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COMPUTER SIMULATION OF MUSICAL SINGER'S VOICE BASED ON MRI AND ACOUSTIC MEASUREMENTS

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Abstract: *An inverse method was used to estimate the vocal tract geometry as a 1 D model on the basis of acoustical characteristics of a professional musical singer before and after vocal exercising. The basic geometrical data for the model were obtained from magnetic resonance images (MRI) registered during sustained phonation of vowels [a:], [i:], [u:] produced in naive and professional ways (before and after exercising respectively). The model was used for numerical simulations of the voice signals. The results of simulation were compared to the acoustic recordings. According to the results, a singer's formant cluster was accomplished after exercising. It seemed to be due to lowering of the larynx and lengthening and narrowing of the epilarynx. The area ratio between the low pharynx and the epilarynx increased for [a:] but decreased for [i:] and [u:] after exercising being between 3.33 and 4.39. There was a qualitative agreement between 3D measurements of MRI and the results of modeling. The results suggest that for a singer's formant cluster a relatively low pharynx over epilarynx ratio may be sufficient, at least if the larynx lowers.*

Keywords: ***Biomechanics of voice, singer's and speaker's formant cluster, acoustic effects of vocal exercises.***

1. Introduction

In operatic singing, singers make use of a special voice quality in order to be heard over the orchestra without a microphone. The important acoustic component which determines the operatic quality of the voice is the so-called "singer's formant" (Sundberg, 2003; Titze, 2000). Similarly the voice quality of speakers, especially actors, is improved by the so-called "speaker's formant" (Leino et al., 2011). Sundberg (1974) formulated an acoustic interpretation of singer´s formant as clustering of formants F3 – F5 in the vicinity of 3 kHz. According to the calculations by Fant (1960) such a situation can occur if the ratio *R* of the cross-sectional area of the lower pharynx over the outlet of the epilaryngeal tube is six or higher. However, the physiological adjustment used in singers or in actors has not been known in sufficient details yet.

The rationale of the present paper was to estimate the anatomical/geometrical adjustments and to model the acoustic changes that occur in the voice of a male professional musical actor after vocal warming up by vocal exercises.

2. MRI measurement and 3D vocal tract modeling

A Czech male musical actor (60 years, baritone) served as a subject in the magnetic resonance imaging investigation. Lying supine in the MRI machine he first produced the vowels [a:], [i:], [u:] in a naive technique and after ca 5 minute vocal exercising again in a professional "musical actor's" manner, aiming at the best voice quality. Lengths of different parts of the vocal tract were measured from midsagittal images. The MR images revealed lowering of the larynx from the fourth to the fifth vertebra, rising of the soft palate, prolongation of the vocal tract and of the epilaryngeal tube,

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widening of the mouth cavity due to a lower position of the tongue, narrowing and lengthening of the epilaryngeal and lower pharyngeal region and widening of the higher pharynx for [i:], and narrowing of it for [a:] and [u:] in phonation after the vocal exercising.

The 3D model of the vocal tract was reconstructed from the MRI images. Especially the areas of the outlet of the epilarynx and the inlet of the low pharynx were studied from transversal slices of the 3D volume models of this part of the vocal tract. For all three vowels [a:], [i:] and [u:] after warm up the ratio was between R=3.33 and R=4.39, i.e. all ratios were lower than the value R=6 considered in the previous studies.

3. Acoustic measurements

The acoustic analyses showed that after exercising a cluster of two or three formants was formed for the vowel [a:] in the range of F3-F5 between 2 and 4 kHz, and similarly in the range of F2-F4 between 1.4 and 3.4 kHz for the vowel [i:] and in the range of F3-F4 between 1.8 and 3 kHz for the vowel [u:]. Such clustering of the higher formants leads to a stronger speaker's/singer's formant.

4. Modeling approach

The possible vocal tract changes resulting in the formation of a speaker's (or singer's) formant cluster were also studied using a 1D mathematical model of voice production (Radolf, 2010). The 1D vocal tract model was developed from the 3D volume model obtained from the MR images (Vampola et al., 2008). The formant frequencies measured from the vowels [a:], [i:] and [u:] recorded from the subject of the present study before and after exercising were prescribed to the model and by a tuning inverse procedure. The resulted area ratios R were obtained between R=2.35 and R=4.10.

5. Conclusions

The area ratios of the lower pharynx over the epilaryngeal tube were lower than earlier hypothesized for the male singers' voice. The results suggest that the origin of the singer's formant is not necessarily associated with an increase of the pharyngeal over the epilaryngeal cross-sectional area ratio but can also be obtained by other geometrical changes of the vocal tract cavity. The conclusions should be considered with caution because all results are only for one subject investigated.

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