

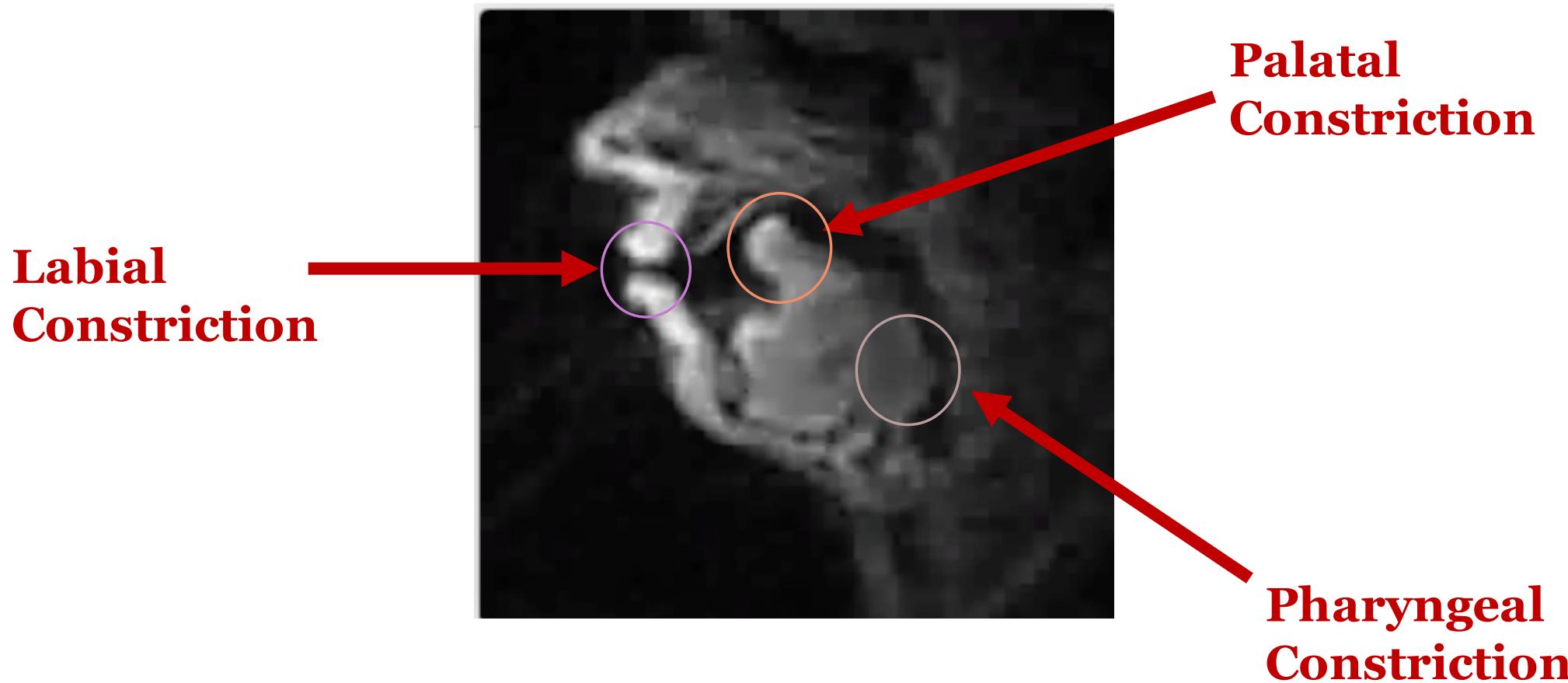


# Quantifying Variation in Labial, Palatal and Pharyngeal Contributions to F3 Lowering in /ɹ/

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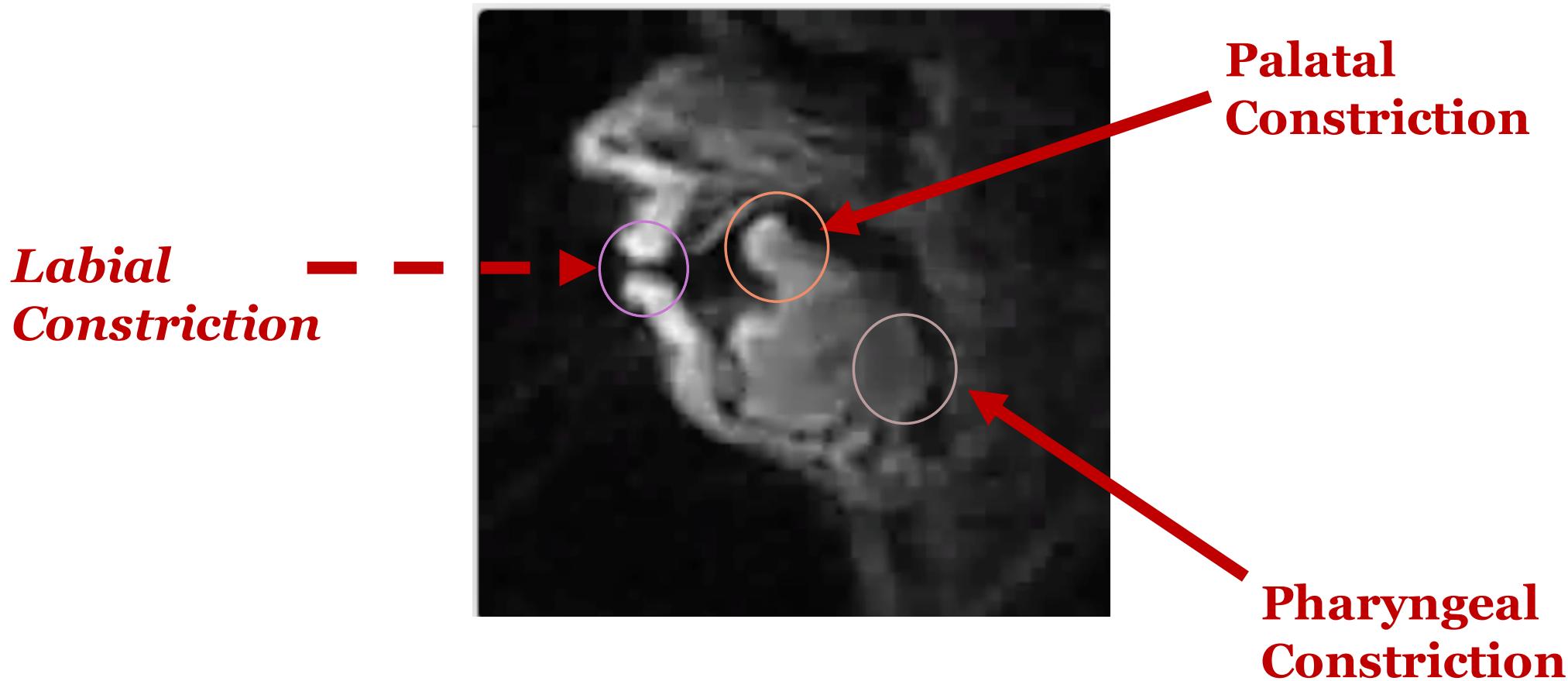
Sarah Harper, Louis Goldstein and Shrikanth Narayanan  
University of Southern California

# AMERICAN ENGLISH /ɹ/ PRODUCTION



**References:** Delattre & Freeman, 1968; Zawadski & Kuehn, 1980; Alwan et al., 1997; Westbury et al., 1998; Guenther et al., 1999; Mielke et al., 2010

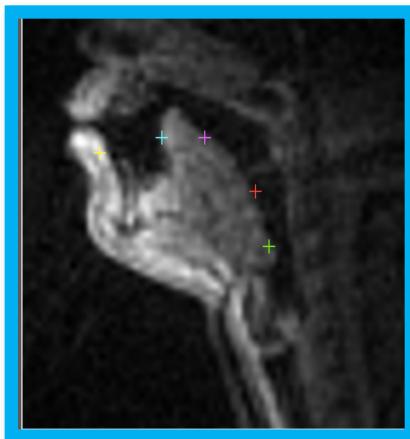
# AMERICAN ENGLISH /ɹ/ PRODUCTION



**References:** Delattre & Freeman, 1968; Zawadski & Kuehn, 1980; Alwan et al., 1997; Westbury et al., 1998; Guenther et al., 1999; Mielke et al., 2010

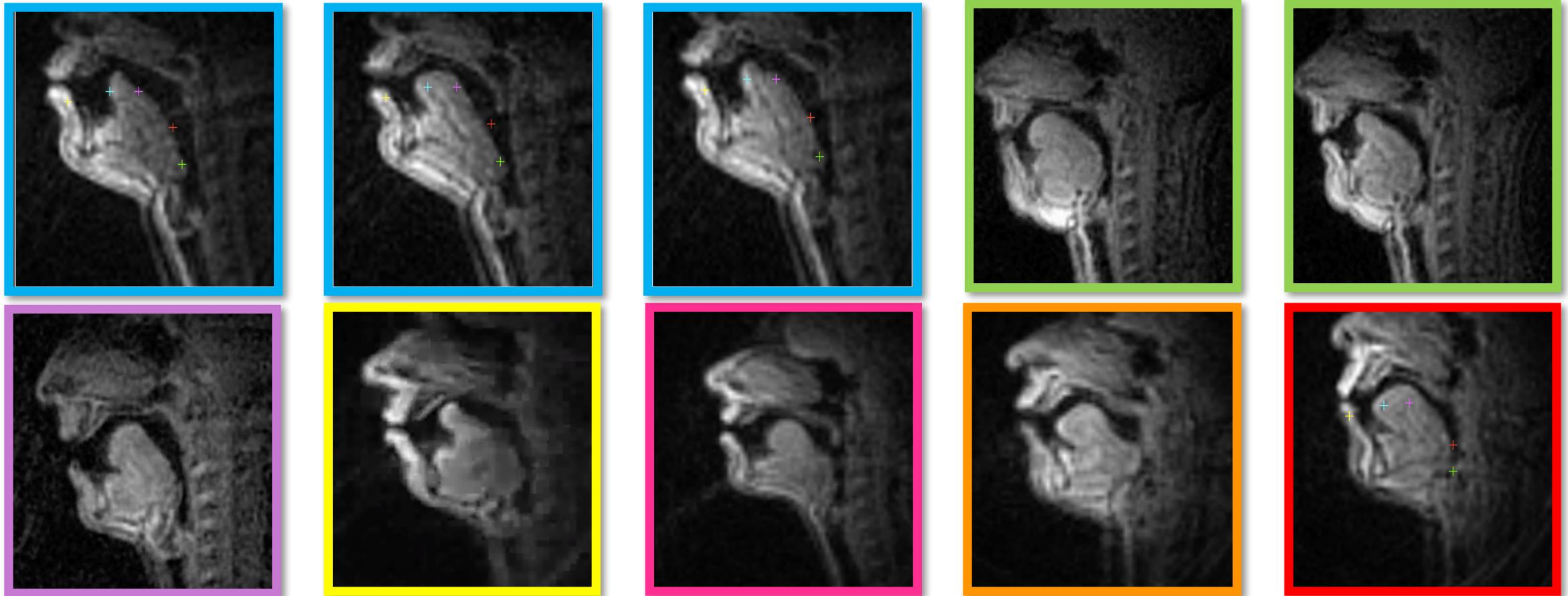
# VARIATION IN /u/

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



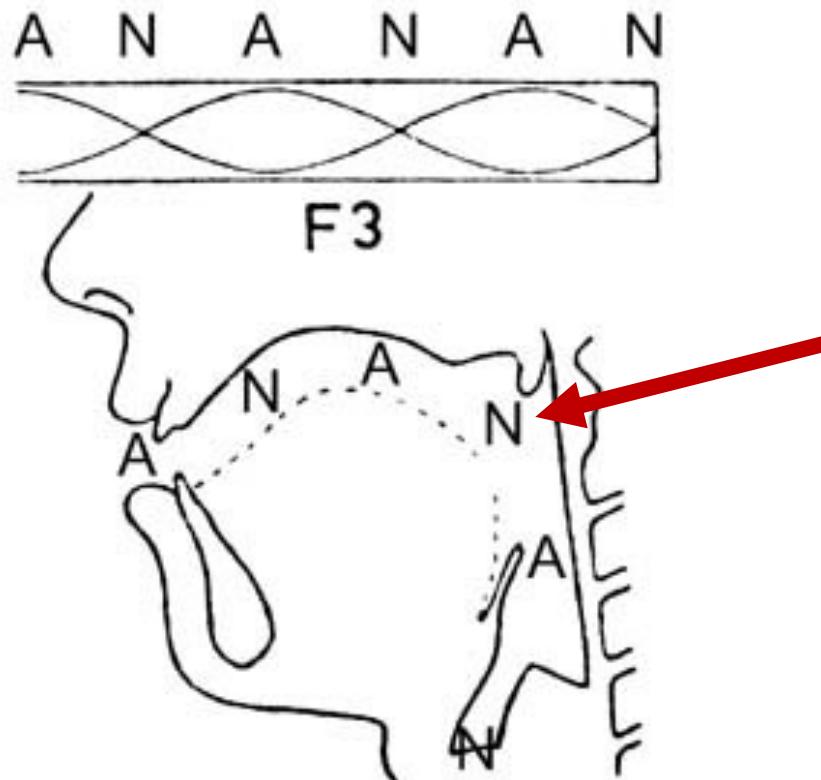
# VARIATION IN /u/

- 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

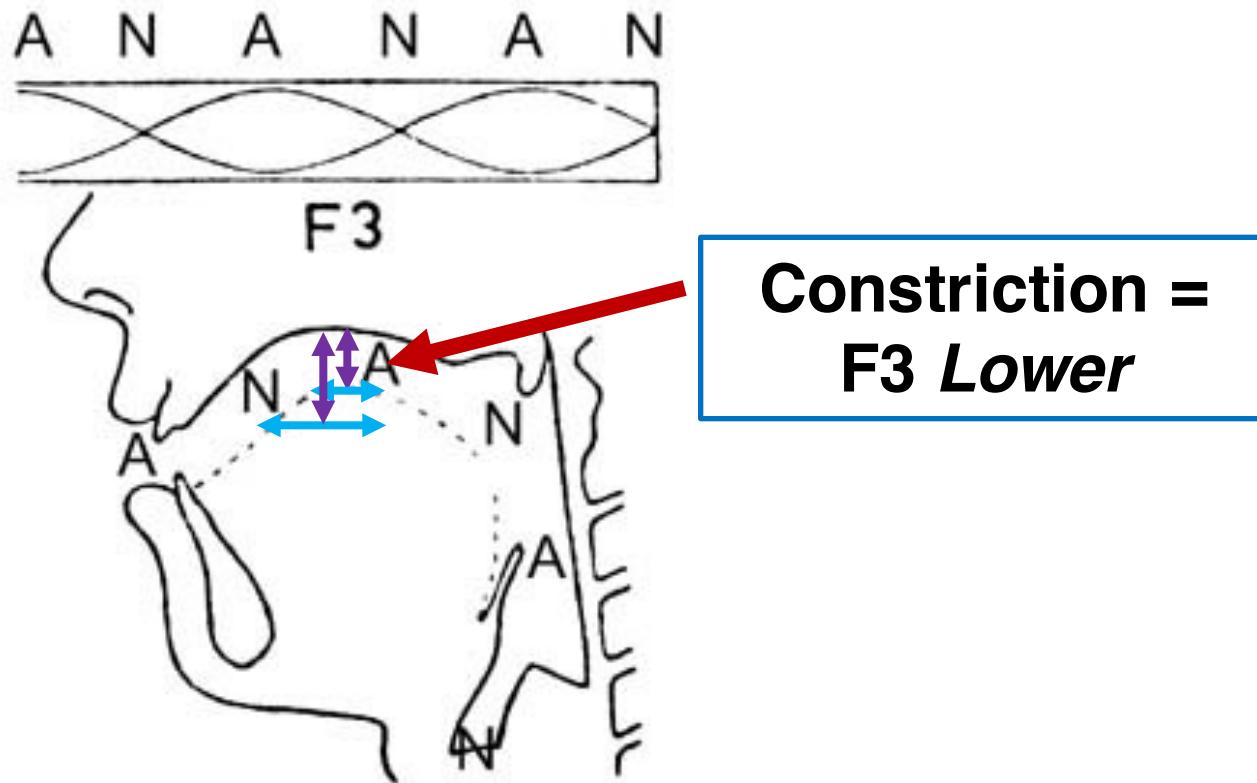
# PERTURBATION THEORY AND F<sub>3</sub> IN /ɹ/



**Constriction =  
F<sub>3</sub> Higher**

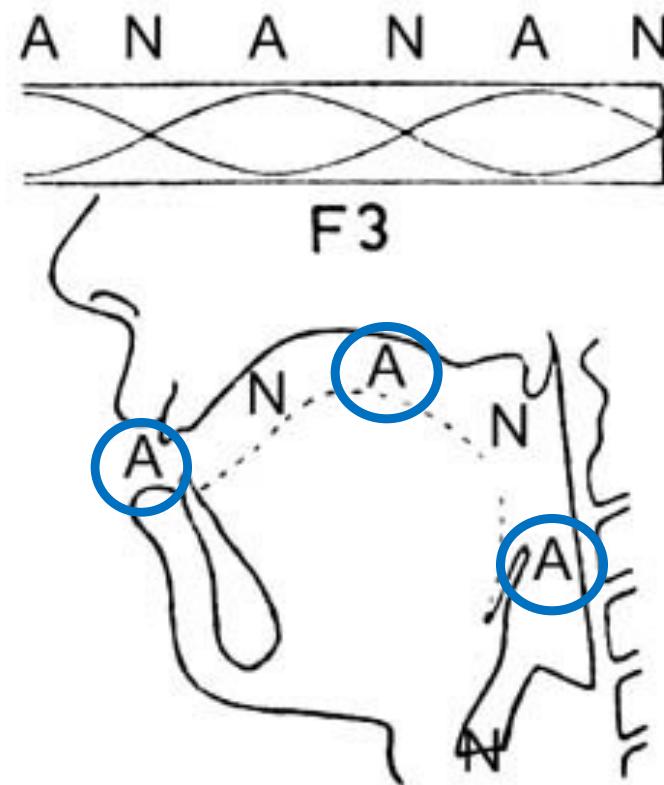
Adapted from Chiba & Kajiyama (1941)

# PERTURBATION THEORY AND F<sub>3</sub> IN /ʌ/



Adapted from Chiba & Kajiyama (1941)

# PERTURBATION THEORY AND F3 IN /ʌ/



Adapted from Chiba & Kajiyama (1941)

# VARIATION IN /ɹ/

- Systematic and parallel variation observed in the degree of constriction and F3 values in /ɹ/

## Constriction Degree:

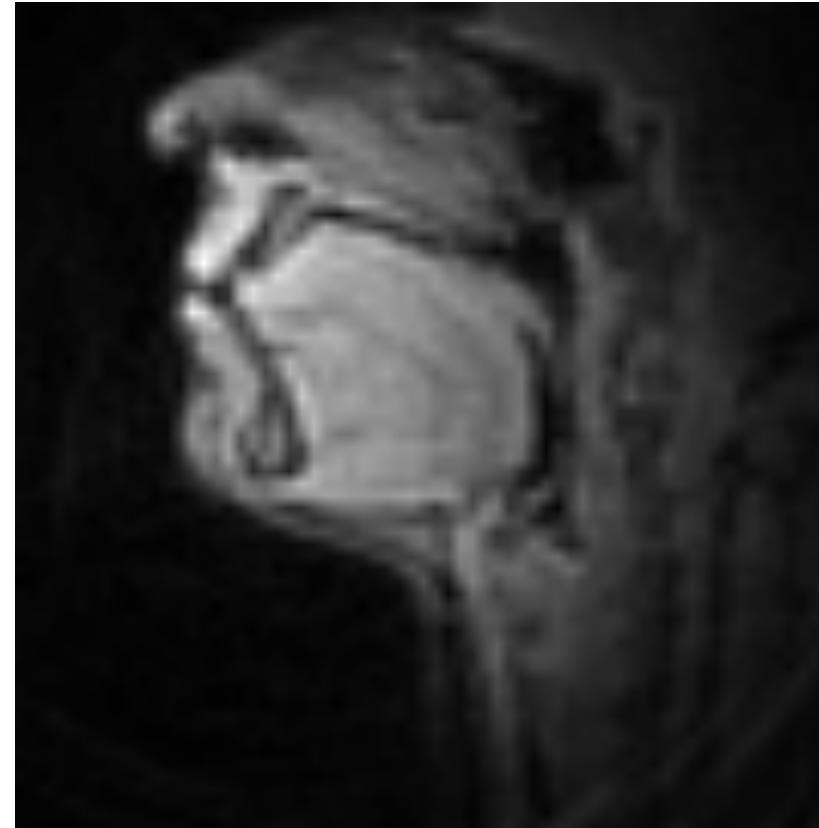
- Reduced palatal and labial magnitude in word- and syllable-final /ɹ/
- Narrower constriction (smaller aperture) in citation form than in connected speech

## 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

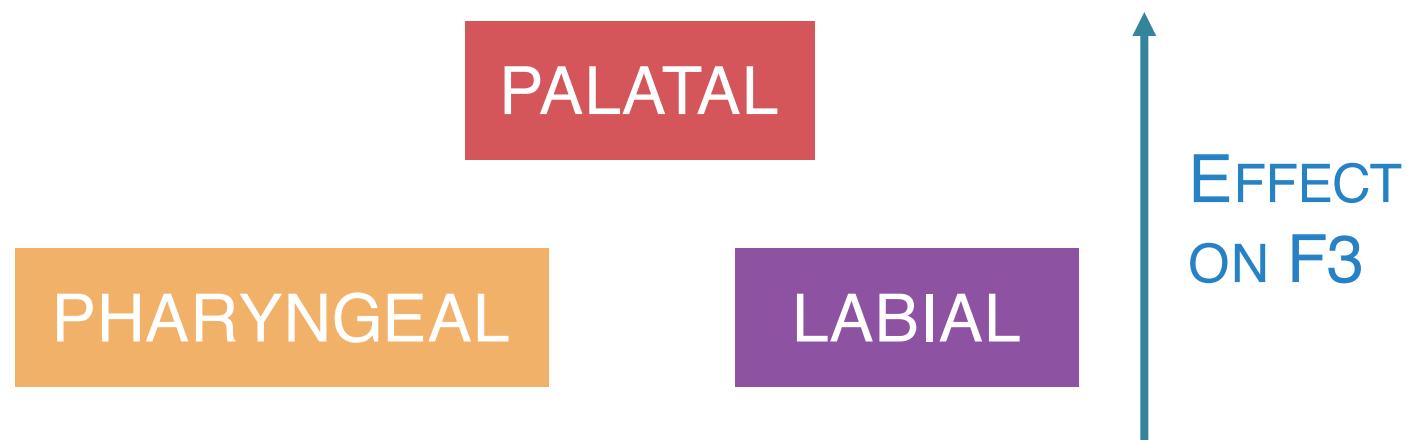
**How does the degree of constriction at these locations affect the value of F3?**

# 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 /ɹ/?
  - Prediction: Yes



# QUESTIONS

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**

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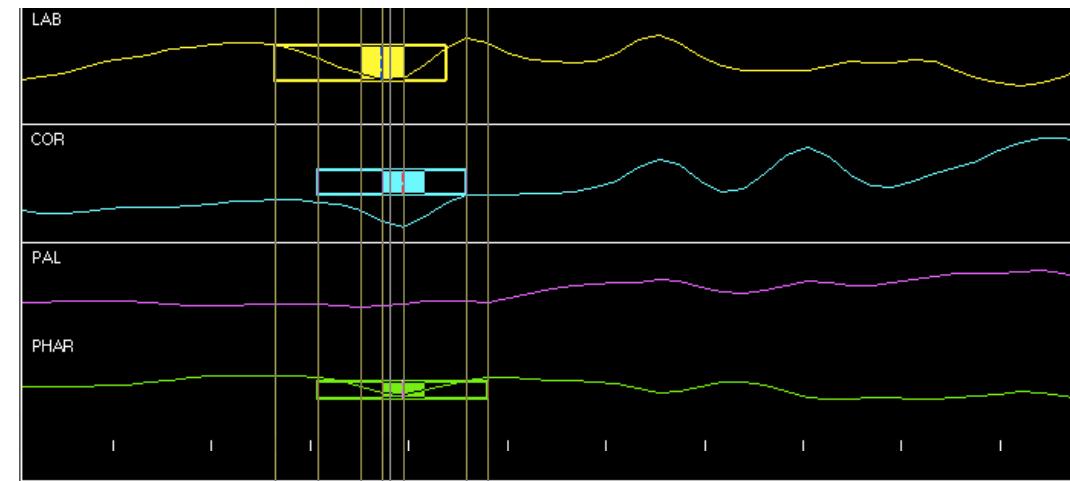
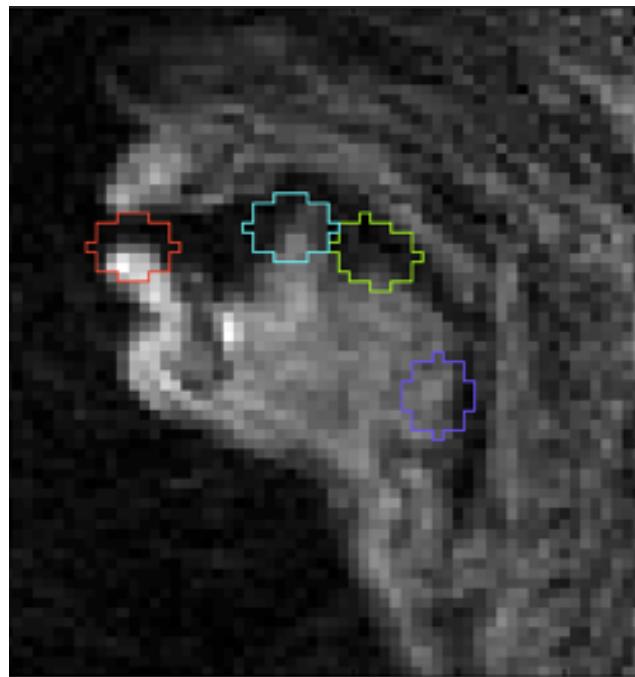
# EXPERIMENT DESIGN

- 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)

# ANALYSIS

## Articulatory Analysis

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

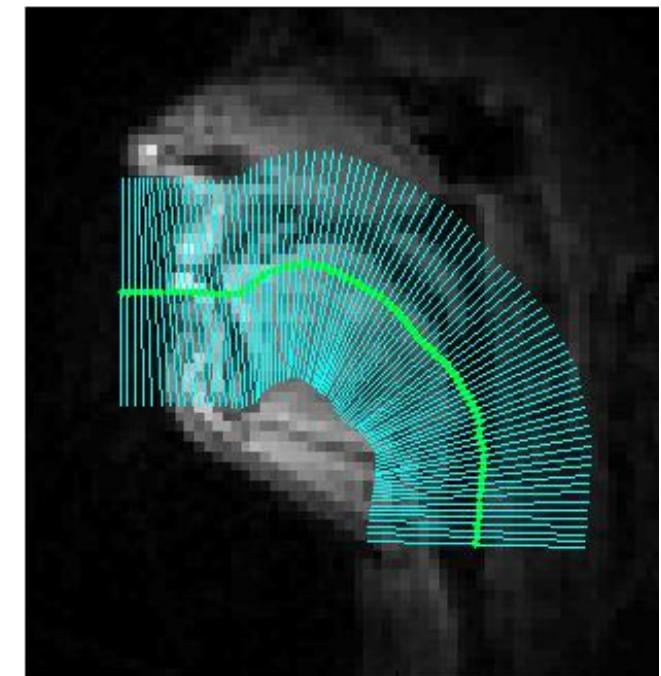
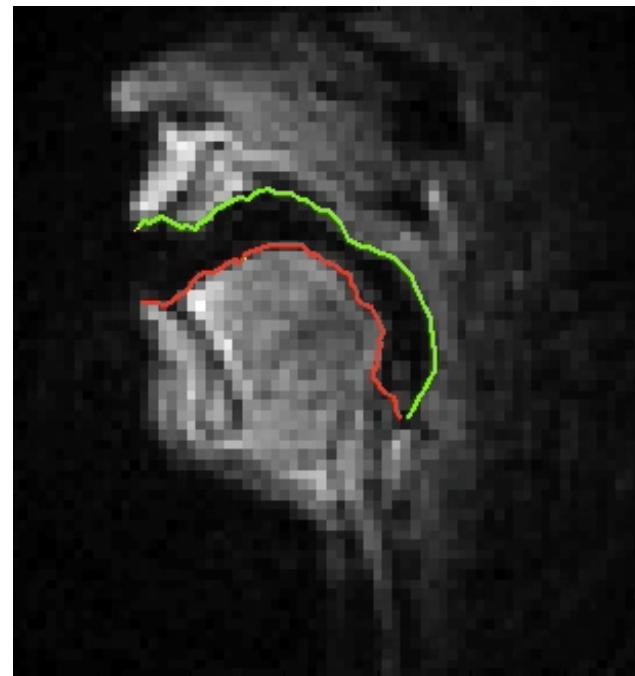


References: Tiede, 2010; Lammert et al., 2013; Lammert et al., 2014; Kim et al., 2014; Boersma & Weenick, 2016

# ANALYSIS

## 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**



# ANALYSIS

## 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**

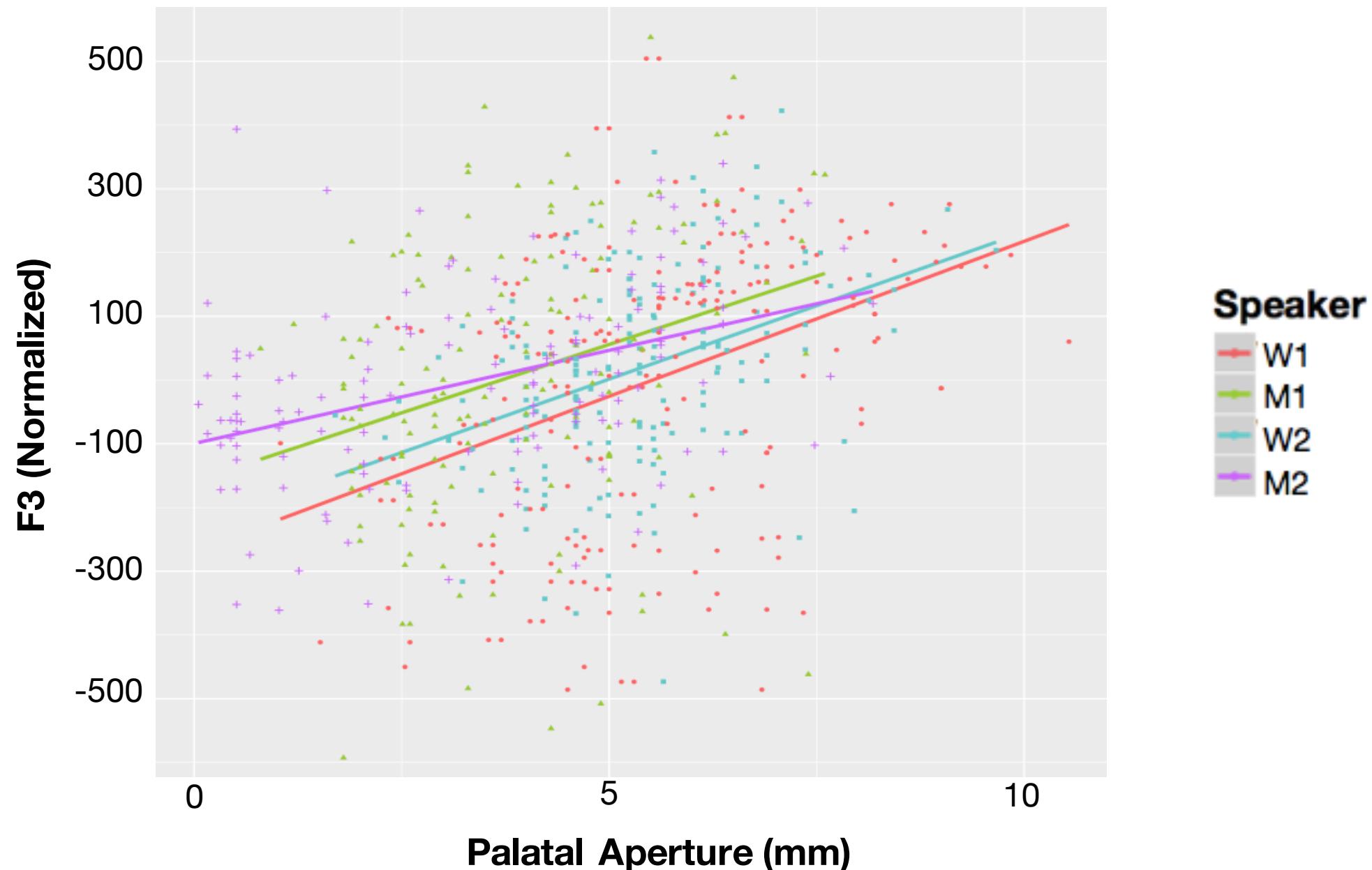
## Acoustic Analysis

- Formant values F<sub>1</sub>, F<sub>2</sub>, **F<sub>3</sub>** and F<sub>4</sub> automatically extracted at time of maximum constriction using a script in Praat

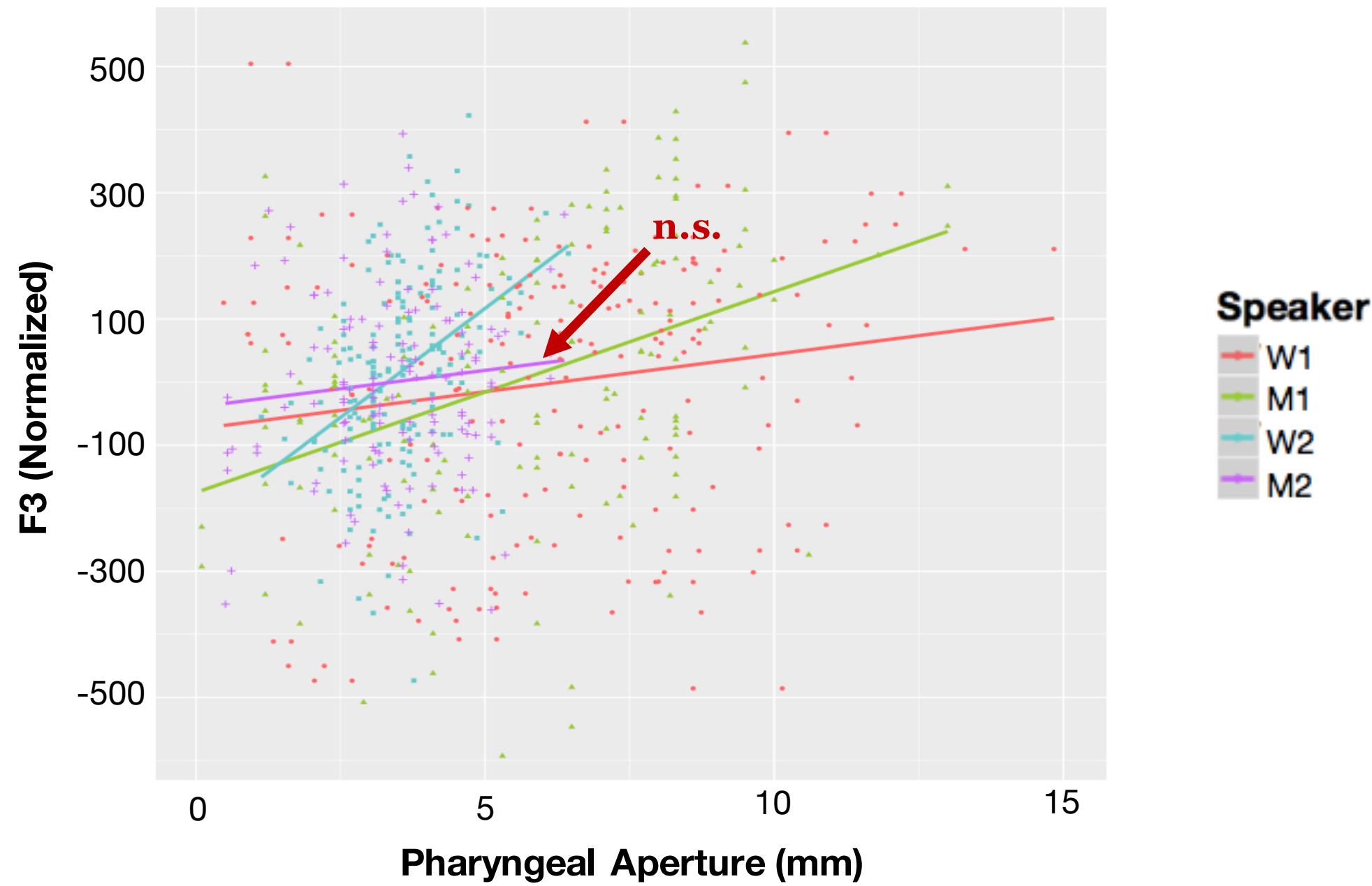
# **RESULTS: MAIN EFFECTS OF APERTURE**

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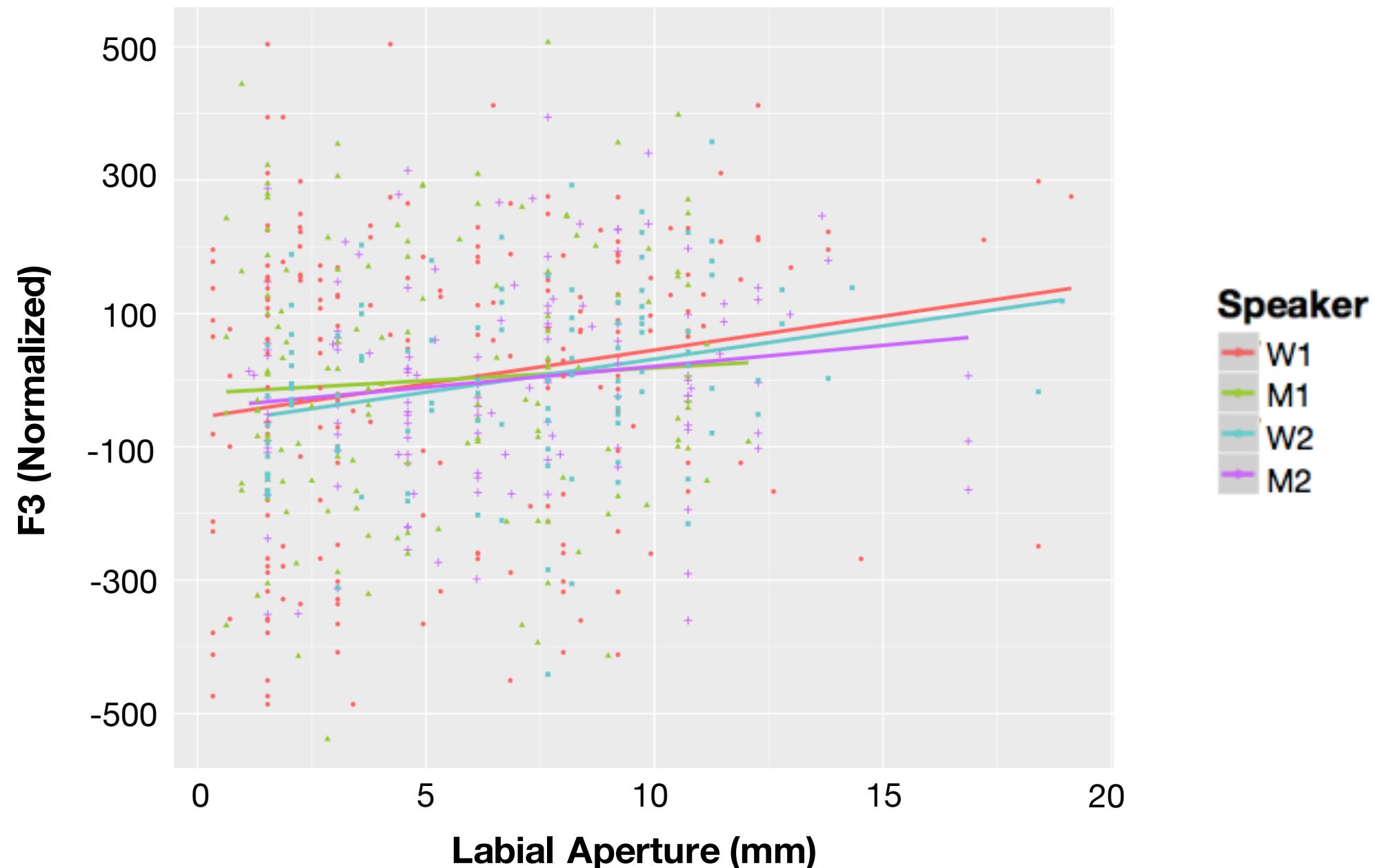
# RELATIONSHIP BETWEEN PALATAL APERTURE AND F3



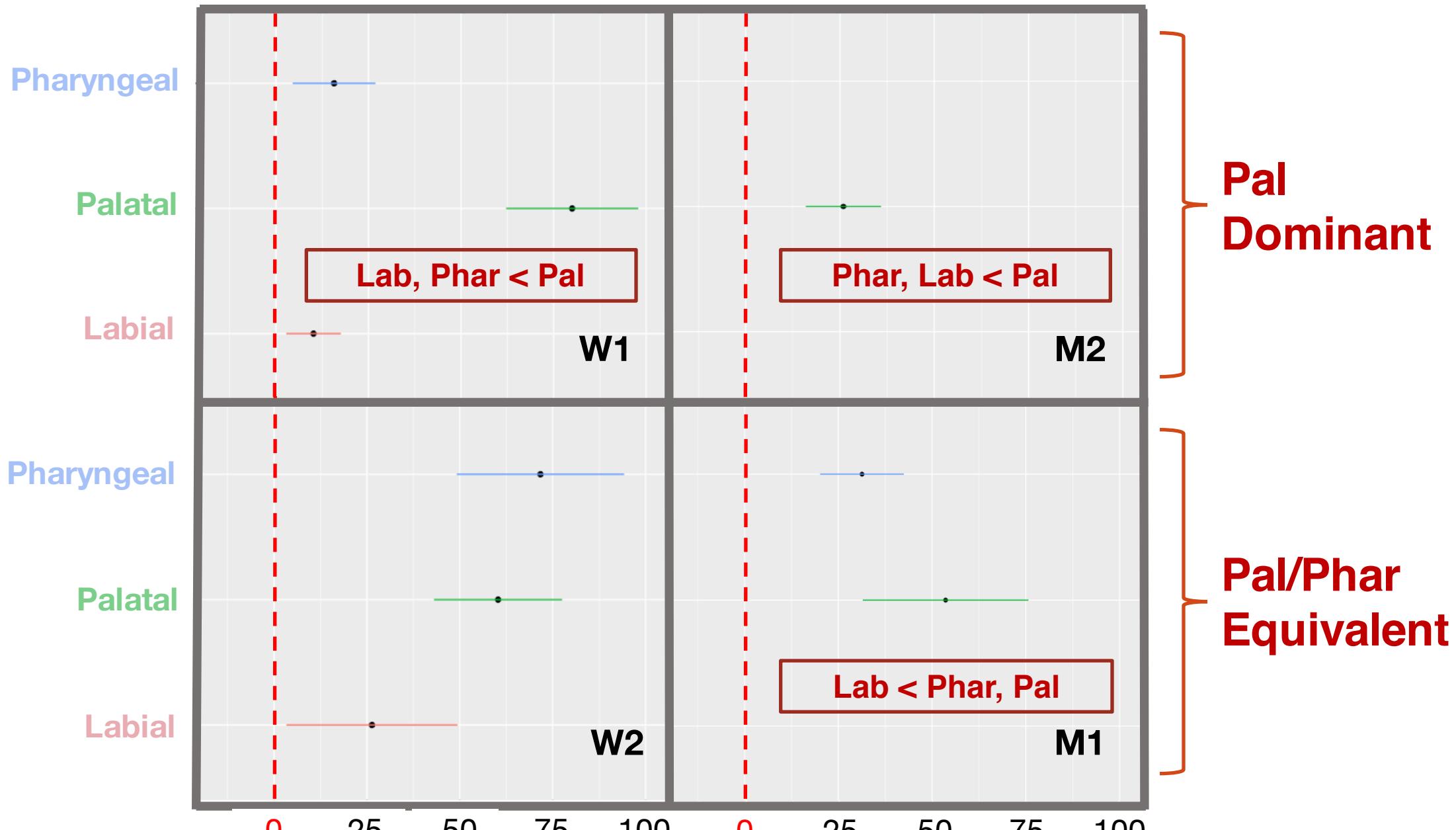
# RELATIONSHIP BETWEEN PHARYNGEAL APERTURE AND F3



# RELATIONSHIP BETWEEN LABIAL APERTURE AND F3



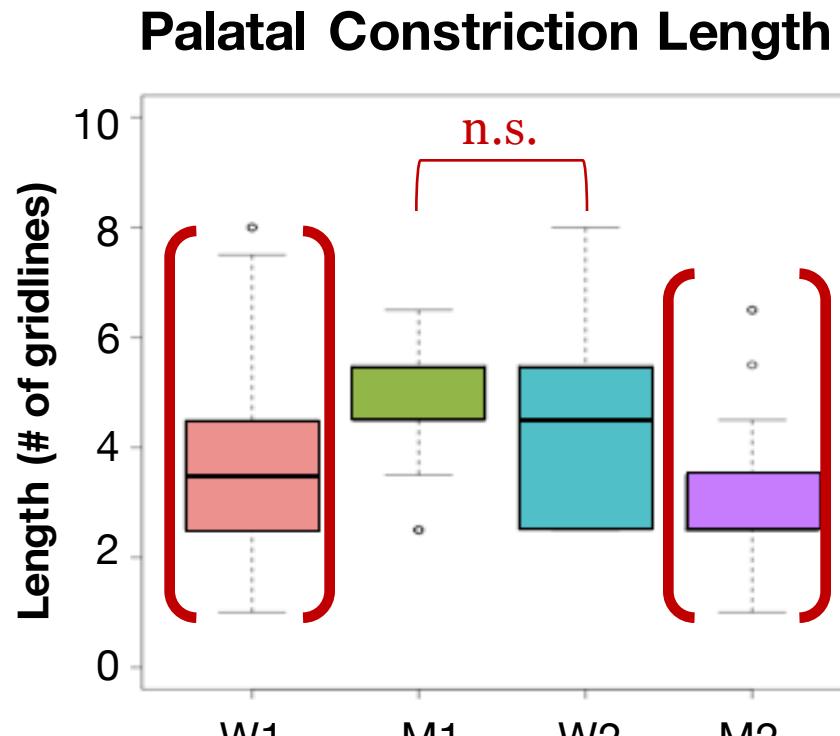
# 95% CI FOR SLOPE OF REGRESSION LINES



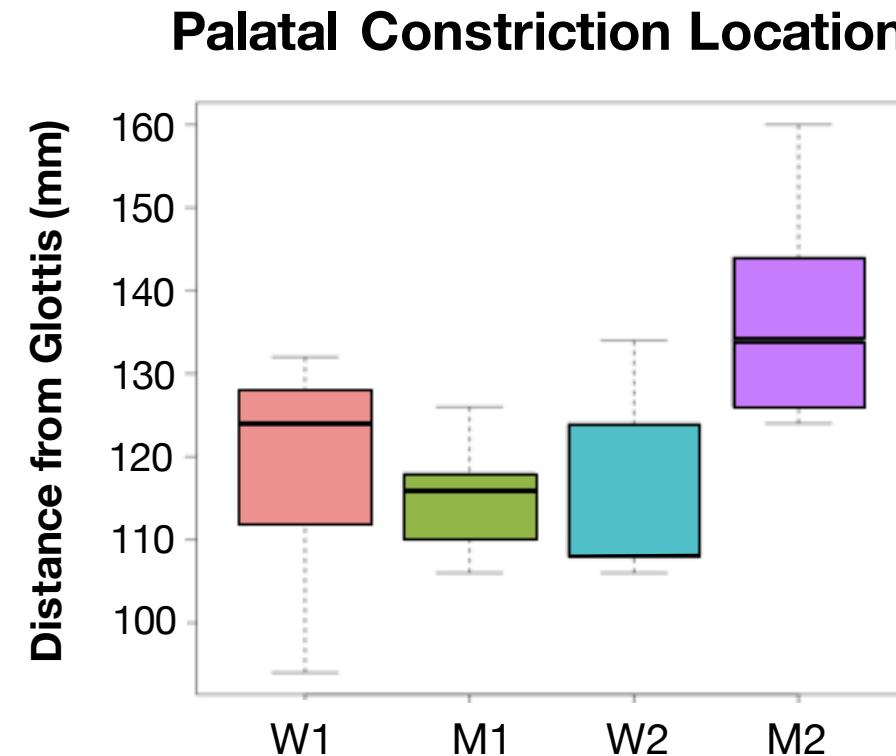
# **RESULTS: INDIVIDUAL DIFFERENCES IN CONSTRICITION LOCATION AND LENGTH**

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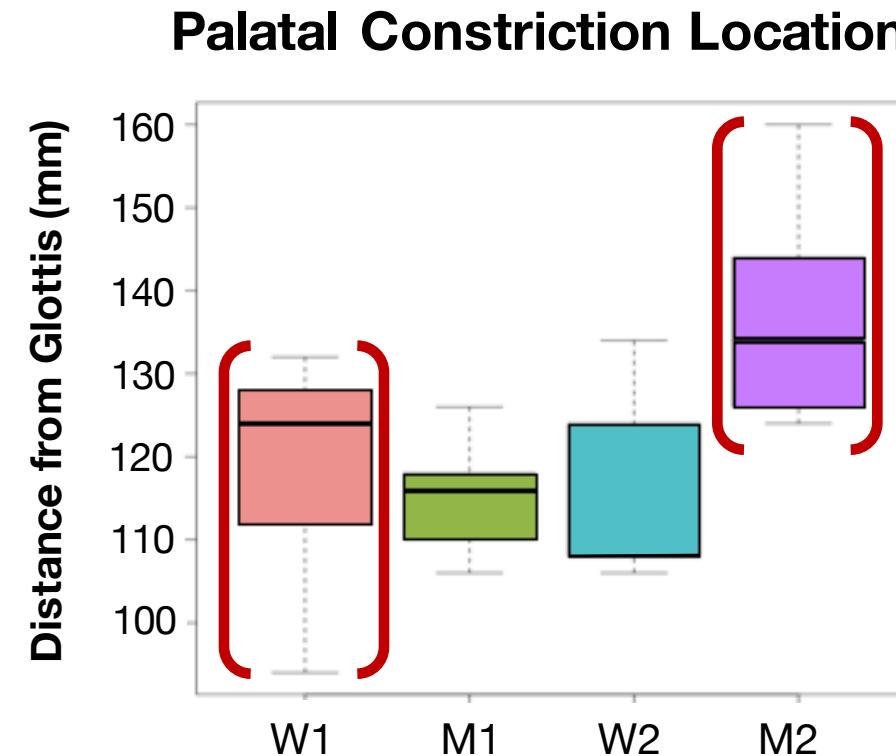
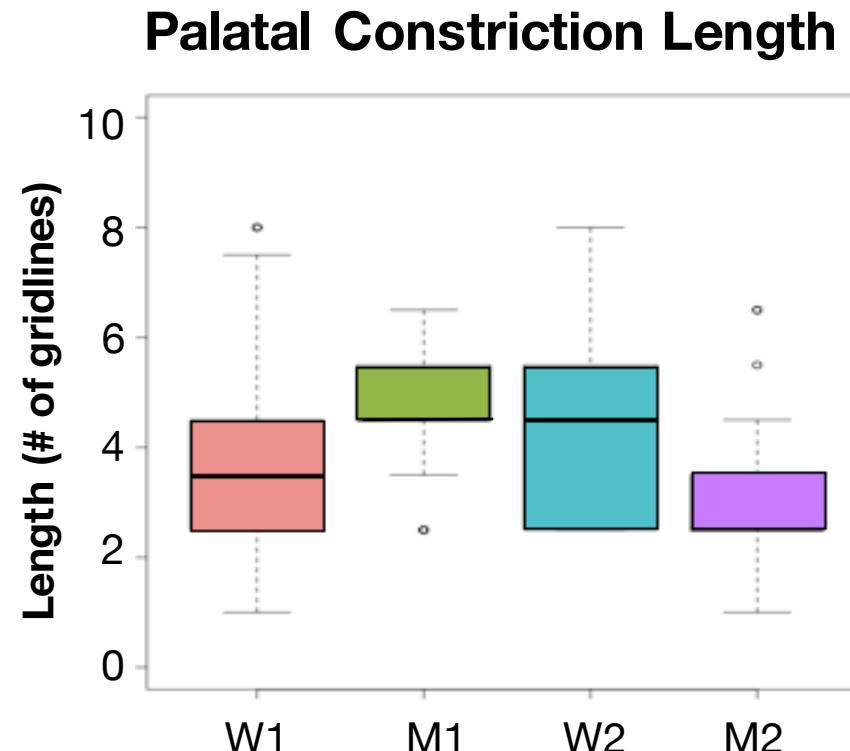
# BETWEEN-SPEAKERS: PALATAL LENGTH & LOCATION



Pal Dominant < Pal/Phar Equivalent

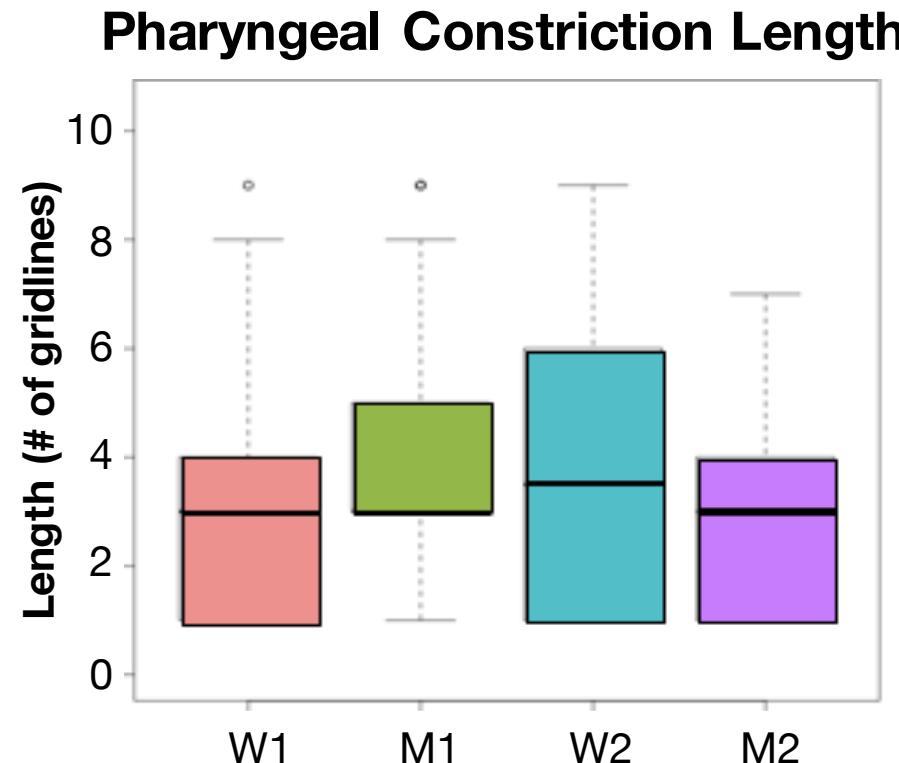


# BETWEEN-SPEAKERS: PALATAL LENGTH & LOCATION

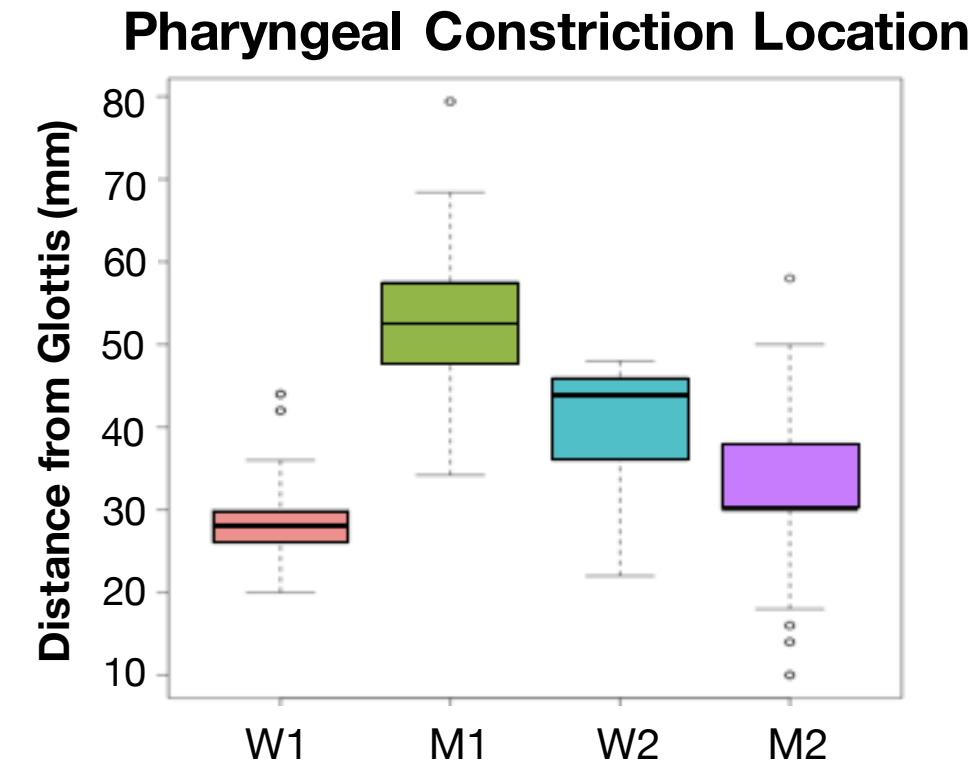


Pal Dominant > Pal/Phar Equivalent

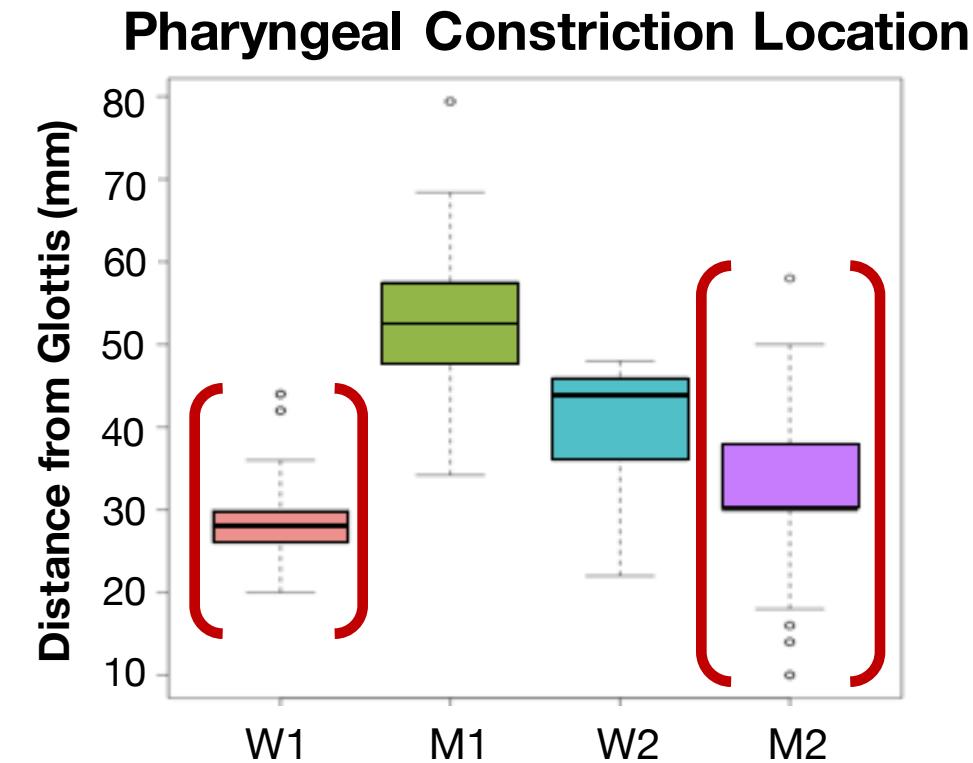
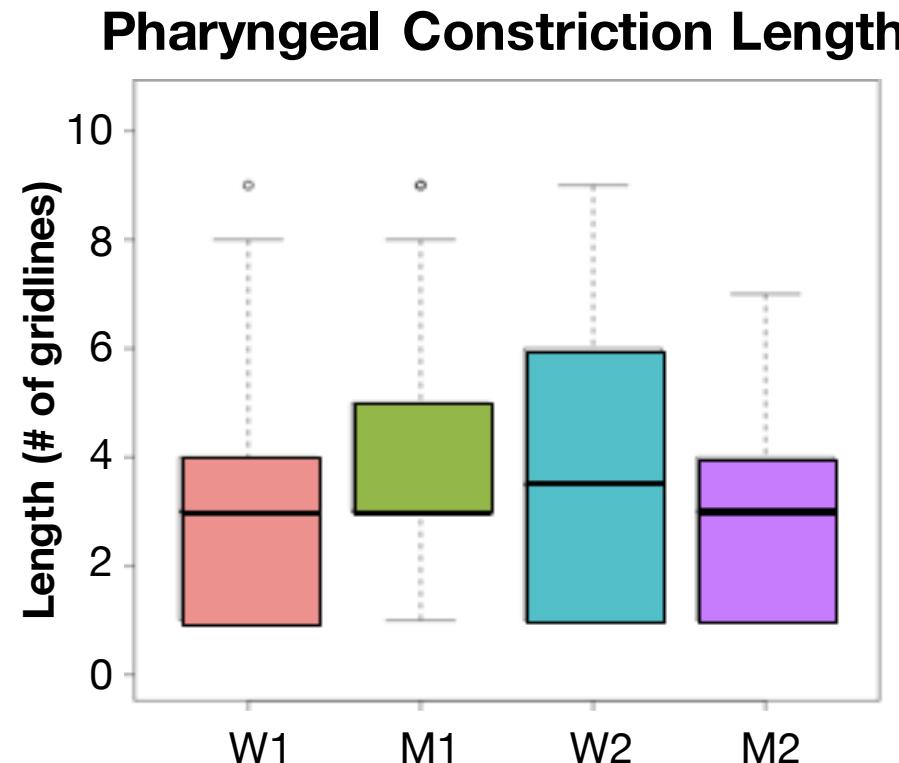
# BETWEEN-SPEAKERS: PHARYNGEAL LENGTH & LOCATION



No significant differences  
between speakers



# BETWEEN-SPEAKERS: PHARYNGEAL LENGTH & LOCATION



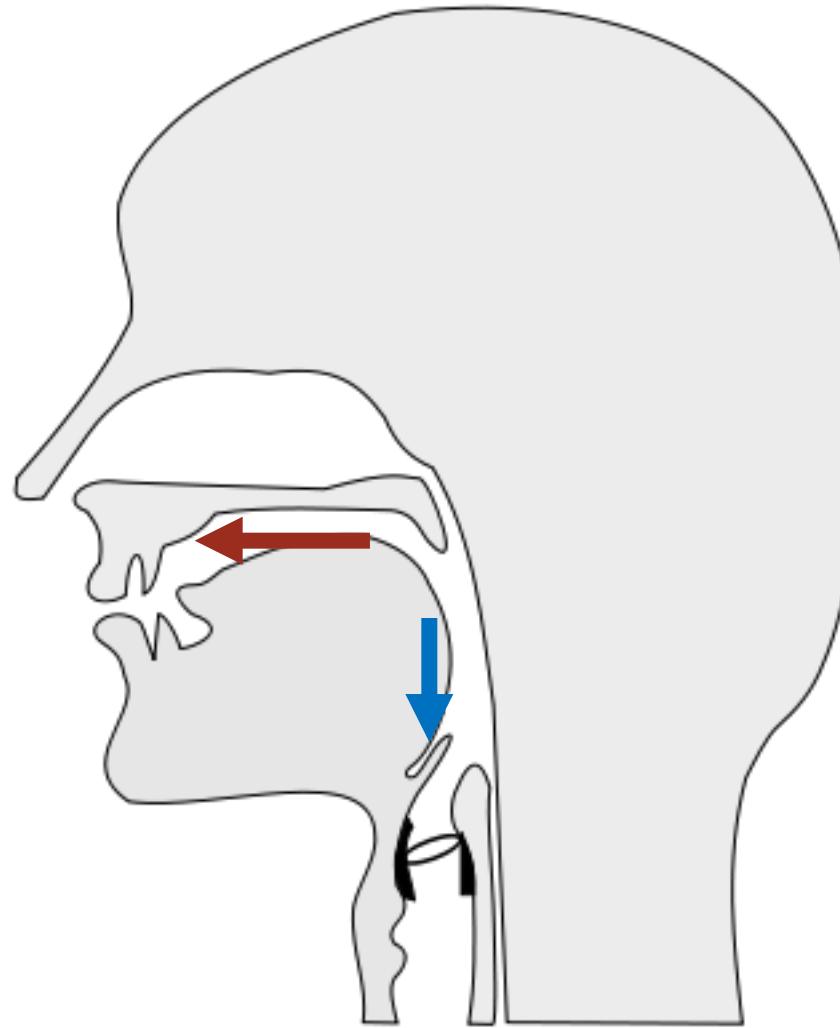
Pal Dominant < Pal/Phar Equivalent

# **DISCUSSION**

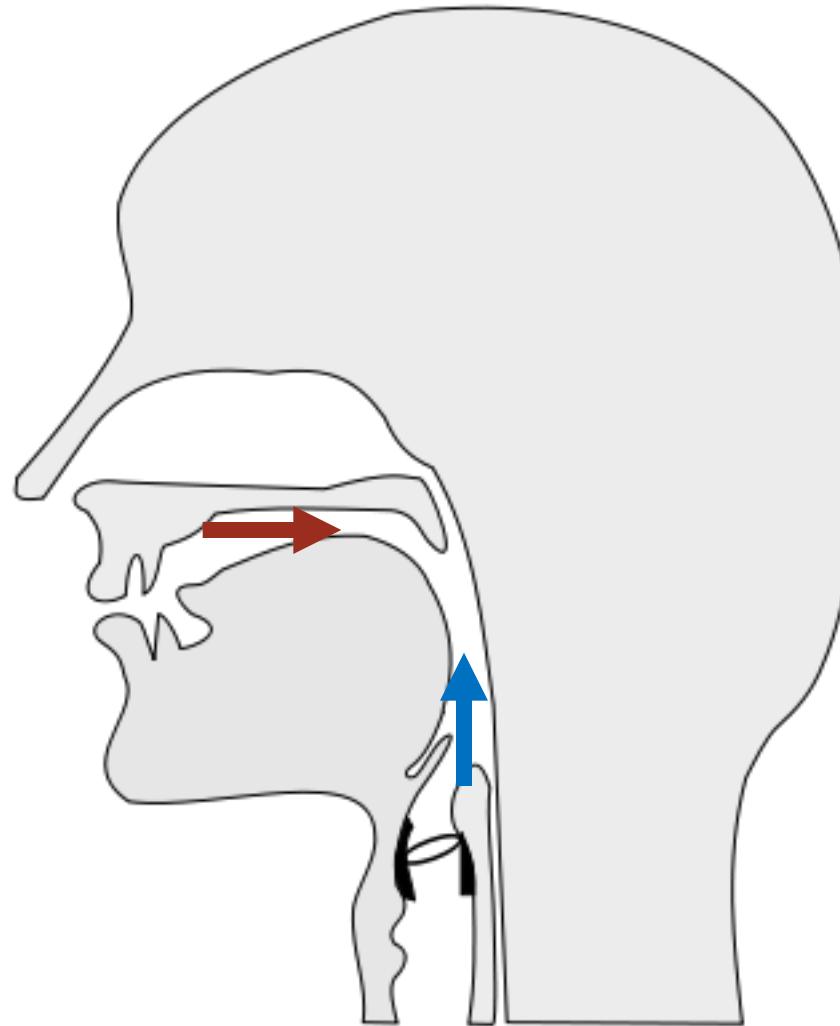
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# QUESTIONS REVISITED

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**



**Palatal = Pharyngeal**

# CONCLUSION

1. Strong evidence that constriction degree directly influences the extent of F3 lowering in /ɹ/
  - 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

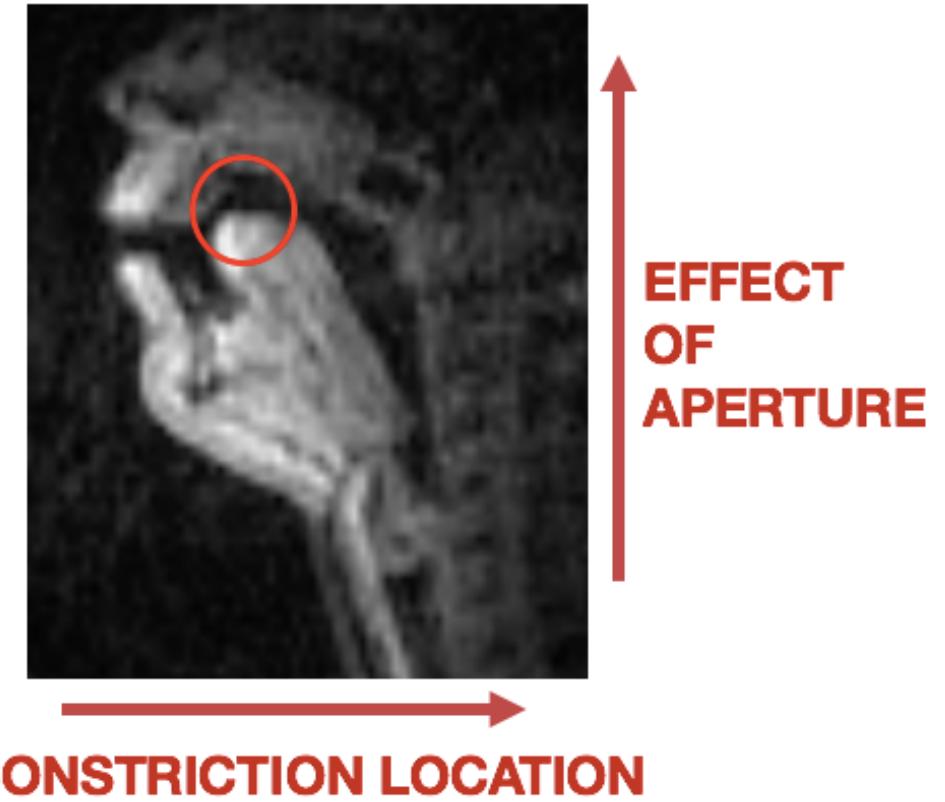
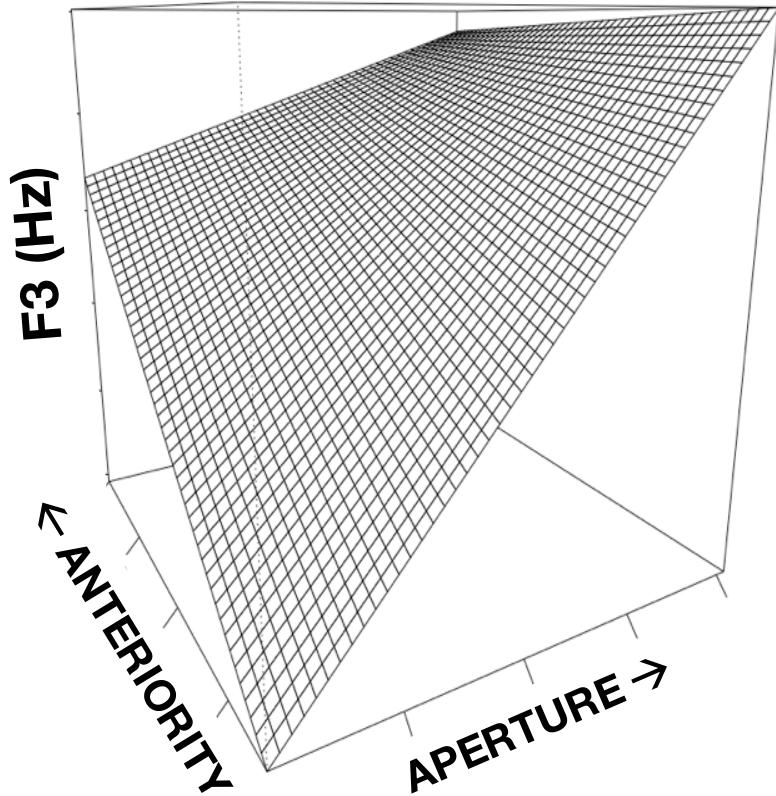
# THANK YOU

**Research supported by NIH Grant DC007124**

For corpus access and more rtMRI research, visit  
<https://sail.usc.edu/span/index.html>

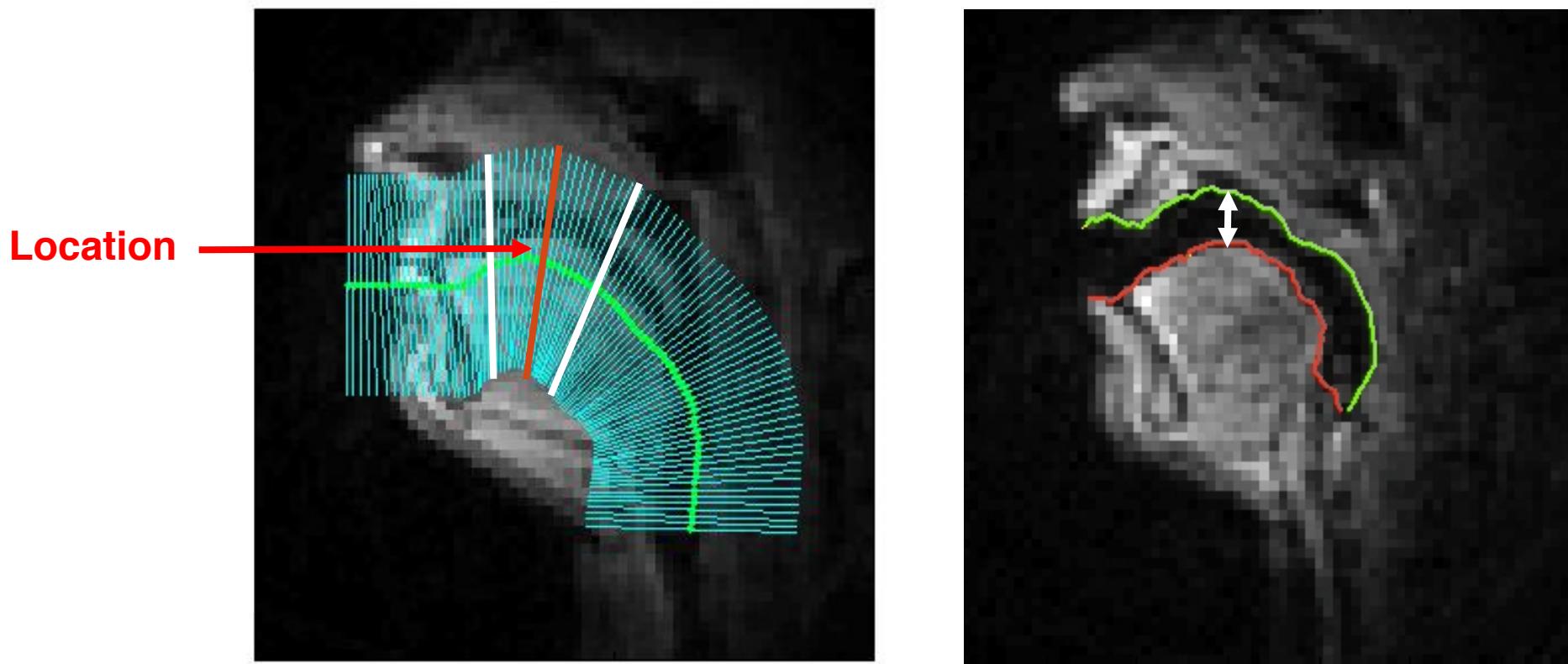
# *EXTRA SLIDES*

# INDIVIDUAL VARIATION



# ARTICULATORY ANALYSIS

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



# ARTICULATORY ANALYSIS

## (2) Air-tissue boundary segmentation

