Vocal Fold Adjustment Caused by Phonation Into a Tube: A Double-Case Study Using Computed Tomography

*Vít Hampala, †Anne-Maria Laukkanen, ‡Marco A. Guzman, §Jaromír Horáček, and *,||Jan G. Švec, *Olomouc and §||Prague, Czech Republic, †‡Santiago, Chile

Summary: Objectives. Phonation into a tube is a widely used method for vocal training and therapy. Previous studies and practical experience show that the phonation becomes easier and louder after such an exercise. The purpose of this study was to find out whether there are systematic changes in the vocal fold adjustment after the exercise.

Methods. Two volunteer subjects (1 male and 1 female) without voice disorders were examined with computed tomography (CT). Both produced a sustained vowel [a:] at comfortable pitch and loudness before and after the tube phonation and a vowel-like phonation into the tube. Computed tomography (CT) scans were obtained before, during, and after the exercise, twice for each condition. The gathered CT images were used for measurements of vertical vocal fold thickness, bulkiness, length, and glottal width.

Results. No prominent trends common to both subjects were found in vocal fold adjustment during and after the phonation into the tube. Variability observed under the same conditions was usually of the same magnitude as the changes before and after the tube phonation.

Conclusions. Changes in vocal tract configuration observed after the resonance tube exercises in previous related studies were more prominent than the changes in vocal fold configuration observed here.

Key Words: Vocal folds–Resonance tube–Computed tomography.

INTRODUCTION

Phonation into a tube is a useful method widely used for vocal training and therapy. It belongs to a wider group of semi-occluded vocal exercises that take advantage of a semi- or full closure of the vocal tract.[1] Other commonly used exercises of this type are tongue trills, nasals, and voiced fricatives.[2] Humming into various small glass tubes started to be used in the beginning of 20th century by Spiess[3] for improving vocal function. Tube phonation has been used, for example, for treatment of hypernasality.[4,5] Method of phonation into glass tubes, so called resonance tubes, has also been used for decades in Finnish voice and speech training and therapy where it has become popular.[6,7] Sovijärvi[8] was at first interested in testing different kinds of glass tubes in the children with hypernasality, but soon he started to use the tubes also with adult singers who had voice problems. According to his observations, phonation into the tubes improved voice quality of the patients with functional phonasthenia, laryngeal paresis, and vocal fold nodules.[6,9] This method has also been used for vocal care and further vocal training in healthy and normophonic subjects using their voice extensively (ie, singers or teachers) because the voice is perceived as being louder and feels to be easier to produce after such an exercise.[7]

Laukkanen et al[10] showed that sound pressure level (SPL) slightly increased after the tube phonation. This was also observed by Vampola et al[11] who calculated SPL values using finite element modeling method. Despite number of studies published about resonance tubes, the exact mechanism of their functioning has not been fully understood. Basically, there are three possibilities of adjustment caused by the exercises, such as (1) change in the voice source (vocal folds), (2) change in the vocal tract (filter), and (3) change caused by the interaction between the voice source and the filter.

To investigate the *changes in the voice source*, Laukkanen[12] analyzed electroglottographic signals of vibrating vocal folds and showed that the quasi-open quotient decreased during and after the exercise, which was possibly related to change in adduction of vocal folds. Speed quotient rose indicating more rapid collisions of the vocal folds. Furthermore, Laukkanen et al[7] studied muscle activities in a single female subject via electromyography (EMG) and found that the ratio of thyroarytenoid (TA) versus cricothyroid muscle activity increased. According to Hirano[13] and Yumoto et al,[14] increased activity of TA muscle makes the vocal fold thicker and bulged. In addition, according to Chhetri et al[15] who investigated neuromuscular mechanisms for modulating glottal posture in canine larynx, TA activation has been shown to close the mid-membranous glottis. So far, however, there has not been any conclusive evidence of specific consistent changes in vocal fold adjustments caused by the semi-occluded voice exercises.

Changes in the vocal tract and size of its cavities caused by the resonance tube exercise were examined by Vampola et al.[16] The study reported that the velum raised and closed the nasopharyngeal port. In addition, cross-sectional areas of vocal tract (nasal cavities excluded) expanded and its total volume became

Accepted for publication October 9, 2014.
This study was presented at the 10th Pan European Voice Conference PEVOC; August 21–24, 2013; Prague, Czech Republic.
From the *Department of Biophysics, Faculty of Science, Voice Research Lab, Palacky University, Olomouc, Czech Republic; †Department of Communication Sciences and Disorders, University of Chile, Santiago, Chile; ‡Department of Otolaryngology, Las Condes Clinic, Santiago, Chile; §Department of Dynamics and Vibrations, Institute of Thermomechanics, Academy of Sciences of the Czech Republic, Prague, Czech Republic; and the ||Voice Centre Prague, Medical Healthcom, Ltd., Prague, Czech Republic.
Address correspondence and reprint requests to Vít Hampala, Department of Biophysics, Faculty of Science, Voice Research Lab, Palacky University, Olomouc, 17. listopadu 12, 77146 Olomouc, Czech Republic. E-mail: vit.hampala@upol.cz
Journal of Voice, Vol. 29, No. 6, pp. 733-742
0892-1997/$36.00

http://dx.doi.org/10.1016/j.jvoice.2014.10.022

considerably larger. Similar results have been reported by Guzman et al.[17]

Interaction between the voice source and the filter has been found to be able to change the vibration properties of the vocal folds solely owing to the changes in the supraglottal tract.[18,19] The use of the resonance tube creates a constriction and this reduction of cross-sectional area increases the vocal tract resistance. Simultaneously, the tube elongates the vocal tract causing the first formant frequency to go down.[20] This increases the inertive reactance of the vocal tract resulting in an increased source-filter interaction.[2] The resonance tube also increases supraglottal pressure that tends to decrease transglottal pressure (ie, the difference between the subglottal pressure and the supraglottic pressure).[1,5] Sufficiently low transglottal pressure makes phonation more economical in terms of preserving the vocal folds from powerful collisions and provides a sensation of maximal outcome achieved with minimal effort.[2,5]

In 1960s, Hollien et al[21–26] published an original methodology for measurement of vocal fold anatomical dimensions *in vivo* using X-ray laminagrams. The contours of the laryngeal tract and vocal folds were outlined in the X-ray images and a system of lines and points was designed to measure the length, thickness, and surface tilting of the vocal folds related to changes in fundamental frequency (F_0). Present study applies the methodology of Hollien et al[21–26] to the modern examination method of computed tomography (CT) imaging (Methods section). The purpose of this study was to find out whether there are systematic changes in the vocal fold adjustment caused by the phonation into a tube. To do that, vocal fold geometry before, during, and after the phonation into the resonance tube was measured and compared.

Based on the studies of Laukkanen et al,[7] who observed increased activity of TA muscle after the tube phonation, the following three hypotheses were formulated and investigated here: (1) the vocal folds are going to be more bulged and thicker, (2) the glottal width is going to decrease, and (3) the length of the vocal folds is not going to change. The first two hypotheses stem from the knowledge on the effect of the TA activity: The TA muscle has been shown to bulge the vocal fold[13] and to shift the vocal fold margin more medially.[13,14] The third hypothesis considers that the phonations before and after the tube phonation are both requested to be produced at comfortable pitch, thus not requiring considerable vocal fold length adjustments.

MATERIALS AND METHODS

Subjects and CT recordings

Two vocally healthy subjects were investigated: subject F—a female, aged 48 years, and co-author A.M.L. and subject M—a male, aged 35 years, and co-author M.A.G. Both subjects had no voice or hearing problems and were experienced in semi-occluded exercises. The subjects were informed about potential risks related to the radiation dose during CT examination and signed a consent form. The recordings were performed at two different occasions using a CT device (Light Speed VCT GE–64 and Toshiba Aquilion). The subjects were placed in supine position. The recording time for subject F was 2 seconds. During this time, 181 images with the resolution of 512 × 512 pixels were collected. The thickness of each slice was 0.625 mm. For subject M, the recording time was 3.36 seconds yielding 510 images with the resolution of 512 × 512 pixels and slice thickness of 0.5 mm. For both subjects, the scanning covered an area from below the larynx up to the bottom of nasal cavities.

Phonatory tasks and CT measurements

The subjects were asked to produce a sustained vowel [a:] at a comfortable pitch and loudness before and after phonating into the resonance tube. The resonance tube training exercise was performed for about 5 minutes into 27-cm long resonance tube (glass) with the inner and outer diameters of 8 and 9 mm. The duration of 5 minutes was previously found long enough for sensing the changes in voice production and causing clear changes in the vocal tract configuration after the exercise.[16,17] To investigate the variability of the glottal configuration during the individual phonations, the CT scanning was performed twice before, twice during, and twice after the phonation into the tube. The freely downloadable software *OsiriX* (version 3.9.4, 32-bit; Osirix, Pixmeo, Switzerland)[27] was used for setting the planes to the desired position and for inserting a calibrated distance line into the image. For further analysis, the gathered images were exported and processed with the *ImageJ* 1.45s software (National Institutes of Health, Maryland, USA), which provided an environment for the final measurements of lengths, thicknesses, and areas, using the calibrated distance line.

To measure the relevant lengths of the vocal folds, it was necessary to set the transverse plane (Figure 1A) to be parallel to the upper surface of both vocal folds (Figure 1B). Then, the transverse plane was shifted to reach the level of glottis (Figure 2) similar to the one as shown by Hirano in a collection

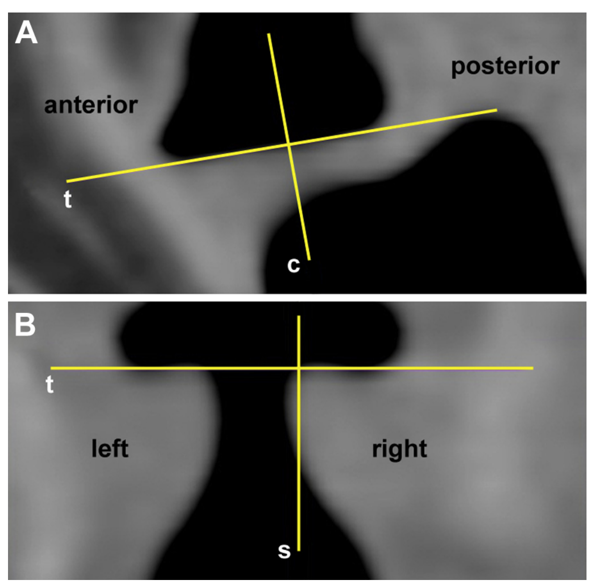

FIGURE 1. The sagittal (**A**) and coronal (**B**) slices demonstrating how the transverse plane was adjusted to be parallel to the upper surface of the vocal folds: t, transverse plane; c, coronal plane; s, sagittal plane.