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Acoustic comparison of physical vocal tract models with hard and soft walls

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Introduction

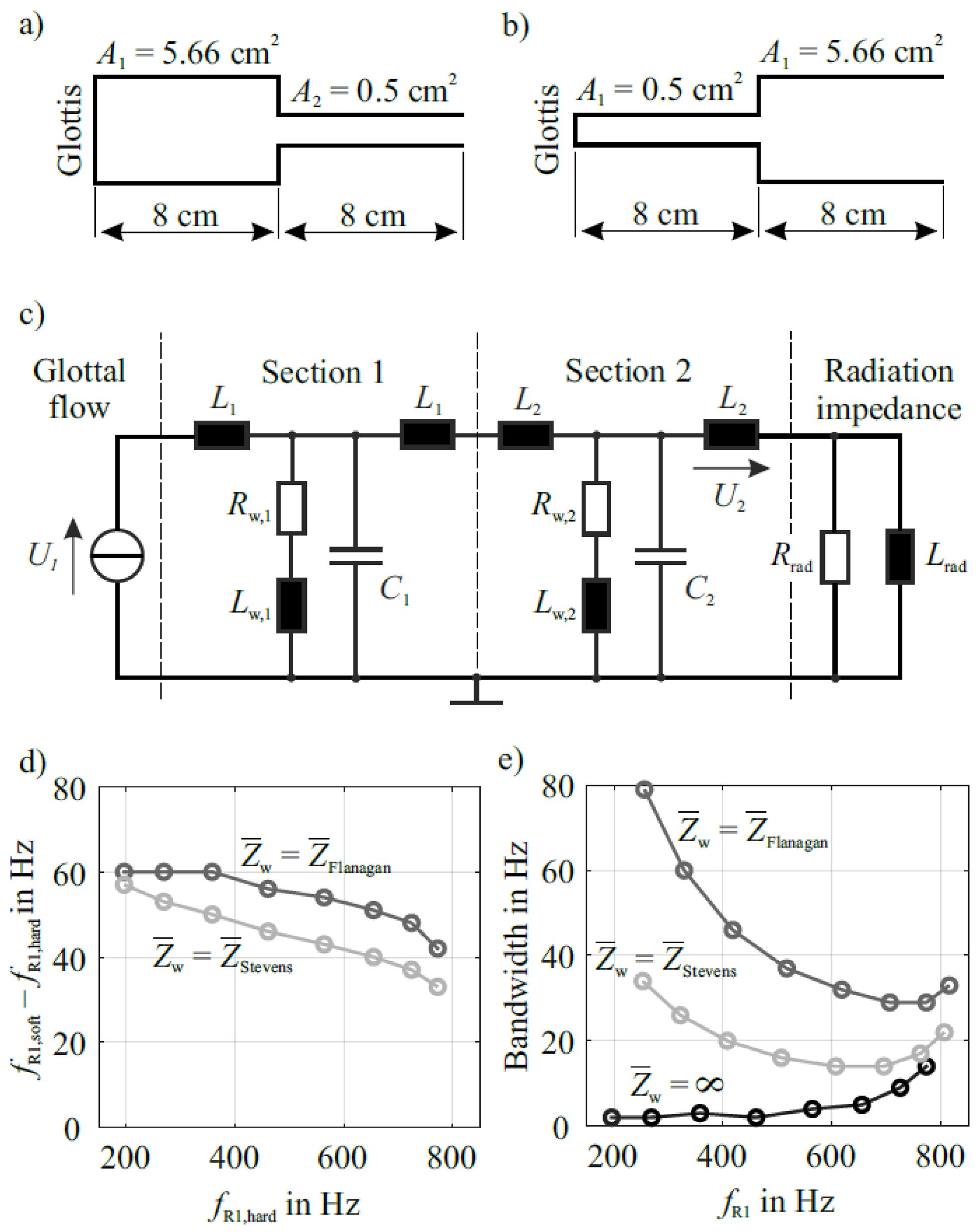
- Physical models of the vocal tract and vocal folds are valuable tools for speech research.
- While physical vocal *fold* models are often quite advanced, the vocal *tract* is often simplified as a resonator with hard walls.
- The fleshy surfaces of the *human* vocal tract are not rigid and have a finite mechanical impedance.
- So far, the effect of soft walls on the acoustic resonances was mainly analyzed in terms of mathematical models that represent wall impedance as a lumped mass-compliance-viscous loss combination.
- Here we compare the general predictions of the mathematical models with acoustic measurements using vowel resonators with hard versus soft walls.

Computational analysis

- Ishizaka et al. (1975) inferred from mechanical measurements with human tissue that its mechanical impedance behaves locally like a lumped-element spring-mass-damper system.
- Neglecting the spring element, this is equivalent to an acoustic $R_{w,i}$-$L_{w,i}$ branch (Fig. c)
- With a two-tube approximation of the vocal tract (Fig. a-c) that varies from /i/ to /a/, the effect of the wall impedance model on f_{R1} and B_{R1} were simulated.
- Considered settings for the soft walls:

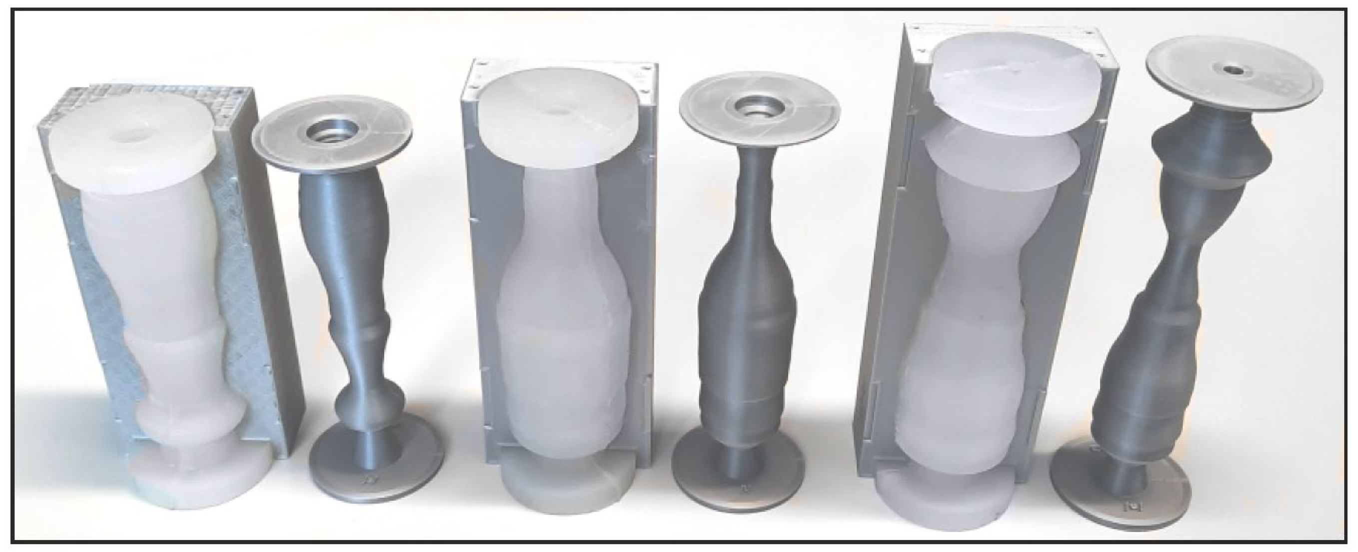
$$\underline{Z}_{\text{Flanagan}} = (1600 + j\omega \cdot 1.5)\ \text{g}\,\text{s}^{-1}\,\text{cm}^{-2},$$
$$\underline{Z}_{\text{Stevens}} = (1000 + j\omega \cdot 2.0)\ \text{g}\,\text{s}^{-1}\,\text{cm}^{-2}.$$

- With soft walls, f_{R1} is increased by 30-60 Hz, and B_{R1} increases up to 80 Hz.



Physical vocal tract models

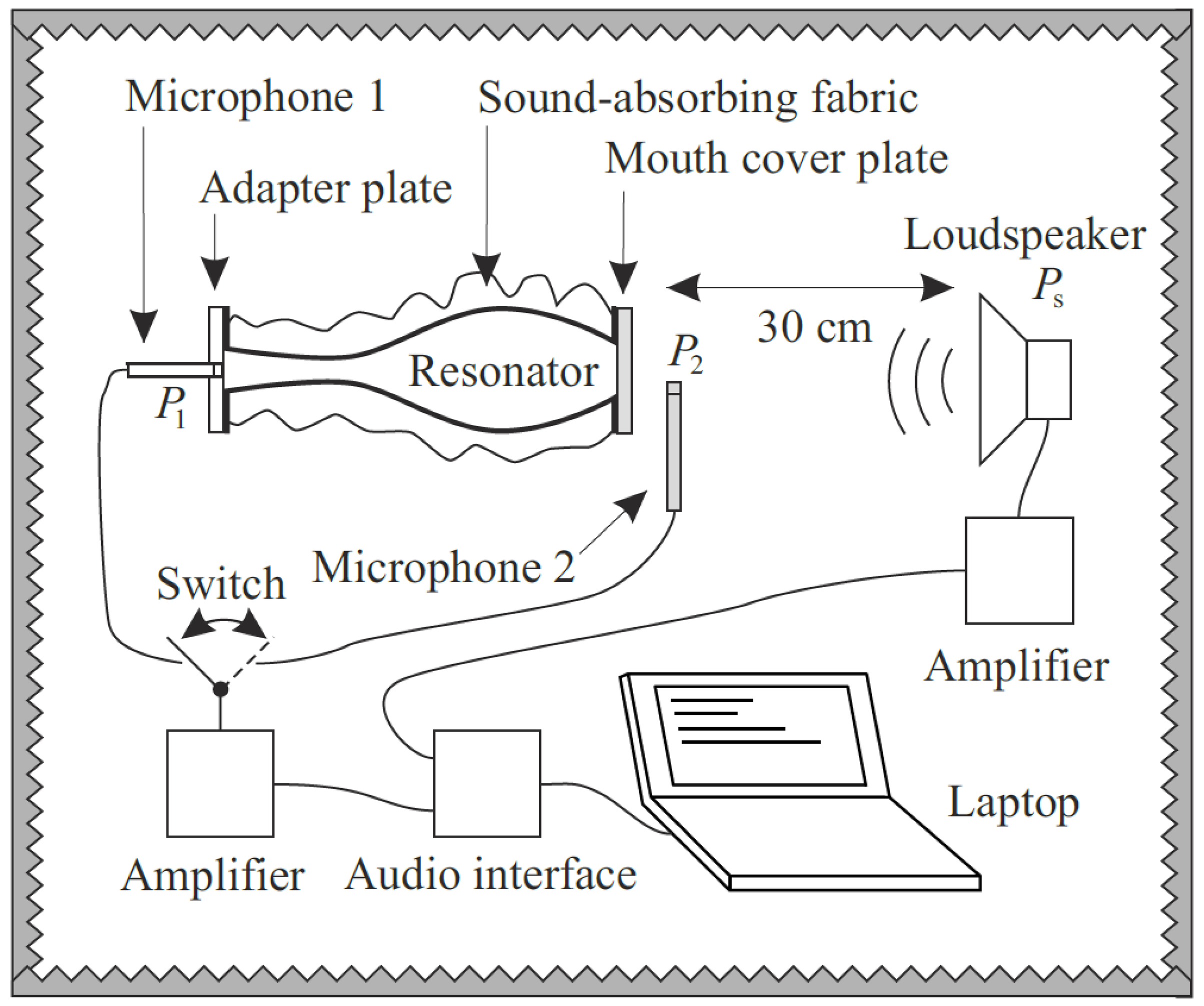
- For each of 10 (inner) vocal tract shapes, one resonator was 3D-printed with hard plastic walls, and one was cast with „super soft" silicone walls (1 cm thick, Shore hardness 00).
- Nine tube shapes were based on vowel area functions from the articulatory synthesizer VocalTractLab (www.vocaltractlab.de), and the 10th was a cylindrical tube.



Measurements

For all 20 physical resonators, the volume velocity transfer function from the glottis to the lips was measured with the highly precise method by Fleischer et al. (2018), as illustrated below.

See also: https://youtu.be/9AoRS9X2BNY



Measurement results

Measured volume velocity transfer functions of 6 of the 10 vowel resonators with hard walls (black) and soft walls (gray):

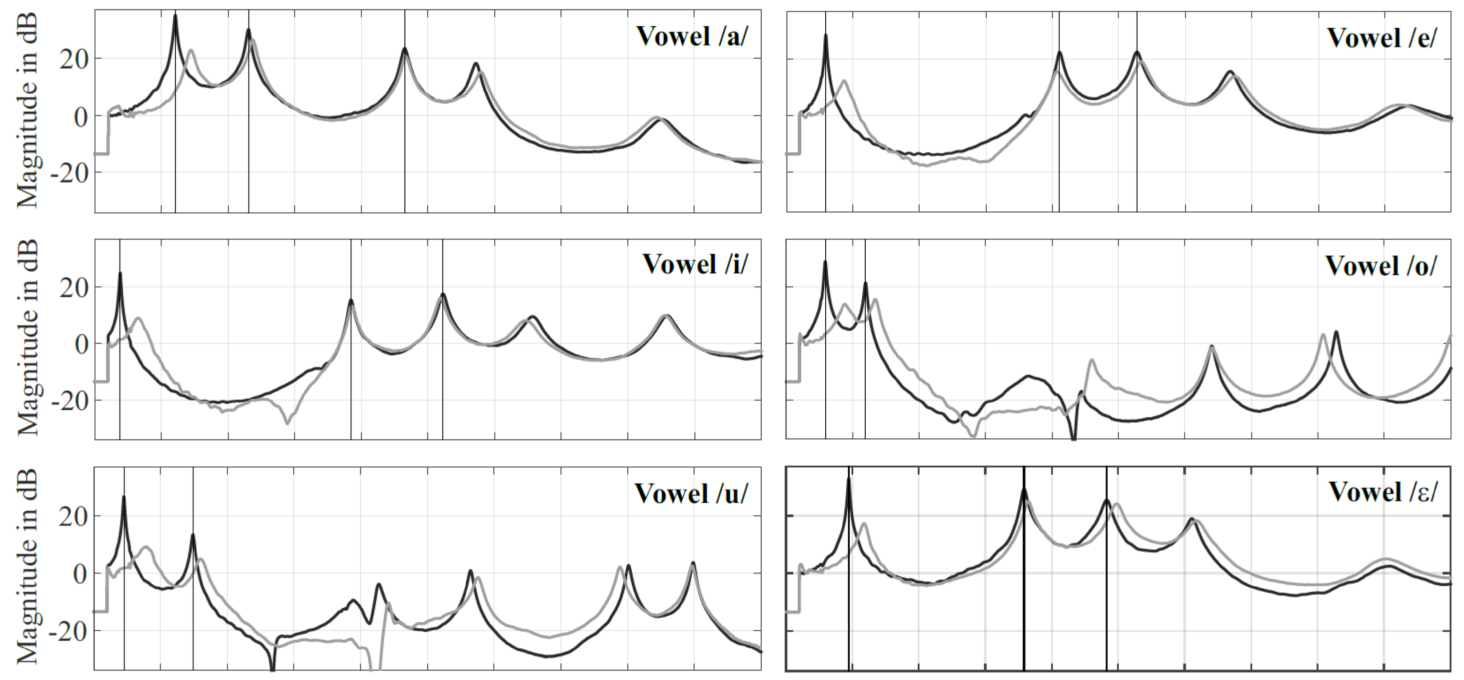
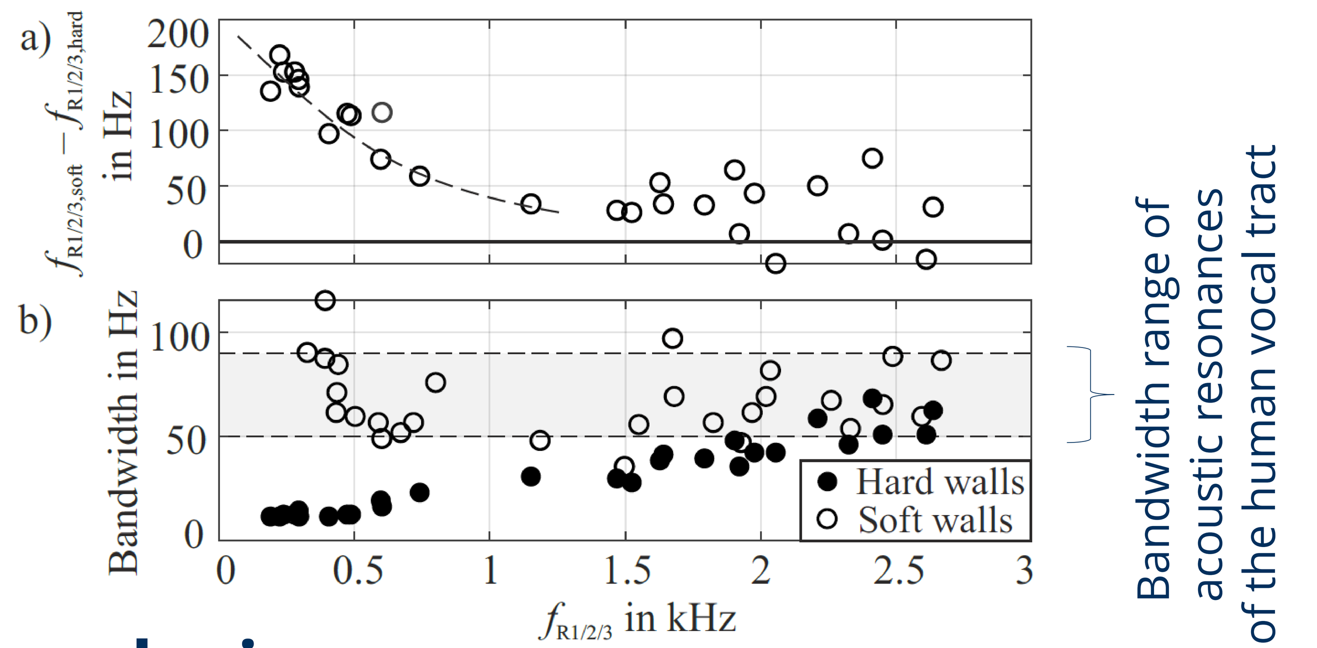


Figure below:

a) Shift of $f_{R1/2/3}$ due to soft walls. The abscissa shows the resonance frequencies of the hard-walled resonators.

b) Bandwidths $B_{R1/2/3}$ of the resonators with hard walls (black circles) and soft walls (white circles).



Conclusions

- The physical measurements confirm the general validity of the lumped-element approach for the wall impedance.
- Soft walls significantly increase the bandwidths and resonance frequencies below 2 kHz.
- The actual effects depend on the parameters of the soft walls, i.e., the wall damping and mass per unit area.

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