VIBRATIONS OF FACIAL TISSUES DURING PHONATION IN “RESONANT” AND “NON-RESONANT” VOICE QUALITY

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Introduction

So-called **"resonant voice"** is an important goal in voice training and therapy 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 harmonics (Barrichelo-Lindström & Behlau, 2009).

Physiologically, resonant voice is produced with barely adducted vocal folds (Verdolini et al., 1998) and with larger glottal flow amplitude and stronger first partial (Sundberg, 2022).

According to modelling (Zhang, 2020), resonant voice reduces impact stress posed on the vocal fold tissue.

Barrichelo-Lindström,V. and Behlau, M. (2009) Resonant voice in acting students: perceptual and acoustic correlates of the trained y-buzz by Lessac. Journal of Voice, 23, 5, pp. 603-609.
Smith, CG., Finnegan, EM. and Karnell, MP. (2005) Resonant voice: spectral and nasoendoscopic analysis. Journal of Voice, 19, 4, pp. 607–622.
Sundberg, J. (2022) Objective characterization of phonation type using amplitude of flow glottogram pulse and of voice source fundamental. Journal of Voice 36, 1, pp. 4-14.
Verdolini, K., Druker, DG., Palmer, PM. and Samawi, H. (1998) Laryngeal adduction in resonant voice. Journal of Voice 12, 3, pp. 315-327.
Zhang, Z. (2020) Laryngeal strategies to minimize vocal fold contact pressure and their effect on voice production. J Acoust Soc Am, 148, 2,

Earlier studies of facial vibrations

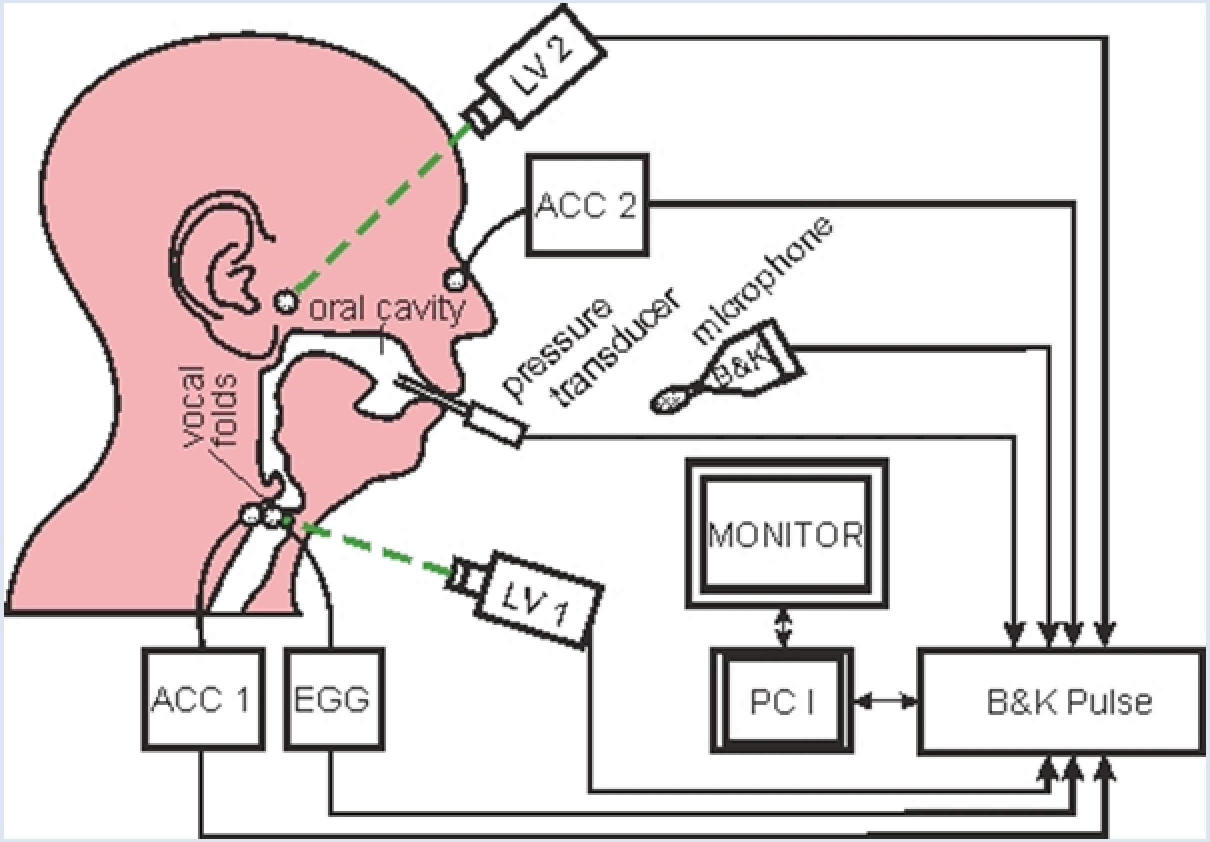
It was observed that facial vibrations are vowel dependent. Forehead, cheek and lower mandible were found to resonate most for closed vowels /i, u/, and less for open vowel /a/. The strongest acoustic component in voice is typically the partial nearest the first formant (F1) (Kirikae et al., 1964).

Skull resonates at high frequencies, the lowest resonance frequencies being around 972 Hz and 1230 Hz according to Håkansson et al. (1993).

The lowest resonance frequency of human skull in vitro was found around 1100 Hz, when the soft brain tissue was substituted by a gelatine, and the most sensitive place to the vibration excitation of the skull was found at the edge of hard palate, behind the front teeth (Horáček et al. 2004).

- **Kirikae, J., Sato, T., Oshima, H. and Nomoto, K. (1964) Vibration of the body during phonation of vowels. Rev. de Laryngologie, Otologie, Rhinologie 85, pp. 317-345.**
- **Håkansson, B., Brandt, A., Carlsson, P. and Tjellström, A. (1994) Resonance frequencies of the human skull in vivo. The Journal of the Acoustical Society of America, 95, 3, pp. 1474-1481.**
- **Horáček, J., Veselý, J., Pešek, L. and Vohradník, M. (2004) Fundamental dynamic characteristics of human skull. Engineering Mechanics, 11, 2, pp. 139 –158.**

Schema of the measurement



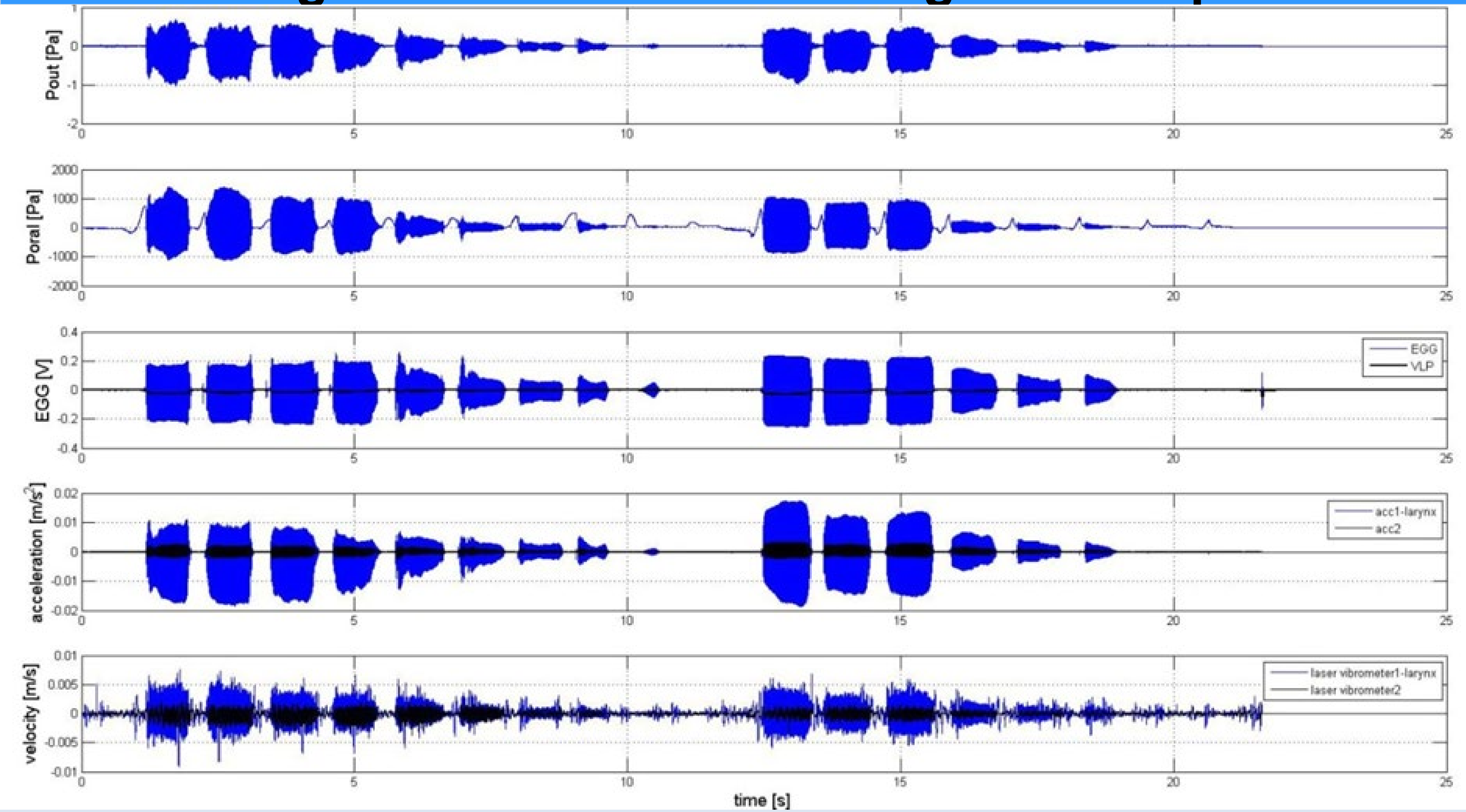
Measurements of external acoustic signal, pressure in oral cavity, EGG signal and laryngeal and facial surface vibrations measured by accelerometers ACC1 and ACC2
and laser vibrometers LV1 and LV2.
The recording was made using 16 kHz sampling frequency and 16-bit resolution.
The measured signals were recorded by the PC controlled B&K measurement system PULSE 10.

MEASUREMENT SET UP
Experiment arrangement during a participant's phonation [pa:], [pi:] and [pu:]

Measurement of voice sound by microphone outside and by air pressure in mouth using the pressure sensor connected with the oral cavity by a compliant plastic tube with inner diameter of about 1.5 mm.

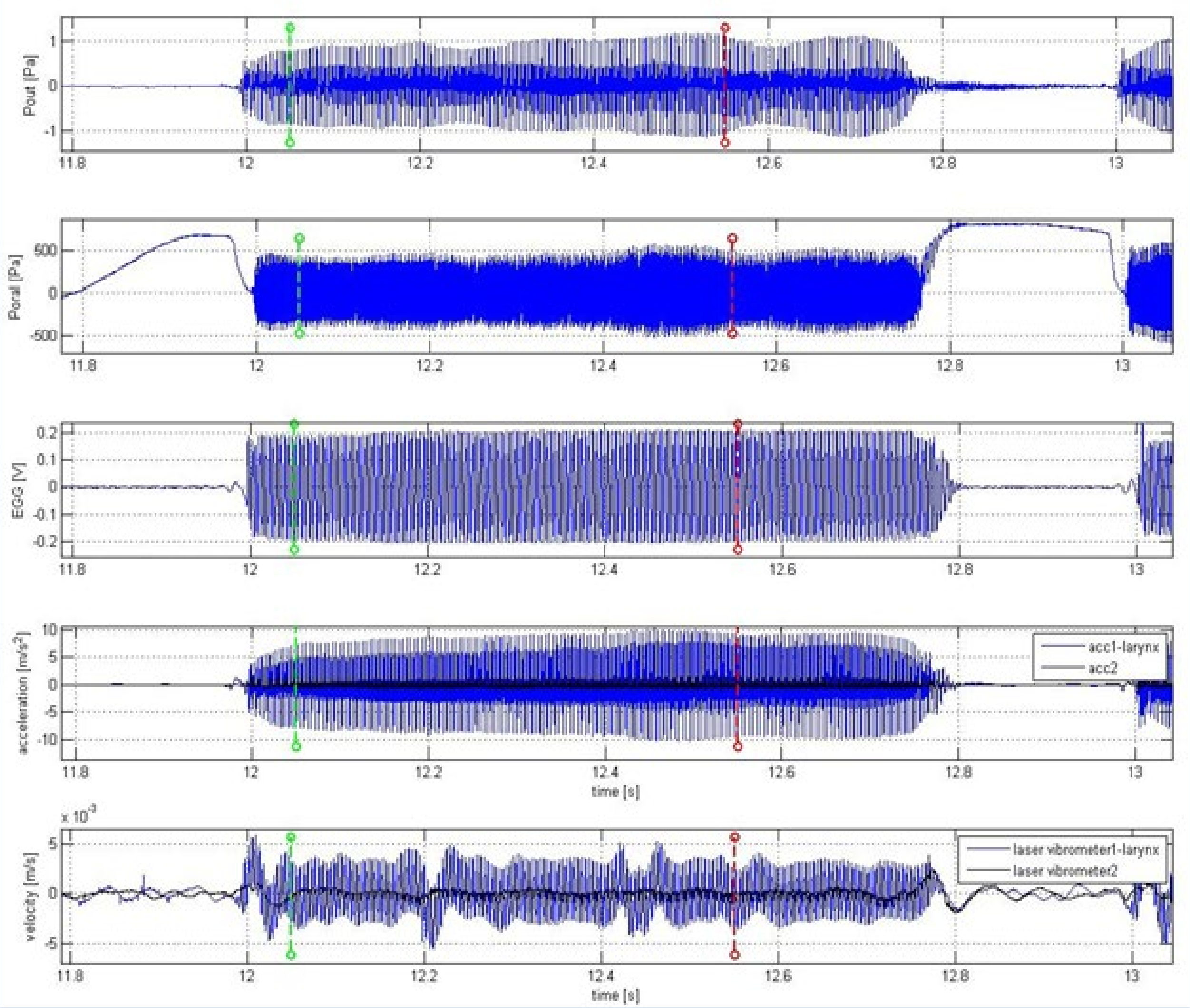
The subject was keeping the lips firmly sealed around the tube at the corner of the mouth to measure oral pressure fluctuation and during the production of voiceless plosive [p] was giving an estimate of subglottic pressure Psub.

Example of uttering diminuendo on /pu: pu:/, all time signals are recorded during one complete trial



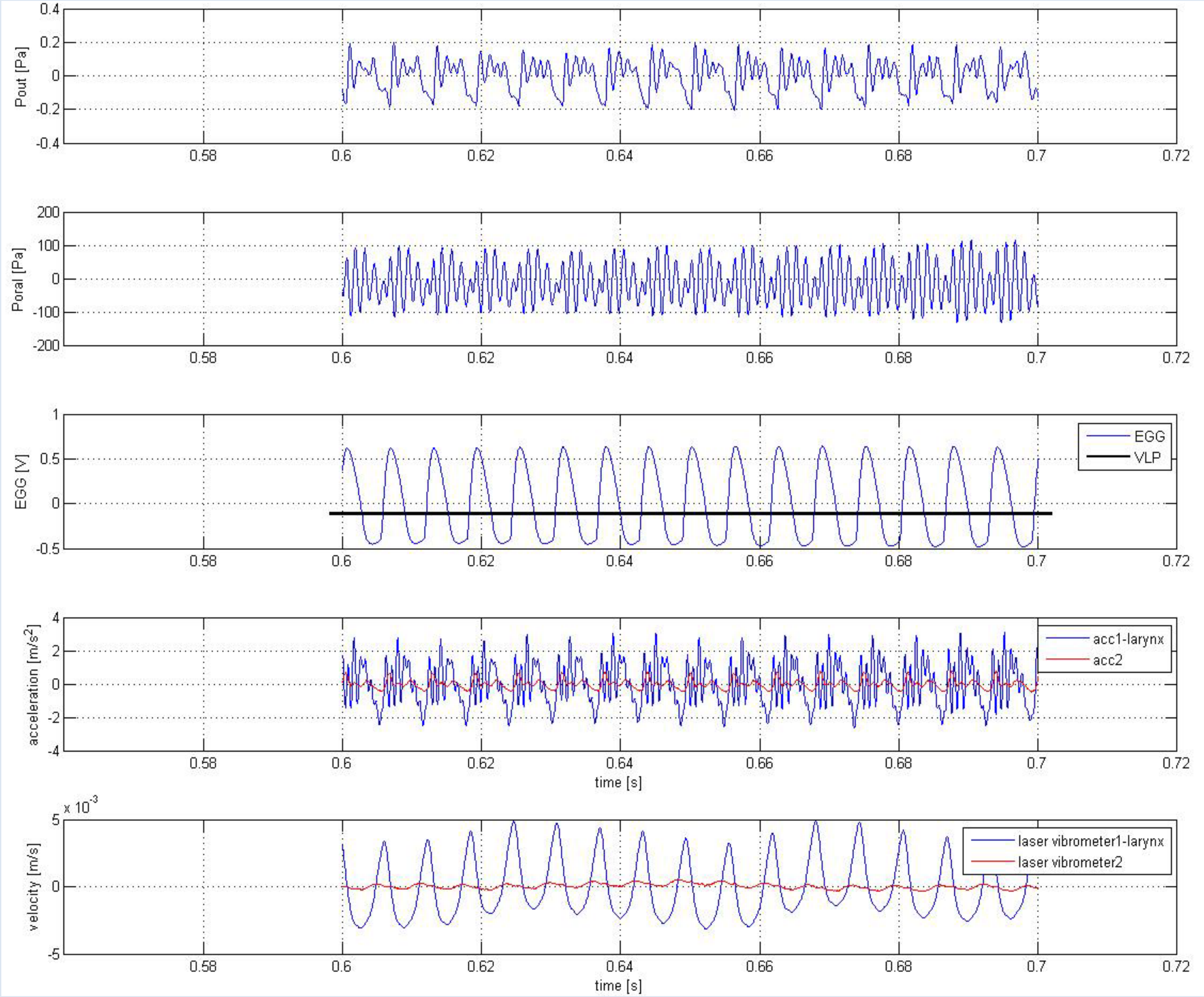
Phonation diminuendo for /pu: pu:/, first in **non-resonant voice** and then in **resonant voice**. Signals from top: microphone signal, Poral, EGG and VLP signals (blue and black, respectively), accelerometric signals (ACC1 and ACC2) and laser vibrometric signals (LV1 and LV2) (for the latter two signals: blue line: registration from the larynx, black line: registration from the face).

Example of recorded time signals for one trial uttering /pa:/



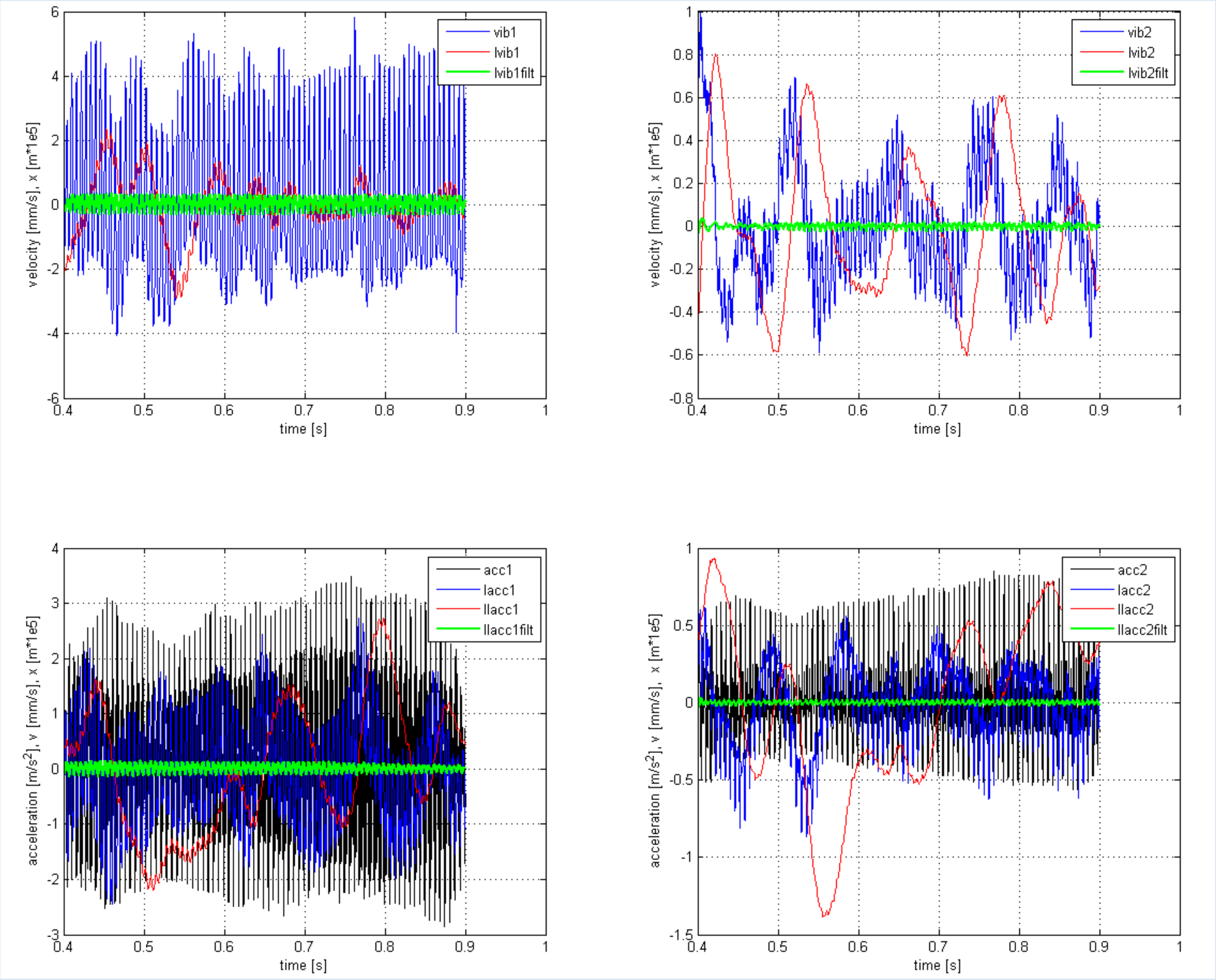
From top: microphone signal, Poral signal, EGG and VLP (vertical position of the larynx) signals (blue and black, respectively), two accelerometers and laser vibrometers signals (blue lines: registration from the larynx, black line: registration from the face).

Evaluated part of recorded time signals for uttering /pa:/



Example of the chosen part of the signals for evaluation of the SPL and RMS values from microphone signal, Poral signal, EGG and VLP (vertical position of the larynx) signals (blue and black, respectively), two accelerometers and laser vibrometers signals (blue lines: registration from the larynx, red lines: registration from the face).

Evaluated structural displacements for /pa:/



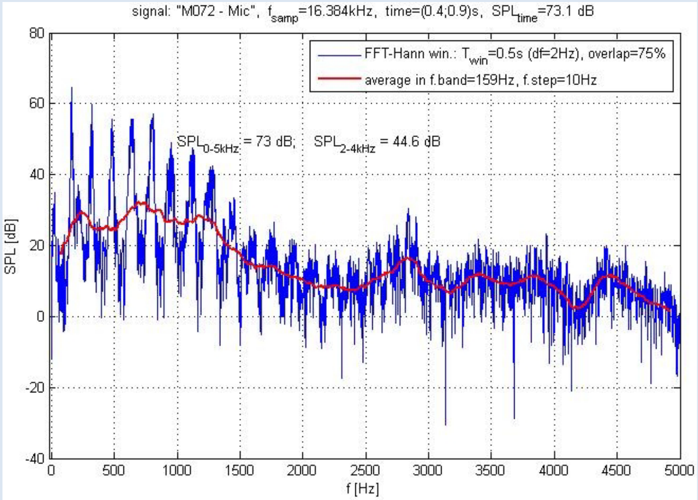
Estimation of structural displacements (marked by green lines) in time domain <u>obtained by integration</u> from velocities of the skin measured by the laser vibrometers: 1/ LV1 on larynx (marked in subpicture by lvib1) and 2/ LV2 on nose (marked by lvib2), and from the accelerometers: 1/ ACC1 on larynx (marked in subpicture by lacc1) and 2/ ACC2 on nose (marked by lacc2) . This measurement was for resonant phonation on [pa:] by female 1 using the fundamental frequency ca =160 Hz and subglottic pressure Psub=115 Pa.

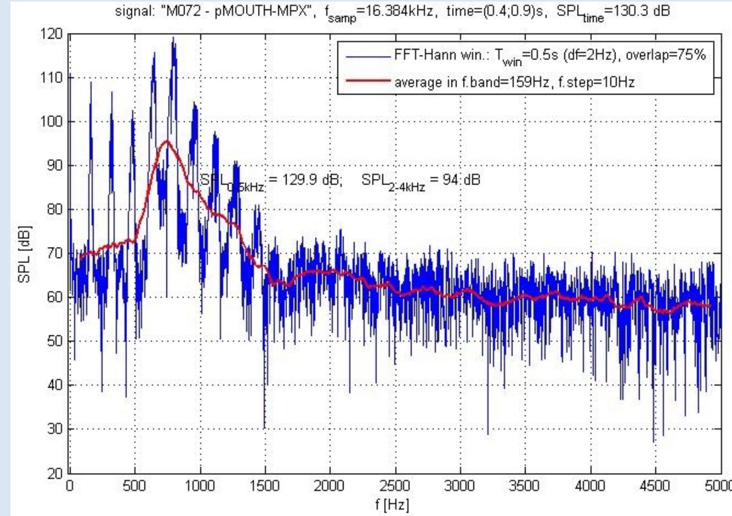
SPL measured by microphone and in mouth

resonant

f0=160 Hz

Psub=115 Pa

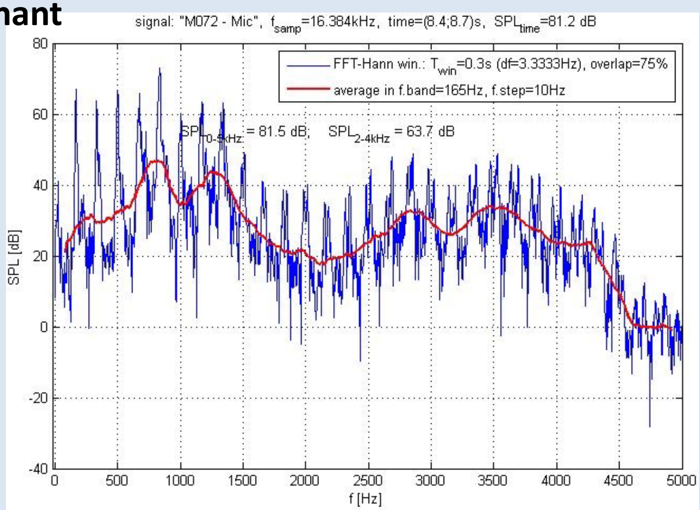


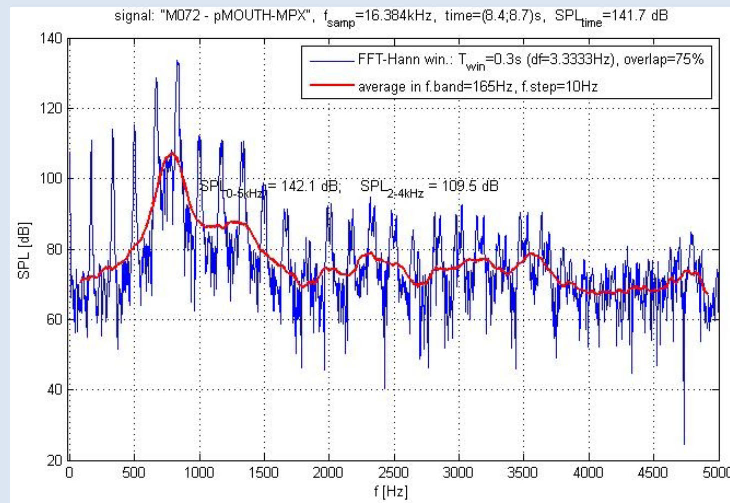


non-resonant

f0=165 Hz

Psub=260 Pa





microphone

oral cavity

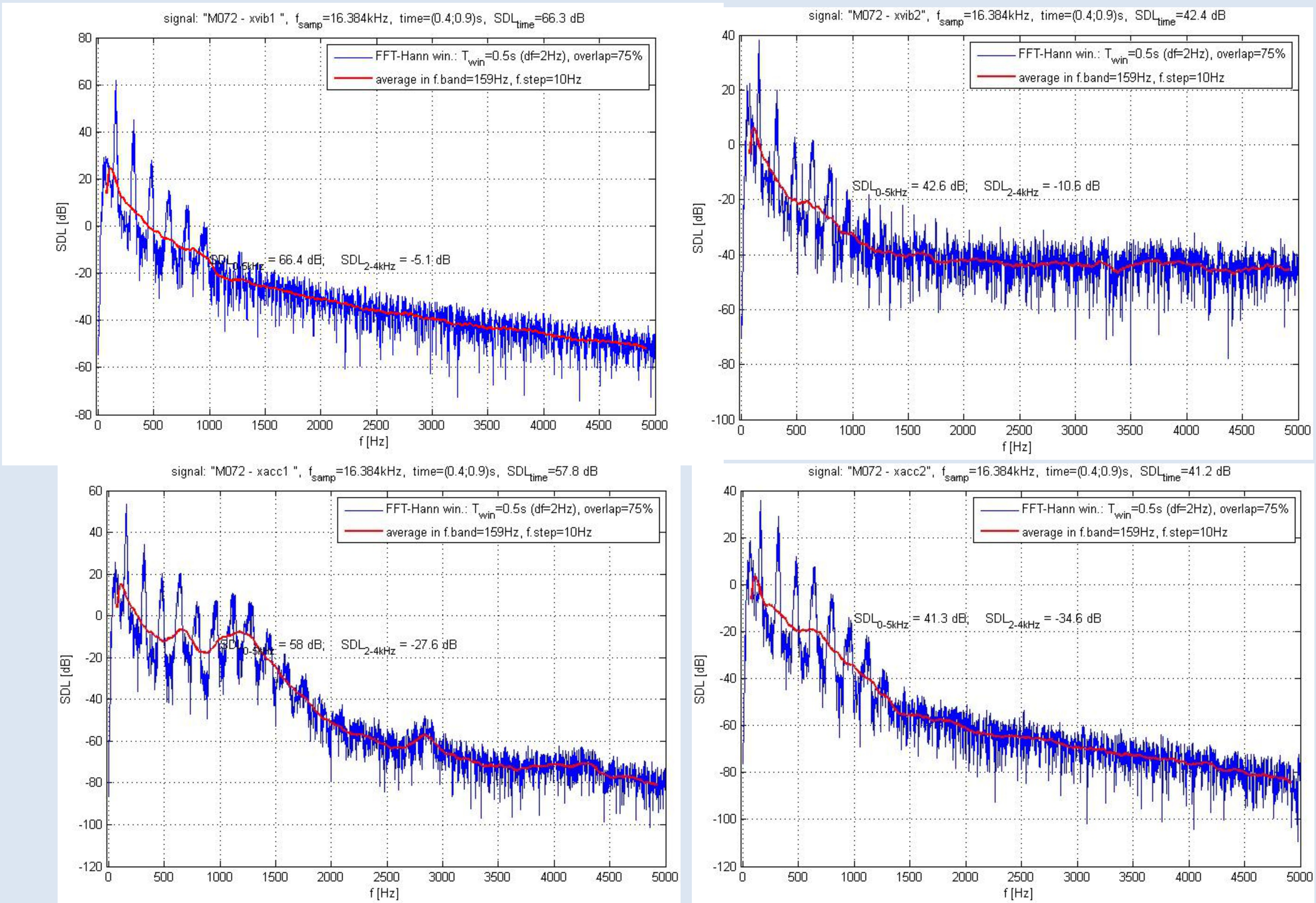
SPL (sound pressure levels) measured by external microphone 13 cm from the lips and in oral cavity. Measurement by female 1 for resonant and non-resonant phonation [pa:].

Spectra of structural skin displacements levels (SDL)

resonant

f0=160 Hz

Psub=115 Pa



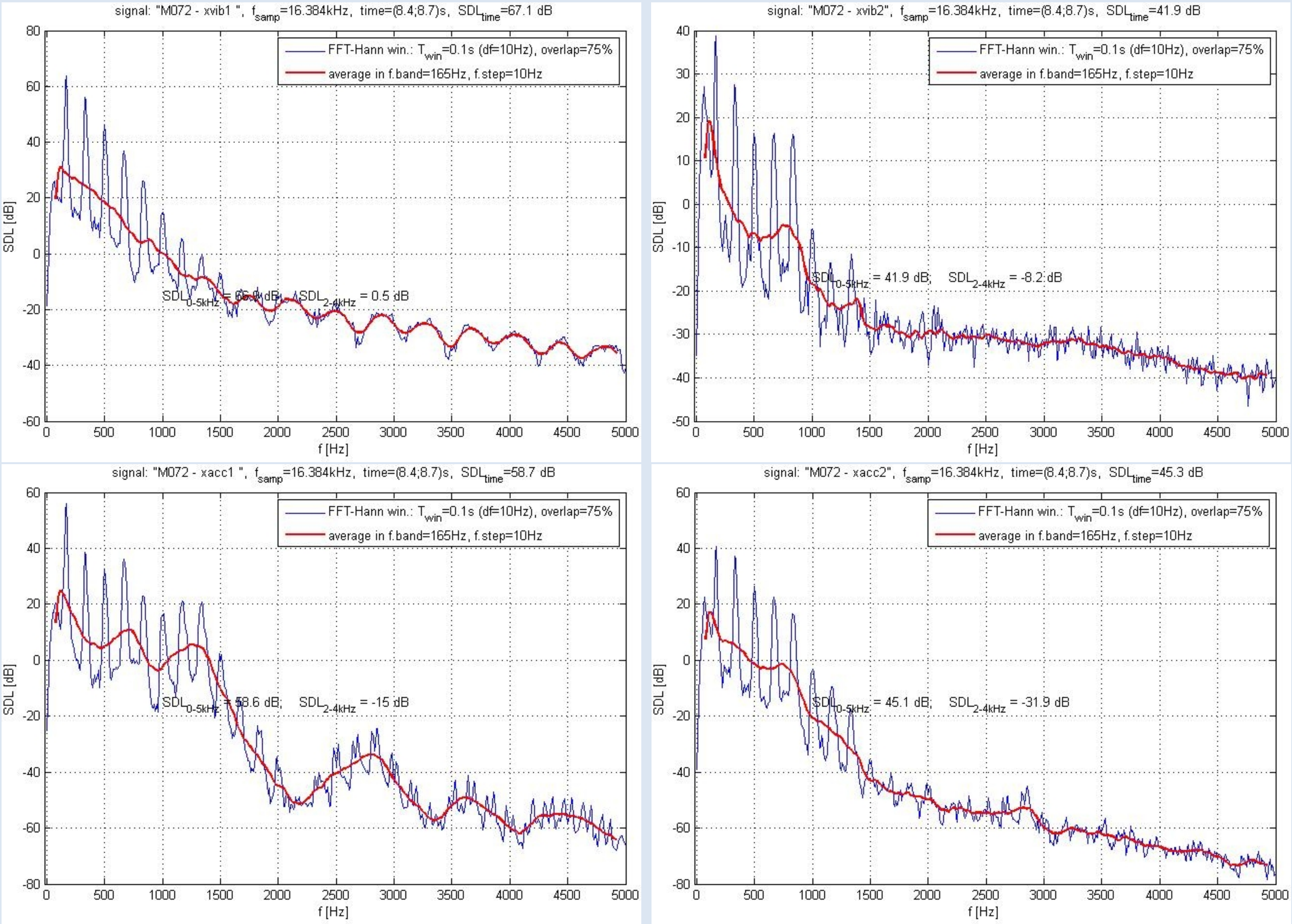
Spectra were measured by laser vibrometers LV1 near larynx (marked by vib1 in first row left) and LV2 on nose (marked in first row by vib2 right) and by accelerometers ACC1 placed on larynx (marked by acc1 in lower row left) and by ACC2 placed near the ear (marked by acc2 in lower row right). Measurement is presented for resonant phonation [pa:] by female 1.

Spectra of structural skin displacements levels (SDL)

non-resonant

f0=165 Hz

Psub=260 Pa



Spectra were measured by laser vibrometers LV1 near larynx (marked by vib1 in first row left) and LV2 on nose (marked in first row by vib2 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

Comparison of resonant and non-resonant phonation data for vowel [a:]

Female 1

Displacements computed from time signals (M109):	VIB1 larynx	VIB2 nose	ACC1 larynx	ACC2 ear
RMS displacement [µm] average for resonant voice	**1.300**	0.165	**0.815**	0.122
RMS displacements [µm] average for non- resonant voice	1.270	**0.265**	0.633	**0.150**
Data resulted from spectra SDL [dB] of displacements				
L_1 [dB] resonant	**60.3**	40.9	**55.6**	38.7
L_1 /dB/ non- resonant	58.9	**44.5**	52.7	**40.1**
F1 [Hz] resonant	/	640	697	620
F1 [Hz] non-resonant	/	/	720	/
F2 [Hz] resonant	/	1140	1228	1225
F2 [Hz] non-resonant	/	/	1244	1400

i

Female 2

Displacements computed from time signals (M072):	VIB1 larynx	VIB2 nose	ACC1 larynx	ACC2 ear
RMS displacement [µm] average for resonant voice	2.09	**0.14**	0.61	0.13
RMS displacements [µm] average for non- resonant voice	2.09	0.10	**0.72**	**0.15**
Data resulted from spectra SDL [dB] of displacements				
L_1 [dB] resonant	61.8	**38.1**	50.9	36.5
L_1 /dB/ non- resonant	**62.8**	35.6	**54.5**	**38.6**
F1 [Hz] resonant	/	590	650	600
F1 [Hz] non-resonant	/	750	750	750
F2 [Hz] resonant	/	/	1170	/
F2 [Hz] non-resonant	/	1400	1250	/

Comparison of resonant and non-resonant phonation data for vowel [a:]

RESULTS FOR L1 computed from spectra RMS DISPLACEMENTS

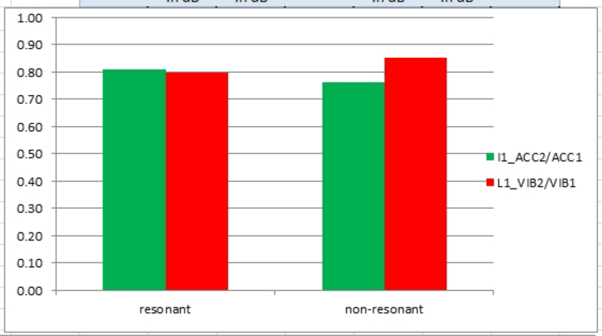
Zuzka [pa:]	M109 [	L1_AC	L1_ACC	I1_ACC	L1_VIB	L1_VIB	L1_VIB
Psub=650Pa	resonant	55.80	39.10	0.81	60.00	41.90	0.80
Psub=175Pa	non-resor	52.70	40.00	0.76	58.90	45.00	0.85
		in dB	in dB		in dB	in dB	

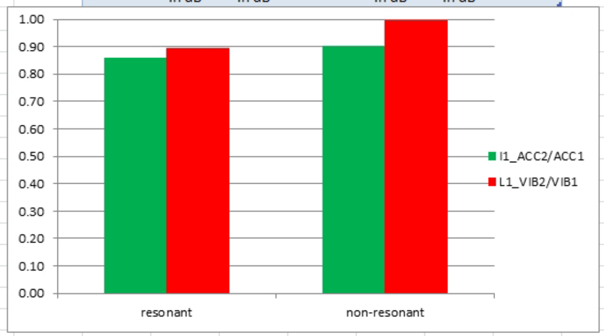
RESULTS FOR L1 computed from spectra RMS DISPLACEMENTS

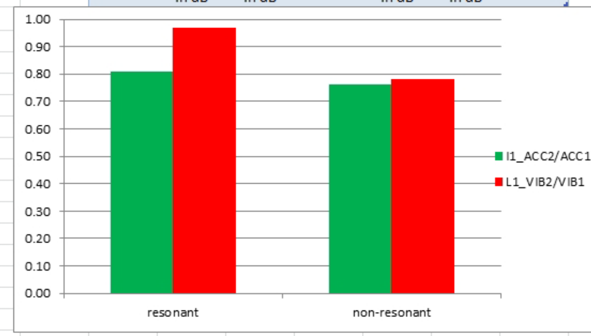
Zuzka [pi:]	M112 [	L1_AC	L1_ACC	I1_ACC	L1_VIB	L1_VIB	L1_VIB
Psub=700Pa	resonant	62.20	53.60	0.86	60.00	53.80	0.90
Psub=335Pa	non-resor	58.60	53.00	0.90	55.10	54.90	1.00
		in dB	in dB		in dB	in dB	

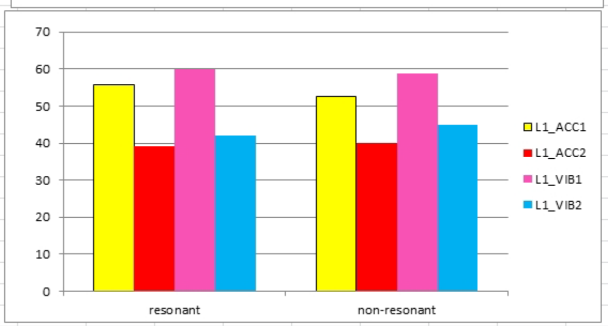
RESULTS FOR L1 computed from spectra RMS DISPLACEMENTS

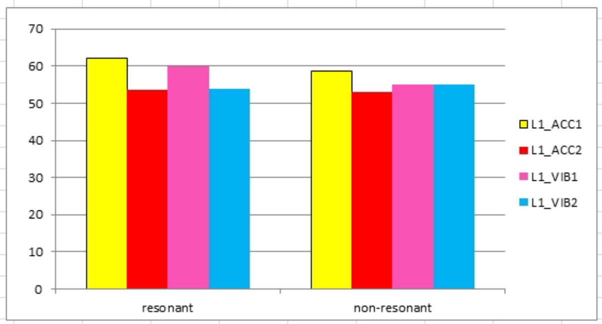
Zuzka [pu:]	M114 [	L1_AC	L1_ACC	I1_ACC	L1_VIB	L1_VIB	L1_VIB
Psub=520Pa	resonant	62.40	50.40	0.81	59.00	47.00	0.97
Psub=565Pa	non-resor	56.80	43.30	0.76	57.70	49.20	0.78
		in dB	in dB		in dB	in dB	

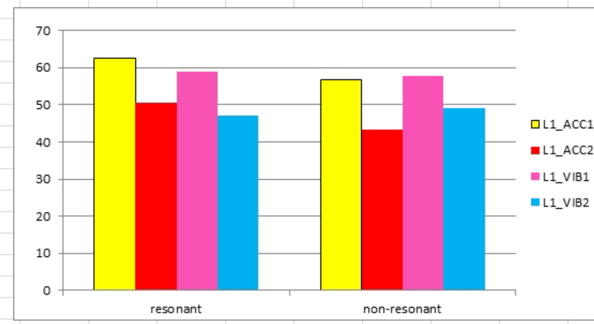












Conclusions

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 measured facial vibrations on human skin are forcedly excited by acoustic pressure fluctuations.

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.

References

- Barrichelo-Lindström,V. and Behlau, M. (2009) Resonant voice in acting students: perceptual and acoustic correlates of the trained y-buzz by Lessac. Journal of Voice, 23, 5, pp. 603-609.
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