From physiology to vibration to perception: Role of the body-layer stiffness

Zhaoyan Zhang[+], Jody Kreiman[+], Bruce R. Gerratt[+], and Marc Garellek[*]

[+]School of Medicine, UCLA, USA
[*] Department of Linguistics, UCLA, USA

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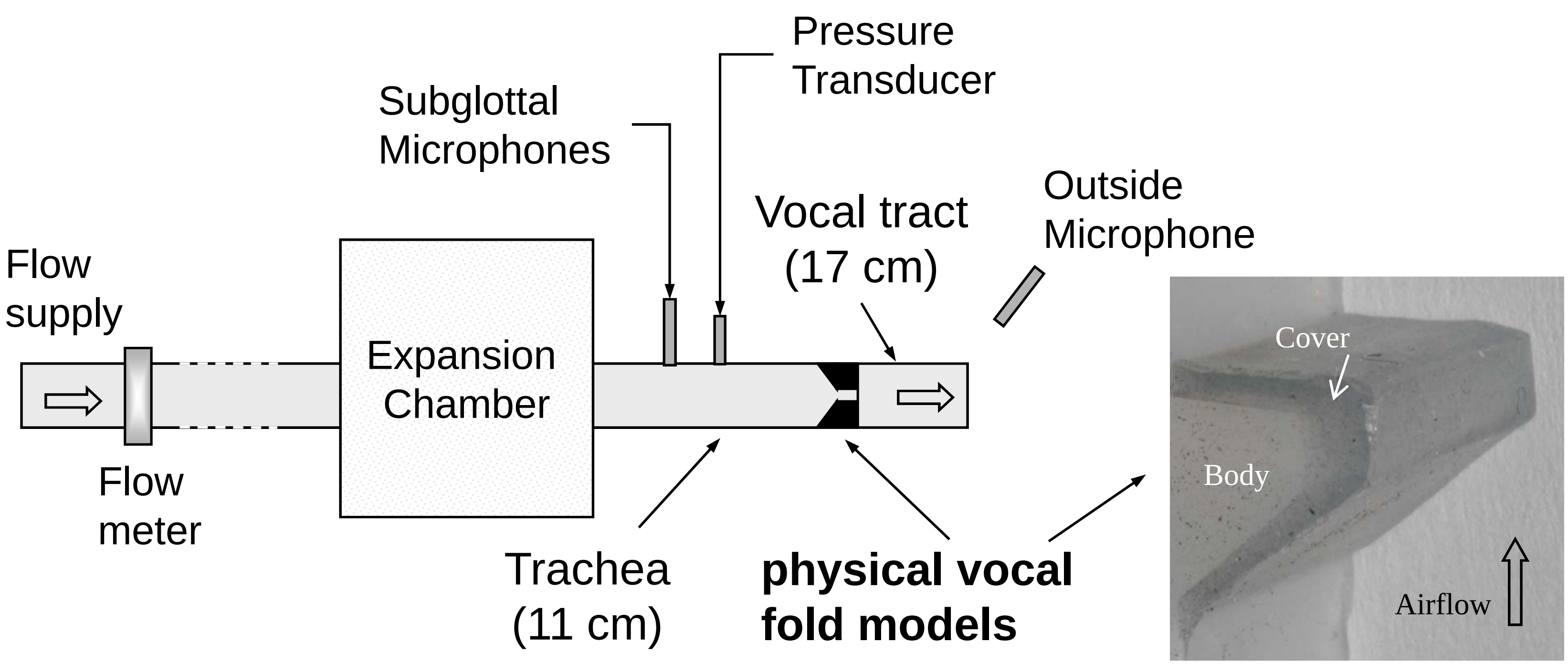
- Objective: Establish a cross-domain cause-effect link between physiology and perception
  - Which physiological properties are perceptually relevant and important?
  - What mechanical adjustments are needed to restore or improve voice

- Focus of this study: acoustic and perceptual importance of body-layer stiffness

- Approach: Systematically vary body-layer stiffness, and observe the acoustic and perceptual consequences.

Approach: experiments

- Systematically vary body-layer stiffness in a two-layer model;



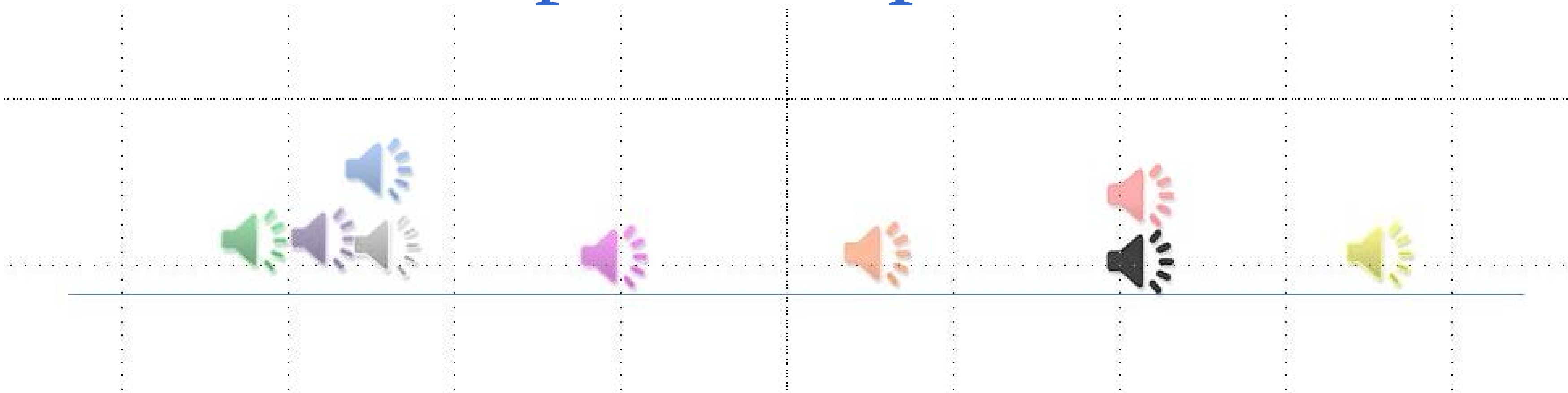
Approach: measurements

- Systematically vary body-layer stiffness in a two-layer model;
- Measurement of voice production
  - Phonation threshold pressure, frequency, and flow rate
  - High-speed video from a superior view of the vocal folds
    - Left-right vibration amplitude ratio
    - Left-right phase difference
  - Outside acoustic pressure
    - Measured at a subglottal pressure 1.1 times of phonation threshold pressure

Approach: Acoustic Analysis

- Normalized for amplitude and pitch
  - Re-synthesized using Praat’s pitch-synchronous overlap-and-add algorithm
- Acoustic measures (using Analysis-by-synthesis approach):
  - H1-H2
  - H2-H4
  - Spectral slope from H4 to 2 kHz
  - Spectral slope from 2 kHz to 5 kHz
  - Noise-to-harmonics ratio (NHR)
  - NumHarm (number of harmonics below 8 kHz in the voice spectra)

Perceptual Experiments



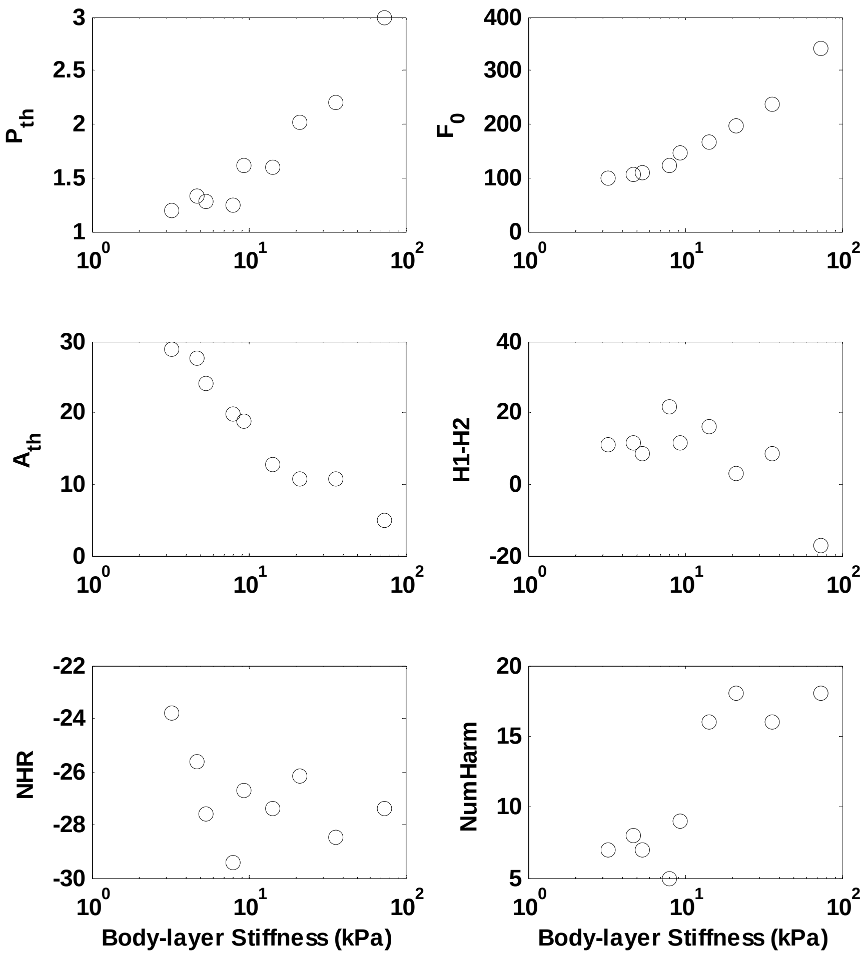
- 17 listeners completed a visual sort and rate task (one trial/listener/experiment)
- Listeners clicked the icons to play the stimuli, then dragged each icon so that stimuli were arranged along the perceived dimension of variation.
- Individual differences non-metric multidimensional scaling (MDS) was then applied to determine what perceptual dimension(s) listeners shared when making their judgments
  - If subgroups were identified, MDS was applied to individual subgroups

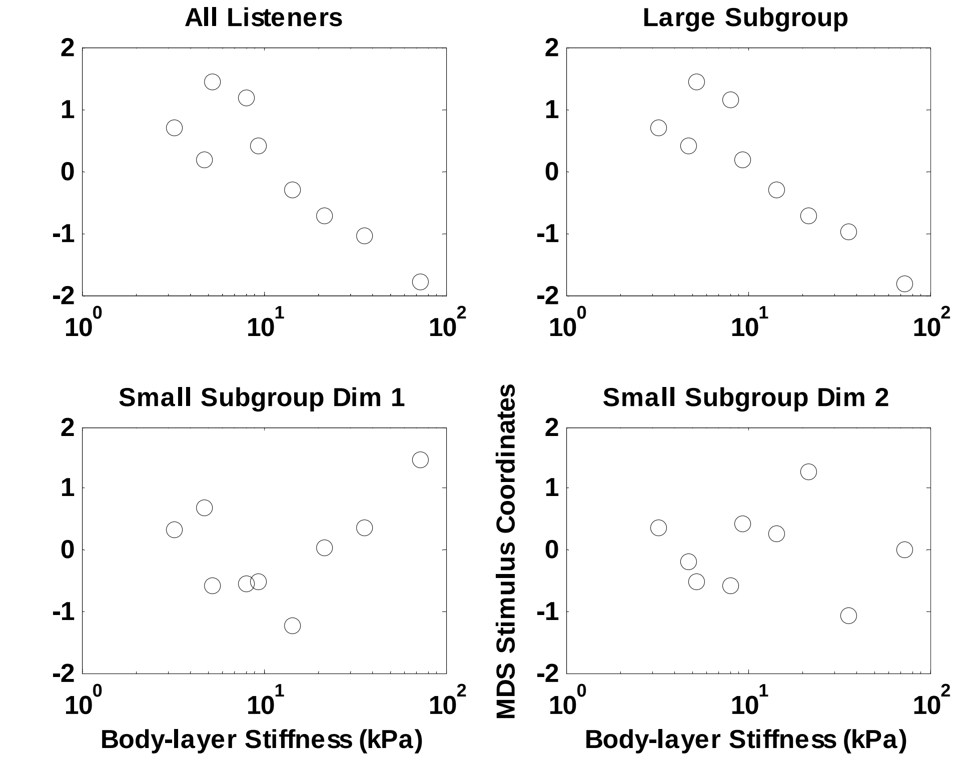
Two series of experiments

Series	I	II
	symmetric	asymmetric
Left fold, body-layer stiffness (kPa)	3.25-73.16	3.25-73.16
Right fold, body-layer stiffness (kPa)	$= E_{b,left}$	73.16 (stiff-body)
Number of conditions	9	9

All models had the same geometry and cover-layer stiffness (3.25 kPa)

Series I: Symmetric conditions





Body layer stiffness

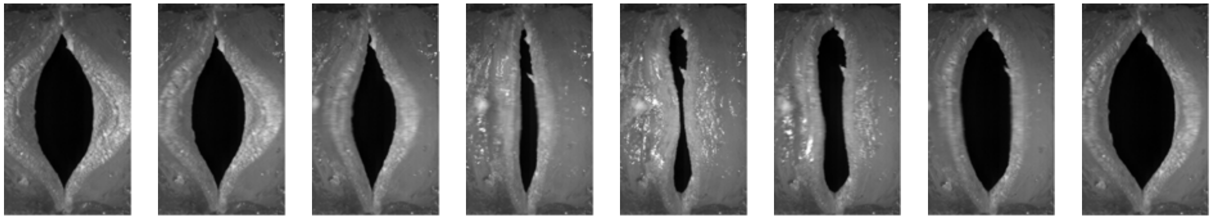
F(3,5)=26.87
p<0.01;
R^2=0.94

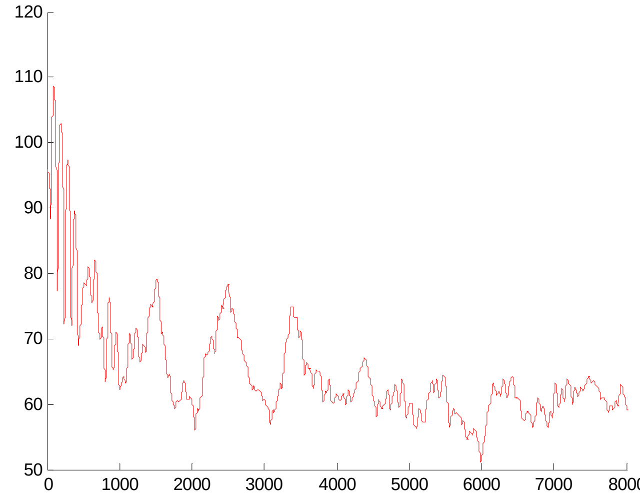
NumHarm
H1-H2

F(1,7)=36.81
p<0.01
R^2=0.84

Perception

Soft-body

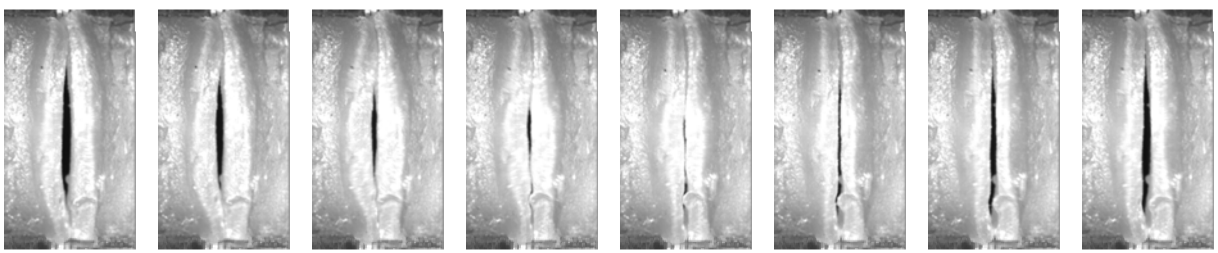


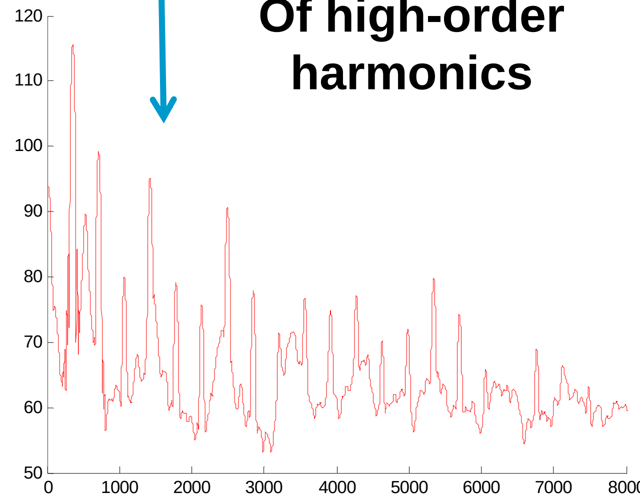


Improved closure

Strong excitation Of high-order harmonics

Stiff-body





Body layer stiffness

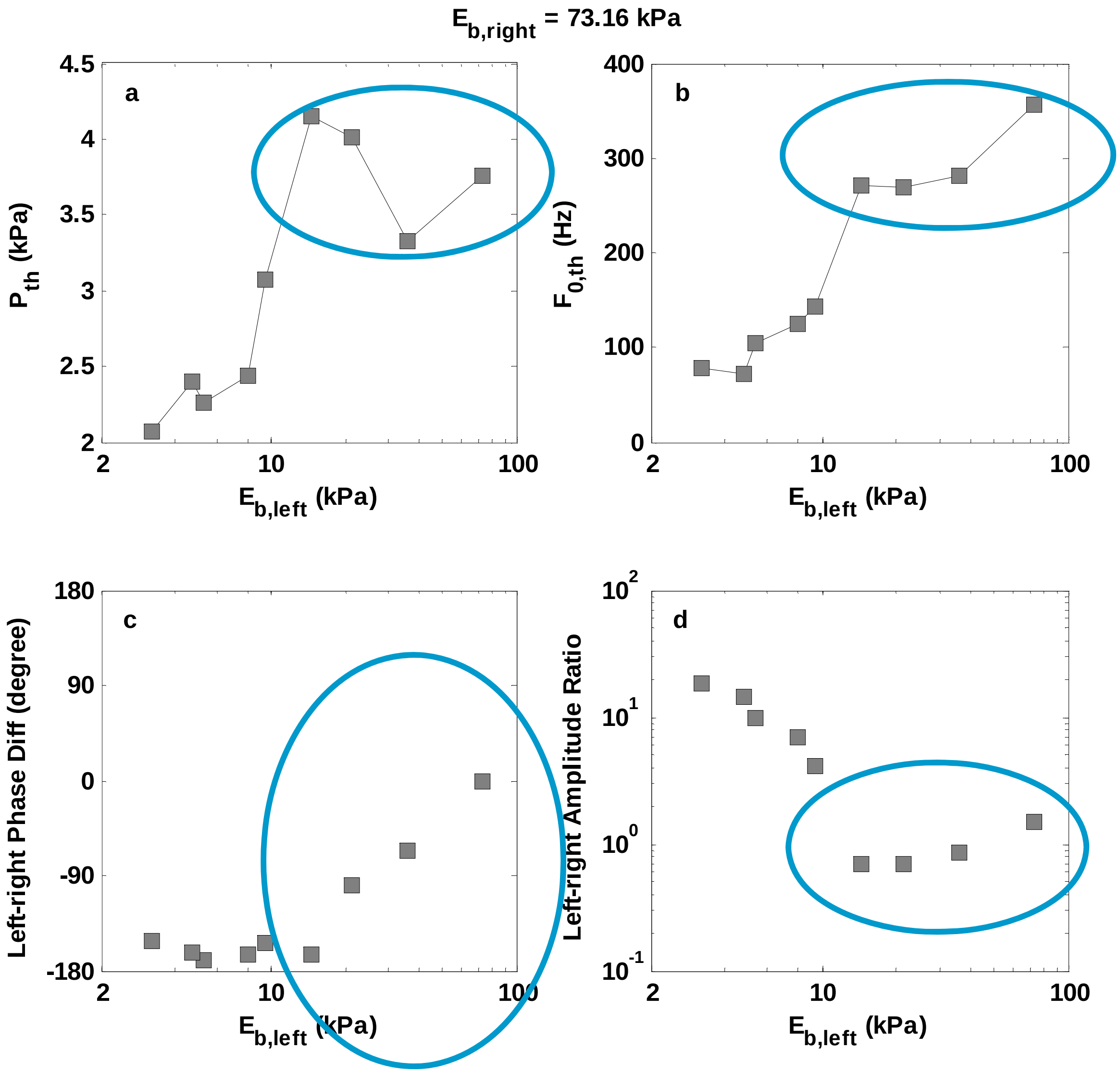
$F(3,5)=26.87$
$p<0.01$;
$R^2=0.94$

NumHarm
H1-H2

$F(1,7)=36.81$
$p<0.01$
$R^2=0.84$

Perception

Series II: Asymmetric condition with a stiff-body right-fold

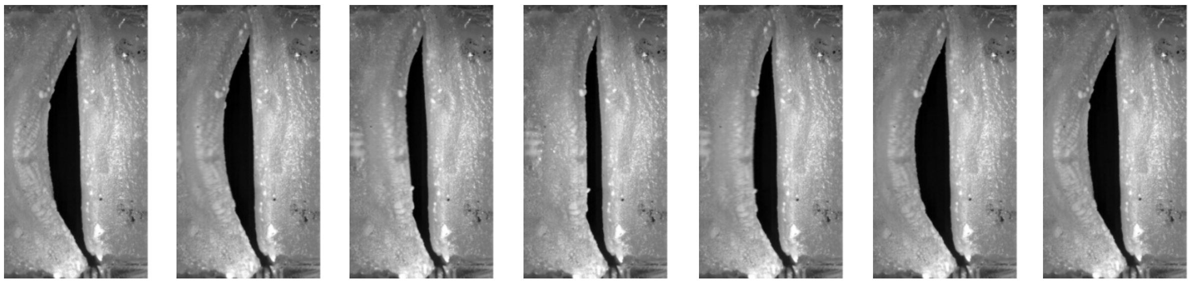


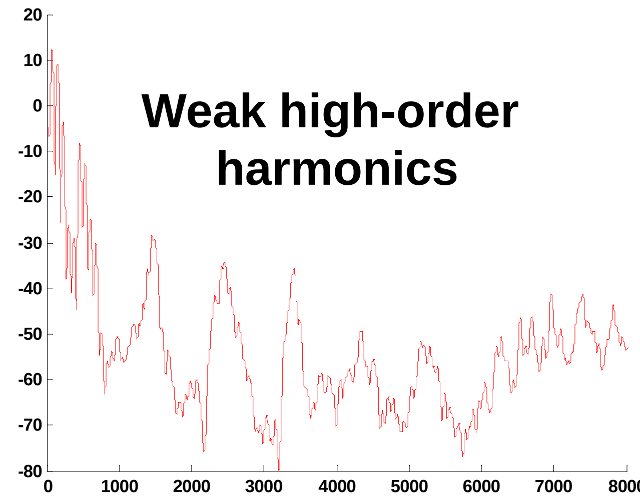
Two vibration regimes:

1. **Large stiffness mismatch;**
2. **Small stiffness mismatch.**

Large left-right Stiffness mismatch

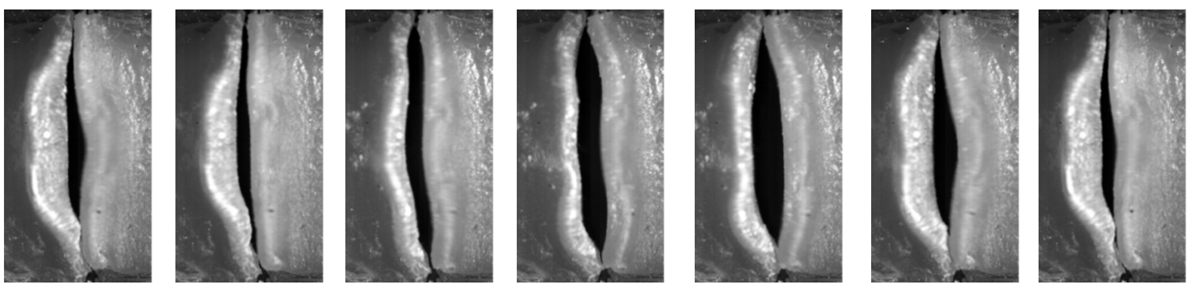
Soft-body fold large vibration amplitude; stiff-body fold barely moved

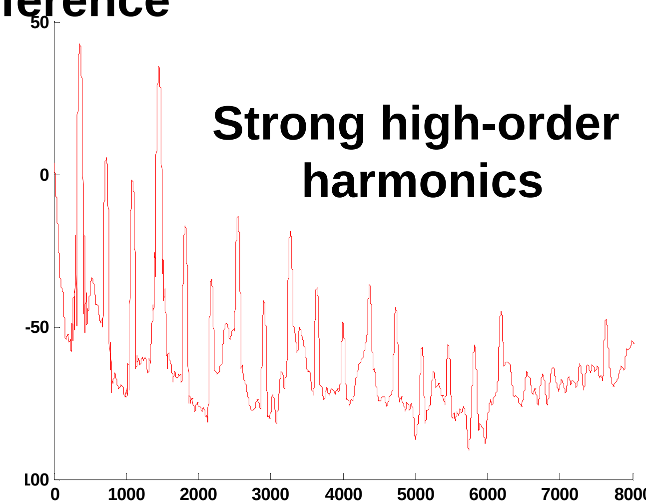




Small stiffness mismatch

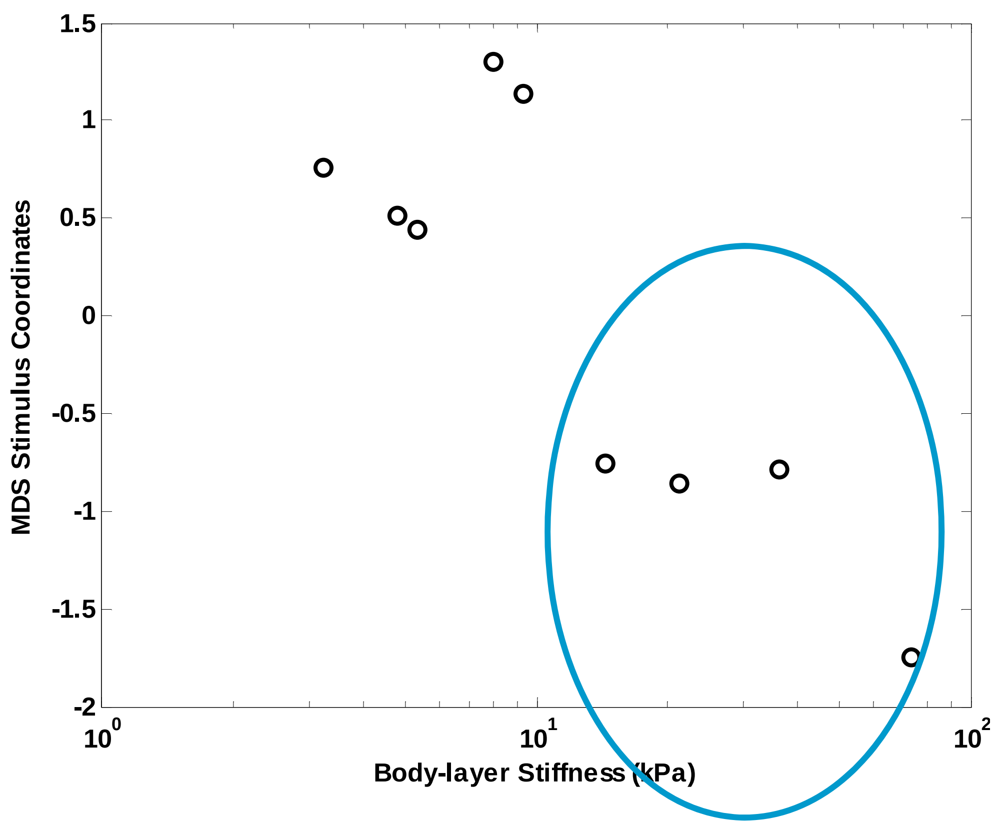
Both folds strongly excited, but with a phase difference





Body layer stiffness	$F(1,7)=28.59$ $p<0.01$; $R^2=0.80$ →	NumHarm NHR

Series II: Perceptual score



Two vibratory regimes correspond to two perceptual regimes:

- Every stimulus in one regime differed significantly from every stimulus in the other regime in perceptual score,
- Within the same regime, no significant differences were observed ($p < 0.01$).

Series II: Cause-effect relationship

- Two vibration regimes
  - Differed primarily in the excitation of high-order harmonics
- Two vibratory regimes correspond to two perceptual regimes
  - Within the same regime, changes in asymmetric vibration did not produce perceptually noticeable difference

Body layer stiffness → F(1,7)=28.59 p<0.01; R^2=0.80 → NHR NumHarm → F(1,7)=109.65 p<0.01; R^2=0.94 → **Perception**

Conclusions

- Control of body-layer stiffness is perceptually important
  - they have significant influence on glottal closure and production of high-order harmonics.
- Thyroarytenoid (TA) muscle is essential to the control of glottal closure and the production of high-order harmonics

- Asymmetry in vibration amplitude and phase was perceptually insignificant unless the vibratory pattern changed from one regime to the other.