Supraglottal pressure failed to increase from the baseline value when oppositional airflow was introduced except for during the 6.5 mm constriction, in which the supraglottal pressure was 0.35 ± 0.15 cmH₂O with the SOFM and 0.41 ± 0.16 cmH₂O without it. When PTF was the dependent variable of interest, variability between groups was similar, both for varying the level of constriction ($P = 0.977$) and extension ($P = 0.998$). When PTP was the dependent variable of interest, variability between groups was also similar, both for varying the level of constriction ($P = 0.993$) and extension ($P = 0.834$). No significant differences were found between the PTP and PTF measurements obtained with or without the SOFM throughout all extension and constriction levels (Tables 2 and 3). Significant differences in PTP and PTF measurements were found in the overall comparison of varying constriction levels, while the same comparison for varying extension levels at least trended towards significance. There was also no significant interaction effect of the mask use and extension or constriction levels (Tables 2 and 3). The results of post hoc t-tests for constriction and extension levels can be seen in Tables 4 and 5, respectively.

Discussion

This study modeled the effects of attaching a SOFM onto the resonance tube of an artificial vocal tract. The aerodynamic parameters PTF and PTP were then compared between this novel setup and the previously verified SOVT setup. It was hypothesized that the inclusion of a SOFM would produce similar results and would not introduce negative effects on vocal economy. These hypotheses are strongly supported by the results obtained in this study. Results show that the differences in the mean PTP and PTF values between the mask and tube setups were not significant. It was also found that there were significant decreases in

both PTP and PTF when introducing varying levels of constrictions and elongations. A reduction in PTP in an excised model is generally strongly correlated to reduced effort and improved vocal economy as perceived by patients. These results are consistent with what was found by Conroy et al. in a previous study.¹² Furthermore, the results showed that the mask and tube produced similar results and did not depend on the level of constriction or extension present.

Previous studies have proven that an increase in vocal economy through straw phonation results from increased impedance and supraglottal pressure.^{1, 22, 23, 24} However, the supraglottal measurements obtained in this study failed to show an increase when oppositional airflow was introduced, except for when the diameter of the outlet was constricted to 6.5 mm. Since this condition subjects the vocal tract to the maximum constriction of this study, this increase in supraglottal pressure is expected. As the outlet is constricted, more air is contained within the constant volume of the vocal tract, which causes an increase in pressure. When no constriction is present, the air supplied by the CPAP will simply leave through the outlet of the SOFM or SOVT to reach atmospheric pressure before making a significant impact on the supraglottal pressure of the larynx. It was also found that the PTP and PTF values between constriction and elongation conditions were similar, even with the addition of increased supraglottal pressure. Furthermore, as only the 6.5 mm constriction elicited an increase in supraglottal pressure, the 17.5 mm constriction had lower mean values for PTP and PTF in both the mask and tube.

The findings of this study neither prove nor disprove the previously reported effects that oppositional airflow has on supraglottal pressure and vocal economy. The relatively low accuracy of the pressure transducer (± 0.1 cmH₂O) and the inability to measure the direct pressure at the superior surface of the vocal folds can explain the lack of results indicating the presence of increased supraglottal pressure. However, the significant results of this study and the findings of Conroy et al., still suggest there is a positive effect that results from including oppositional airflow in both SOVT and SOFM exercises. Applying these findings to the hypothesis, the added dead-space and altered input port for oppositional airflow included with the addition of the SOFM does not produce a significantly different effect on the supraglottal pressure in comparison to SOVT methods.

The clinical significance of using a SOFM in straw therapy is the added ability of the patient to produce continuous speech during treatment procedures. Before testing this setup in human subject studies, SOFM methods must demonstrate equal effectiveness as SOVT methods. The results of this study support this conclusion. The overall effect on aerodynamic parameters was similar between the two methods, and each extension and constriction condition produced statistically similar results. This finding validates the notion that no loss in vocal economy is produced when using the SOFM, suggesting that it would be appropriate to use this approach in human subject studies. Also, due to the lack of difference between the aerodynamic results of the various conditions, any configuration of the SOVT can be used in this novel setup. This may be necessary as the effectiveness of the SOVT depends on the glottal resistance of the individual user.^{10, 16} By using the optimal patient-specific configuration with the SOFM, straw phonation therapy could maximize its impact on vocal economy while also allowing for continuous speech. This is advantageous

as continuous speech more closely resembles the vocal output that patients use in their daily lives than the single phoneme tasks used in traditional SOVT therapies. Therefore, performing continuous speech tasks using a SOFM allows for a smoother transition from treatment to everyday speech.

Future studies on SOFM therapies can use the setup and inputs that were validated in this study to further investigate the effects on vocal economy in human subjects. Human subject studies provide more information regarding the dynamic and behavioral reactions of true physiological relevance. Furthermore, there are certain parameters within this therapy that must be monitored, and can only be quantified through human subject studies, such as comfort and phonatory effort. The researchers are also given a higher degree of freedom in creating the study design for those including human subjects, rather than excised laryngeal studies, as they are able to create specific phonatory tasks. This means that they will be able to implement phonatory tasks with continuous speech, while also controlling the duration of the tasks. This allows the effects of various types and durations of phonatory tasks to be monitored. This aspect of including human subjects is an essential focus for future straw phonation therapy studies, as allowing for continuous speech was the driving force behind validating the use of a SOFM. By combining the findings of this paper with the results of previous studies, further investigation of increasing the positive impact of straw therapy through human subject studies is achievable.

Conclusion

This study introduces SOFM therapies as an alternative to traditional SOVT methods. This novel class of therapies has the benefit of allowing for connected speech, making the transition to everyday speech more natural for subjects. Through the use of an excised canine model, it was shown that SOFM techniques led to the same decreases in PTF and PTP as has been observed with traditional methods. This suggests that this novel method can be used to achieve continuous speech production while still producing the same gains in efficiency seen in standard SOVT therapies. With this knowledge, future studies should test these SOFM techniques in human subjects to allow for clinical use.

Acknowledgments

This study was funded by National Institutes of Health grant number R01 DC008153 from the National Institute of Deafness and other Communication Disorders.

References

1. Titze IR. Voice training and therapy with a semi-occluded vocal tract: rationale and scientific underpinnings. *J Speech Lang Hear Res.* 2006; 49(2):448–59. [PubMed: 16671856]
2. Titze IR, Story B. Acoustic interactions of the voice source with the lower vocal tract. *J Acoust Soc Am.* 1997; 101(4):2234–43. [PubMed: 9104025]
3. Raphael, LJ., Borden, GJ., Harris, KS. *Speech Science Primer: Physiology, Acoustics, and Perception of Speech.* 6. Baltimore: Williams & Wilkins; 2011.
4. Berry D, Verdolini K, Montequin DW, Hess MM, Chan RW, Titze IR. A quantitative output-cost ratio in voice production. *J Speech Lang Hear Res.* 2011; 44(1):29–37.

5. Titze IR, Laukkanen AM. Can vocal economy in phonation be increased with an artificially lengthened vocal tract? A computer modeling study. *Logoped Phoniatr Vocol*. 2007; 32(4):147–56. [PubMed: 17917981]
6. Maxfield L, Titze I, Hunter E, Kapsner-Smith M. Intraoral pressures produced by thirteen semi-occluded vocal tract gestures. *Logoped Phoniatr Vocol*. 2015; 40(2):86–92. [PubMed: 24865621]
7. Laukkanen AM. About the so-called “resonance tubes” used in Finnish voice training practice. *Scand J Logoped Phoniatr*. 1992; 17(3–4):151–61.
8. Bohlender J. Diagnostic and therapeutic pitfalls in benign vocal fold diseases. *GMS Curr Top Otorhinolaryngol Head Neck Surg*. 2013; 12:1–18.
9. Titze IR. Acoustic interpretation of resonant voice. *J Voice*. 2001; 15(4):519–28. [PubMed: 11792028]
10. Titze, IR. Principles of Voice Production. Iowa City, IA: National Center for Voice and Speech; 2000. p. 99-103.
11. Andrade PA, Wistbacka G, Larsson H, et al. The flow and pressure relationships in different tubes commonly used for semi-occluded vocal tract exercises. *J Voice*. 2016; 30(1):36–41. [PubMed: 25873546]
12. Titze, I., Verdolini, K. *Vocology: The Science and Practice of Voice Habilitation*. Salt Lake City: National Center for Voice & Speech; 2012.
13. Radolf V, Horá ek J, Dlask P, Ot enášek Z, Geneid A, Laukkanen AM. Measurement and mathematical simulation of acoustic characteristics of an artificially lengthened vocal tract. *J Sound Vibration*. 2016; 366:556–570.
14. Bele IV. Artificially lengthened and constricted vocal tract in vocal training methods. *Logoped Phoniatr Vocol*. 2005; 30(1):34–40. [PubMed: 16040438]
15. Conroy ER, Hennick TM, Awan SN, Hoffman MR, Smith BL, Jiang JJ. Effects of variations to a simulated system of straw phonation therapy on aerodynamic parameters using excised canine larynges. *J Voice*. 2014; 28(1):1–6. [PubMed: 24286626]
16. Guzmán M, Castro C, Madrid S, et al. Air Pressure and Contact Quotient Measures During Different Semioccluded Postures in Subjects With Different Voice Conditions. *J Voice*. 2015
17. Borragán, A., del Barrio, JA., Gutierrez, JN. *El juego vocal para prevenir problemas de la voz*. Archidona, Malaga: Aljibe; 1999.
18. Fouquet ML, Vieira TPG, Murata CJM, Gonçalves AJ. Hands-over-mouth exercise in supracricoid horizontal partial laryngectomy: initial study. *Revista da Sociedade Brasileira de Fonoaudiologia*. 2012; 17(3):346–50.
19. Andrade PA, Wood G, Ratcliffe P, Epstein R, Pijper A, Svec JG. Electroglottographic study of seven semi-occluded exercises: LaxVox, straw, lip-trill, tongue-trill, humming, hand-over-mouth, and tongue-trill combined with hand-over-mouth. *J Voice*. 2014; 28(5):589–95. [PubMed: 24560003]
20. Rosenberg MD. Using Semi-Occluded Vocal Tract Exercises in Voice Therapy: The Clinician’s Primer. *SIG 3 Perspectives on Voice and Voice Disorders*. 2014; 24(2):71–79.
21. Jiang JJ, Titze IR. A methodological study of hemilaryngeal phonation. *Laryngoscope*. 1993; 103(8):872–82. [PubMed: 8361290]
22. Story B, Laukkanen AM, Titze I. Acoustic impedance of an artificially lengthened and constricted vocal tract. *J Voice*. 2000; 14(4):455–69. [PubMed: 11130104]
23. Guzman M, Castro C, Testart A, Muñoz D, Gerhard J. Laryngeal and pharyngeal activity during semioccluded vocal tract postures in subjects diagnosed with hyperfunctional dysphonia. *J Voice*. 2013; 27(6):709–16. [PubMed: 24075912]
24. Guzman M, Higuera D, Fincheira C, Muñoz D, Guajardo C, Dowdall J. Immediate acoustic effects of straw phonation exercises in subjects with dysphonic voices. *Logoped Phoniatr Vocol*. 2013; 38(1):35–45. [PubMed: 23350916]

Figure 1.

SOVT used in excise larynx setup with SOFM attached. Both an extension and constriction are attached to show the location of each attachment during SOFM conditions. For conditions using only the SOVT, extension/constriction attachments were placed on outlet of the SOVT instead of the SOFM.

Figure 2.
Excised larynx bench used for data collection.

Table 1

Summary of data collected for each condition. Values are represented as mean $\pm$ standard deviation. Oppositional airflow of 200 mL/s was administered during each control and condition.

Control Description	Tube		Mask	
	PTP	PTF	PTP	PTF
Control	9.56 $\pm$ 1.86	8.50 $\pm$ 3.00	9.74 $\pm$ 1.92	8.54 $\pm$ 2.99
17 mm Constriction	9.04 $\pm$ 1.76	8.21 $\pm$ 3.17	9.18 $\pm$ 1.89	8.01 $\pm$ 2.94
6.5 mm Constriction	9.32 $\pm$ 1.88	8.34 $\pm$ 3.58	9.56 $\pm$ 1.97	8.28 $\pm$ 2.98
15 cm Elongation	9.34 $\pm$ 1.84	8.34 $\pm$ 3.20	9.54 $\pm$ 1.91	8.28 $\pm$ 2.83
30 cm Elongation	9.27 $\pm$ 1.93	8.32 $\pm$ 3.36	9.47 $\pm$ 1.84	8.28 $\pm$ 3.00

Results from two-way repeated measures test for constriction conditions. The control was defined as a constriction of 25 mm. The interaction effect of the mask use was not found for both PTF ($P=0.555$) and PTP (0.403). Therefore the main effects were ignored.

Table 2

Constrictions						
Dependent Variable	Source of Variation	DF	SS	MS	F	P
PTF	Mask or Tube	1	0.244	0.244	0.114	0.738
	Constriction Level	2	5.222	2.611	6.089	0.004
	Mask or Tube vs. Constriction Level	2	0.436	0.218	0.595	0.555
PTP	Mask or Tube	1	1.322	1.322	1.889	0.180
	Constriction Level	2	8.407	4.204	16.564	<0.001
	Mask or Tube vs. Constriction Level	2	0.237	0.119	0.924	0.403

Table 3

Results from two way repeated measures test for extension conditions. The control was defined as an extension of 0 cm. The interaction effect of the mask use was not found for both PTF ($P=0.848$) and PTP ($P=0.656$). Therefore the main effects were ignored.

Extensions						
Dependent Variable	Source of Variation	DF	SS	MS	F	P
PTF	Mask or Tube	1	0.019	0.019	0.009	0.924
	Extension Level	2	1.882	0.941	2.819	0.068
	Mask or Tube vs. Extension Level	2	0.083	0.042	0.166	0.848
PTP	Mask or Tube	1	1.777	1.777	2.212	0.148
	Extension Level	2	2.814	1.407	9.322	<0.001
	Mask or Tube vs. Extension Level	2	0.103	0.052	0.425	0.656

Table 4

Results from the post hoc t-tests using the Bonferroni correction for constriction conditions. The control was defined as a constriction of 25 mm.

Constrictions				
Dependent Variable	Constriction Levels (mm)	Diff of Means	t	P
PTF	0 vs. 17.5	0.417	3.489	0.003
	0 vs. 6.5	0.217	1.815	0.224
	6.5 vs. 17.5	0.200	1.674	0.299
PTP	0 vs. 17.5	0.528	5.744	< 0.001
	0 vs. 6.5	0.235	2.551	0.040
	6.5 vs. 17.5	0.294	3.193	0.007

Table 5

Results from the post hoc t-tests using the Bonferroni correction for constriction conditions. The control was defined as an extension of 0 cm.

Extensions				
Dependent Variable	Extension Levels (cm)	Diff of Means	t	P
PTF	0 vs. 30	0.220	2.087	0.124
	0 vs. 15	0.214	2.024	0.143
	15 vs. 30	0.007	0.062	1.000
PTP	0 vs. 30	0.298	4.207	< 0.001
	0 vs. 15	0.209	2.946	0.014
	15 vs. 30	0.089	1.261	0.637