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The effect of resonance tubes on facial and laryngeal vibration – A case study

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ABSTRACT

The effects of resonant tubes of different lengths and diameters were measured by means of accelerometers placed on the subject's larynx, forehead and cheek. The electroglottographic (EGG) and acoustical signals were also recorded. The aim of the study was to find the frequency at which the resonance tubes have maximal effect and to find, based on the analysis of the measured signals, the experimental method for the estimation of the resonance frequencies of the elongated vocal tract. The measured data were compared with transmission line modeling (TLM) and the yielding wall model (YWM). Our results show a better fit with the YWM modeled data than with TLM. The experimental data reveal two important kinds of measured maxima which can be identified as the maximum efficiency of the extended vocal tract (the maximum laryngeal vibration) and the correlation coefficient maximum (CCM) between laryngeal vibration and the EGG signal, that we assume to be above the resonance frequency of the extended vocal tract. The vibrational maximum frequency always lies below the CCM and their relative position does not differ by more than 25 Hz.

1. Introduction

Semi-occlusion or significant narrowing of the vocal tract together with the extension of the vocal tract using resonance tubes is a method often applied in vocal pedagogy and therapy. This method is known as semi-occluded vocal tract (SOVT) exercises.

Apart from resonance tubes, SOVT exercises can also include the LaxVox methods, use of straws, lip and tongue trills, voiced bilabial fricatives and plosives [v:, b:], hand-over-mouth, brumendo (humming) and their combinations [1–3]. These methods increase source-filter interaction by means of a resonant effect.

The effect of vocal tract and vocal fold vibration interaction has been described theoretically in several sources [3–5]. The effect is based on facilitating the vocal folds' self-oscillation by vocal tract resonance.

Under normal conditions, the resonant frequencies of the vocal tract, typically expressed by the position of formant frequencies (F1-F4), are very distant from the fundamental frequency of vocal fold vibration. Prolongation (via a tube or pursing the lips) and the constriction of the vocal tract cause increased vocal tract impedance. As a result there is a significant reduction in the first formant frequency, which enters the frequency range of deep harmonics with which it interacts [6].

Setting the position of the fundamental frequency or some of the first harmonics just below the frequency of the first formant helps the vocal cords to move and the air to flow through the glottis. Inertive reactance is the most significant component of the feedback on the vocal fold vibration. The phase relations of acoustic pressure and airflow through the glottis are in such a state when the vocal fold oscillations are most enhanced.

Increasing the inertive reactance of the system results in a significant reduction of the phonation threshold pressure (PTP) [7], which corresponds to easier glottal vibration at a lower pressure. In addition, the intra-oral pressure increases. Model [8] shows how the mouth pressure increases up to three-times its the natural value just behind the lips when the resonance tube is used. Increased oral pressure results in an accentuation of the facial vibration sensation.

Nonlinear source-filter coupling is theoretically described in [9]. Interaction based on positive (inertive) vocal tract reactance skews the glottal flow pulse to the right; this produces new harmonics in the source spectra and raises the overall harmonic energy. Nonlinear interaction shows that collision of vocal folds (mainly near the glottal closing) is not essential for the production of source harmonics. The effect of nonlinear formant-harmonic coupling in the glottal flow is to distribute the acoustic energy over the entire spectrum rather than to accentuate it at the center of a formant.

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Table 1
The length and the inner diameter of the resonance tubes used in the experiment.

Diameter (mm)	Length (cm)				
14			60		
12	80	70	60	50	40
10			60	50	40
8			60	50	

The combination of compliant (negative) subglottal reactance and inertive (positive) supraglottal reactance provides the ideal reinforcement to vocal fold vibration in the modal register. Other effects of source-filter interaction when the dominant harmonics are close to formants are frequency jumps and instabilities such as subharmonics and non-random noise.

The effect of resonance tubes has also been monitored by means of electroglotography, where their influence on the contact quotient (CQ) of the vocal folds was assumed. Experimental studies have not demonstrated that SOVT has a consistent influence on the CQ yet. According to Gaskill and Ericsson [10] the effect was present with each subject, but the general trend (increasing or decreasing) could not be proven statistically. Singers have demonstrated the effect of SOVT on increasing CQ, flow, and SPL [2]. Study [1] divided SOVT exercises into two groups, measuring the CQ and the difference of F1-F0. The first group (named steady or single source) reduced the CQ and F1-F0 difference. This group included hand-over-mouth, humming, and straw exercises. The second group (fluctuating or dual source) resulted in greater variability of the CQ and F1-F0 difference. This group involved tongue and lip trills and LaxVox exercises.

The value of the estimated F1 frequency significantly varies in the literature [7,11–13]. There is still no simple and recognized method of measuring this parameter when resonance tubes are used. The influence of the tube length and diameter on the flow and pressure properties during the exercise has been discussed recently [14] without any clear therapeutic recommendation for specific targeted purposes.

The main goal of the present study is to measure the effect of resonance tube parameters (their length and diameter) on the vibration properties of the larynx, cheek and forehead surface and on intraoral pressure.

The study's secondary aim is to determine the relationship between the measured signals and to find a method suitable for measuring experimentally the maximal effect of resonance tube exercises on the vocal fold vibration properties.

2. Material and methods

2.1. Theoretical part

Resonance frequencies for extended vocal tracts were modeled by two different methods. The first was the usual one dimensional transmission line modeling (TLM) [15], which deals with the vocal tract as if it were a set of cylindrical tubes, taking thermoviscous losses into account, but assuming the walls to be solid. The second approach was introduced by Radolf et al. [16]. A simplified

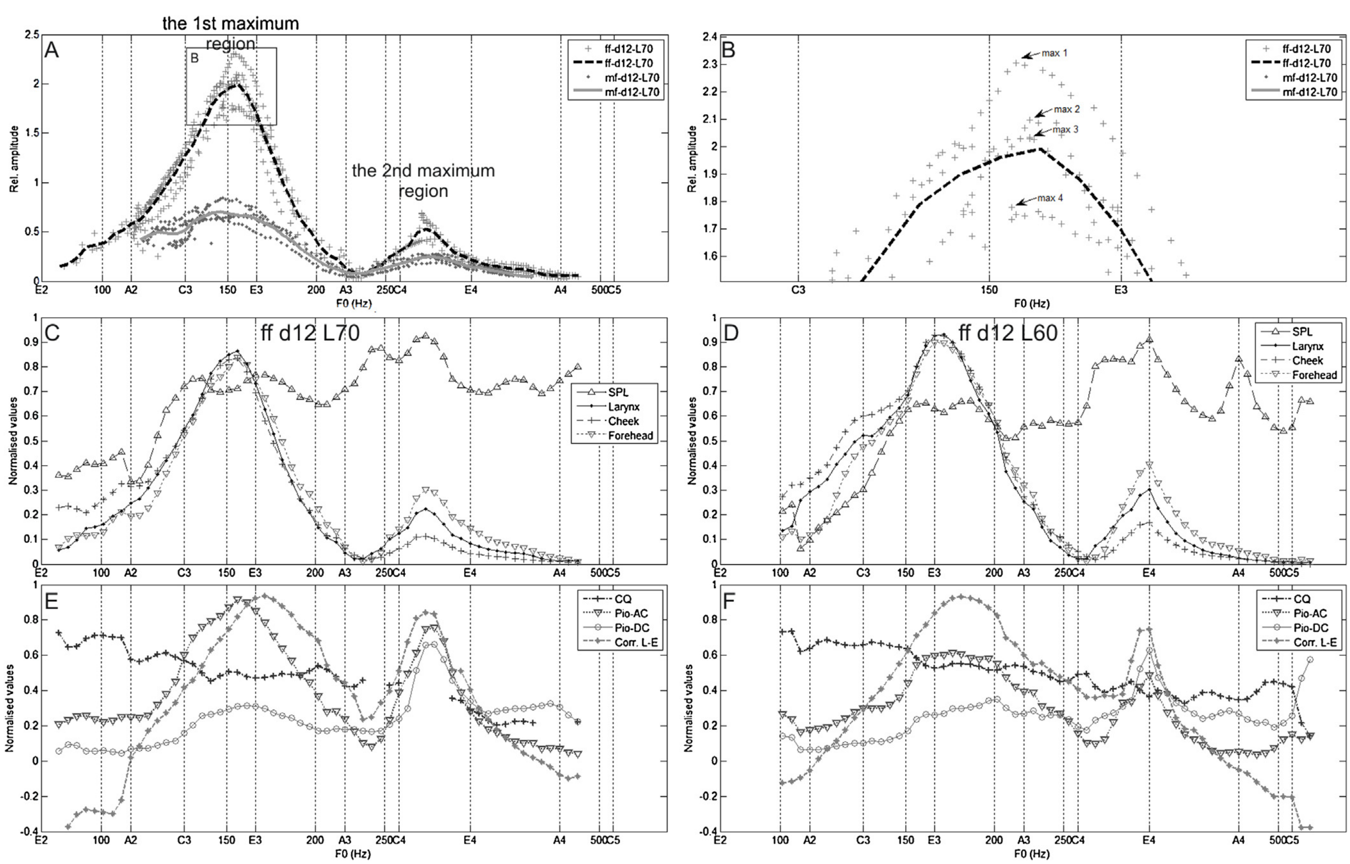

Fig. 1. A) Relative larynx amplitude as a function of fundamental frequency during glissando utterance in mezzo forte and forte dynamics, respectively. The averaged amplitudes for four utterances for mf and ff dynamics are displayed with dashed and solid lines, respectively. B) Detail of the first maximum amplitude region in ff dynamics, arrows show the measured maxima; a dashed line depicts the averaged amplitude value for the given fundamental frequency. Averaged values normalized to measured maximum value of SPL, laryngeal, cheek, and forehead vibration amplitude, respectively: C) for 70 and D) for 60 cm long RT with diameter 12 mm. Averaged normalized values of measured intra-oral pressure (Pio) AC part and DC part, and correlation coefficient between laryngeal vibration and EGG signals (Corr L-E) E) for 70 and F) for 60 cm long RT with diameter 12 mm.

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