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

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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

<table>
<thead>
<tr>
<th>Series</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>symmetric</td>
<td>asymmetric</td>
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<tr>
<td>Left fold, body-layer stiffness (kPa)</td>
<td>3.25-73.16</td>
<td>3.25-73.16</td>
</tr>
<tr>
<td>Right fold, body-layer stiffness (kPa)</td>
<td>$= E_{b,\text{left}}$</td>
<td>73.16 (stiff-body)</td>
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<td>Number of conditions</td>
<td>9</td>
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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;
R²=0.94

NumHarm H1-H2

F(1,7)=36.81
p<0.01
R²=0.84

Perception
Soft-body

Improved closure

Stiff-body

Improved closure

Improved closure

Strong excitation

Of high-order harmonics

Body layer stiffness

NumHarm H1-H2

Perception

F(3,5) = 26.87
p < 0.01; R² = 0.94

F(1,7) = 36.81
p < 0.01; R² = 0.84
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;
R²=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

\[ F(1,7)=28.59, p<0.01; R^2=0.80 \]
\[ F(1,7)=109.65, p<0.01; R^2=0.94 \]
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.