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# VIBRATIONS OF FACIAL TISSUES DURING PHONATION IN "RESONANT" AND "NON-RESONANT" VOICE QUALITY

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**Abstract:** *This preliminary study measures the facial vibrations using accelerometric and vibrometric sensors placed on the positions where the vibrations were observed. From acceleration and velocity, the RMS values of displacement were obtained and their spectra were studied. One female with singing background was studied when phonating syllable strings on [pa:], [pi:] and [pu:] in speaking voice using resonant and non-resonant voice qualities. Acoustic signal, oral air pressure and electroglottogram (EGG) were also registered. The results suggested that the facial vibrations are dominantly excited at the fundamental frequency $f_0$ by the acoustic signal, which is for the resonant voice rather associated with lowering the first formant frequency by prolongation of the vocal tract.*

**Keywords: Resonant voice, Accelerometry, Laservibrometry, Oral pressure, EGG and acoustic signals**

## 1. Introduction

The so-called "resonant voice" is an important goal in voice training and therapy. It is well-projecting, feels easy to produce and causes sensations of vibrations on the facial area (Verdolini et al., 1998; Smith et al., 2005). Acoustically, it has been found to imply tuning of the first vocal tract resonance to the lowest voice source harmonics (Barrichelo-Lindström & Behlau, 2009). Physiologically, resonant voice is produced with barely adducted vocal folds (Verdolini et al., 1998). This is, according to modelling, efficient and vocally economic as it reduces impact stress posed on the vocal fold tissue (Zhang, 2020). Phonation with barely adducted vocal folds results in voice with larger glottal flow amplitude and stronger first partial (Sundberg, 2022).

Earlier studies have observed that phonation related facial vibrations are vowel dependent. Forehead, cheek and lower mandible were found to resonate most for closed vowels /i, u/, and least for open vowel /a/ (Kirikae et al., 1964). Since the strongest acoustic component in voice is typically the partial nearest the first formant (F1), facial vibrations have been explained as co-vibrations of F1.

Skull resonates at high frequencies, the lowest resonance frequencies being around 972 Hz and 1230 Hz according to Håkansson et al. (1993). More insights were obtained by the study of Horáček et al. (2004), which was focused on frequency modal analysis of human skull *in vitro*. The influence of the soft brain tissue on dynamics of the skull was simulated by especially prepared gelatin. The lowest resonance frequency was found around 1100 Hz. The most sensitive place to the vibration excitation of the skull was found at the edge of hard palate, behind the front teeth.

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## 2. Methods

Facial and laryngeal vibrations were registered by two accelerometers (ACC1 and ACC2) and two laser vibrometers (LV1 and LV2) placed on the facial area and on the larynx, to obtain skin acceleration level (SAL) and skin velocity level (SVL). Accelerometer ACC1 and vibrometer LV1 measured the voice source signal on larynx, and ACC2 and LV2 measured the skin acceleration and velocity signals on ear and on nose, respectively, see Fig.1.

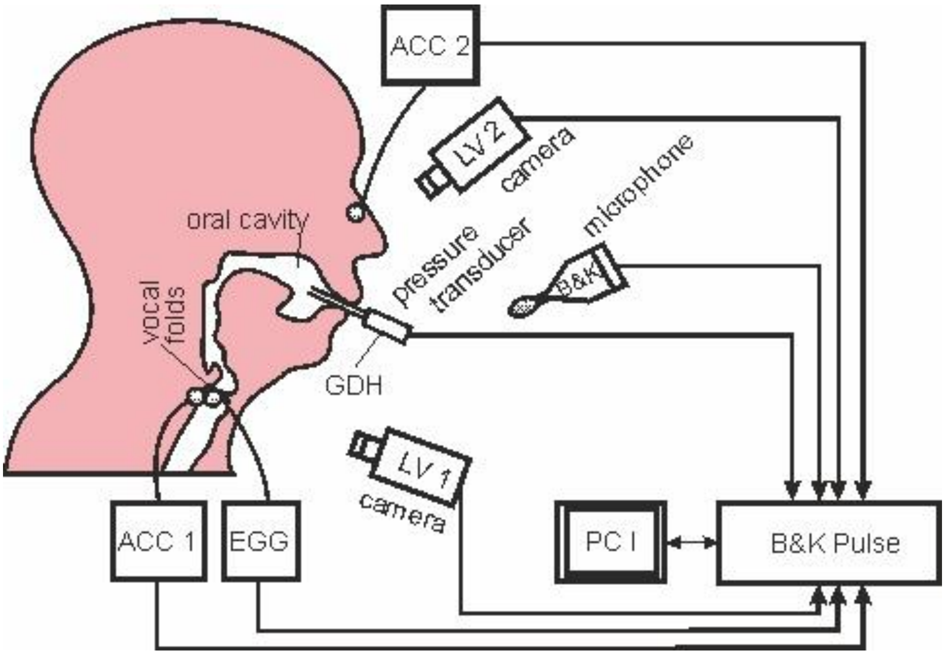


*Fig. 1: Scheme of the measurement set-up.*

The vibratory displacements in time domain were obtained by numeric integration. For this pilot investigation, we focus on one female subject only. Examples of evaluated vibratory displacements of the facial tissues in time domain are shown in Fig. 2.

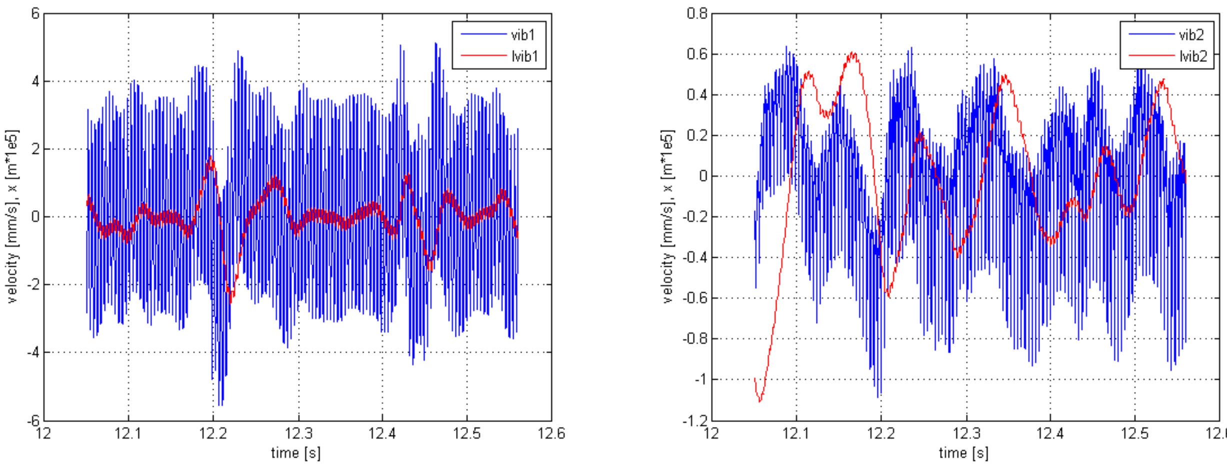


*Fig. 2: Estimation of structural displacements (marked by red lines) in time domain obtained from velocities of the skin measured by laser vibrometers LV1 on larynx (marked in subpicture by Ivib1) and by LV2 on nose (marked by Ivib2). Measurement for resonant phonation [pa:] by female 2 within the time interval 12.05-12.55 s with the fundamental frequency* $f_0$=233 Hz.

## 3. Results

Figure 3 shows examples of spectra obtained from the sounds measured by microphone in front of the lips and by pressure transducer in the mouth. Clearly visible are formants F1=ca 730 Hz, F2=ca 1200 Hz and F3=ca 2800 Hz measured by microphone. The strongest SPL=ca 140 dB is measured at F1 in mouth cavity at the third harmonic.

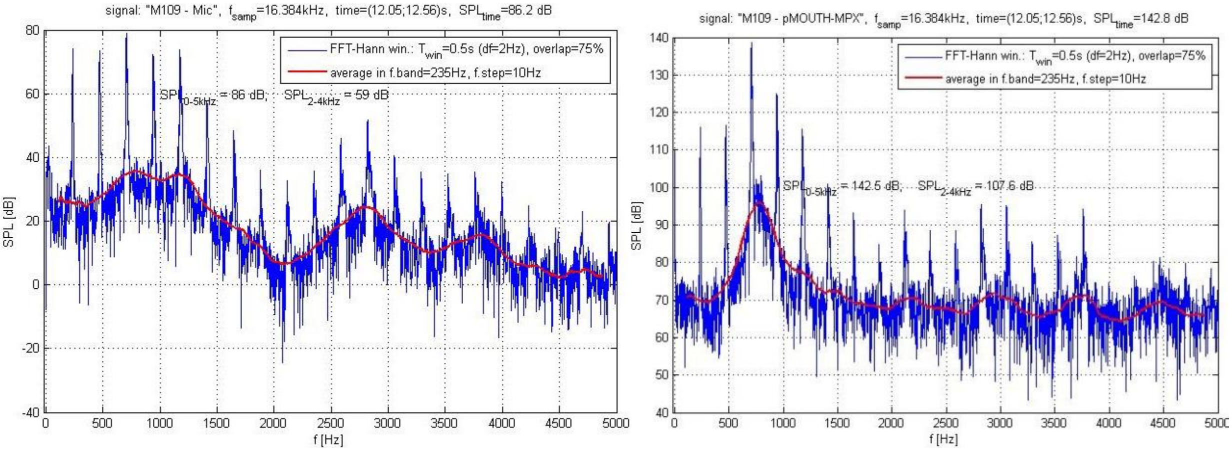


*Fig. 3: SPL (sound pressure levels) measured by external microphone 13 cm from the mouth and in oral cavity. Measurement for resonant phonation [pa:] by female 2 within the time interval 12.05-12.55 s with the fundamental frequency $f_0$ =233 Hz.*

Figure 4 presents spectra of the displacement signals obtained by integration of time signals measured by vibrometers VIB1 and VIB2, and by accelerometers ACC1 and ACC2. Maxima of skin displacements levels (SDL) are in all four cases dominant at the first harmonics. Formants F1 and F2 are slightly detectable in the displacement's spectra.

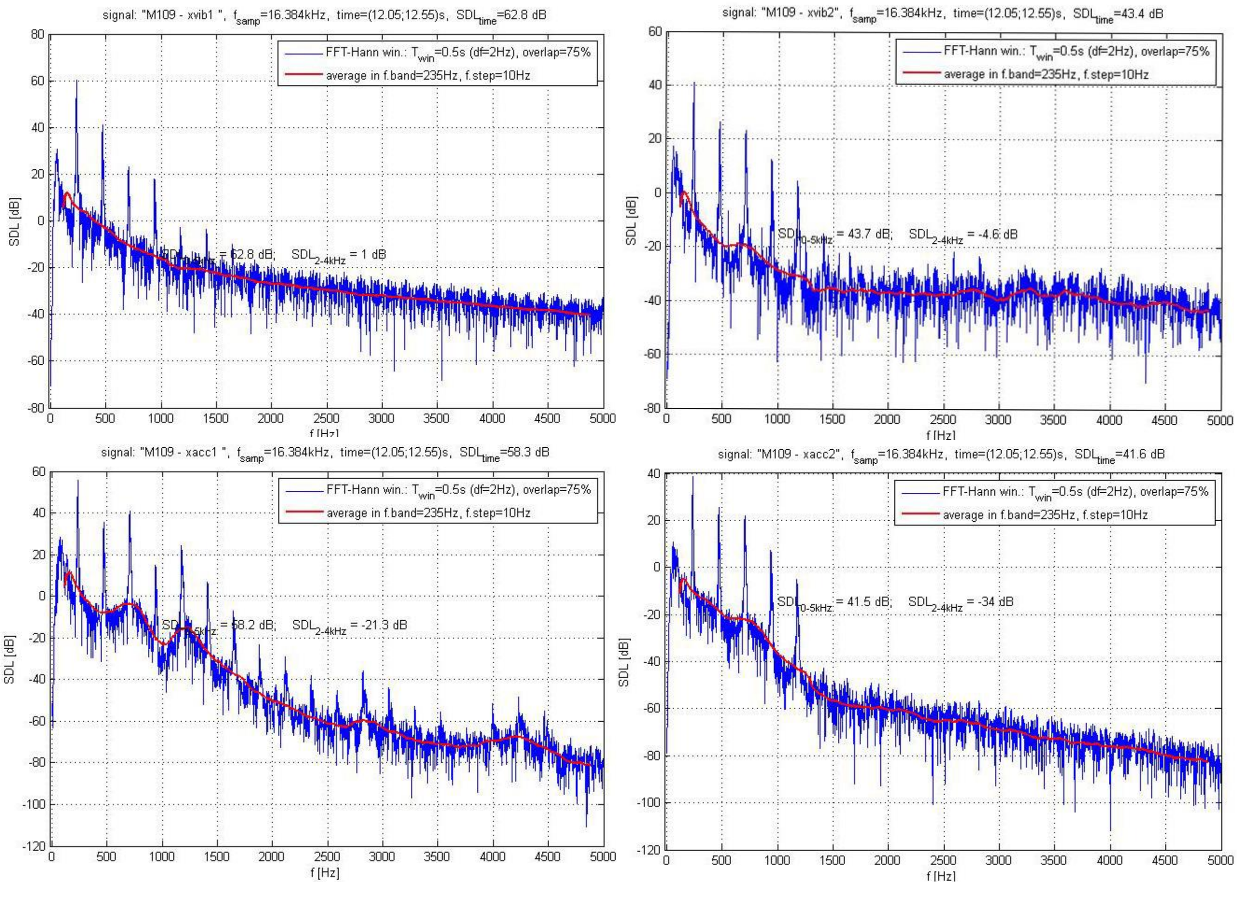


*Fig. 4: Spectra of structural skin displacements levels (SDL) measured by laser vibrometers LV1 near larynx (marked by vib1 in first row left) and LV2 on nose (marked by vib2 in first row right) and by accelerometers ACC1 placed on larynx (marked by acc1 in lower row left) and by ACC2 placed near the ear (marked by acc2 in lower row right). Measurement is presented for resonant phonation [pa:] by female 2.*

Table 1 compares the measured data for resonant voice, that correspond to Figs. 2-4, with the data for non-resonant voice. The RMS displacement values measured on ear for non-resonant voice are lower than for resonant voice. In opposite, the RMS and the level of the first harmonic $L_1$ on nose are higher for non-resonant voice. Formants F1-F4 are visible in the spectrum of the microphone signal.

*Tab. 1: Comparison of resonant and non-resonant phonation data for vowel [a:] (from [pa:]).*

| **Displacements computed from time signals:** | VIB1 larynx | VIB2 nose | ACC1 larynx | ACC2 ear |
|---|---|---|---|---|
| RMS displacement [μm] average for resonant voice | 5.18 | 2.68 | 5.93 | 2.72 |
| RMS displacements [μm] average for non- resonant voice | 3.67 | 2.93 | 4.53 | 1.90 |
| **Data resulted from spectra SDL [dB] of displacements** | | | | |
| $L_1$ [dB] resonant | 60.0 | 41.9 | 55.8 | 39.1 |
| $L_1$ /dB/ non- resonant | 58.9 | 45.0 | 52.7 | 40 |
| F1 [Hz] resonant | not detected | 640 | 688 | 620 |
| F1 [Hz] non-resonant | 535 | 675 | 725 | not detected |
| F2 [Hz] resonant | 1285 | 1140 | 1209 | 1225 |
| F2 [Hz] non-resonant | 1450 | 1400 | 1250 | 1400 |

## 4. Conclusions

Rather than corresponding to the previously measured mechanical (vibrational) resonances of the human head, the facial vibrations appear to correlate with the acoustic pressure oscillations in the mouth, corresponding to L1 level at the first harmonic frequency $f_0$ of the voice. The resonant voice shows lowering the first two formant frequencies F1, F2 closer to the frequency $f_0$. This effect can be attributed to prolongation of the vocal tract. The RMS displacements and the level of the first harmonic show contradicting results at the larynx, nose and ear for the resonant versus non-resonant phonations in these pilot data. We plan these to be readdressed in future investigations.

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