Simulation of differences between male and female vocal fold configuration during phonation

M. Kob[1,2], Ph. Dejonckere[3,4], E. Calderon[2], S. Kaynar[2]
[1] *RWTH Aachen University, Germany*
[2] *University of Music Detmold, Germany, Email: kob@hfm-detmold.de*
[3] *Institute of Phoniatrics, University Medical Center, Utrecht, The Netherlands*
[4] *Institute of Occupational Diseases, Brussels, Belgium*

Introduction

Statistically, some vocal fold lesions such as vocal fold nodules – considered as a localized tissue reaction to voice loading – are much more frequent in female (~ 95 %) than in male (~ 5 %) adult humans. This can only partially be explained by the about two times higher oscillation frequency during voice production in females.

In previous studies, gender-related differences in the shape of the vocal fold edge have been observed that can be related to different geometries of the laryngeal framework [1]. With a time-domain model of vocal fold function the oscillation patterns and resulting forces between and inside the vocal folds can be investigated [2] . The aim is to validate the concept of hourglass-shaped vibration pattern, responsible for localised tissue reaction, clinically defined as vocal fold nodules.

Gender-specific voice physiology

The vocal folds are stretched between the thyroid and the arytenoids, and during phonation fine-tuned by the tension of the musculus vocalis. The length of the vocal folds differs between 13-17 mm in female adults and 15-23 mm in male adults. Also the geometric conditions of the laryngeal framework are different for females and males due to the different angle between the left and right wings or laminae of the thyroid cartilage (120 ° in females and 90 ° in males). The average fundamental speaking frequency of females is about two times higher (~ 220 Hz) than the fundamental speaking frequency of males (~ 120 Hz).

Differential prevalence of vocal fold nodules: relation with vibration pattern?

Vocal fold nodules are among the most frequent pathologies of the larynx. Herrington-Hall et al. report 21,6 % in 1262 cases [3]. A high prevalence of this pathology occurs in professional voice users such as teachers and popsingers, and a strong gender-related difference of prevalence can be observed. Vocal fold nodules are much more frequent in female (~ 95 %) than in male (~ 5 %) adult humans.

A possible reason for this difference is certainly the about two-times higher phonation frequency of females compared to males. Another reason might be the different shape of the vocal fold edge, to some extent related to the different angle between the laminae of the thyroid cartilage. This different laryngeal set-up could lead to different vocal fold rest configurations which – in turn – could result in different impact conditions of the vocal folds.

For a slightly concave vocal fold edge the impact of both vocal folds at each vibration cycle is not similar to that one of vocal folds with a rather straight margin. If there is a slight defect in dorsal glottis closure, as usually observed in patients with vocal fold nodules, vocal folds with (rather) straight margins show, during vibration, a zipper-like closing and opening pattern.

In contrary, slightly curved vocal fold edges would result in a localised impact, limited to a rather small part of the vocal folds. The corresponding description of the phoniatrician is then a "hour glass-shaped" vibration pattern. This configuration could result in a locally increased impact stress and impulse of the vocal fold tissue that could contribute to a higher load and increased probability of tissue damage.

In experiments on excised canine hemilarynges, higher subglottal pressure (and closer distance between the arytenoids) appeared positively correlated with peak impact stress during phonation [4]. Measurements in a similar excised canine larynx model showed that increases in subglottal pressure resulted in increased glottal gap, and in turn, increased acceleration and impact stress [6].

Vocal fold model

The simulations were carried out using the multiple-mass model "VOX" [2] which consist of a combination of two masses in the vertical and an arbitrary number of masses in the caudal-cranial dimension. For these calculations a number of 14 mass-pairs were used for each side.

According to the findings described in [1] the masses were adjusted according to the mean pre-phonatory rest positions for the female (n=10), male (n=9) and linear cases. A sub-glottal pressure of 980 Pa and an effective stress of 60 kPa was used. A dorsal gap between the vocal folds of 1.2 mm was assumed.

Results

Based upon the different vocal fold configurations described above, simulations were carried out using adequate vocal fold shapes in VOX, see figure 1.

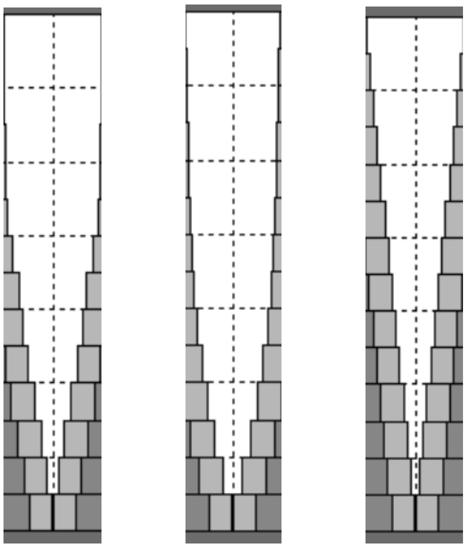

Figure 1: Comparison of vocal fold setting for male (left), female (centre), and linear (right) cases.

During continuous phonation the settings were changed, and the corresponding distribution of contact forces along the vocal fold length were recorded for the upper and the lower masses. The results of the calculation of contact forces in x-direction, i.e. in direction of the main oscillation, are shown in Figure 2.

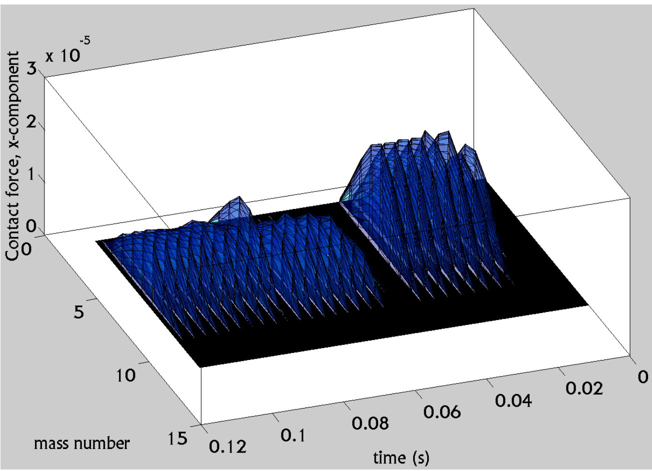

Figure 2: Comparison of successive simulation of the male, female and linear vocal fold configuration.

The visualisation of the maximum contact forces show different amplitudes and distributions for the three cases. The linear case exhibits the largest amplitudes but also the broadest distribution of contact forces along the vocal folds. In the case of the male configuration the amplitudes are smaller but the distribution is as broad as in the linear case. The simulations that are based on the female configuration show similar amplitudes as the male case, but the distribution is not as broad.

The temporal analysis exhibits different closing phases as well. In the linear case the vocal folds close successively along their length. In the male case, the closing is very similar. In the female case the closing starts at a location near the centre of the vocal folds and extends about one third of the vocal fold length in cranial and caudal directions.

Discussion

The simulations seem to support the assumption that the vocal fold shape plays an important role for the impact stress in colliding vocal folds. Gender-related differences in the simulation set-up correspond to results that seem to indicate that in females a more localised impact stress occurs in comparison to the male or linear cases.

Currently a JAVA tool has been developed for access to the vocal fold model. Future versions of this applet shall allow the simulation of normal and pathologic vocal fold configurations via web browser. The validation of our findings with experimental methods such as the measurement of contact forces during phonation [5, 4] and the determination of the vocal fold shape during phonation using innovative MRI techniques [7].

Acknowledgements

The work was done in the frames of the Innovative Teaching Fund of the University Hospital Aachen and COST Action 2103 “Advanced Voice Function Assessment”.

References

[1] Dejonckere, P.H.: Gender differences in the prevalence of occupational voice disorders: Some anatomical factors possibly contributing; in Dejonckere PH (ed.): Occupational voice, care and cure. The Hague, Kugler Publications, 2001, 11 - 20.

[2] Kob, M.: Physical modelling of the singing voice. Dissertation RWTH Aachen Univ., Logos, Berlin, 2002.

[3] Herrington-Hall, B. L., Lee, L., Stemple, J. C., Niemi, K. R., McHone, M. M.: Description of laryngeal pathologies by age, sex, and occupation in a treatment-seeking sample. J Speech Hear Disord **53** (1988), 57-64.

[4] Jiang, J.J., Titze, I.R.: Measurement of vocal fold intraglottal pressure and impact stress. J Voice **8** (1994), 132-144.

[5] Hess, M.M., Verdolini K., Bierhals W., Mannsmann U., Gross M.: Endolaryngeal contact pressures. J Voice **12** (1998), 50-67.

[6] Jiang J.J., Shah A.G., Hess M.M., Verdolini K., Banzali F.M., Hanson D.G.: Vocal fold impact stress analysis. J Voice **15** (2001), 4-14.

[7] Frauenrath, T., Niendorf, T., Kob, M.: Acoustic method for synchronization of Magnetic Resonance Imaging (MRI). Acta Acustica united with Acustica **94** (2008), 148-155.