EXPERIMENTAL INVESTIGATION OF FLUID-STRUCTURE-ACOUSTIC COUPLINGS BY STUDYING THE RESONANCE PROPERTIES OF VOCAL TRACT MODELS WITH YIELDING WALLS

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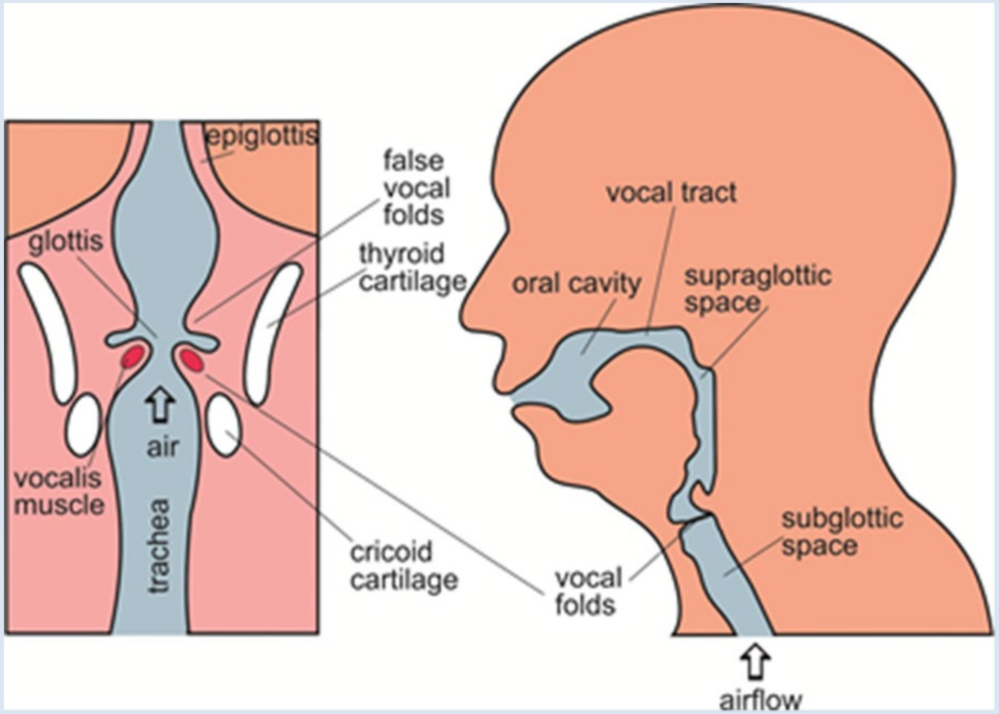
INTRODUCTION

Human voice - produced by self-oscillating vocal folds (VF) excited by air flowing from the lungs.

VF vibration - modulates the stream of air generating the primary sound.

This sound propagates inside the supraglottal cavities (i.e., in the vocal tract - VT) which modify its quality.

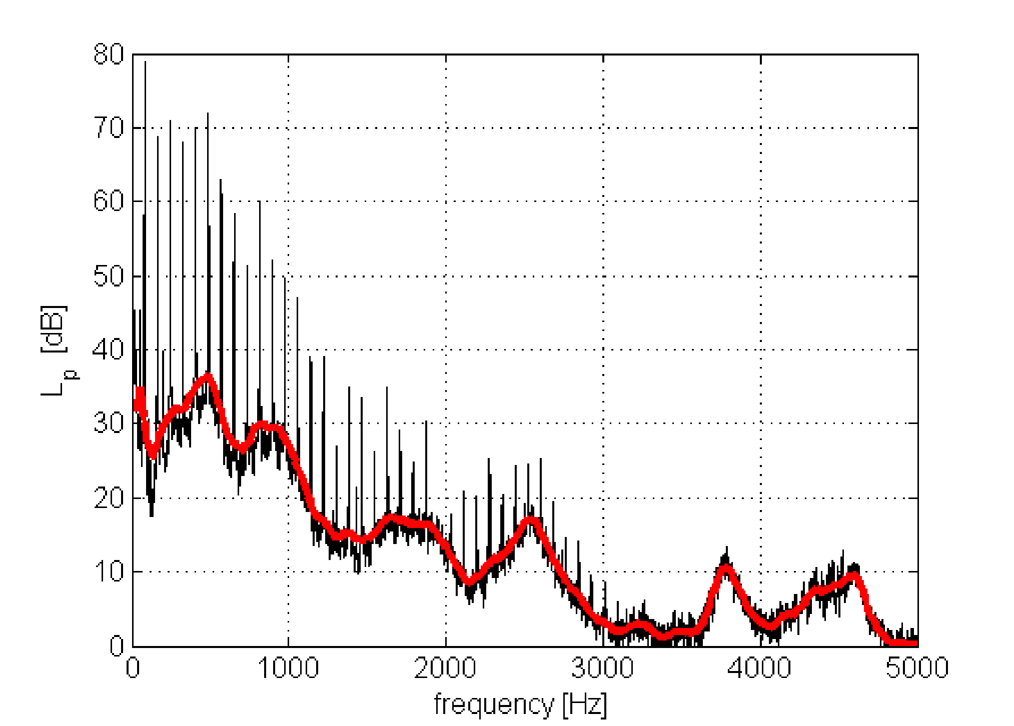


INTRODUCTION

Acoustic resonances of VT
 – create so-called formants - peaks in the envelope of the voice spectrum.

Formants define vowels and the voice timbre.

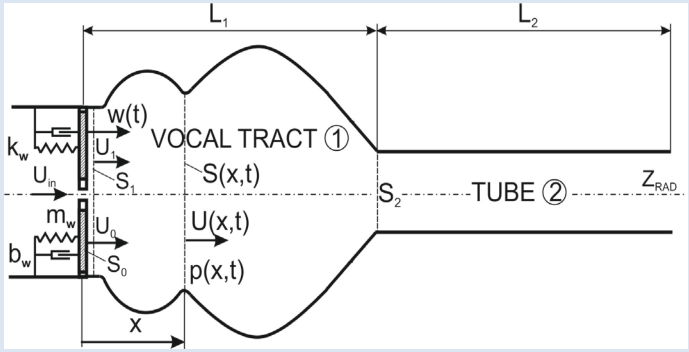
Final sound quality - given both by characteristics of VF vibration and by VT properties, see e.g. [1].



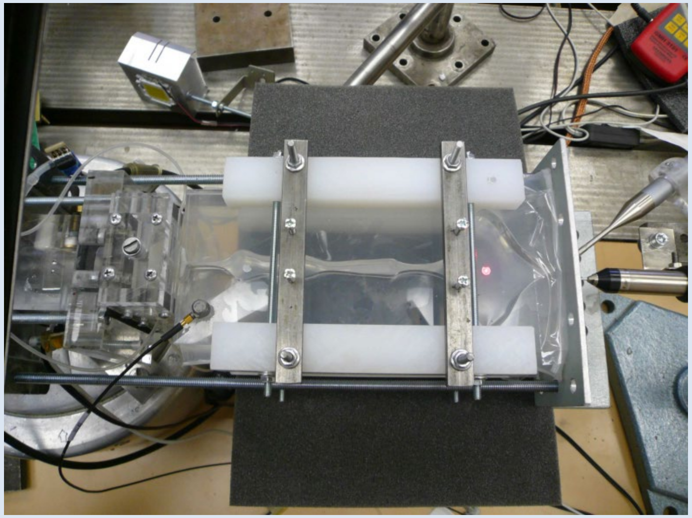
[1] Sundberg J.: The science of the singing voice, DeKalb, Illinois: N. Illinois Univ. Press, 1987.

INTRODUCTION

Compliance of the soft tissues of VT
- influence freq. and amplitude of formants
  - mainly the lowest formant frequencies [2].



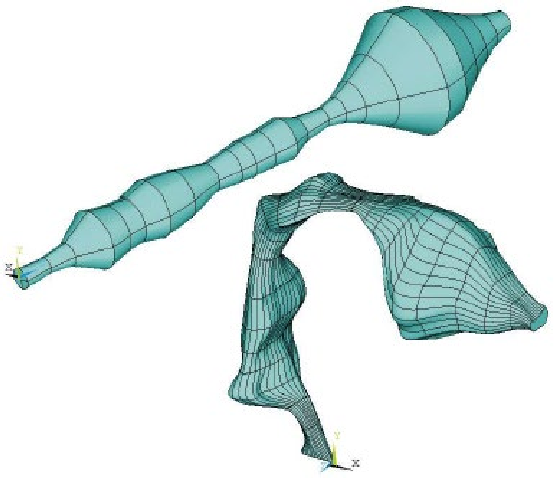
Experimental simulations
- clarify details of acoustic-structural interaction of VT cavities with a dynamical system originated in mechanical resonances of the soft tissue.



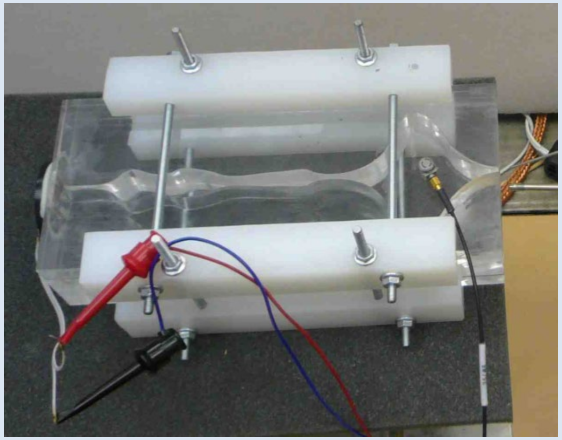
[2] Radolf V., Horáček J., Dlask P., Otčenášek Z., Geneid A., Laukkanen A.M.: Measurement and mathematical simulation of acoustic characteristics of an artificially lengthened vocal tract. Journal of Sound and Vibration 366, 2016, 556-570.

METHODS

3D VT model created from the MRI measurement of a male subject during phonation [u:], see [3].



- Simplified vocal tract model (plexiglass)
- Cross-sectional areas A(x) correspond to A(x) of 3D VT model.

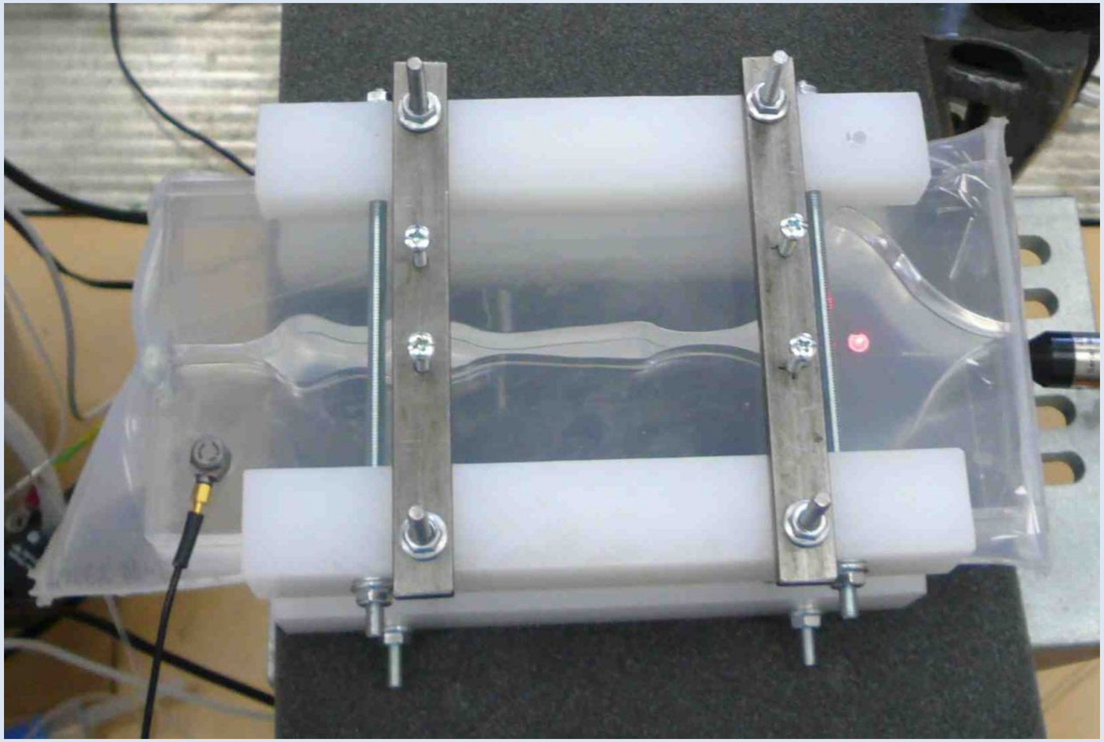


[3] Vampola T., Horáček J. Švec J.G.: FE modeling of human vocal tract acoustics. Part I: Production of Czech vowels. Acta Acustica united with Acustica 94, 2008, 433-447.

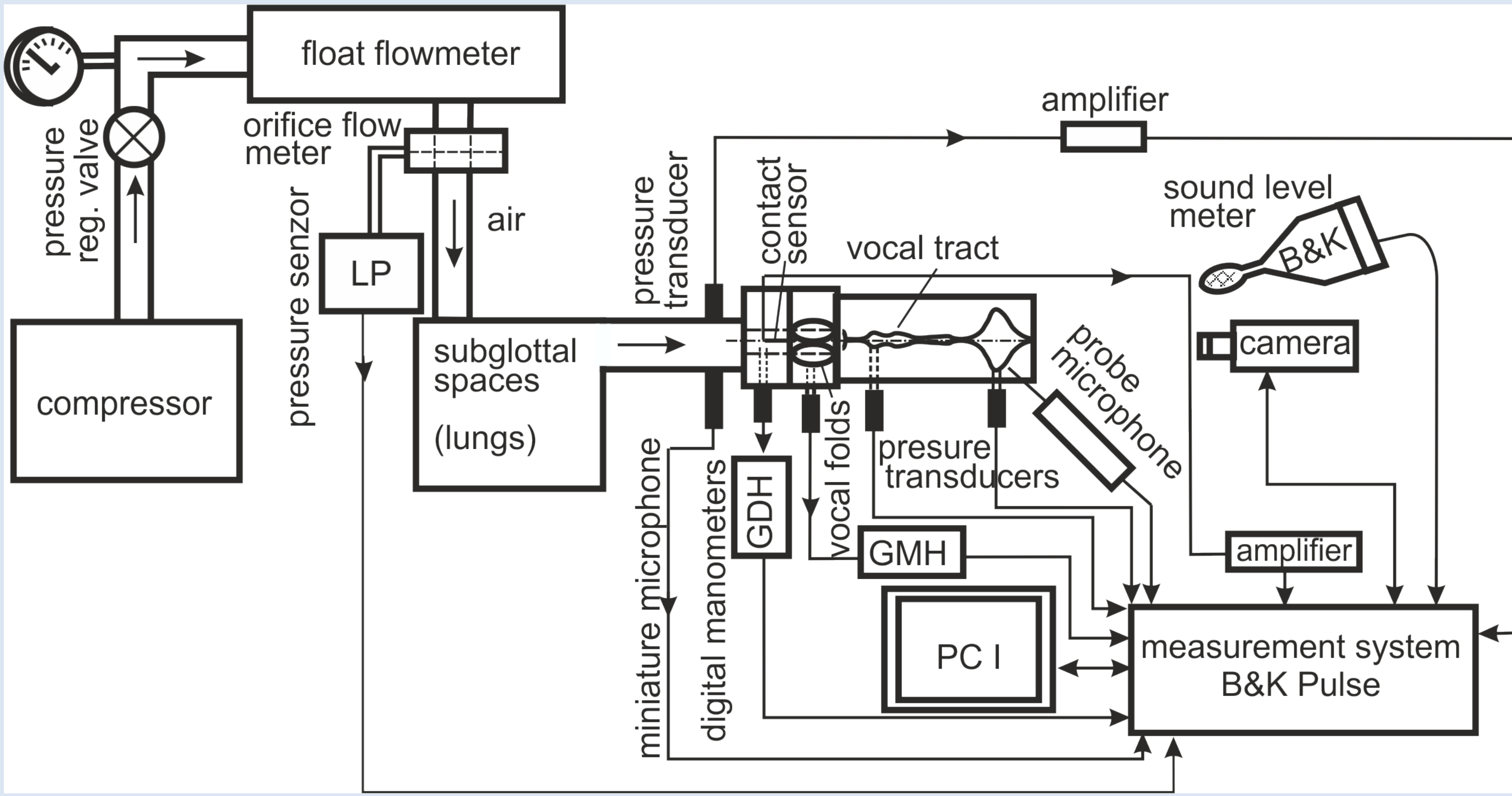
METHODS

Upper wall of the VT model replaced with a soft membrane

- silicone rubber Ecoflex™ 00-50
- thickness 1 mm
- slightly stretched



SCHEMA OF THE MEASUREMENT SET UP

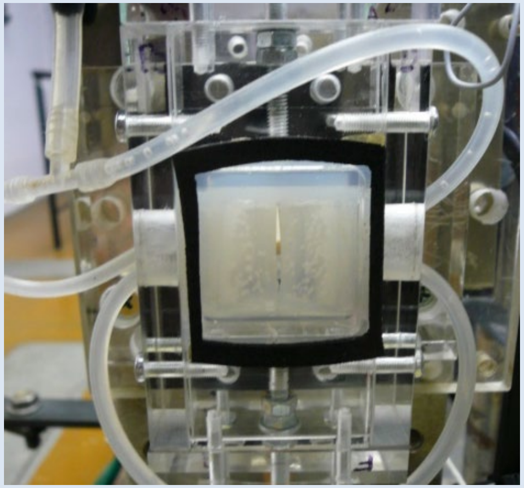


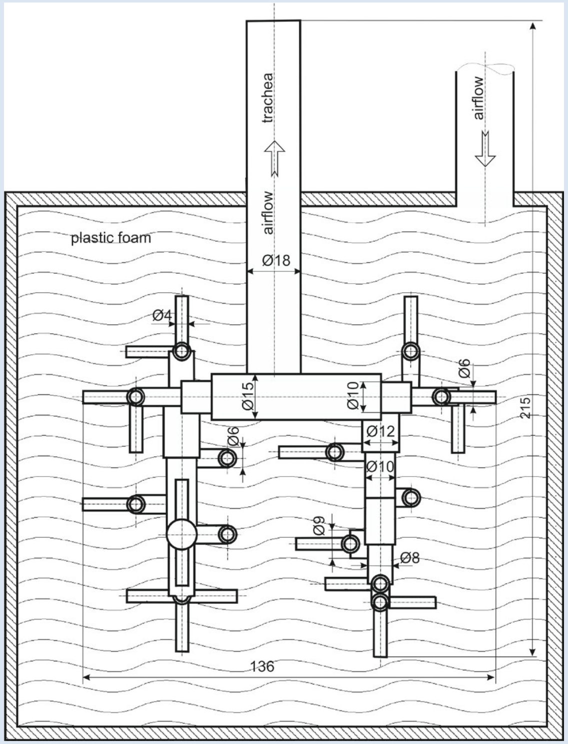
METHODS

Measurements performed with a 1:1 scaled three-layer vocal folds model.

The airflow rate was increased step by step

- from the phonation onset
- up to the airflow rate and the subglottic pressure, which are physiologically relevant values for a normal human voice production.

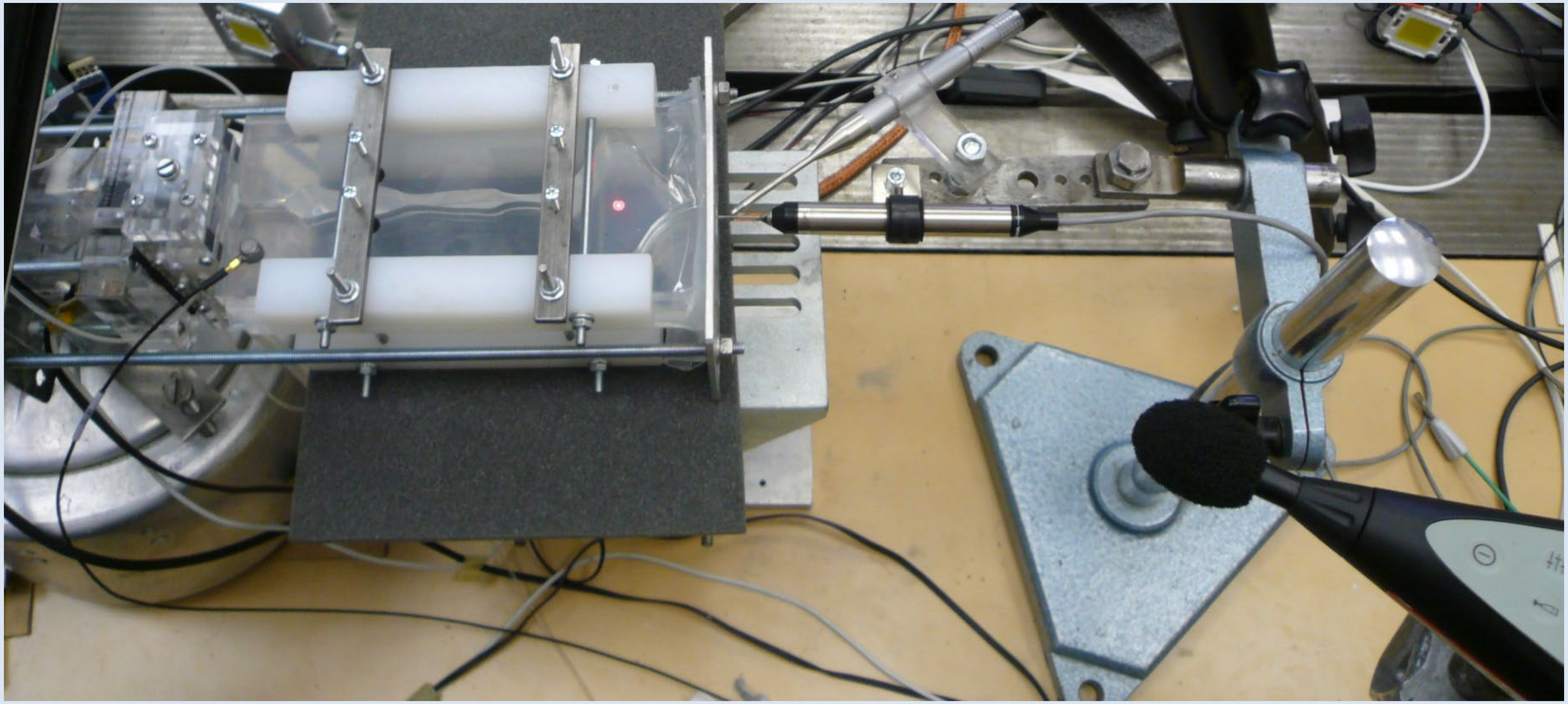




MEASUREMENT SET UP

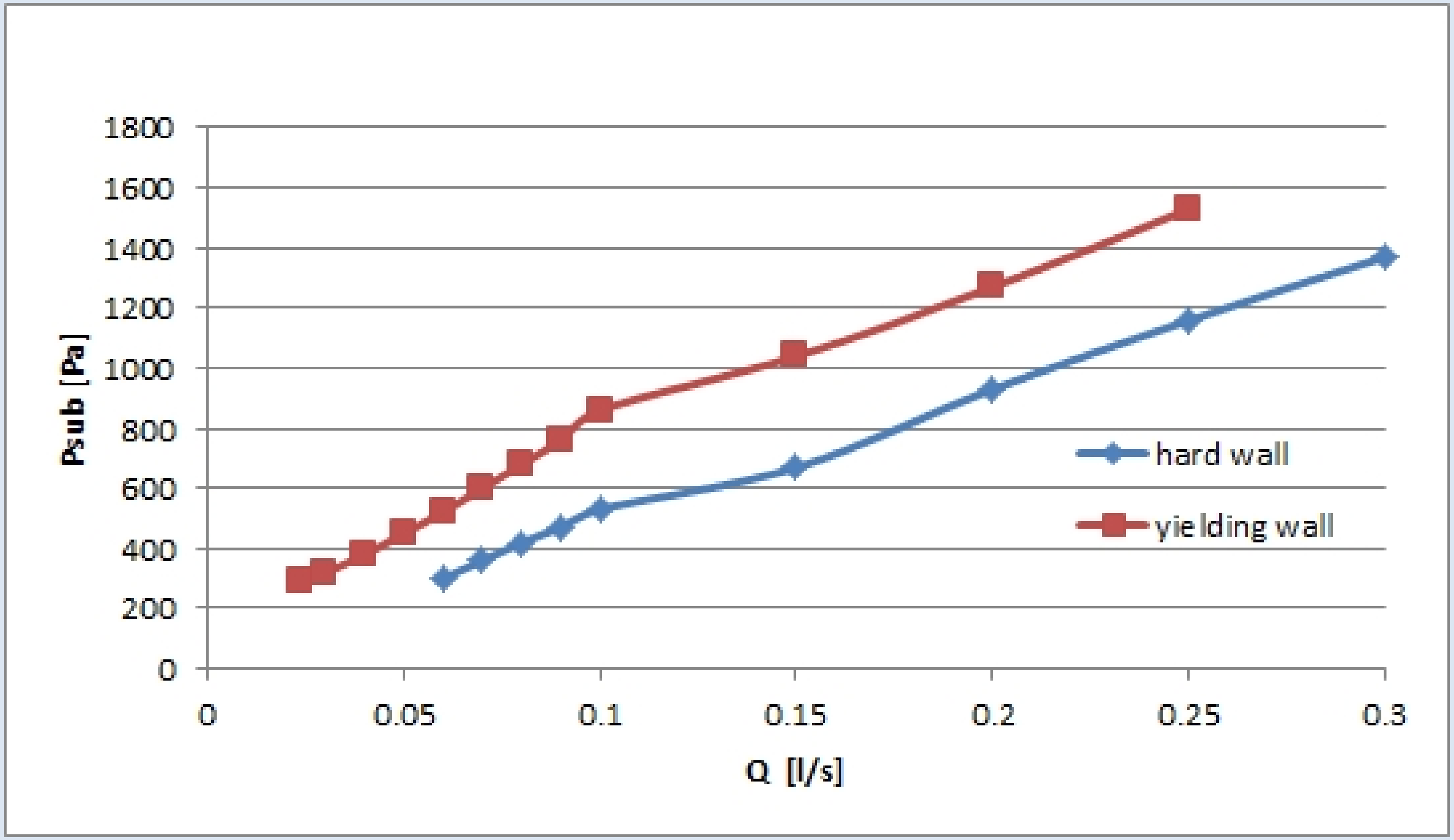
Excitation by the self-oscillating vocal folds model

- subglottal pressure measured by dynamic semiconductor pressure transducer
- the sound level meter B&K 2239 installed 20 cm from the mouth
- membrane vibration measured with Laser vibrometer Polytec OFV-505
- signals simultaneously sampled by 16.384 kHz



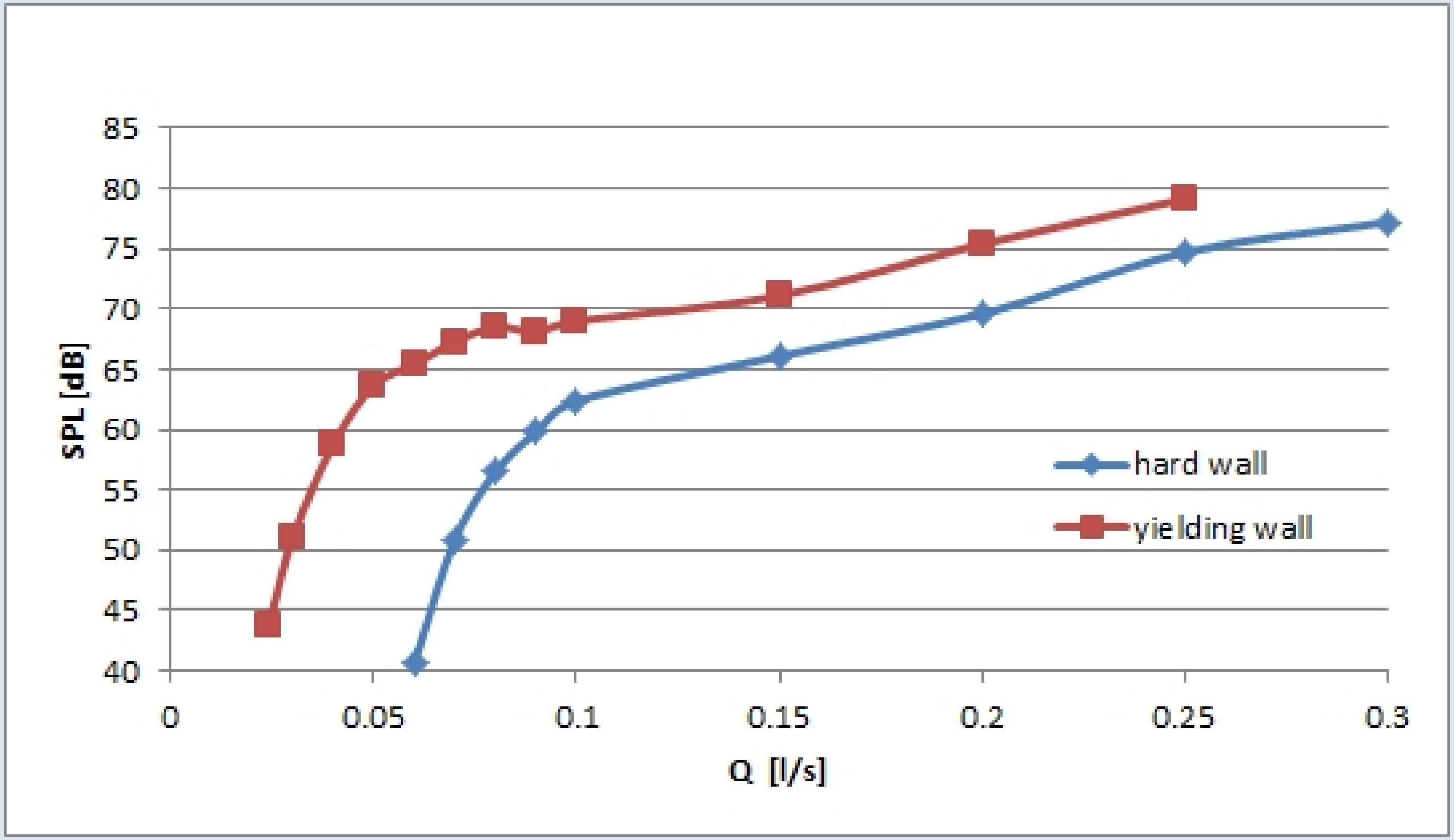
RESULTS

- **Mean subglottal pressure**



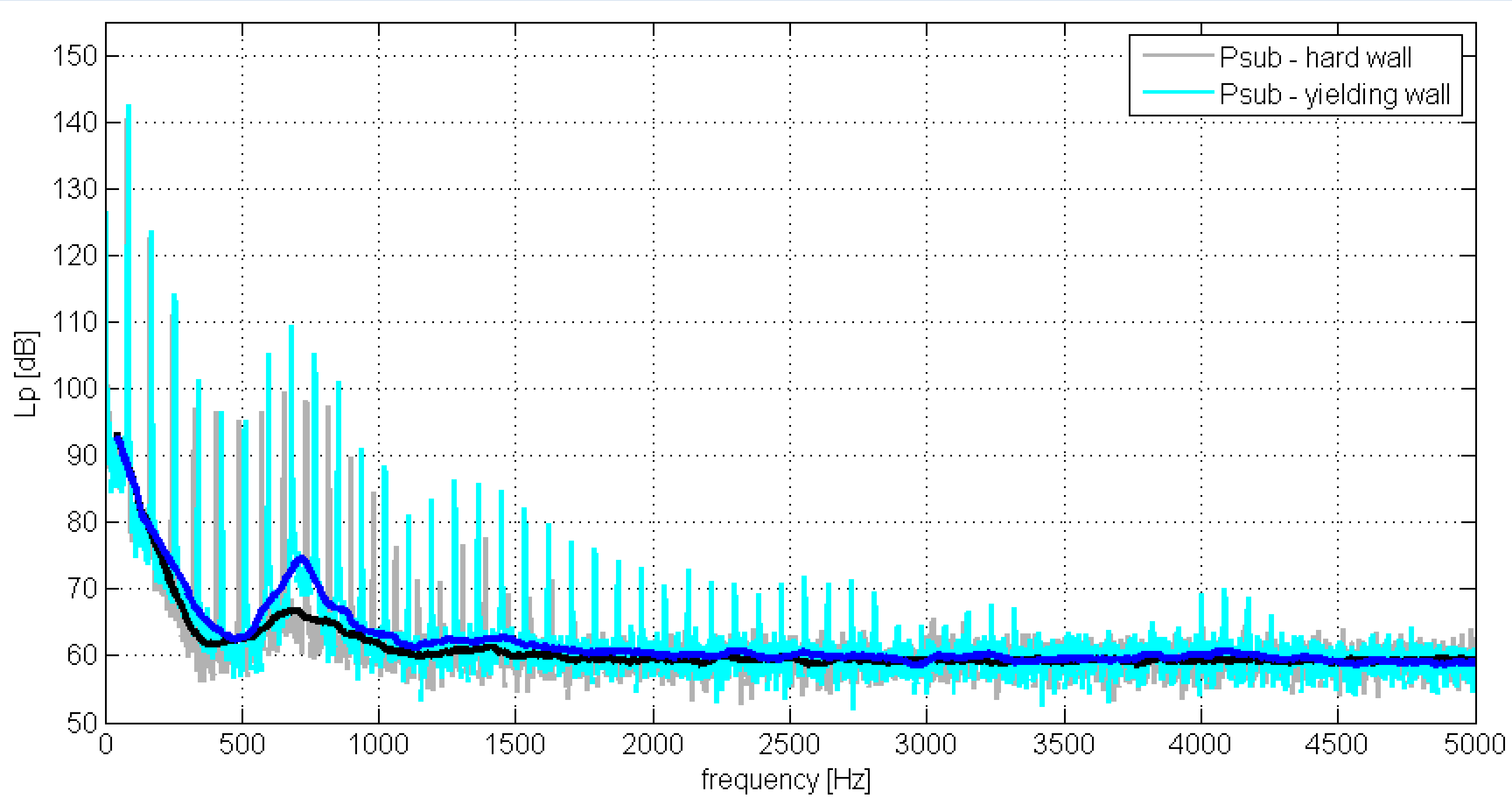
RESULTS

- **Sound pressure level radiated from the mouth**



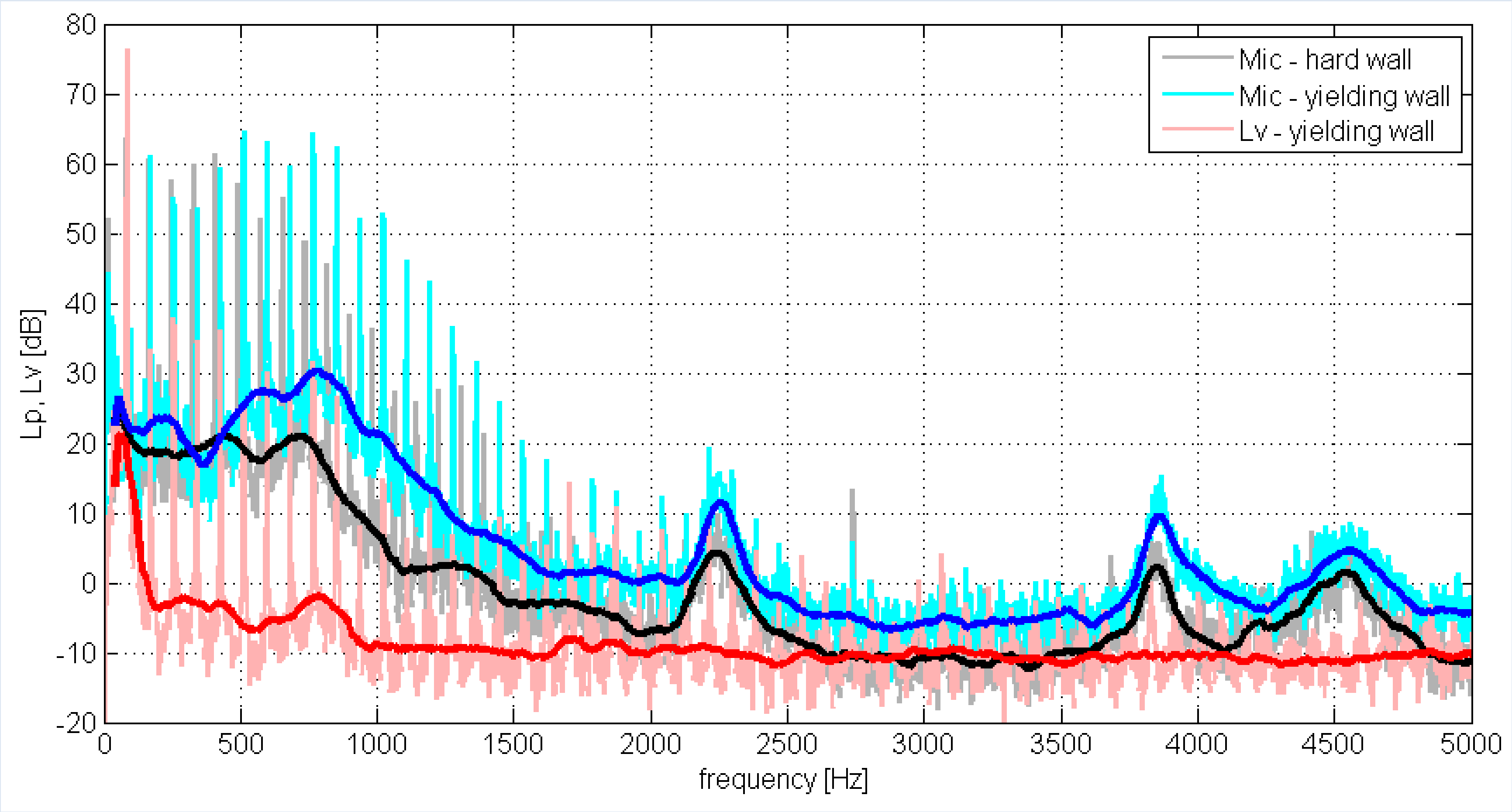
RESULTS

- **Subglottal pressure spectra, Q = 0.1 l/s (fo = 82 Hz and 85 Hz)**



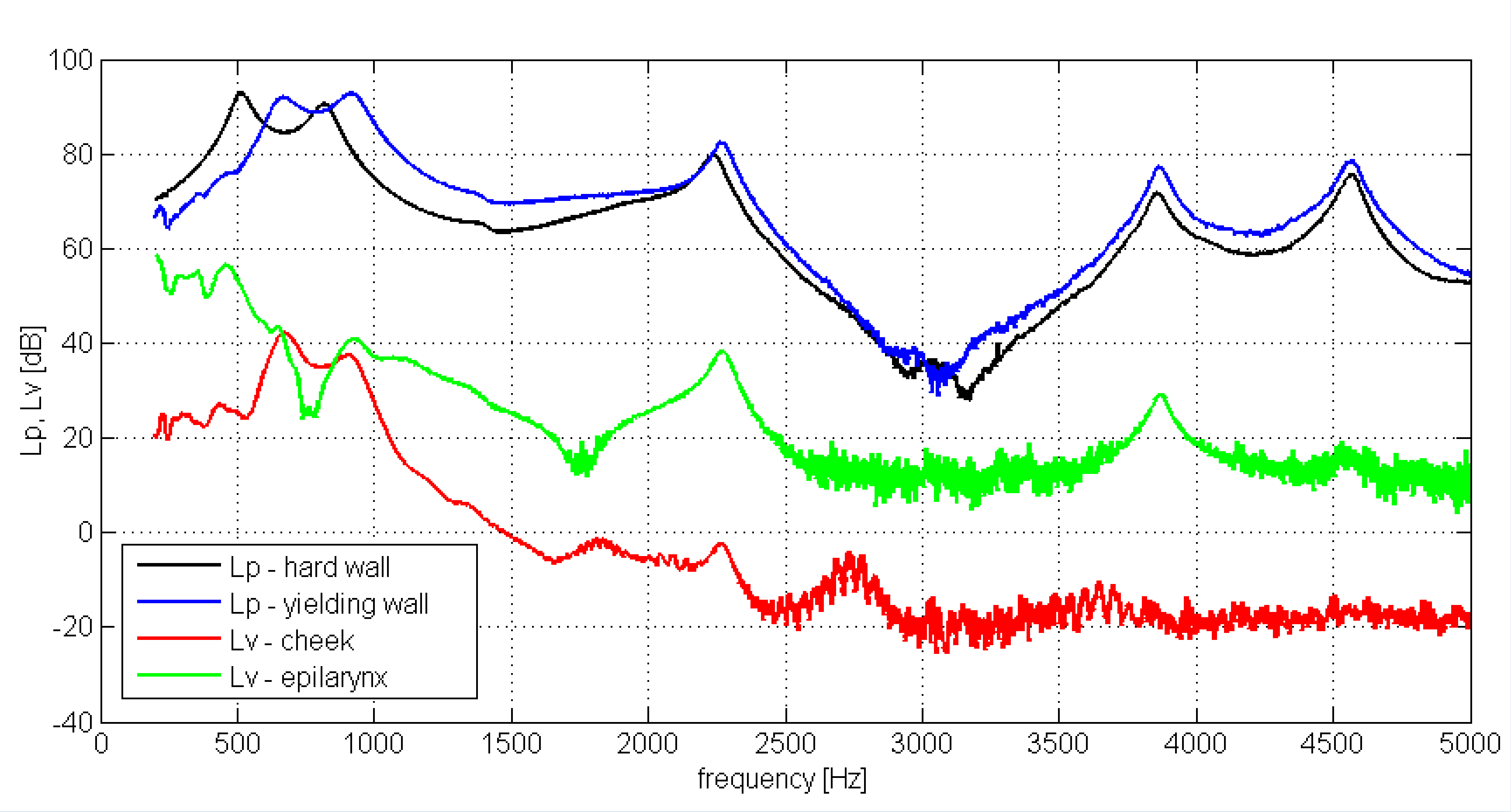
RESULTS

- **Sound pressure spectra, vibrating yielding wall spectra , Q = 0.1 l/s**



SOUND PRESSURE and VELOCITY SPECTRA

- **Excitation by 40mm speaker placed instead of VF (Radolf et al., 2020)**



CONCLUSION

Compliance of VT walls
 - significantly shifts the phonation threshold - very small airflow is sufficient to vibrate the vocal folds.
Comparing the same flow rates, the Psub and SPLout are higher with a compliant wall.
However, the phonation threshold Psub remains approximately the same for both models.

The shift of acoustic resonances towards higher frequencies due to the compliant wall is consistent with previous experimental and numerical simulations.

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APPENDIX
SOUND PRESSURE and VELOCITY SPECTRA

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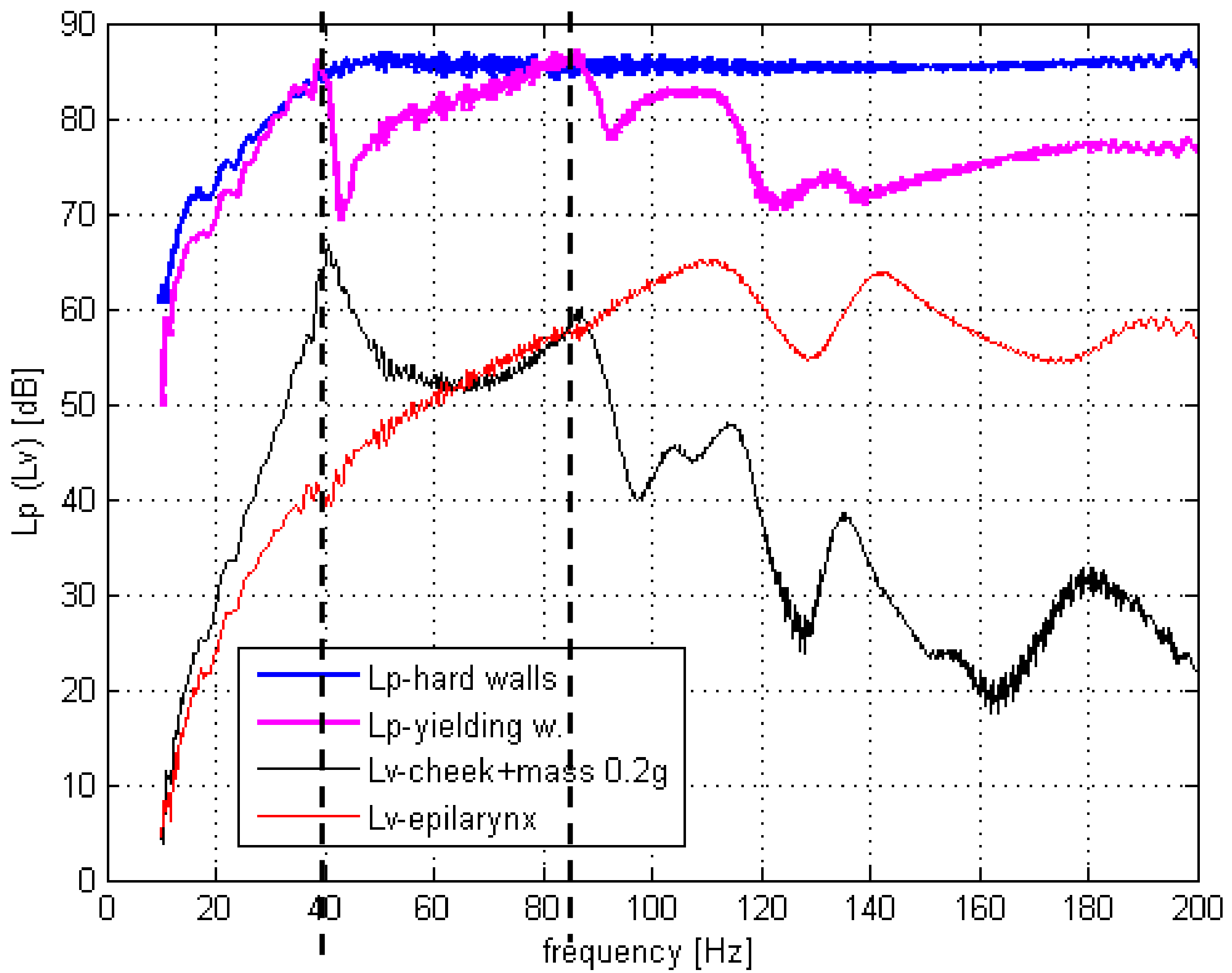

APPENDIX
TRANSFER FUNCTIONS velocity / pressure

- **Excitation by the 170mm loudspeaker**