Efficacy of different straw phonation doses for vocal fatigue prevention.

1) Elaine Kwong, PhD. (corresponding author)

Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University

Hung Hom, Kowloon, Hong Kong.

+852 3400 8559

2) Suen Yue Sarah Poon, Master of Speech Therapy

Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University

Hung Hom, Kowloon, Hong Kong.

3) Cheuk Yiu Tse, Master of Speech Therapy

Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University

Hung Hom, Kowloon, Hong Kong.

Mailing address: Department of Chinese and Bilingual Studies, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

Short running title: **Straw phonation for vocal fatigue prevention**

Keywords: Vocal fatigue, prevention, straw phonation, Semi-occluded vocal tract

Abstract

Purpose. The aim of the present study was to investigate the efficacy of different straw phonation doses for vocal fatigue (VF) prevention.

Method. Thirteen males and 13 females participated in the study. Each subject received seven preventive treatments (i.e. voice rest with hydration for 15 minutes, straw phonation into air or water for one, three and five minutes) in separate visits. Phonatory threshold pressure (PTP) and self-perceived vocal fatigue symptoms severity (PVF) were adopted as the primary and secondary outcome measures respectively. Measurements were taken before and after the preventive treatment, and after a 90-minute VF-inducing task.

Result. PTP was maintained in four of the straw phonation doses, namely; the 1-minute into air, 1-minute, 3-minute and 5-minute into water conditions; but not in the voice rest condition. Straw phonation into water of a depth of 5cm for one minute was considered the optimal dose for VF prevention. PVF, however, was not maintained after VF-inducing task in all treatment conditions.

Conclusion. Straw phonation into water for one minute was capable of preventing phonatory efficiency (as measured with PTP) from deteriorating. The dose identified in the present study may be adopted for future prevention studies in population that is vulnerable to VF.

Keywords

Vocal fatigue, prevention, straw phonation, Semi-occluded vocal tract

Introduction

Vocal fatigue (VF) is one of the major complaints in occupational voice users (Mattiske, Oates, & Greenwood, 1998). It was reported by Gotaas and Starr (1993) that as many as 80% of teachers experience regular VF due to the high vocal demand in the teaching profession. Moreover, there are studies suggesting a linkage between VF and functional and/or organic voice disorders (Koufman & Blalock, 1988; Welham & Maclagan, 2003). Studies on prevention and remediation of VF are therefore of paramount clinical importance.

A conceptual model proposed by McCabe and Titze (2002) stated that VF includes both behaviourally-observed and self-perceived phenomena. The behaviourally-observed phenomena are physiological and biomechanical in nature. According to Titze (1994), prolonged voice use may result in change in fluid composition of the vocal folds and thus increase their viscosity. This will in turn reduce an individual's overall phonatory efficiency. Traditionally, aerodynamic measurement of phonatory efficiency is obtained from the ratio between orally radiated acoustic power and aerodynamic power (as calculated by mean subglottal air pressure times mean glottal air flow) (Schutte, 1984). Phonatory efficiency in the present context, however, was defined as the minimum subglottal pressure, or phonatory threshold pressure (PTP), required to initiate vocal fold oscillation (Solomon & DiMattia, 2000). As PTP indicates phonatory efficiency, it is also believed to be reflective of the extent of one's VF. The self-perceived phenomena primarily manifest as increased phonatory effort (McCabe & Titze, 2002). However, they could also be extended comprehensively to a set of self-perceived symptoms (Nanjundeswaran, Jacobson, Gartner-Schmidt, & Verdolini-Abbott, 2015).

Vocal warm up exercise and VF prevention

Vocal warm up exercises may increase blood flow in laryngeal muscles and thus may lower muscle viscosity and promote smoother muscle contractions (Elliot, Sundberg, & Gramming, 1995; Milbrath & Solomon, 2003), which could be indicated by decreased PTP and reduced phonatory effort (Milbrath & Solomon, 2003; Titze, 2009). Semi-occluded vocal tract (SOVT) exercises have been used as a kind of physiological vocal warm up by singers for decades. They work by creating a narrow constriction at a point of the vocal tract so that acoustic energy may be directed backward and some back pressure may be exerted to the vocal folds. This allows the vocal folds to vibrate at a barely separated gesture and thus result in better vocal economy, that is, the ratio between output acoustic energy and mechanical impact stress experienced by the vocal folds (Verdolini, Druker, Palmer, & Samawi, 1999). Titze (2006) proposed an alternative definition of vocal economy based on the non-linear source-filter interaction hypothesis between the vocal tract and vocal folds. It was suggested that SOVT exercises may create an improved impedance matching between glottis and vocal tract and thus result in improved vocal economy, as measured by the ratio between maximum flow declination rate in the glottis and maximum glottal area declination rate. Among the variations of SOVT exercises, straw phonation technique has been used extensively in voice clinics and singing training. The straw, which acts as a resonance tube, resembles an artificial extension of the vocal tract which creates the semi-occlusion. This technique requires individuals to phonate into straws with different dimensions and the distal end may be placed in air or water with different depths (Guzman et al., 2016; Guzman, Laukkanen, et al., 2013; Titze, 2006).

To date, there are only a few studies that had specifically investigated the efficacy of straw phonation as vocal warm up exercises. Duke, Plexico, Sandage, and Hoch (2015) compared the acoustic effects of straw phonation and traditional vocal warm up exercise. They found no significant difference among straw phonation, traditional warm up and no-warm up conditions in terms of singing power ratio and the subjects' self-reported perceived phonatory effort (PPE) measured using a 100mm long visual analogue scale. Another study by Portillo, Rojas, Guzman, and Quezada (2018) found that straw phonation is comparable to traditional vocal warm up exercises in most outcome measures. It was found that straw phonation exercise resulted in a significant pre-post improvement in self-reported voice quality among Contemporary Commercial Music singers.

The above studies set out to investigate acoustic, aerodynamic, electroglottographic and also self-perceived changes brought about by straw phonation. However, authors of the two studies did not address the efficacy of straw phonation in VF prevention, which is believed to be one of the products of successful vocal warm up. By incorporating a vocal loading task, the present study was the first to investigate directly the efficacy of straw phonation in VF prevention.

Objective and research questions

The aim of the present study was to investigate the efficacy of different doses of straw phonation for VF prevention. It was hypothesized that a certain dose of straw phonation exercise is adequate to prevent vocal fatigue from developing even after a considerable amount of vocal loading. Dose in the present context referred to the duration of the straw phonation exercise and whether the straw ended in air or water. Specifically, the following research questions were addressed:

1) Can straw phonation exercise reduce deterioration in phonatory efficiency after a VF-inducing task?

2) What is the optimal dose of straw phonation that can efficaciously reduce the above-mentioned deterioration?

Materials and Methods

A repeated measure design was adopted. Treatment condition was regarded as the independent variable, whereas aerodynamic PTP and self-reported perceived VF (PVF) were regarded as the dependent variables. The outcome measures were selected based on McCabe and Titze's conceptual model (McCabe & Titze, 2002). PTP was selected to be the primary outcome measure as a valid, behavioural and objective index of VF (Chang & Karnell, 2004), whereas PVF was selected as the secondary and subjective outcome measure.

Participants

The present study was approved by the Human Subjects Ethics Sub-committee, the Hong Kong Polytechnic University (Ref. HSEARS20180301001) and informed consent had been obtained from all participants. A total of 26 adults (aged from 21 to 60) of both genders (13 males and 13 females) took part in the present study. Although no gender difference was expected to exhibit in the outcome measures selected (Chang & Karnell, 2004), the gender ratio was balanced to make the findings of the present study more representative and applicable to both genders. All participants were vocally-healthy and their voices were screened auditory-perceptually by the first author (E. K., a speech therapist who had over 15 years of experience in managing voice disorders). Participants should have no history of voice disorders and no experience of formal vocal training and or voice therapy. These were to ensure that the induced VF was not complicated by the presence of any vocal condition and was not delayed due to previous training.

Procedures

Each subject visited the experimental site seven times. Each visit was at least one week apart to ensure that the subject had recovered fully from previous VF-inducing tasks. A timeline illustrating the events occurred in each visit is found in Figure 1. At each of the measurement timepoints (i.e. Pre-treatment baseline, Post-treatment and Post-fatigue), measurements of PTP and PVF were conducted.

[put Figure 1 here]

Outcome measurements. PTP was estimated from the intraoral pressure measured with a flexible plastic tube inserted in the oral cavity using the AeroviewPlus Phonatory Aerodynamics System (Glottal Enterprises) connected to a laptop computer (model: ideapad y700-15ISK, Lenovo). The average measurement error of the aerodynamic system from the manufacturer was reported to be less than 5% (Hertegård, Gauffin and Lindestad, 1995). Subjects were required to produce the string /ipipipipipipipi/ with his/her lowest possible loudness at a rate of 1.5 syllables/s as suggested by Smitheran and Hixon (1981). To establish the lowest possible loudness, subjects were instructed to produce the string with a whispering voice and gradually increase his/her loudness until the string is produced with a minimally phonated voice. Three practice trials (with the face mask put on and the plastic tube inserted) were given before the actual recording and three trials that were representative for the client's lowest speaking intensity were recorded for later data extraction.

For PVF measurement, subjects were required to rate the severity of eight commonly reported VF symptoms instead of a single symptom of "phonatory effort". This was to increase the coverage and comprehensiveness of self-perceived level of VF. The symptoms were derived from some of the items of the Vocal Fatigue Index (VFI) (Nanjundeswaran et al., 2015), which the Hong Kong-Chinese version was still in the process of validation by the first author at the time the present study was conducted. During the cross-cultural adaptation process of the Hong Kong version VFI, the symptoms were also found to be culturally appropriate and commonly reported by individuals with voice problems in the local context. Severity rating was conducted using an 11-point equal-appearing interval scale (0 = "normal" and 10 = "extremely severe"). The symptoms are listed in Appendix 1.

Treatment conditions. During each of the seven visits, subjects received one of the following treatments in a randomized order: voice rest (Voice rest); one, three and five minutes of straw phonation that ends in air (Air-1, Air-3 and Air-5); one, three and five minutes of straw phonation that ends in water with a depth of 5cm (Water-1, Water-3 and Water-5).

All straw phonation exercises were coached by a student speech therapist who was trained to manage voice disorders. Subjects were instructed to phonate into plastic straws (dimensions: 30cm in length and 6.5mm in inner diameter (Conroy et al., 2014; Mills, Rivedal, DeMorett, Maples, & Jiang, 2018)) that ended either in air or water (depth: 5cm). The phonatory tasks included phonating a sustained vowel /u:/ using the subject's habitual pitch and loudness, ascending and descending glissandos through a comfortable range, and pitch and loudness accents (Guzman, Angulo, Muñoz, & Mayerhoff, 2013). During the "Voice rest" visit, subjects were instructed to completely rest his/her voice for 15 minute and drink as much water as they wish during the period.

VF-inducing task. Subjects read aloud passages from Chinese newspapers or other materials for 90 minutes. They were required to read at an intensity 10dB above their habitual one to ensure the occurrence of VF. A tablet (Ipad 9.7, Apple Inc.) installed with an vocal intensity monitoring application (Voice Analyst: pitch & volume, Speechtools Limited) was placed 30cm away from the subject's mouth to monitor the subject's loudness. Throughout the VF-inducing task, no voice rest and hydration were allowed.

Data extraction

The three recorded trials of the /ipipipipipipipi/ string were analysed using the Aeroview program (Glottal Enterprises). Within each trial, the first, the second and the last peak pressure were excluded from analysis. PTP was calculated by averaging the pressure produced in the remaining four peaks. The least PTP extracted was selected to represent the subject's *threshold* pressure for phonation.

Statistical analyses

All statistical analyses were carried out using the IBM SPSS Statistics 25 software. Since it was difficult to control for factors like hydration and prior-to-visit VF level, it was deemed inappropriate to assume subjects started off similarly (this was confirmed by the across-treatment condition differences in the primary outcome measure at the Pre-treatment timepoint. See below). In light of this potential variability, planned comparisons were adopted instead of repeated measure ANOVA. For each treatment condition and each outcome measure, two paired-sample *t*-tests were conducted to compare the difference between the Pre-treatment and the other two timepoints (i.e. Post-treatment and Post-fatigue). A total of 14 paired-sample *t*-tests were conducted at an Alpha level of 0.05 for each outcome measure. Since the null hypotheses of the present study corresponded to “the intervention has no effect on deterioration", no correction on the Alpha level was administered in order to minimize the probability of inflating the Type II error.

Results

PTP: the primary outcome measure

Results of one-way ANOVA suggested significant across-treatment condition differences in PTP at the Pre-treatment timepoint ($F(6, 173) = 4.436$, $p < 0.001$). Table I and Figure 2 summarize the descriptive statistics of PTP data and Table II summarizes results from the paired-sample *t*-tests. In the Pre-treatment-Post-treatment comparisons, the only significant increase in PTP was found in the Air-5 condition ($t(25) = -2.504$, $p = 0.019$) and a close-to-significant increase was found in the Air-3 condition ($t(21) = -2.068$, $p = 0.051$). Non-significant increases in PTP were found in the Voice rest ($t(25) = -0.540$, $p = 0.594$) and Water-5 ($t(25) = -1.516$, $p = 0.142$) conditions. Slight decreases were found in the Air-1 ($t(24) = 0.916$, $p = 0.369$), Water-1 ($t(22) = 0.574$, $p = 0.572$) and Water-3 ($t(23) = 0.255$, $p = 0.801$) conditions and such decreases were statistically non-significant.

[put Table I here]

[put Table II here]

[put Figure 2 here]

In the Pre-treatment-Post-fatigue comparisons, consistent increases in PTP were found across all treatment conditions. However, only Voice rest ($t(25) = -2.948$, $p = 0.007$), Air-3 ($t(21) =$

-2.211, $p = 0.038$) and Air-5 ($t(25) = -4.121$, $p < 0.001$) conditions had statistically significant increases. Water-1 condition had the least increase from Pre-treatment ($M = 2.610\text{cmH}_2\text{O}$, $SD = 1.252$) to Post-fatigue ($M = 2.622\text{cmH}_2\text{O}$, $SD = 0.985$) in PTP ($t(22) = -0.075$, $p = 0.941$).

Perceived VF (PVF): the secondary outcome measure

Table III and Figure 3 summarize the data from descriptive statistics and Table IV summarizes the inferential statistical data of PVF.

[put Table III here]

[put Table IV here]

[put Figure 3 here]

In the Pre-treatment-Post-treatment comparisons, decreases in PVF were found in the conditions of Voice rest, Air-1 and Water-3. However, only the decrease in the Voice rest condition was statistically significant ($t\ (25) = 2.345$, $p = 0.027$) and decreases in the conditions of Air-1 ($t\ (25) = 0.943$, $p = 0.355$) and Water-3 ($t\ (25) = 0.427$, $p = 0.673$) were non-significant. Increases in the same comparisons was found the Air-3, Air-5, Water-1, and Water-5 conditions. Significant increases were only found in the Air-3 ($t\ (25) = -2.492$, $p = 0.020$) and Water-5 conductions ($t\ (25) = -2.163$, $p = 0.040$), whereas non-significant increases were found in the Air-5 ($t\ (25) = -1.010$, $p = 0.322$) and Water-1 ($t\ (25) = -1.367$, $p = 0.184$) conditions.

All Pre-treatment-Post-fatigue comparisons in PVF showed significant increases across all treatment conditions ($p < 0.001$). Voice rest resulted in the greatest increase in PVF among all conditions (Pre-treatment: $M = 9.35$, $SD = 10.729$; Post-fatigue: $M = 28.31$, $SD = 14.416$).

Discussion

PTP

PTP indicates phonatory efficiency and also the extent of VF of an individual (Boucher & Ayad, 2010; Chang & Karnell, 2004; Milbrath & Solomon, 2003; Titze, 2006). The preventive effects of each treatment conditions were studied by reviewing the change in PTP from the Pre-treatment time point. When looking at the pattern of PTP change, it was surprising to find deteriorated, instead of improved, phonatory efficiency as a result of straw phonation in four out of the seven treatment conditions (i.e. Air-1, Air3, Air-5 and Water-5). The post-treatment deterioration in the Air-5 condition was even found to be statistically significant and that in Air-3 was found to be close-to-significant. As the subjects were naïve to straw phonation, these conditions may be unfavourable for them to improve impedance matching between glottis and vocal tract, especially without the sensation of back pressure created by the water pressure (Titze, 2006). These "doses" of straw phonation (i.e. Air-3 and Air-5) may even be considered VF-inducing and are not recommended, especially for persons who are amateur in practicing straw phonation.

Deteriorations in phonatory efficiency were found in the Pre-treatment-Post-fatigue comparisons across all treatment conditions. Deteriorations were statistically significant in the Voice rest, Air-3 and Air-5 conditions. The Voice rest condition resembled the "conventional treatment" for VF prevention adopted by untrained voice users and laypersons. Significant deteriorations in the Voice rest condition, however, indicated that VF prevention as measured by PTP could not be achieved simply by preserving and hydrating one's voice, and the read-aloud task adopted in the present study was capable of inducing VF. Moreover, straw phonation that ends in air for three (Air-3) and five minutes (Air-5) were not only inefficacious in VF prevention as measured by PTP, but also VF-inducing. This further confirmed that those two doses should not be recommended for VF prevention.

The Pre-treatment-Post-fatigue PTP increases were non-significant in the Air-1, Water-1, Water-3 and Water-5 conditions. The phonatory efficiency was therefore considered maintained in these conditions, despite the 90-minute VF-inducing task. The four treatment conditions were capable of preventing VF as measured by PTP and they were superior to voice rest (with hydration) for 15 minutes in this regard. The least PTP increase was found in the Water-1 condition. To sum up, the Water-1 condition 1) exhibited a slight Pre-treatment-Post-treatment improvement in PTP, 2) required the least amount of time, and 3) exhibited the least post-fatigue deterioration in PTP. Therefore, straw phonation into water (with a depth of 5cm) for one minute may be considered as the optimal dose, among those studied in the present study, for VF prevention as measured by PTP.

PVF

The self-reported PVF score is reflective of the severity of VF, which is believed to be identified by a set of relevant symptoms (Nanjundeswaran et al., 2015), from the subjects' perspective. Among the seven treatment conditions, the only significant Pre-treatment-Post-treatment improvement was observed in the Voice rest condition. Voice rest for 15 minutes with hydration was able to alleviate VF symptoms originated from daily vocal demand that had occurred before their visit, although the visits were not scheduled at about the same time of the day. Furthermore, as the subjects were required to rate the self-perceived severity on a list of VF symptoms and those symptoms would typically improve with rest (Kitch & Oates, 1994; Nanjundeswaran et al., 2015; Solomon, 2008), it was not surprising that the PVF measure was sensitive to the changes occurred in the Voice rest condition. The significant

Pre-treatment-Post-treatment deterioration in PVF in the Air-3 and Water-5 conditions, on the other hand, suggested that these two doses of straw phonation may be VF-inducing, even from the subjects' perspective.

Significant Post-fatigue increases in PVF were found in all treatment conditions, suggesting voice rest and all doses of straw phonation failed to prevent deterioration in VF from the subjects' perspective. Despite the significant Pre-treatment-Post-treatment improvement mentioned above, Voice rest condition exhibited the greatest Post-fatigue deterioration. In other words, although voice rest with hydration are frequently employed by voice users in relation to VF, it has the least preventive effect when compared with straw phonation. Future studies that allow across-treatment condition comparisons is warranted to confirm this.

It is noteworthy that there are mismatches between the findings obtained from the two outcome measures. PTP and PVF respectively measure the behaviourally observed phenomena and self-perceived phenomena occurred in the event of VF (McCabe & Titze, 2002). Although the two phenomena are expected to be correlated (Chang & Karnell, 2004), there are evidence showing that VF perceived by voice users does not necessarily align with the physiological changes involved (Solomon & DiMattia, 2000; Verdolini, Titze, & Fennel, 1994). Subjects' PVF ratings were not specific to the PTP task but corresponded to their general perception of VF at individual timepoints (Solomon, Glaze, Arnold, & Van Mersbergen, 2003). This may also account for the mismatch between the PTP and PVF findings. Considering that the questionnaire used was not validated and also the subjectivity of PVF measure, examination of the preventive treatment effect was based primarily upon PTP, which is proved to be indicative of phonatory efficiency and thus the biomechanical vocal fold viscosity and extent of VF (McCabe & Titze, 2002).

VF prevention and clinical implications

The purpose of the present study was to investigate the efficacy of different doses of straw phonation for VF prevention. Certain doses of straw phonation were capable of preventing phonatory efficiency from deteriorating upon induced VF (Research question #1). When subjects were instructed to exercise straw phonation into air for one minute, into water for one, three and five minutes before a 90-minute VF-inducing task, their PTPs were maintained despite the prolonged period of loud reading. Such maintenance was not observed when no preventive straw phonation was exercised (i.e. the Voice rest condition). Further, straw phonation into water that was 5-cm in depth for one minute (Water-1) is considered the optimal dose being studied (Research question #2). It was because 1) this dose had exhibited a preventive effect for vocal fatigue; 2) its preventive effect was considered the most prominent as the least post-fatigue deterioration in PTP was observed; and 3) the least amount of time was required for this straw phonation dose.

Findings from the present study carry several potential significant implications. The optimal dose of straw phonation found had laid the ground work for upcoming clinical trials in the next phase. It was found that straw phonation is an easy-to-acquire clinical technique, as only minimal training was required for the participants even if they are amateur to this technique. This is of clinical significance as individuals who are vulnerable to VF, for instance local school teachers and other occupational voice users, often do not have the opportunity to receive formal and extensive training just for the sake of VF “prevention”. The short duration of the optimally-dosed straw phonation exercise (i.e. one minute) is also considered practically feasible for occupational voice users to incorporate it into their daily routine, such that the preventive effect against VF may be maximized.

Limitations and recommendations

The hydration levels of individual subjects were not controlled, despite that there are evidence suggesting PTP may be affected by hydration level of the vocal fold mucosa (Leydon, Wroblewski, Eichorn, & Mahalakshmi, 2010; Solomon & DiMattia, 2000; Verdolini-Marston, Titze, & Druker, 1990). To minimize confounding factors due to inconsistent hydration level, it is recommended to control for the amount of water intake prior to visit in future studies. Subjects may also be scheduled to visit the experimental site at about the same time of the day so as to control for pre-visit VF level. Although the questionnaire adopted for PVF measurement included a number of symptoms that are associated to VF, the list may not be exhaustive and the questionnaire was not validated. Such limitations may account for the mismatch between findings obtained from the primary and secondary outcome measures. A validated measurement tool, for instance a culturally adapted Hong Kong version of the Vocal Fatigue Index (Nanjundeswaran et al., 2015), is therefore recommended to measure the extent of VF from the participants' perspective in future studies. Furthermore, the design of the present study did not allow direct comparisons among treatment conditions, especially those against voice rest with hydration. A randomized controlled clinical trial on the population who are highly vulnerable to VF (e.g. local school teacher) is recommended to provide higher-levelled evidence and to confirm the preventive effect of the optimal dose of straw phonation determined from the present study.

Conclusion

The present study was the first to date that directly investigated the preventive effect of an SOVT exercise for VF. Four of the straw phonation doses studied were capable of preventing VF from deteriorating as measured by PTP. Specifically, straw phonation into water of a depth of 5cm for one minute was considered the optimal dose for VF prevention. Findings from the present study provide basis for the upcoming randomized controlled trials of VF prevention in the populations that are vulnerable to VF.

Acknowledgments

This work is supported by the Dean's reserve Start-up Fund (Ref: BE20), The Hong Kong Polytechnic University. The author would also like to express gratitude to Hiu Tong Yuen, Natalie Yeung, and Janice Chu for their effort in the data collection and extraction processes.

Declaration of interest statements

There are no financial conflicts of interest to disclose.

References

Boucher, V. J., & Ayad, T. (2010). Physiological attributes of vocal fatigue and their acoustic effects: a synthesis of findings for a criterion-based prevention of acquired voice disorders. *Journal of voice, 24*(3), 324-336. doi:10.1016/j.jvoice.2008.10.001

Chang, A., & Karnell, M. P. (2004). Perceived phonatory effort and phonation threshold pressure across a prolonged voice loading task: a study of vocal fatigue. *Journal of voice, 18*(4), 454-466. doi:10.1016/j.jvoice.2004.01.004

Conroy, E. R., Hennick, T. M., Awan, S. N., Hoffman, M. R., Smith, B. L., & Jiang, J. J. (2014). Effect of variations to a simulated system of straw phonation therapy on aerodynamic parameters using excised canine larynges. *Journal of voice, 28*(1), 1-6. doi:10.1016/j.jvoice.2013.08.004

Duke, E., Plexico, L. W., Sandage, M. J., & Hoch, M. (2015). The effect of traditional singing warm-up versus semioccluded vocal tract exercises on the acoustic parameters of singing voice. *Journal of voice, 29*(6), 727-732. doi:10.1016/j.jvoice.2014.12.009

Elliot, N., Sundberg, J., & Gramming, P. (1995). What happens during vocal warm-up? *Journal of voice, 9*(1), 37-44. doi:10.1016/s0892-1997(05)80221-8

Gotaas, C., & Starr, C. D. (1993). Vocal fatigue among teachers. *Folia Phoniatrica et Logopaedica, 45*(3), 120-129. doi:10.1159/000266237

Guzman, M., Angulo, M., Muñoz, D., & Mayerhoff, R. (2013). Effect on long-term average spectrum of pop singers' vocal warm-up with vocal function exercises. *International journal of speech-language pathology, 15*(2), 127-135. doi:10.3109/17549507.2012.702283

Guzman, M., Castro, C., Madrid, S., Olavarria, C., Leiva, M., Muñoz, D., Laukkanen, A.-M. (2016). Air pressure and contact quotient measures during different semioccluded postures in subjects with different voice conditions. *Journal of voice, 30*(6), 759. e751-759. e710. doi:10.1016/j.jvoice.2015.09.010

Guzman, M., Laukkanen, A.-M., Krupa, P., Horáček, J., Švec, J. G., & Geneid, A. (2013). Vocal Tract and Glottal Function During and After Vocal Exercising With Resonance Tube and Straw. *Journal of voice, 27*(4), 523.e519-523.e534. doi:10.1016/j.jvoice.2013.02.007

Hertegård, S. , Gauffin, J., Lindestad, P. (1995) A comparison of subglottal and intraoral pressure measurements during phonation. J*ournal of Voice*, 9(2), 149-155.

Kitch, J. A., & Oates, J. (1994). The perceptual features of vocal fatigue as self-reported by a group of actors and singers. *Journal of voice, 8*(3), 207-214. doi:10.1016/s0892-1997(05)80291-7

Koufman, J. A., & Blalock, P. D. (1988). Vocal fatigue and dysphonia in the professional voice user: Bogart-Bacall syndrome. *The Laryngoscope, 98*(5), 493-498. doi:10.1288/00005537-198805000-00003

Leydon, C., Wroblewski, M., Eichorn, N., & Mahalakshmi, S. (2010). A Meta-Analysis of Outcomes of Hydration Intervention on Phonation Threshold Pressure. *Journal of voice, 24*(6), 637-643.

Mattiske, J. A., Oates, J. M., & Greenwood, K. M. (1998). Vocal problems among teachers: a review of prevalence, causes, prevention, and treatment. *Journal of voice, 12*(4), 489-499. doi:10.1016/s0892-1997(98)80058-1

McCabe, D. J., & Titze, I. R. (2002). Chant therapy for treating vocal fatigue among public school teachers. *American Journal of Speech-Language Pathology*. doi:10.1044/1058-0360(2002/040)

Milbrath, R. L., & Solomon, N. P. (2003). Do vocal warm-up exercises alleviate vocal fatigue? *Journal of Speech, Language, and Hearing Research*. doi:10.1044/1092-4388(2003/035)

Mills, R. D., Rivedal, S., DeMorett, C., Maples, G., & Jiang, J. J. (2018). Effects of straw phonation through tubes of varied lengths on sustained vowels in normal-voiced participants. *Journal of voice, 32*(3), 386. e321-386. e329. doi:10.1016/j.jvoice.2017.05.015

Nanjundeswaran, C., Jacobson, B. H., Gartner-Schmidt, J., & Verdolini-Abbott, K (2015). Vocal Fatigue Index (VFI): development and validation. *Journal of voice, 29*(4), 433-440. doi:10.1016/j.jvoice.2014.09.012

Portillo, M. P., Rojas, S., Guzman, M., & Quezada, C. (2018). Comparison of effects produced by physiological versus traditional vocal warm-up in contemporary commercial music singers. *Journal of voice, 32*(2), 200-208. doi:10.1016/j.jvoice.2017.03.022

Schutte, H. (1984). Efficiency of Professional Singing Voices in Terms of Energy Ratio. *Folia phoniatrica 36*, 267-272.

Smitheran, J. R., & Hixon, T. J. (1981). A clinical method for estimating laryngeal airway resistance during vowel production. *Journal of Speech and Hearing Disorders, 46*(2), 138-146. doi:10.1044/jshd.4602.138

Solomon, N. P. (2008). Vocal fatigue and its relation to vocal hyperfunction. *International journal of speech-language pathology, 10*(4), 254-266. doi:10.1080/14417040701730990

Solomon, N. P., & DiMattia, M. S. (2000). Effects of a vocally fatiguing task and systemic hydration on phonation threshold pressure. *Journal of voice, 14*(3), 341-362. doi:10.1016/s0892-1997(00)80080-6

Titze, I. R. (1994). *Principles of voice production*. Englewood Cliffs, NJ: Prentice Hall.

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*. doi:10.1044/1092-4388(2006/035)

Titze, I. R. (2009). Phonation threshold pressure measurement with a semi-occluded vocal tract. *Journal of Speech, Language, and Hearing Research*. doi:10.1044/1092-4388(2009/08-0110)

Verdolini, K., Druker, D. G., Palmer, P. M., & Samawi, H. (1999). Laryngeal adduction in resonant voice. *Journal of voice, 12*(3), 315-327.

Verdolini, K., Titze, I. R., & Fennel, A. (1994). Dependence of Phonatory Effort on Hydration Level. *Journal of Speech and Hearing Research, 37*, 1001-1007.

Verdolini-Marston, K., Titze, I. R., & Druker, D. G. (1990). Changes in phonation threshold pressure with induced conditions of hydration. *Journal of voice, 4*(2), 142-151.

Welham, N. V., & Maclagan, M. A. (2003). Vocal fatigue: current knowledge and future directions. *Journal of voice, 17*(1), 21-30. doi:10.1016/s0892-1997(03)00033-x