Quantifying Variation in Labial, Palatal and Pharyngeal Contributions to F3 Lowering in /ɹ/
AMERICAN ENGLISH /ɪ/ PRODUCTION

Labial Constriction
Palatal Constriction
Pharyngeal Constriction

References: Delattre & Freeman, 1968; Zawadski & Kuehn, 1980; Alwan et al., 1997; Westbury et al., 1998; Guenther et al., 1999; Mielke et al., 2010
AMERICAN ENGLISH /ɹ/ PRODUCTION

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**Variation in /ɹ/**

- Extensive range of observed articulatory configurations
  - Variation in tongue posture can be context-dependent or idiosyncratic

References: Guenther et al., 1999; Westbury et al., 1998; Tiede et al., 2004; Mielke et al., 2010, 2016
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Perturbation Theory and $F_3$ in /ʃ/
PERTURBATION THEORY AND F3 IN /ɹ/
Perturbation Theory and F3 in /ɹ/
Systematic and parallel variation observed in the degree of constriction and F3 values in /ɹ/

Constriction Degree:
- Reduced palatal and labial magnitude in word- and syllable-final /ɹ/
- Narrower constriction (smaller aperture) in citation form than in connected speech

F3 Values:
- Higher F3 values observed in syllable- and word-final /ɹ/ than in initial /ɹ/
- F3 tends to be higher in connected read speech than in citation form

How does the degree of constriction at these locations affect the value of F3?

References: Lehiste, 1964; Hagiwara, 1995; Gick, 1999; Campbell et al., 2010; Harper, 2017
ARTICULATORY VARIABILITY IN NATURAL SPEECH
RESEARCH QUESTIONS

1. Are narrower constriction degrees associated with lower values of F3 for different speakers?
   - Prediction: Yes

2. Does the effect of constriction aperture on F3 differ across the three gestures involved in the production of /ʃ/?
   - Prediction: Yes
1. Do differences in constriction aperture reflect differences in F3 between tokens of /ɹ/?
   ◦ Prediction: Yes

2. Does the effect of constriction aperture on F3 differ across the three gestures involved in the production of /ɹ/?
   ◦ Prediction: Yes

3. Does variation in constriction length and location influence the effect of aperture on F3 values?
   ◦ Prediction: Yes
EXPERIMENT DESIGN AND ANALYSIS
**Experiment Design**

- Real-time MRI capture of four speakers reading sentences in the USC-TIMIT corpus (Narayanan et al., 2004; Narayanan et al., 2014)
  - Speaker airways imaged in the midsagittal plane

- Noise-canceled audio recordings collected simultaneously with MRI capture (Bresch et al., 2006)

- Word-initial and word-final /ɹ/ selected for analysis
  - Coded for position in the word and segmental environment
  - 135-200 tokens analyzed for each speaker (668 total)

References: Narayanan et al., 2004; Bresch et al., 2006; Narayanan et al., 2014
Articulatory Analysis

1. **Time** of maximum constriction identified for each constriction gesture
Articulatory Analysis

1. **Time** of maximum constriction identified for each constriction gesture
2. Measurements taken at time of maximum constriction:
   - Minimum **Aperture**
   - Constriction **Length**
   - Constriction **Location**

References: Tiede, 2010; Lammert et al., 2013; Lammert et al., 2014; Kim et al., 2014; Boersma & Weenick, 2016
Articulatory Analysis

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   - Minimum **Aperture**
   - Constriction **Length**
   - Constriction **Location**

Acoustic Analysis

- Formant values $F_1$, $F_2$, $F_3$ and $F_4$ automatically extracted at time of maximum constriction using a script in Praat

References: Tiede, 2010; Lammert et al., 2013; Lammert et al., 2014; Kim et al., 2014; Boersma & Weenick, 2016
RESULTS:
MAIN EFFECTS OF APERTURE
**Relationship Between Palatal Aperture and F3**

Significant for all speakers ($p < 0.0001$).
**RELATIONSHIP BETWEEN PHARYNGEAL APERTURE AND F3**

The graph illustrates the relationship between pharyngeal aperture (in millimeters) and the normalized F3 frequency. The data points are color-coded by speaker, with different symbols representing each speaker. The trend lines indicate a positive correlation between the two variables, though the statistical significance (n.s.) suggests that the relationship may not be statistically robust.

- **F3 (Normalized)**: The y-axis represents the normalized F3 frequency, ranging from -500 to 500.
- **Pharyngeal Aperture (mm)**: The x-axis represents the pharyngeal aperture in millimeters, ranging from 0 to 15.

The graph includes symbols and lines indicating the relationship for different speakers, with W1, M1, W2, and M2 represented by distinct colors and markers.
RELATIONSHIP BETWEEN LABIAL APERTURE AND F3
95% CI for Slope of Regression Lines

Pharyngeal

Palatal

Labial

Pharyngeal

Palatal

Labial

W1

Lab, Phar < Pal

Phar, Lab < Pal

M2

W2

Lab < Phar, Pal

M1

Lab < Phar, Pal

Pal Dominant

Pal/Phar Equivalent
RESULTS:

INDIVIDUAL DIFFERENCES IN CONSTRICITION LOCATION AND LENGTH
**Between-Speakers: Palatal Length & Location**

**Palatal Constriction Length**

Length (# of gridlines)

<table>
<thead>
<tr>
<th></th>
<th>W1</th>
<th>M1</th>
<th>W2</th>
<th>M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

- Pal Dominant < Pal/Phar Equivalent

**Palatal Constriction Location**

Distance from Glottis (mm)

<table>
<thead>
<tr>
<th></th>
<th>W1</th>
<th>M1</th>
<th>W2</th>
<th>M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>n.s.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Between-Speakers: Palatal Length & Location**

![Palatal Constriction Length](image1)

![Palatal Constriction Location](image2)

Pal Dominant > Pal/Phar Equivalent
**Between-Speakers: Pharyngeal Length & Location**

**Pharyngeal Constriction Length**

- Length (# of gridlines)
- W1: 8
- M1: 7
- W2: 6
- M2: 5

**Pharyngeal Constriction Location**

- Distance from Glottis (mm)
- W1: 30
- M1: 40
- W2: 50
- M2: 60

**No significant differences between speakers**
**Between-Speakers: Pharyngeal Length & Location**

**Pharyngeal Constriction Length**

- Length (# of gridlines)
  - W1: 10
  - M1: 8
  - W2: 6
  - M2: 4

**Pharyngeal Constriction Location**

- Distance from Glottis (mm)
  - W1: 2
  - M1: 3
  - W2: 2
  - M2: 1

**Pal Dominant < Pal/Phar Equivalent**
DISCUSSION
1. Are narrower constriction degrees associated with lower values of F3 for different speakers?
   ◦ Finding: Yes

2. Does the effect of constriction aperture on F3 differ across the three gestures involved in the production of /ɹ/?
   ◦ Finding: Variable (by speaker)

3. Does variation in constriction length and location influence the effect of aperture on F3 values?
   ◦ Finding: Yes
Palatal = Pharyngeal
CONCLUSION

1. Strong evidence that constriction degree directly influences the extent of F3 lowering in /u/
   ◦ Consistent with the predictions of perturbation theory

2. The relative effect of palatal, pharyngeal and labial aperture on F3 varies across speakers
   ◦ Appears to be affected by differences in articulatory strategies

3. Findings provide a mechanism for explaining patterns of systematic F3 variation across different linguistic contexts
THANK YOU

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For corpus access and more rtMRI research, visit
https://sail.usc.edu/span/index.html
EXTRA SLIDES
INDIVIDUAL VARIATION

F3 (HZ)

ANTERIORITY

APERTURE

CONSTRICION LOCATION

EFFECT OF APERTURE
ARTICULATORY ANALYSIS

(2) Air-tissue boundary segmentation → Aperture, Length and Location

References: Kim et al., 2014
ARTICULATORY ANALYSIS

(2) Air-tissue boundary segmentation

References: Kim et al., 2014