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IN VIVO MEASUREMENTS OF AIR PRESSURE, VOCAL FOLDS VIBRATION AND ACOUSTIC CHARACTERISTICS OF PHONATION INTO A STRAW AND A RESONANCE TUBE USED IN VOCAL EXERCISING

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Abstract: *The study investigates the differences between three most widely used methods in voice training and therapy: Phonation into a glass resonance tube (1) the outer end in the air, (2) the outer end submerged 2-10 cm below water surface in a bowl ('water resistance therapy' with bubbling effect), and (3) phonation into a very thin straw. One female speech trainer served as subject. Acoustic samples, electroglottographic signals and both mean and dynamic airpressures in the mouth cavity were registered for repetitions of [pu:pu], and for phonation into the tubes, while the outer end was randomly shuttered, in order to get an estimate of subglottic pressure. Both phonation threshold and ordinary, most comfortable phonation were recorded.*

Keywords: ***Biomechanics of voice; subglottal, oral and transglottal pressure; phonation into tubes.***

1. Introduction

Phonation into straws and tubes is widely used in vocal exercising and voice therapy (see e.g. Titze et al., 2002). In Scandinavia a resonance tube and water resistance therapy methods have been used (see Simberg & Laine, 2007). Phonation into a resonance tube (25-28 cm in length, 8 mm inner diameter, made of glass) in air has been used for voice training of normal voiced subjects to improve loudness and voice quality in an effortless way. Phonation into resonance tube either 2 cm or down to 10 cm under water surface has been used for voice patients to treat both hypofunctional and hyperfunctional voice disorders (Sovijärvi, 1964; Simberg & Laine, 2007). The water bubbling has been regarded to bring along a massage resembling effect which may relax excessive muscle tension and improve fluid circulation in the tissue, and thus offer a possible healing effect. Based on practical observations and research results Titze has recommended phonation into a narrow straw for singers to train respiratory muscles for high subglottic pressures needed in singing and without much collision between the vocal folds. In this way, phonation into a thin straw may also help in finding a falsetto way of reaching high pitches.

Story et al. (2000) have estimated the effects of various vocal tract configurations on the acoustic input impedance of the vocal tract. According to their results F1 lowers with a prolongation or a semi-occlusion or occlusion of the vocal tract. Reactance increases at the fundamental frequency range of speech, which may explain a beneficial experience of using semi-occlusions and phonation into tubes in exercising since higher reactance of the vocal tract lowers phonation threshold pressure and may alter the voice source waveform in such a way that slightly higher SPL and stronger overtones (louder and brighter) voice are obtained (Titze & Story, 1997).

The present study aims to compare the most common tube training methods: resonance tube in air, resonance tube 2 cm under water and 10 cm under water, and stirring straw from the point of view

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of phonation threshold pressure, and subglottal pressure as well as electroglottographic parameters for the most comfortable phonation at habitual speaking pitch.

2. Measurement set-up and measurement procedure

One female voice trainer, phonated (in speech mode) at comfortable pitch on [pu:] both at comfortable loudness and phonation threshold (soft phonation), and into a straw (12.7 cm in length, 2.5 mm in inner diameter) in the air, into a resonance tube (made of glass, 27 cm in length, 6.8 mm in inner diameter) in the air and with the other end submerged 2 cm and 10 cm below water surface in a big bowl - see the measurement schema in Fig. 1.

The sound pressure level (*SPL*) inside the oral cavity was measured using the B&K special microphone probe designed for measurement of acoustic pressure in small cavities, and the mean oral pressure (P_{oral}) was measured by the digital manometer connected with the oral cavity by a small compliant tube. Pressure during [pu:] and manual shuttering of the other end of the tube gave an estimate of subglottic pressure (P_{sub}). The nose was closed with a clip to prevent any leakage of air through the nose. Generated acoustic signal outside the vocal tract model was recorded using the microphone (B&K sound level meter) installed at a distance of 20 cm from the lips. Electroglottographic signal was registered using a dual channel EGG device (Glottal Enterprises). The recording was made using 32.8 kHz sampling frequency by the PC controlled measurement system B&K PULSE 10. The fundamental vibration frequencies *F0* and the formant frequencies (acoustic resonances) were evaluated from the spectra of the pressure signals.

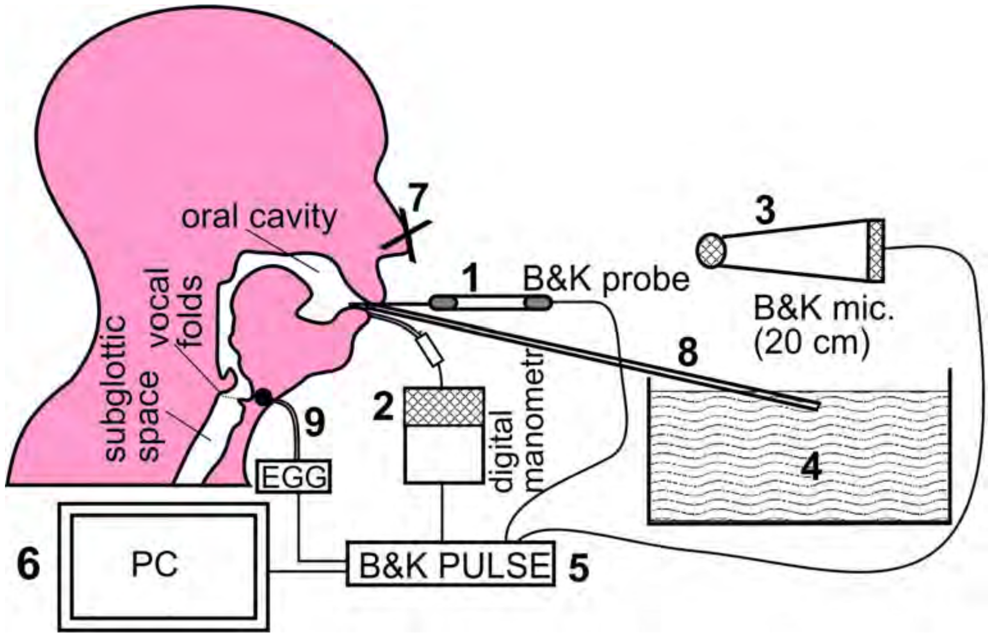

Fig. 1 – Schema of the measurement set up: 1 - B&K microphone probe 4182, 2 – digital manometer Greisinger Electronic GDH07AN, 3 – sound level meter B&K 2239, 4 – aquarium, 5 – B&K measurement system PULSE 10 with Controller Module MPE 7537 A, 6 – personal computer, 7 – clip, 8 – impedance tube, 9 - EGG device Glottal Enterprises.

3. Results

Compared to vowel phonation and the other vocal exercises, phonation into resonance tube in air brought about the lowest **phonation threshold pressure PTP** (P_{sub} = 308 Pa), tube 10 cm under water the highest (1.37 kPa) and straw second highest (915 Pa), see the upper line in Fig. 2 (left) and Tab. 1. The lower PTP for straw than tube 10 cm in water may be due to some over blowing from the lips. The subglottic pressure was lower with tube in air than for vowel [u:] only in the case of soft phonation where both the mean oral pressure and its oscillation (peak-to peak value) were lower. The lower **oral pressure** P_{oral} for tube in air compared to vowel [u:] may be caused by a reduced lip opening during the vowel phonation. Thus a very closed vowel seems to be an effective exercise, increasing oral pressure compared to more open vowels.

Oral pressure oscillation was highest for tube in water (about 270 Pa and 550 Pa peak-to-peak for soft and normal phonation, respectively), which may offer strongest massage effect on the vocal tract and vocal folds. **Transglottal pressure** ($P_{trans} = P_{sub} - P_{oral}$) was larger for all exercises, being largest in those exercises which seem to offer highest supraglottic impedance. Thus, the subject of the present study seems to overcompensate for an increase in oral pressure by increasing P_{sub}

Tab. 1: Mean values of the measured subglottal, oral and transglottal pressures, peak-to-peak values of oral pressures and fundamental frequency for soft phonation on vowel [u:], into the resonance tube in air, into the tube submerged in water and into the narrow straw.

soft phonation	P_{sub} **[Pa]**	P_{oral} **[Pa]**	P_{trans} **[Pa]**	$P_{oral,p\text{-}t\text{-}p}$ **[Pa]**	$F0$ **[Hz]**
[u:]	308	105	203	72	164
tube in air	264	16	248	31	151
tube 2 cm H2O	529	150	379	244	160
tube 10 cm H2O	1370	930	440	273	154
straw in air	915	400	515	118	160

Tab. 2: Mean values of the measured subglottal, oral and transglottal pressures, peak-to-peak values of oral pressures, fundamental frequency and closed quotient for normal phonation on vowel [u:], into the resonance tube in air, into the tube submerged in water and into the narrow straw.

normal phonation	P_{sub} **[Pa]**	P_{oral} **[Pa]**	P_{trans} **[Pa]**	$P_{oral,p\text{-}t\text{-}p}$ **[Pa]**	$F0$ **[Hz]**	CQ_{50}
[pu:]	710	220	490	257	162	0.38
tube in air	746	47	699	429	152	0.42
tube 2 cm H2O	942	240	702	553	151	0.44
tube 10 cm H2O	1480	920	560	551	151	0.49
straw in air	1580	670	910	289	153	0.46

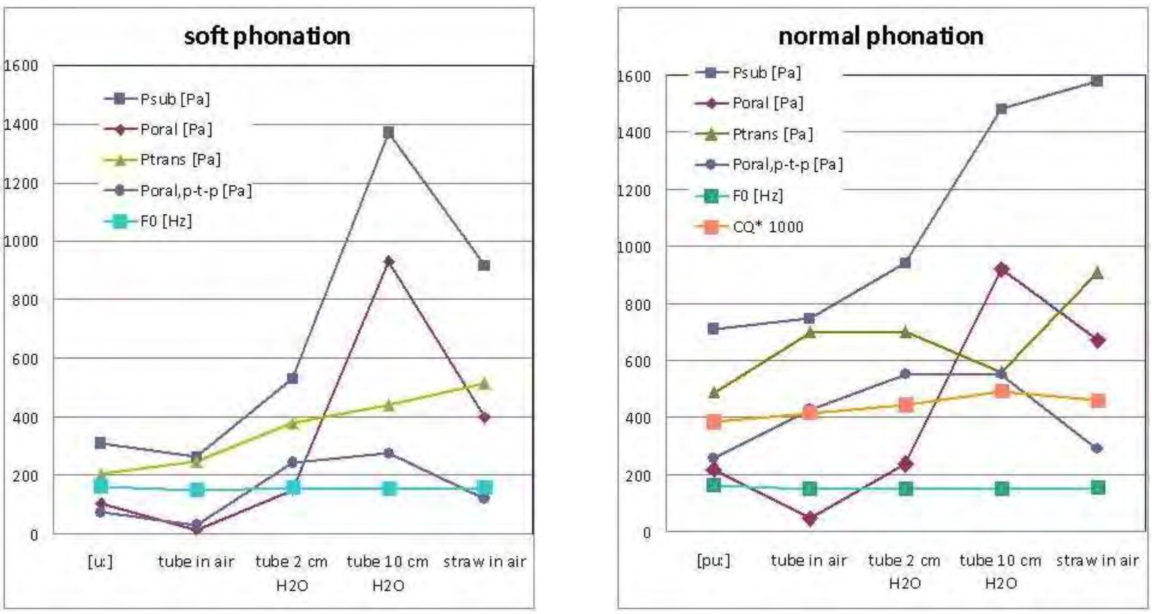

Fig. 2: Measured values for soft phonation (left) and normal phonation (right): Mean values of subglottal, oral and transglottal pressures, peak-to-peak values of oral pressures, fundamental frequency and closed quotient (for normal phonation only) for phonation on vowel [u:], into the resonance tube in air, into the tube submerged in water and into the narrow straw.

In **EGG signal** of the comfortable phonation, the closed quotient *CQ* was higher for the tubes compared to vowel phonation. The largest change was observed for tube 10 cm in water. It could be caused by increased adduction, in order to compensate for increased supraglottic load. It was also possible to see the effect of water bubbling on the EGG signal (see Fig. 3). That causes a baseline shift of the signal, due to variation in vertical laryngeal position caused by water bubbling, at a frequency of 15 Hz and also a decrease in the vocal fold contact. It may be either due to increased intraglottal airpressure or an artefact related to changes in vertical position of the larynx.

The values for tube 10 cm in water with decreased P_{trans} and increased *CQ* (see Fig. 2, right) could be an example of how the semi-occlusions may help the subjects to adjust their adduction in relation to varying transglottal pressure.

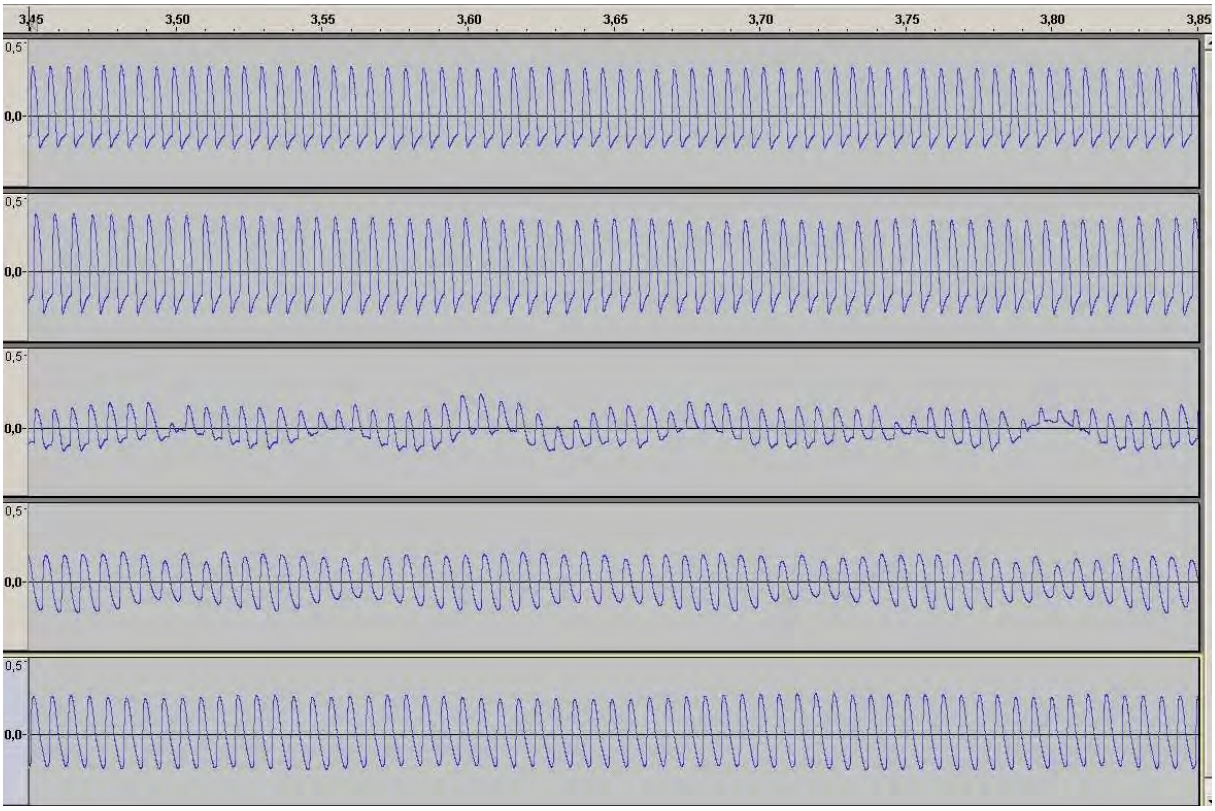

Fig. 3: EGG signals for comfortable phonation (from the top): on vowel [u:], into the resonance tube in air , into the tube submerged 2cm and 10 cm deep in water and into the narrow straw.

Acoustic results show that fundamental frequency *F0* lowers with the resistance of the tube. During water bubbling *F0* pulsated at a frequency about 15 Hz. First formant frequency *F1* is expected to lower, as the tube length increases and/or its diameter decreases. If F1 decreases to F0, it should increase reactance of the vocal tract (see e.g. Story et al., 2000) which has beneficial effects on phonation. However it is difficult to find this low-frequency formants in the spectrum of measured acoustic signal when it is excited by vocal folds vibration with fundamental frequency over 150 Hz. Thus, proper estimation of the lowest formant frequencies will be studied in another paper.

Spectra of the measured signal from the microphone outside the vocal tract for normal phonation into the resonance tube in air are shown in the upper part of Fig. 4. The peaks can be compared to that from the computed transfer function of the vocal tract model of vowel [u:] with the resonance tube (see the lower part of Fig. 4). The 1D vocal tract model was developed from the 3D volume model obtained from the MR images (Vampola et al., 2008). For detail of the mathematical model used for computing the transfer function see Radolf et al. (2012). The measured formant frequencies well agree with the computed formants up to frequency about 3 kHz. This frequency range corresponds to a validity of 1D mathematical model of the vocal tract that can’t capture transversal acoustic modes.

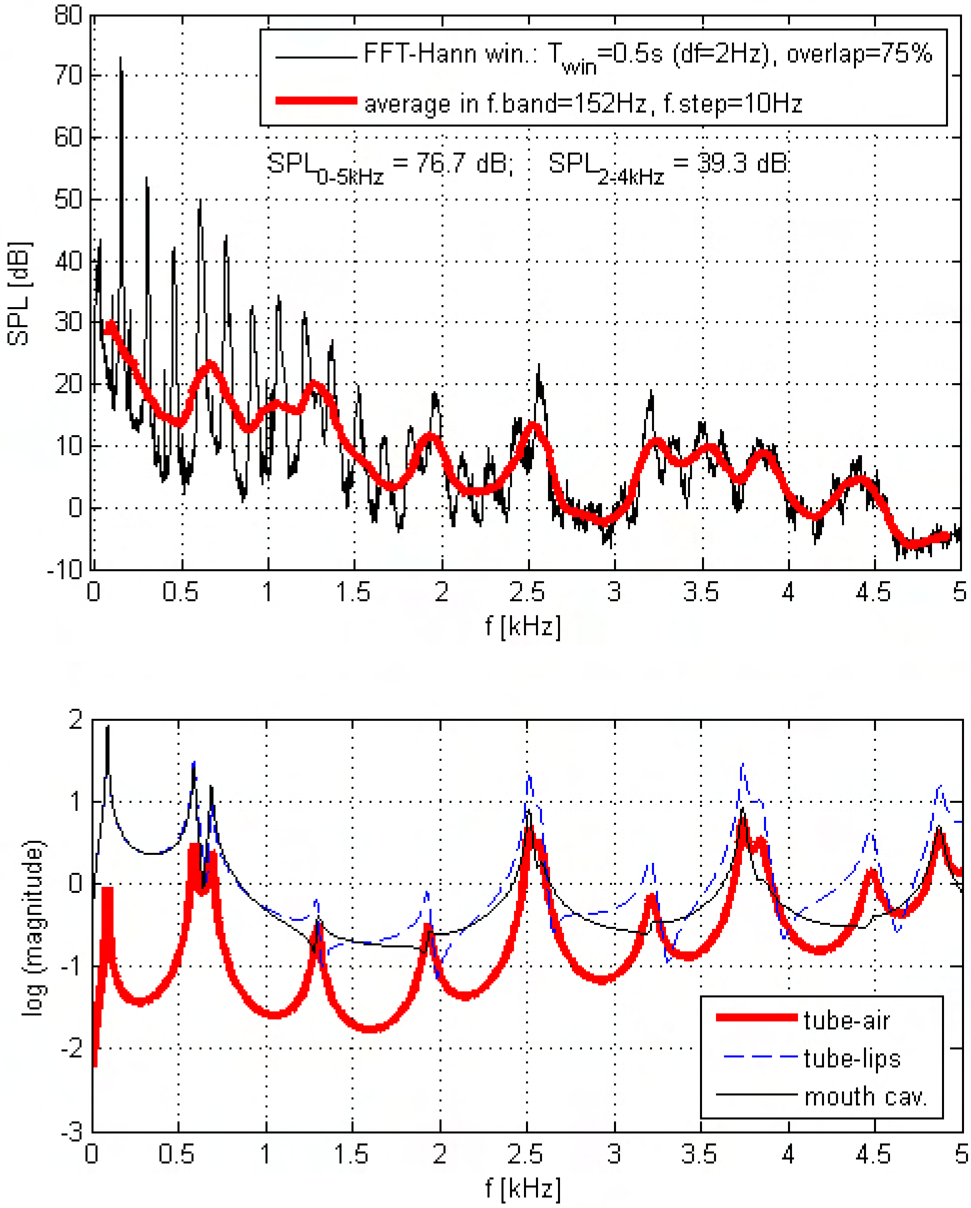

Fig. 4: Measured spectra of the signal from the microphone outside the vocal tract for normal phonation into the resonance tube in air (upper panel), computed transfer function of the vocal tract model of vowel [u:] with the resonance tube (lower panel).

4. Discussion and Conclusions

Exercises that increase supraglottic airpressure offer a possibility to train glottal and respiratory adjustments under the influence of increased backpressure which may both assist vocal fold vibration and prevent excessively loading vocal fold collision.

Voice therapy tradition pays attention to that tube 10 cm under water should only be used for a short time and proper guidance of phonation is needed (see Simberg & Laine, 2007). With a higher supraglottic resistance a higher subglottic pressure and tighter adduction is needed. However, the airpressure inside the glottis also increases, thus reducing collision between the vocal folds. However, if high subglottic pressure is required, then adductory muscles may tire. The pressure oscillation has been regarded as beneficial since it may offer a relaxing massage kind of an effect.

Another possible cause of the largest change in CQ that was for tube 10 cm in water, could be either increased glottal area variation or the possibility that during the semi-occlusions the laryngeal configuration may change, due to increased activity of Thyroarytenoid muscle over the Cricothyroid muscle.Such results have been reported earlier (Titze et al., 2002). This kind of a change would make the vocal fold thicker and thus increase contact area, and maybe also lead to increased contact quotient.

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