27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#75**, pp. 321–324, doi: 10.21495/51-2-321

DAMPING OF HUMAN VOCAL FOLDS VIBRATION

Radolf V.[*], Horáček J.[*], Bula V.[*], Geneid A.[**], Laukkanen A-M.[***]

Abstract: *This study investigates the biomechanics of the end-part of phonation, i.e. the so-called phonation offset, experimentally. This information of vocal fold damping is important for testing and further development of mathematical modelling of phonation. The measurements of the damping ratio, based on high-speed videolaryngoscopic registrations, were realized on a male subject phonating on the vowel [o:]. The results show during the phonation offset a remarkable decrease of vibration frequency of the vocal folds and an increased damping ratio limiting to the value D≅ 0.2. The results for vocal folds' damping are in agreement with previous measurements performed on humans using different methods.*

Keywords: Damping ratio measurement, Phonation offset, High-speed videolaryngoscopy.

1. Introduction

Damping is an important input parameter in mathematical modelling of self-sustained vibrations of human vocal folds that are generated by the airflow coming from the lungs. In humans it is practically impossible to study damping of living vocal fold tissue which is composed of several layers of different material properties. The classical frequency-modal analysis methods, frequently used in mechanical engineering, are problematic to apply because such an approach requires exactly defined excitation forces, see (Kaneko et al., 1987) and (Švec et al., 2007). Identification of damping from phonation offset is also not fully adequate, because vocal fold vibrations are not completely free, i.e. without any external excitation, up to the total end of phonation. The subglottic pressure and airflow rate in the glottis decrease to zero at the total end of phonation, but the length of this decrease is influenced by lung volume, see (DeJonckere and Lebacq, 2020).

2. Methods

Laryngoscopic data were obtained from a normal-voiced male participant by High-Speed Video System (KayPentax, model 9710) with a spatial resolution of 512x512 pixels and a sampling frequency of 2 kHz. A rigid scope was inserted through a mouthpiece into the pharynx. The participant sustained vowel [o:] on his habitual speaking pitch and loudness. Simultaneous recordings of the acoustic, electroglottographic (EGG), and oral pressure (P_{oral}) signals were made with Computerized Speech Laboratory (KayPentax). The acoustic signal was recorded using a head-mounted microphone (Type C477; AKG Acoustics). P_{oral} was registered by a pressure transducer (Glottal Enterprises, PT75). EGG signal, which shows variation in glottal contact, was measured by a dual-channel device (Glottal Enterprises, EG2). See more details in (Laukkanen et al., 2020), where the same experimental human set-up was used for another study.

In this study we analysed the recordings of phonation offset from the end of the sustained vowel. The fundamental frequency of the sustained phonation was 114 Hz.

[*] Ing. Vojtěch Radolf, PhD.: Institute of Thermomechanics of the Czech Academy of Sciences, Dolejškova 1402/5, 182 00, Prague, CZ, radolf@it.cas.cz

[*] Ing. Jaromír Horáček, DrSc.: Institute of Thermomechanics of the Czech Academy of Sciences, jaromirh@it.cas.cz

[*] Ing. Vítězslav Bula: Institute of Thermomechanics of the Czech Academy of Sciences, bula@it.cas.cz

[**] adj. Prof. Ahmed Geneid: Phoniatric Clinic, Helsinki University Hospital, Finland, Ahmed.Geneid@hus.fi

[***] Prof. Anne-Maria Laukkanen: Speech and Voice Research Laboratory, Faculty of Social Sciences, Tampere University, Tampere, Finland, Anne-Maria.Laukkanen@tuni.fi

2.1. Analyses of high-speed images

Firstly, the time interval of phonation offset was determined from the audio recordings, and a series of video images corresponding to the selected time interval was extracted. Then, the images were rotated so that the direction of the longitudinal axis of the glottis was vertical. The area of interest was cropped for the next analysis. The next step was to select from the series of images the perpendicular cross line (the same for all frames), see the green line in Fig. 1. This line was set at the best position for viewing the vocal folds' superior edge (ridge) during all phonation offset. The superior edge of the vocal folds represented the glottal width at the individual times of the video recording. The cross lines were successively assembled one underneath the other to form a kymogram, see Fig. 1 and (Švec et al., 2007). Before measuring the glottal width, the kymogram was modified by special procedures changing the intensity and brightness in the images in order to obtain final clear black and white contours of both vocal folds' ridges, see Fig. 2. The number of white pixels between the black edges of the vocal fold ridge contours in the figure was in each time step counted using an in-house MATLAB program to obtain the time waveform of the glottal width variation $GW(t)$.This quantity was studied in pixels, since it was not possible to calibrate the high-speed registration.

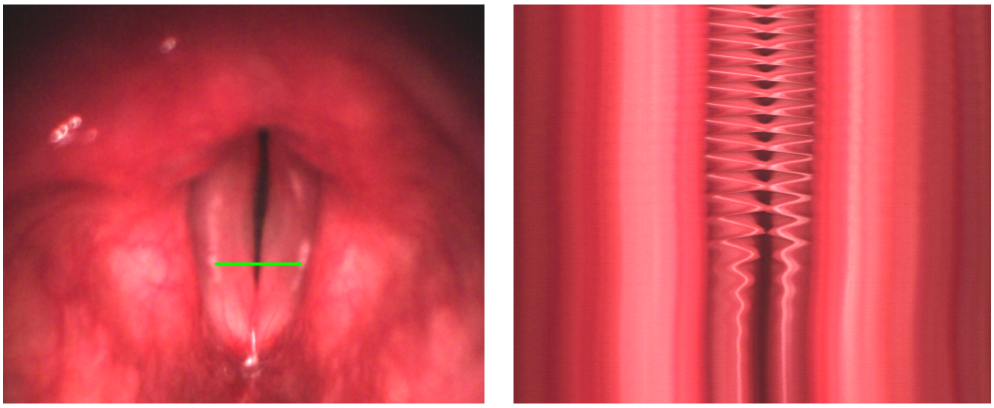

Fig. 1: Image of the vibrating vocal folds (left) and the kymogram (right) evaluated during phonation offset at the glottis cross-section marked by the green line on the vocal folds' image. Time in the kymogram is going from ordinary phonation at the upper edge of the figure to the completely open glottis at the lower edge of the figure.

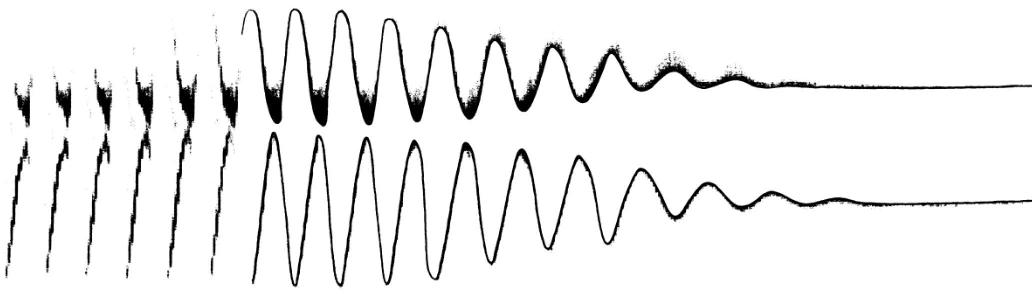

Fig. 2: Modified and left-rotated kymogram before GW(t) analysis. Time increases from left to right.

3. Results

Figure 3 shows all signals measured synchronously during the phonation offset and the glottal width waveform $GW(t)$ computed from the modified kymogram shown in Fig. 2. The acoustic (Mic) signal, similarly as P_{oral} and EGG signals decreased basically to zero shortly after the last vocal folds' contact, which was possible to detect at the time instant $t \cong 22.35$ s.

Before evaluation of damping, the glottal width waveform $GW(t)$ was transformed in two steps, see Figure 4. First, the $GW(t)$ record was time shifted to start from zero, and the linear regression was applied to the signal, see Fig. 4a. Then the $GW(t)$ values were centralized around the values calculated by the linear regression in the first step according to the formula:

$$GW(t) = GW(t) - (50.343 - 51.955\ t). \quad (1)$$

The transformed *GW*(*t*) is shown in Fig. 4b, where the arrow marks the time from which the positive and negative amplitudes were taken into account and from where no vocal fold collisions appeared along the entire length of the vocal folds. We should note that the chosen line for creating the kymogram (see Fig. 1) does not monitor the complete glottis closure.

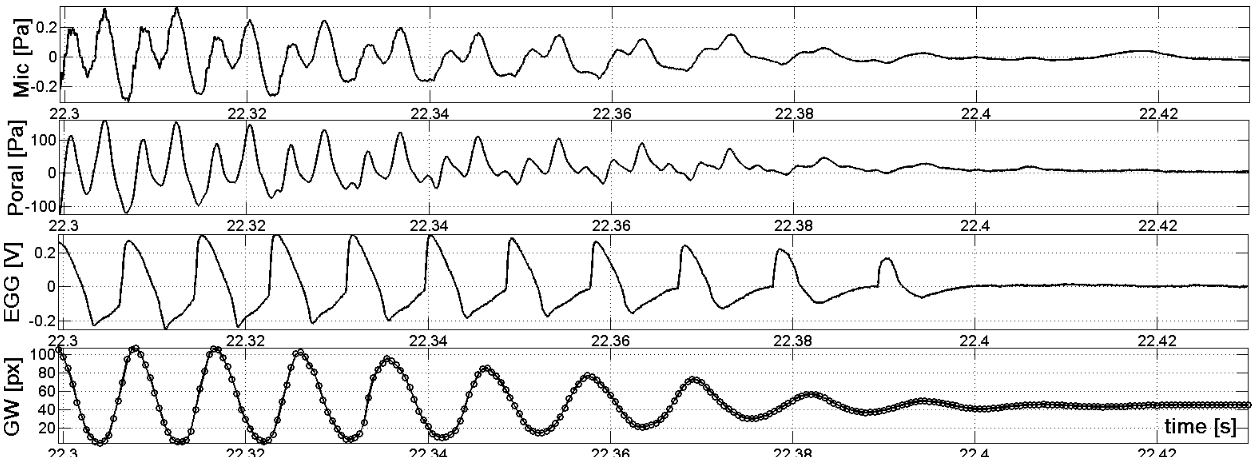

Fig. 3: Synchronously measured acoustic (Mic), oral pressure (Poral) and EGG signals together with glottal width (GW).

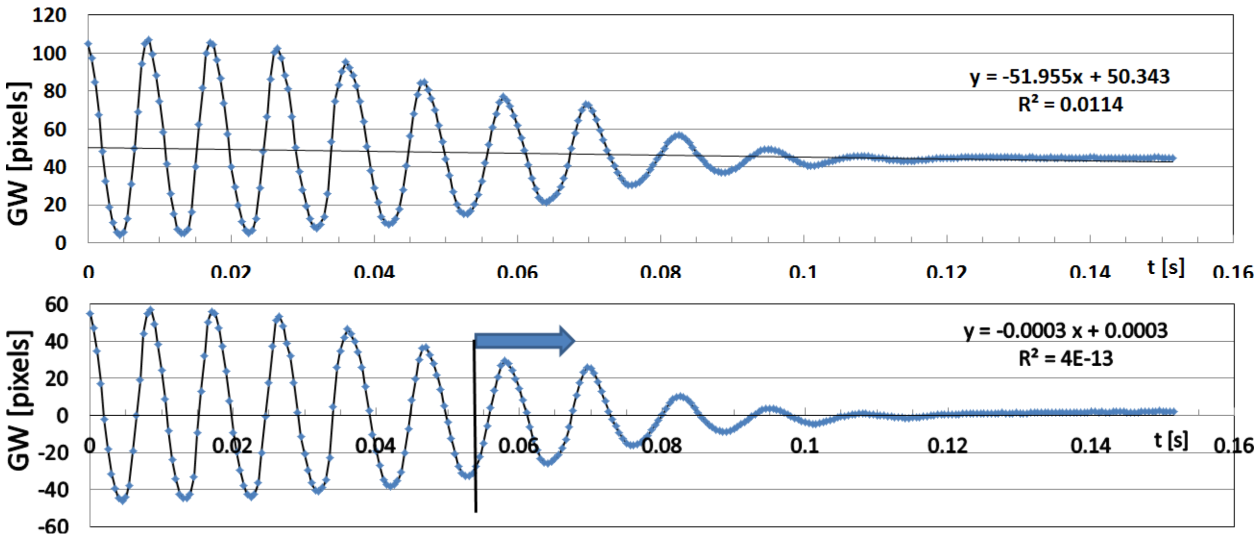

Fig. 4: Two transformation steps of glottal width waveforms for analyses of the damping.

Figure 5 shows the results of the glottal width *GW*(*t*) waveform analysis: 1/ the decrease of vibration frequency *f*(*t*) of the vocal folds during phonation offset and in opposite 2/ the increase of damping ratio *D* calculated in time domain after the last contact of the vocal folds. The frequency *f*(*t*) was calculated from the time intervals *T*(*t*) of positive and negative amplitudes of vibration periods as $f(t_n)=1/T(t_n)$ and the damping ratio as

$$D(t_n) = \delta_n / \sqrt{[(2\pi / T(t_n))^2 + \delta_n^2]} \quad \text{and} \quad \delta_n = (1/T(t_n))\ \ln(a(t_n)/a(t_{n+1})), \quad (2)$$

where *a* are the *GW*(*t*) amplitudes. We took into account both extremes, i.e. minima and maxima of *GW*(*t*).

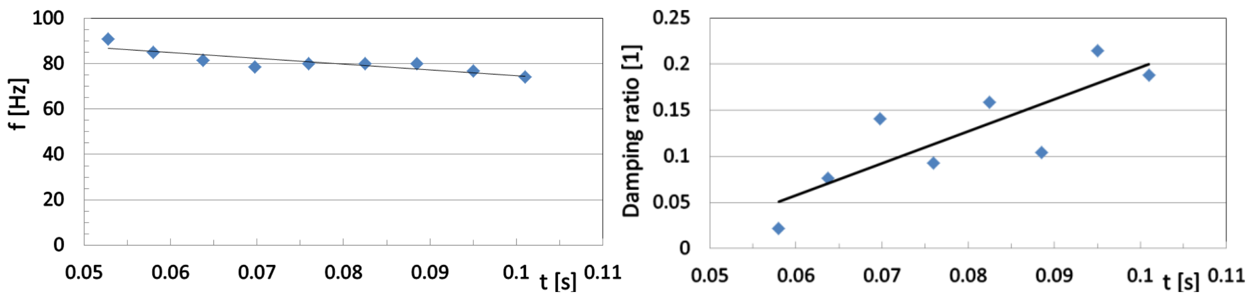

Fig. 5: Vibration frequency f (left) and damping ratio D (right) of vocal folds during phonation offset.

4. Conclusions

The results obtained from the measurements show that during the phonation offset the vibration frequency of vocal folds decreases and the damping ratio increases. The main reason probably is a slow decrease of the subglottic pressure which means that the vocal folds' vibrations are during decay of the vibration amplitude still remarkably supported by the intraglottal pressure; therefore, the vibrations are not completely free. For this reason, a real damping ratio of the vocal fold tissue itself is a limit value at the end of the phonation offset. Therefore, in our measurement the true damping ratio was found to be D≅0.2.

This value is in the rank of results published on damping measured in humans by external excitation of the vocal folds. Švec et al. (2000) used a sweep harmonic excitation of human vocal folds in phonation position by an exciter joint to the larynx and found the damping ratio D≅0.13 for the second mode of vocal folds vibration at the frequency of 171 Hz. Similarly, using impulse excitation, Kaneko et al. (1987) found D≅0.12 for the first vocal folds eigenfrequency 100 Hz. DeJonckere & Lebacq (2020) found D≅0.07-0.16 for high lung volume and D≅0.10-0.18 for low lung volume using photoglottography for investigation of glottal width waveforms in phonation offset when the participant was producing fast repetition of /epepep…/.

The results for vocal folds damping obtained in the present study can be applied in improving mathematical modelling of human voice production.

Acknowledgement

The research was performed within a pilot project with institutional support RVO: 61388998.

References

DeJonckere, P. H. and Lebacq, J. (2020) Lung volume affects the decay of oscillations at the end of a vocal emission. *Biomedical Signal Processing and Control*, 62, p. 102148, pp. 1-11.

Kaneko, T., Masuda, T., Shimada, A., Suzuki, H., Hayasaki, K. and Komatsu, K. (1987) Resonance characteristics of human vocal fold in vivo and in vitro by an impulse excitation, in: Baer, T., Sasaki, C. and Haris, K. S., eds., *Laryngeal Function in Phonation and Respiration,* Boston: A College-Hill Press/Little, Brown and Company, pp. 349–365.

Laukkanen, A. M., Geneid, A., Bula, V., Radolf, V., Horáček, J., Ikavalko, T., Kukkonen, T., Kankare, E. and Tyrmi, J. (2020) How much loading does water resistance voice therapy impose on the vocal folds? An experimental human study. *Journal of Voice*, 34(3), pp. 387-397.

Švec, J. G., Horáček, J., Šram, F. and Veselý, J. (2000) Resonance properties of the vocal folds: In vivo laryngoscopic investigation of the externally excited laryngeal vibrations. *Journal of the Acoustical Society of America*, 108(4), pp. 1397-1407.

Švec, J. G., Šram, F. and Schutte, H. K. (2007) Videokymography in voice disorders: What to look for? *Ann Otol Rhinol Laryngol*, 116, pp. 172-180.