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AIR-PRESSURE CHARACTERISTICS AND VISUALIZATION OF BUBBLING EFFECT IN WATER RESISTANCE THERAPY

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Abstract: *This study investigates the influence of a widely used method in voice training and therapy, phonation into a resonance tube with the outer end submerged in water ('water resistance therapy' with bubbling effect). Acoustic and electroglottographic (EGG) signals and air pressures in the mouth cavity were registered and the formation of bubbles was studied using high speed camera. Bubbling frequency dominates in the spectra of the pressure signal being about 15 dB higher than the amplitude of the first harmonic, which reflects the fundamental frequency of the vocal folds' vibration. Separation of the bubbles 10 cm under water surface starts when the buoyancy force acting on the bubble is approximately equal to the aerodynamic force in the tube.*

Keywords: Biomechanics of voice, Phonation into tubes, Voice therapy.

1. Introduction

Different variants of phonation into tubes and straws have become increasingly popular in voice training and therapy. In Scandinavia a resonance tube and water resistance therapy methods have been used (see Sovijärvi, 1964; Laukkanen, 1992; Simberg and 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 submerged into water has been used for voice patients with many types of voice disorders. Immersion depth of 1-2 cm is used to treat both hypofunctional and hyperfunctional voice disorders, while the depth 5-15 cm has been used for patients with incomplete vocal fold closure (Simberg and Laine, 2007).

The present study investigates the mechanism that causes formation of the bubbles and separates them from the tube end.

2. Methods

One female and one male volunteered as subjects. This study focused on ordinary (most comfortable) phonation of the female subject into glass resonance tube, 27 cm in length, 7 mm in inner diameter, where the target fundamental frequency, chosen by the subject and controlled throughout the experiment was 165 Hz.

The sound pressure level (*SPL*) inside the oral cavity was measured using the B&K 4182 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 Greisinger Electronic GDH07AN connected with the oral cavity by a small compliant tube (inner diameter 1.5 mm, length 8 cm). The nose was closed with a clip to prevent any leakage of air through the nose. Electroglottographic signal (EGG) was registered using a dual channel device (Glottal Enterprises). The recording was made using 16.4 kHz sampling frequency by the PC controlled measurement system B&K PULSE 10 synchronized with a high speed camera that registered bubbling with the rate of 1000 frames per second.

Frequency range of the digital manometer started at 0 Hz but attenuated gradually frequencies above 80 Hz. The microphone probe was set to work in the range from 20 Hz to its upper limit 20 kHz. It means

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that quite low frequency of bubbling F_B could not be detected by the microphone probe properly. Contrary to that, fundamental frequencies of the vibrating vocal folds F_0, that were above 100 Hz, were correctly recorded by this probe.

3. Results

Example of simultaneously recorded time signals for the dynamic oral pressure, EGG signal, oral air pressure and images of formation of the bubbles are presented in Figs. 1 and 2.

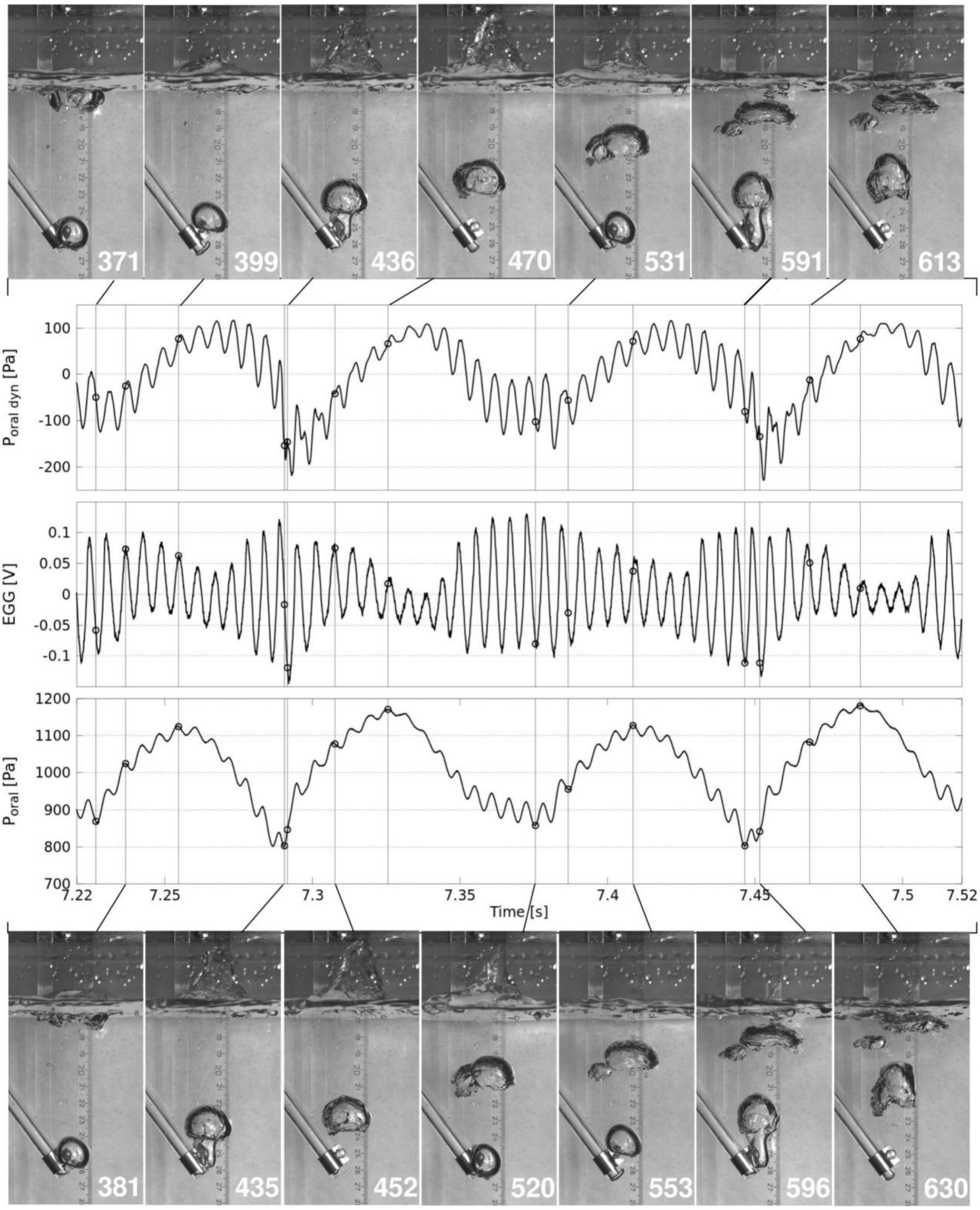


Fig. 1: Dynamic oral pressure, electroglottographic signal (EGG), oral air pressure (P_{oral}) and images taken by the high speed camera at the time instants marked by circles during a comfortable phonation into the resonance tube submerged 10 cm deep in water.

Comfortable phonation of the female subject into the tube submerged 10 cm deep in water is shown in Fig. 1. The time instants marked by small circles correspond to the images taken by the high speed camera. These images represent minimum of the oral pressure (see images 371, 435, 520, 591), maximum of the oral pressure (images 399, 470, 553, 630) and separation of a bubble from the tube end (381, 436, 531, 596). The other images (452, 613) represent the moments of maximum water level inside the tube measured from the outer end of the bottom tube.

The oral pressure multiplied by the cross-sectional area of the tube gives an airpressure force in the range from 31 mN to 45 mN. Buoyancy force acting on a bubble, when it is separated from the tube, was computed on the basis of volume of the bubble estimated from the corresponding image. This force was 41 mN and 46 mN for the frames 381 and 531, respectively, being slightly higher than the force in the tube at these time instants. Therefore we can conclude, that the bubble separation starts when the buoyancy force acting on the bubble is equal or a bit higher than the airpressure force in the tube.

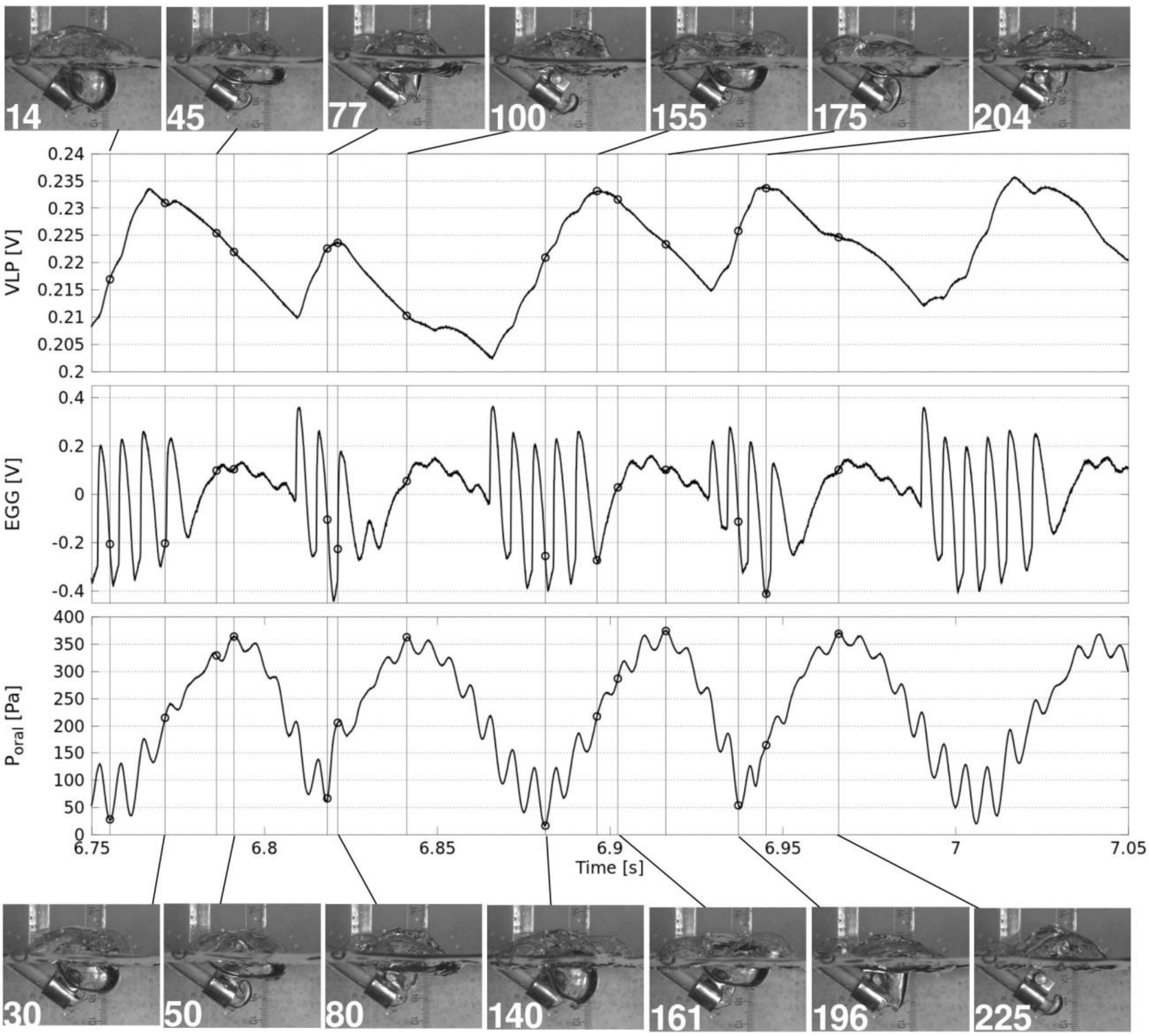
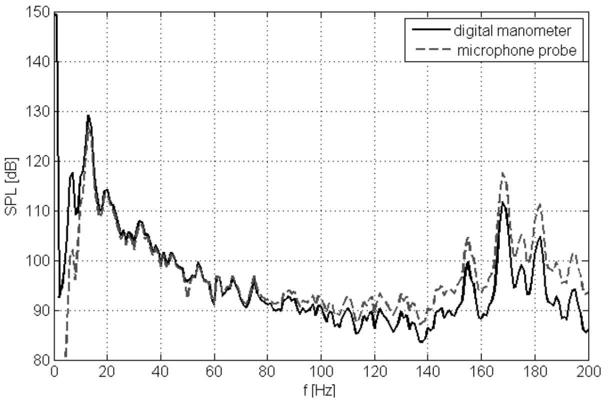


Fig. 2: Vertical larynx position (VLP), electroglottographic signal (EGG), oral air pressure (P_{oral}) and images taken by the high speed camera at the time instants marked by circles during a comfortable phonation into the resonance tube submerged 2 cm deep in water.

Comfortable phonation of the female subject into the tube 2 cm deep in water is presented in Fig. 2. The time instants marked by small circles correspond to the images from the high speed camera and represent minimum of the oral pressure (see images 14, 77, 140, 196), maximum of the oral pressure (images 50, 100, 175, 225) and separation of bubbles from the tube end (30, 45, 80, 155, 161, 204). The bubbles seem to be bigger in their volume because of lower hydrostatic pressure at the tube end submerged 2 cm in the water. However in this case the volume of the bubbles could not be properly estimated because the bubbles reach the water level before separating from the tube end. The oral pressure multiplied by cross-sectional area of the tube gives the airpressure force in the range from 1 mN to 14 mN.

Oscillations caused by bubbling influence both the oral air pressure and vocal folds contact area as can be seen in EGG time signals. The bubbling frequency even affects vertical position of the larynx derived from amplitude difference between the two pairs of electrodes in EGG. See the upper graph in Fig. 2, where the maxima correspond to the time instants of separation the bubbles (images 30, 80, 155, 161, 204).

Frequency spectra of oral air pressure measured both by the digital manometer and by the microphone probe are displayed in Fig. 3 in the frequency range 0 – 200 Hz. The maximum peak of the intensity nearly 130 dB is located at the frequency of bubbling F_B = 13 Hz and F_B = 16 Hz for the tube end submerged 10 cm and 2 cm under water level, respectively. Lower peak at the frequency $F_B/2$ indicates a subharmonic effect in bubbling separation which can be recognized in the time signals as the lowest minima at 7.29 s and 7.45 s in Fig. 1 and 6.75 s, 6.88 s and 7.01 s in Fig. 2. Fundamental frequency of vibrating vocal folds around F_0 = 165 Hz is characterized by a peak of the level less than 120 dB (see the dashed lines in Fig. 3) surrounded by smaller peaks at frequency $F_0 \pm F_B$, that indicates amplitude modulation of F_0 by the bubbling frequency.



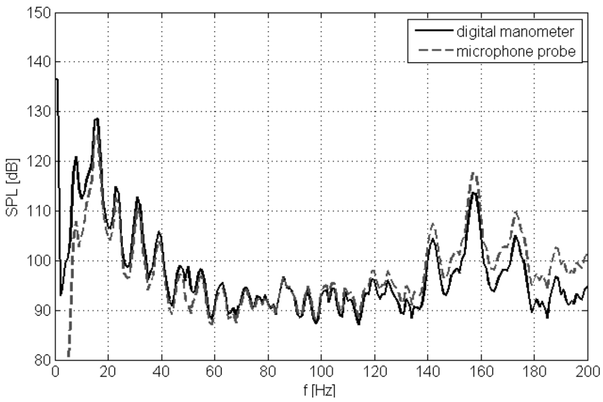


Fig. 3: Frequency spectra of oral air pressure signal registered by microphone probe (dashed line) and by digital manometer (full line) during comfortable phonation into the resonance tube submerged 10 cm (left) and 2 cm (right) deep in water.

4. Conclusions

Phonation into the resonance tube submerged under water surface substantially influences the oral-air pressure and vibration pattern of vocal folds by formation of the bubbles and their separation from the tube end. These changes show periodic character with the frequency 13 Hz and 16 Hz for 10 cm and 2 cm of water level, respectively. This bubbling frequency dominates in the spectra of the pressure signal being about 15 dB higher than the amplitude of the first harmonic, corresponding to vocal folds vibration at the fundamental frequency. Separation of the bubbles 10 cm under water starts when the buoyancy force acting on the bubble is approximately equal to the airpressure force inside the tube.

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