Validation and Evaluation of the Effects of Semi-Occluded Face Mask Straw Phonation Therapy Methods on Aerodynamic Parameters in Comparison to Traditional Methods

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Summary: Objectives/Hypothesis. Traditional semi-occluded vocal tract 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 an 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 and phonation threshold flow measurements obtained with or without the SOFM throughout all extension and constriction levels. Significant differences in phonation threshold pressure and phonation threshold flow were observed when varying the tube diameter while the same comparison for varying the tube length at least trended toward 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 semi-occluded vocal tract methods. Future studies should test this novel technique in human subjects to validate its use in a clinical setting.

Key Words: Face mask–Straw phonation therapy–Phonation threshold flow–Phonation threshold pressure–Excised larynx.

INTRODUCTION

Voice disorders are common in the United States, 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.[1,4–6] 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 may 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 necessary to induce phonation.[9–11] 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:

$$I = \frac{\rho \cdot \ell}{A} \tag{1}$$

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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:

$$\mathrm{C} = \frac{LA}{\rho c^2} \tag{2}$$

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.[6,11,14]

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.[15] 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 phonation threshold flow (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, 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.[18–20] 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 an 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 an SOFM is as effective as currently available methods. Thus, we hypothesize that performance of exercises using an SOFM will fail to show statistically significant changes in aerodynamic measures from the same exercises using only the resonance tube of an 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 polyvinyl chloride 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 composed 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.