AIR-PRESSURE, VOCAL FOLD VIBRATION AND ACOUSTIC CHARACTERISTICS OF PHONATION DURING VOCAL EXERCISING.

PART 1: MEASUREMENT IN VIVO

Vojtěch Radolf*, Anne-Maria Laukkanen**, Jaromír Horáček*, Dong Liu***

The study investigates differences between three most widely used methods in voice training and therapy: Phonation into a resonance tube with the outer end in the air or submerged 2–10 cm in water ('water resistance therapy' with bubbling effect), and phonation into a very thin straw. One female speech trainer served as subject. Acoustic and electroglottographic (EGG) signals, and both mean and dynamic air pressures 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. Soft and normal phonations were recorded. Phonation threshold decreased with tube in air, suggesting that increased input reactance assists small amplitude oscillation of the vocal folds. Oral pressure (P_{oral}) increased with increasing impedance offered by the tube and straw, most when the tube was 10 cm in water. In most cases subglottic pressure (P_{sub}) increased relatively more than P_{oral}, so that transglottic pressure (P_{trans}) was higher in the exercises compared to vowel. Contact quotient (CQ) from EGG increased, which may be due to increased P_{trans}. In tube 10 cm in water P_{trans} decreased and CQ increased suggesting increased adduction as compensation. Exercises that increase oral air-pressure offer a possibility to train glottal and respiratory adjustments under the influence of increased flow resistance which may prevent excessively strong vocal fold collisions.

Keywords: *biomechanics of voice, subglottal, oral and transglottal pressure, electroglottography, phonation into tubes*

1. Introduction

Phonation into straws and tubes is widely used in vocal exercising and voice therapy [6]. In Scandinavia a resonance tube and water resistance therapy methods have been used [2]. Phonation into a resonance tube 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 [2, 3]. 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

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* Ing. V. Radolf, PhD., Ing. J. Horáček, DrSc., Institute of Thermomechanics, Academy of Sciences of the Czech Republic, Dolejškova 5, 182 00 Prague 8

** prof. A. M. Laukkanen, Speech and Voice Research Laboratory, School of Education, University of Tampere, FIN-33014, Tampere, Finland

*** M.Sc. D. Liu, Inverse Problems Group, Department of Applied Physics, University of Eastern Finland, Kuopio, Finland

effect. Based on practical observations and research results, Titze et al. [6] 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. [4] estimated the effects of various vocal tract configurations on the acoustic input impedance of the vocal tract. According to their results first acoustic resonance (formant frequency F_1) lowers with a prolongation or a semi-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 sound pressure level (*SPL*) and stronger voice overtones (louder and brighter) are obtained [5].

The present study aims to compare the most common tube training methods: resonance tube in air, or in water, and stirring straw from the point of view of phonation threshold and subglottal pressure as well as electroglottographic parameters for a normal phonation at a habitual speaking pitch.

2. Measurement set-up and procedure

One female voice trainer phonated (in speech mode) at comfortable pitch and both at comfortable loudness and at phonation threshold (soft phonation) on [pu:pu], 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 and 10 cm below water surface (Fig. 1).

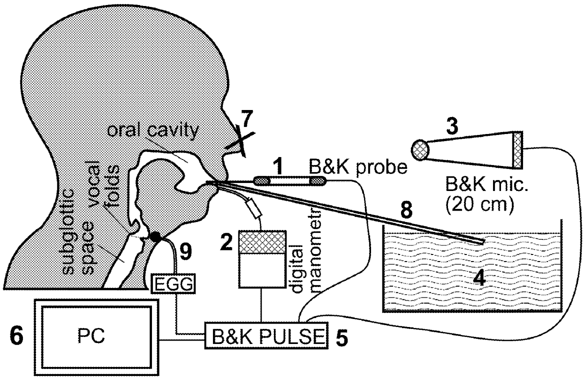

Fig. 1: Schema of the measurement set up: 1 – B&K microphone probe 4182, 2 – digital manometer Greisinger Electronic GDH07AN, 3 – sound level meter B&K 2239, 4 – aquarium, 5 – B&K measurement system PULSE 10 with Controller Module MPE 7537 A, 6 – personal computer, 7 – clip, 8 – impedance tube, 9 – EGG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

The *SPL* inside the oral cavity was measured using the special microphone probe. The mean oral pressure (P_{oral}) was measured by a digital manometer connected with the oral cavity by a small short compliant tube. Pressure during the voiceless plosive [p] in [pu:pu] and during manual random shuttering of the other end of the tube gave an estimate of subglottic pressure (P_{sub}). The subject's nostrils were closed with a clip to prevent any leakage of air through the nose. The generated acoustic signal outside the vocal tract model was recorded using the microphone installed at a distance of 20 cm from the lips. EGG signal was registered using a dual-channel device. The parallel recording of all measured signals was made with a PC controlled measurement system using 32.8 kHz sampling frequency. The fundamental vibration frequency F_0 and the formant frequencies were evaluated from the spectra of the pressure signals.

Acoustic analysis was done in Matlab by averaging frequency spectra, calculated by FFT, using 0.5–1 s time windows with 75 % overlap and the *SPL* was computed for each harmonic. Then the spectra were averaged in the frequency bands (windows) equal to the fundamental frequency F_0 with overlap of $F_0 - 10$ Hz. The maxima of these ‘filtered spectra’ were considered as formants.

From the EGG signal the contact quotient (CQ = time of contact of the vocal folds divided by the period length) was calculated using Matlab. The beginning and end of contact between the vocal folds was defined by setting the threshold-level to 50 % of the peak-to-peak amplitude of the signal.

3. Results

The measured data for soft and normal phonation are summarized in Tabs. 1–2 and Figs. 2–3. Compared to vowel phonation and the other vocal exercises, phonation into resonance tube in air brought about the lowest **phonation threshold pressure PTP** ($P_{\mathrm{sub}} = 264$ Pa), tube 10 cm under water the highest (1.37 kPa) and straw the 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 air leakage 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.

soft phonation	P_{sub} [Pa]	P_{oral} [Pa]	P_{trans} [Pa]	$P_{\mathrm{oral,p\text{-}t\text{-}p}}$ [Pa]	F_0 [Hz]
[u:]	308	105	203	72	165
tube in air	264	16	248	31	152
tube 2 cm in water	529	150	379	244	160
tube 10 cm in water	1370	930	440	273	154
straw in air	915	400	515	118	167

Tab.1: Mean values of the measured subglottal, oral and transglottal pressures, peak-to-peak values of oral pressure, 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

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** ($P_{\mathrm{trans}} = P_{\mathrm{sub}} - P_{\mathrm{oral}}$) 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}.

Measurable EGG cannot be obtained for phonation threshold. In EGG signal of the normal phonation, the contact quotient CQ was higher for the tubes compared to vowel phonation. The largest change was observed for tube 10 cm in water. It was also possible

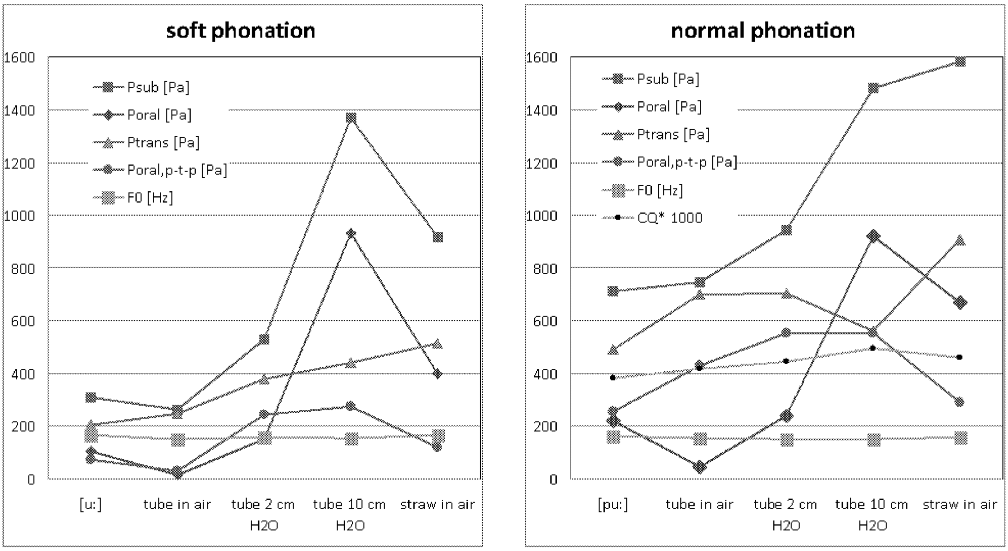

Fig.2: Measured values for soft phonation (left) and normal phonation (right): mean values of subglottal (P_{sub}), oral (P_{oral}) and transglottal (P_{trans}) pressures, peak-to-peak values of oral pressure ($P_{\text{oral,p-t-p}}$) , fundamental frequency F_0, and contact quotient (CQ for normal phonation only) for phonation on vowel [u:], into the resonance tube in air, into the tube submerged 2 cm and 10 cm in water, and into the narrow straw

soft phonation	P_{sub} [Pa]	P_{oral} [Pa]	P_{trans} [Pa]	$P_{\text{oral,p-t-p}}$ [Pa]	F_0 [Hz]	CQ_{50}
[u:]	710	220	490	257	164	0.38
tube in air	746	47	699	429	156	0.42
tube 2 cm in water	942	240	702	553	152	0.44
tube 10 cm in water	1480	920	560	551	149	0.49
straw in air	1580	670	910	289	158	0.46

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

to see the effect of water bubbling on the EGG signals, both for tube 2 and 10 cm in water (see Tab. 2 and Fig. 3). A baseline shift is seen in the signal, due to variation in vertical laryngeal position caused by water bubbling, at the frequency of 15 Hz, and also a repeatedly occurring decrease in the vocal fold contact, which may be either due to increased intraglottal air-pressure 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 (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. It looks like that tube in air offers the highest amplitude and tube in water the smallest, which may mean that contact area is largest for tube in air.

Acoustic results summarized in Tab. 3 show that fundamental frequency F_0, given by the vocal folds vibration, slightly varied and had a weak tendency to decrease with the resistance of the tube. Moreover, during water bubbling the oral pressure pulsated at a dominant

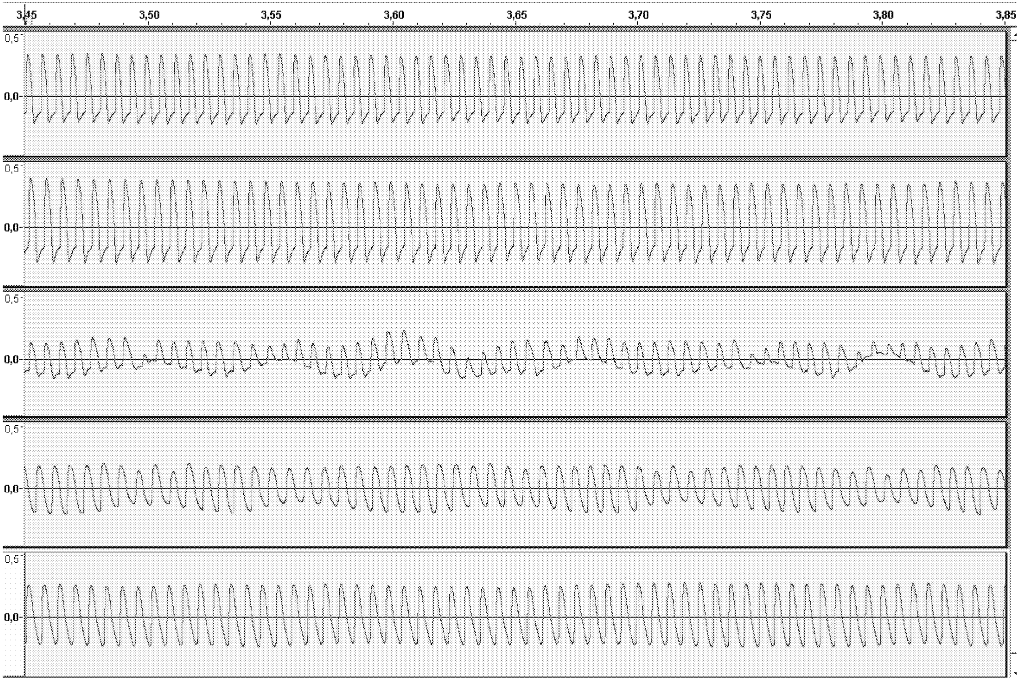

Fig.3: EGG signals for normal phonation (from the top): on vowel [u:], into the resonance tube in air, into the tube submerged 2 and 10 cm deep in water, and into the narrow straw (increasing contact is oriented upwards)

Frequencies [Hz]	f_B	F_0	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8
[u:] – soft phonation		165		1050	2760	3560	4200			
[u:] – normal phonation		164	360	720	2840	3580	4120			
tube in air – soft		152		1130	2810	3560	4350			
tube in air – normal		156	190	1050	2680	3580	4470			
straw in air – soft		167	170	1200	2630	3630				
straw in air – normal		158	160	1220	2530	3620				
tube in water 2 cm – soft	11–17	160		(310)	940	1240	1550	2200	(2630)	(2820)
tube in water 2 cm – norm.	16	152	(160)	(320)	990		(1550)	(2190)	2700	
tube in water 10 cm – soft	12	154		(330)	(950)	1240	(1540)	(2160)	2640	3560
tube in water 10 cm – norm.	14	149	(150)	(330)	1030		1550	2180	2700	3490

Tab.3: Bubbling (f_B), fundamental (F_0) and formant frequencies (F_1–F_8) for phonation on vowel [u:], into the resonance tube in air, into the narrow straw and into the tube submerged in water for soft and normal phonation. The values that were not clear in the spectra are written in brackets

frequency of about $f_B = 15$ Hz. Spectra of the signals measured by the microphone probe in the mouth cavity for phonation into the resonance tube with the other end submerged 10 cm below the water surface are shown in Fig. 4. Both in case of soft and normal phonation the highest peak in the frequency spectrum was located at the frequency of bubbling with the level of about 10 dB higher than the level of the peak at the fundamental phonation frequency F_0. First formant frequency F_1 for [u:] lowered for phonation in the tube and straw. If F_1 decreases to F_0 it should increase the input reactance of the vocal tract (see e.g. [4]), which has beneficial effects on phonation. Current results seem to be in line with this hypothesis, nevertheless for phonation into the straw F_1 seems to be too close to F_0. However, it is difficult to locate exactly such low- frequency formants in the spectrum of measured acoustic signals when it is excited by vocal fold vibration with fundamental frequency over 150 Hz.

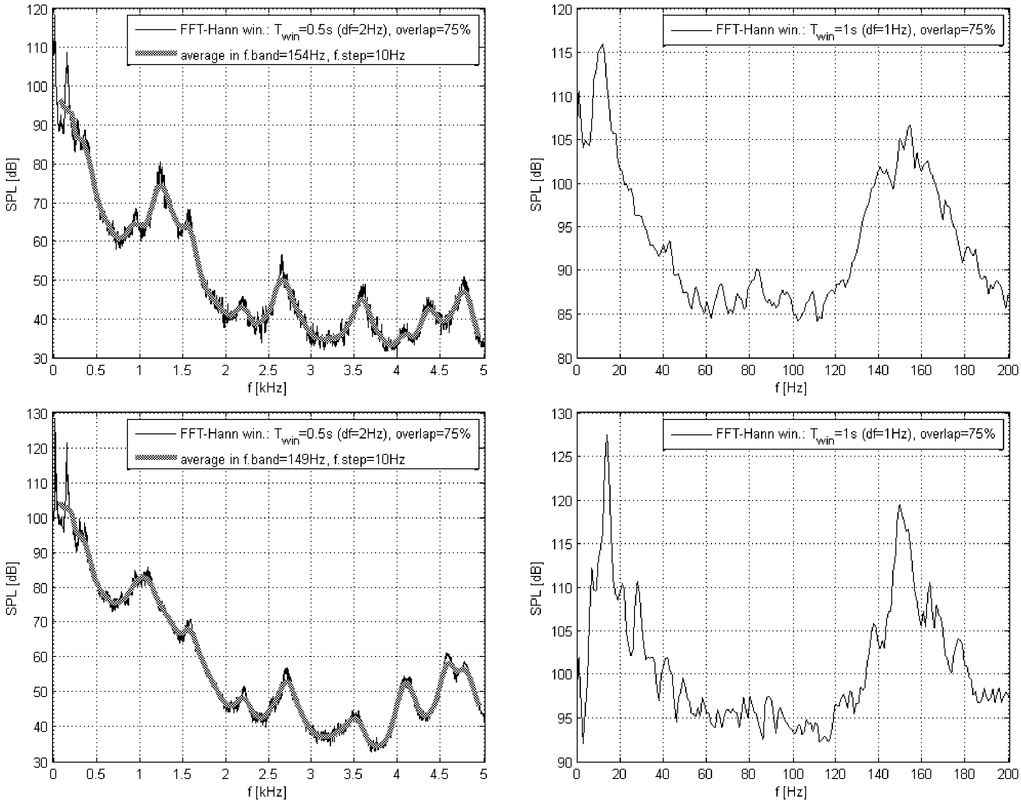

Fig.4: Measured spectra of the signals from the microphone probe placed in the mouth cavity for soft phonation (upper panel) and normal phonation (lower panel) into the resonance tube 10 cm below the water surface; formant frequencies up to 5 kHz are visible as the peaks of thick line on the left, bubbling and fundamental frequencies on detailed spectra on the right

4. Discussion and conclusions

Exercises that increase supraglottic air-pressure offer a possibility to train glottal and respiratory adjustments under the influence of increased flow resistance which may both assist vocal fold vibration and prevent excessively loading the vocal fold tissue during the collisions.

Voice therapy tradition pays attention to the tube phonation 10 cm under water. This technique should only be used for a short time and a proper guidance of phonation is needed (see [2]). With a higher supraglottic resistance a higher subglottic pressure and tighter adduction are needed. However, the air pressure inside the glottis also increases, thus reducing collision between the vocal folds. Nevertheless, 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.

The higher oral pressure in [u:] than in tube in air 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.

Increased contact quotient CQ observed during tube and straw phonation may be a consequence of increased transglottal pressure that increases glottal vibratory amplitude. Another possible cause could be 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 by Titze et al. [6] for phonation on different types of semi-occlusions. This kind of a change would make the vocal fold thicker and thus increase contact area (reflected in the measured larger EGG signal amplitude), and possibly also lead to increased contact quotient due to the fact that a longer glottis (in vertical dimension) facilitates vocal fold vibration.

Higher contact quotient for phonation into tubes could be caused by increased vocal folds adduction in order to compensate for increased supraglottic loading. In earlier studies, high subglottic pressure and small CQ have been reported for phonation in a straw [6, 7], and it has been recommended as an exercise to train respiratory muscles and falsetto kind of high pitched phonation without excessive collision between the vocal folds and possibly also suited for reducing hyperadduction in voice patients. According to the present study the contact quotient increased in straw phonation. Similar increase is also seen for one subject at a speaking pitch phonation in [6]. Thus the result may vary according to the individual's reaction to increased supraglottic load and to the pitch.

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