The role of the tongue and pharynx in enhancement of vowel nasalization: A real-time MRI investigation of French nasal vowels.

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Introduction: nasalization

- Nasal vowels are characterized by some degree of coupling between the nasal and oral cavities.
  - Velopharyngeal coupling, i.e., “nasalization”.
- It is well known that nasalization significantly alters the acoustic spectrum of vowels (Hawkins & Stevens, 1985; Katakoa et al., 2001; Pruthi et al., 2007).
- Aside from acoustic effects such as formant amplitude reduction and bandwidth widening, modeling and acoustic studies suggest that the F1/F2 frequencies modulated.

Introduction: effect on F1/F2

- The frequencies are **centralized along the F1 dimension** (i.e, F1 is raised for high vowels and lowered for low vowels). (Fujimura & Lindqvist, 1971; Diehl et al., 1991; Serrurier & Badin, 2008; Feng & Castelli, 1996)
- The **F2 frequency is lowered** for all non-back vowels (Serrurier & Badin, 2008; Feng & Castelli, 1996; Carignan, 2013).

Introduction: F1/F2 (cont.)

- Krakow et al. (1988) observed that the F1 variation inherent in nasalization is similar to acoustic changes associated with tongue height and jaw position, and that the effect of nasalization on F1 can be perceived as a change in tongue height.
  - Nasalized high vowels perceived as lower, nasalized low vowels perceived as higher
- Lingual height centralization is also well-documented typologically for phonemic nasal vowels.
  - In a variety of languages, under the influence of nasalization, high vowels are transcribed as lower and low vowels are transcribed as higher (Beddor, 1983; Hajek, 1997; Sampson, 1999).
- Delvaux (2009) shows that F2 lowering alone may help trigger the percept of nasality in French vowels.

Vowel nasalization's problem of ambiguity

- Ambiguity in the acoustic signal
  - Formant changes due to nasalization or changes in oral articulation?
- Ambiguity in perception
  - Formant changes due to nasalization or changes in oral articulation?
- NB: acoustic signal alone is not enough to determine the effect of the respective articulatory contributions to the acoustic realization.

Vowel nasalization → misperception of source?

- Given the perceptual confusion between formant changes due to nasalization and formant changes due to oral articulation, there is likely a tendency for the acoustic centralization of F1 and lowering of F2 (due to nasalization) to be misperceived as oral articulatory changes.
- Following Ohala (1993, 1996), this misperception may lead to consistent, systematic changes in oral articulatory configuration as concomitants of nasal vowel phonologization.

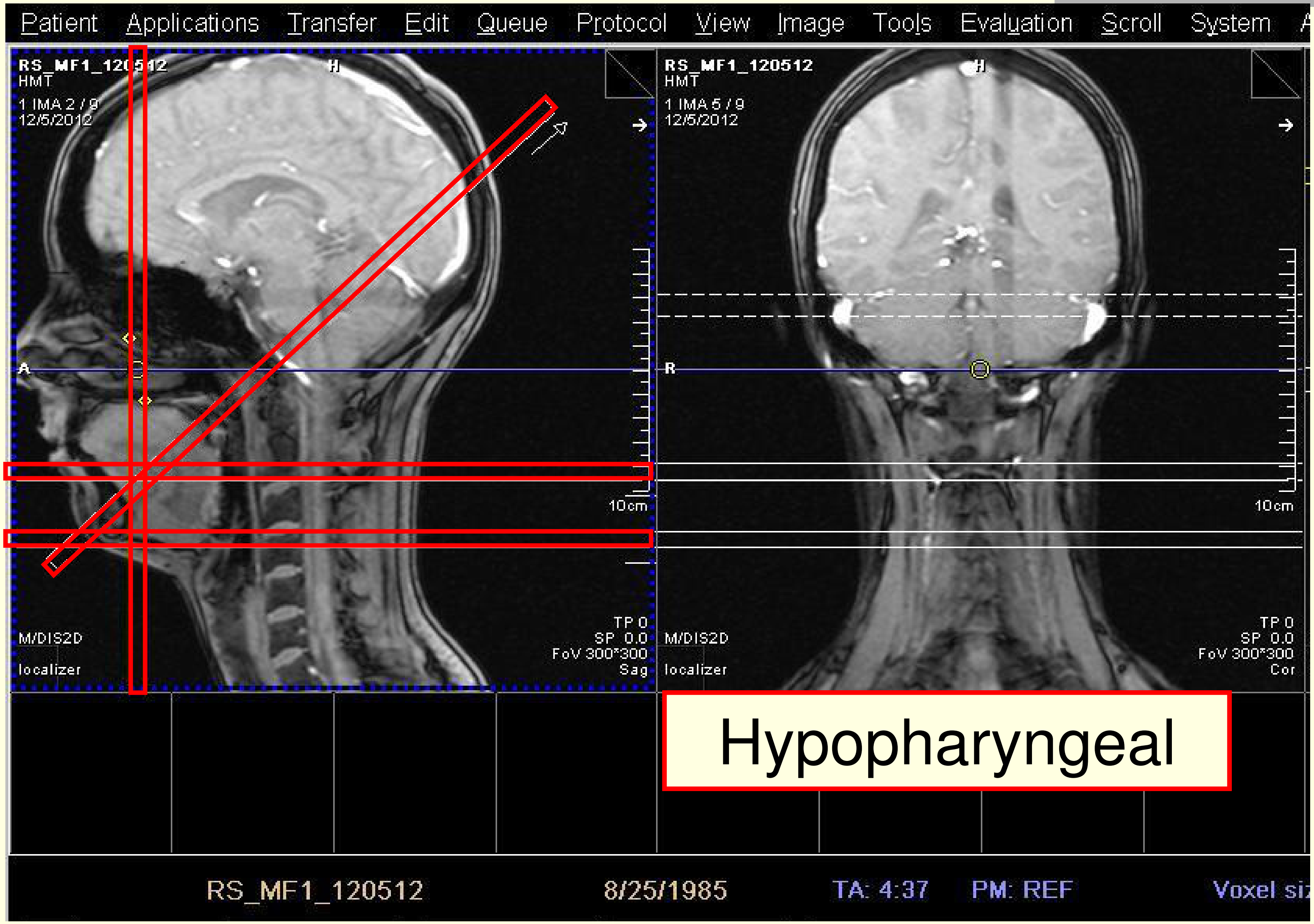
Disambiguating NMF nasal vowels

- Previous research has observed that there are oral articulatory differences between nasal vowels and their oral counterparts in Northern Metropolitan French (NMF)
  - (Straka, 1965; Bricher-Labaeye, 1970; Zerling, 1984; Bothorel et al., 1986; Montagu, 2002; Delvaux et al., 2002; Carignan, 2013)
- Using AG200 and AG500, Carignan (2013) found that F1/nasalization discrepancy not predicted by lingual/labial articulation in some cases.
  - Pharyngealization plays a role in the acoustic manifestation of some NMF nasal vowels?

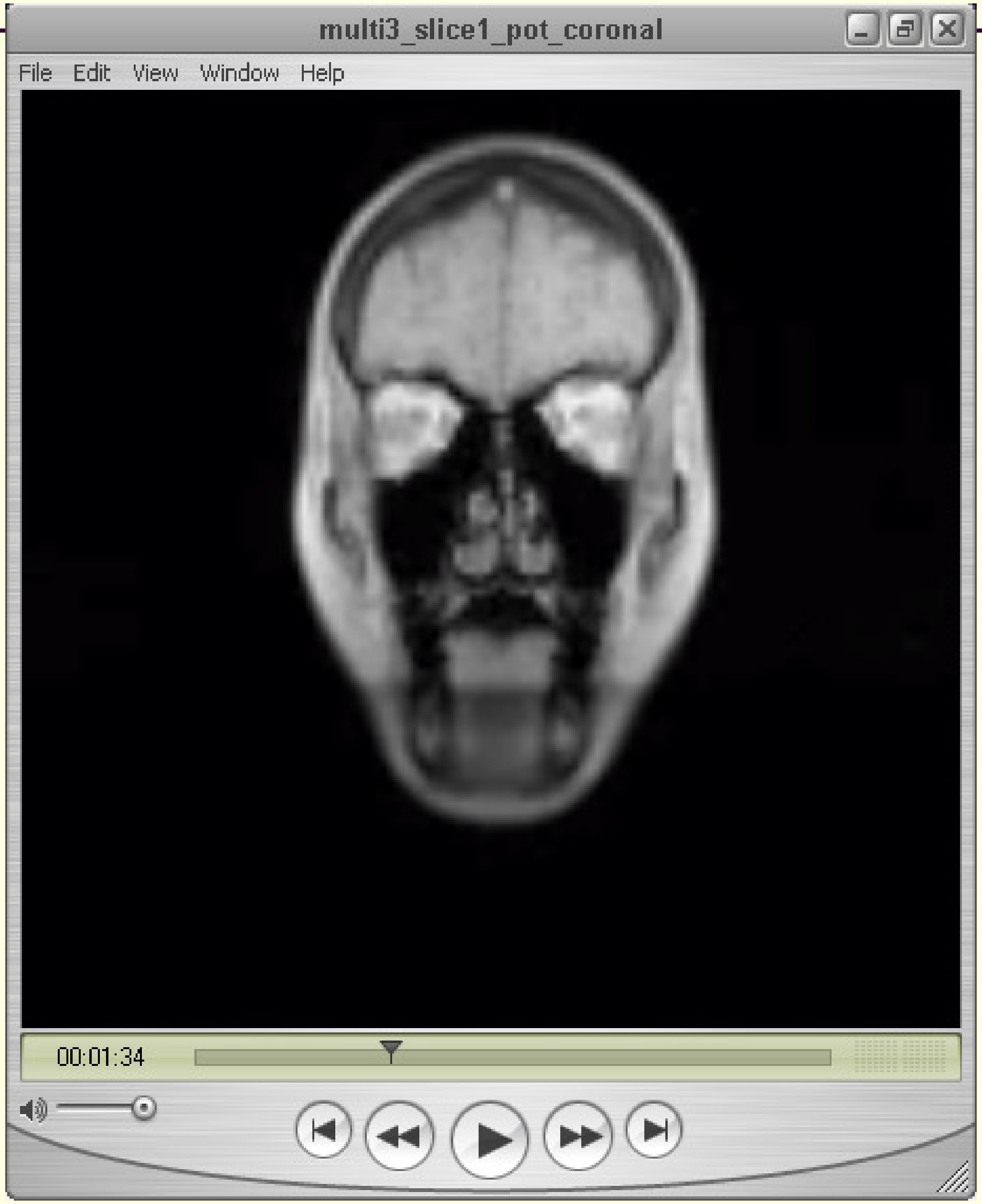
Methodology

- Real-time MRI using partially separable functions (Liang, 2007)
- 128 × 128 voxels
- Voxel resolution: 2.2 mm × 2.2 mm × 8.0 mm
- ~25 fps for each of four simultaneously recorded slices.
- Four slices:
  - Coronal
  - Oblique (velopharyngeal)
  - Hyperpharyngeal
  - Hypopharyngeal

rtMRI tomography



rtMRI video (example)



- *Il retape pot parfois.*
- ‘He retypes pot/jar sometimes.’
- /o/
- Coronal slice

Methodology (cont.)

- Three NMF female speakers
- Word list containing six French lexical items, with the target vowel in open syllable, preceded by [p]:
  - /pɛ/: *paix* ‘peace’
  - /pɛ̃/: *pain* ‘bread’
  - /pa/: *pa**pa*** ‘daddy’
  - /pɑ̃/: *paon* ‘peacock’
  - /po/: *pot* ‘pot/jar’
  - /pɔ̃/: *pont* ‘bridge’
- Vowel boundaries segmented using noise-cancelled audio signal.

Methodology: rotation and ROI

- MR image for each vowel repetition was used to calculate an average MR image for the vowel set.
- Each MR image in a vowel set was rotated and translated with respect to the average MR image to correct for minor movements made by the speaker between repetitions.
- Average MR images for each of the six target vowel sets were used to determine the region of interest (ROI) for each MR slice for that vowel.
- The maximal bounds (i.e., *x-y* coordinates) of all six vowels determined the bounds of the ROI.

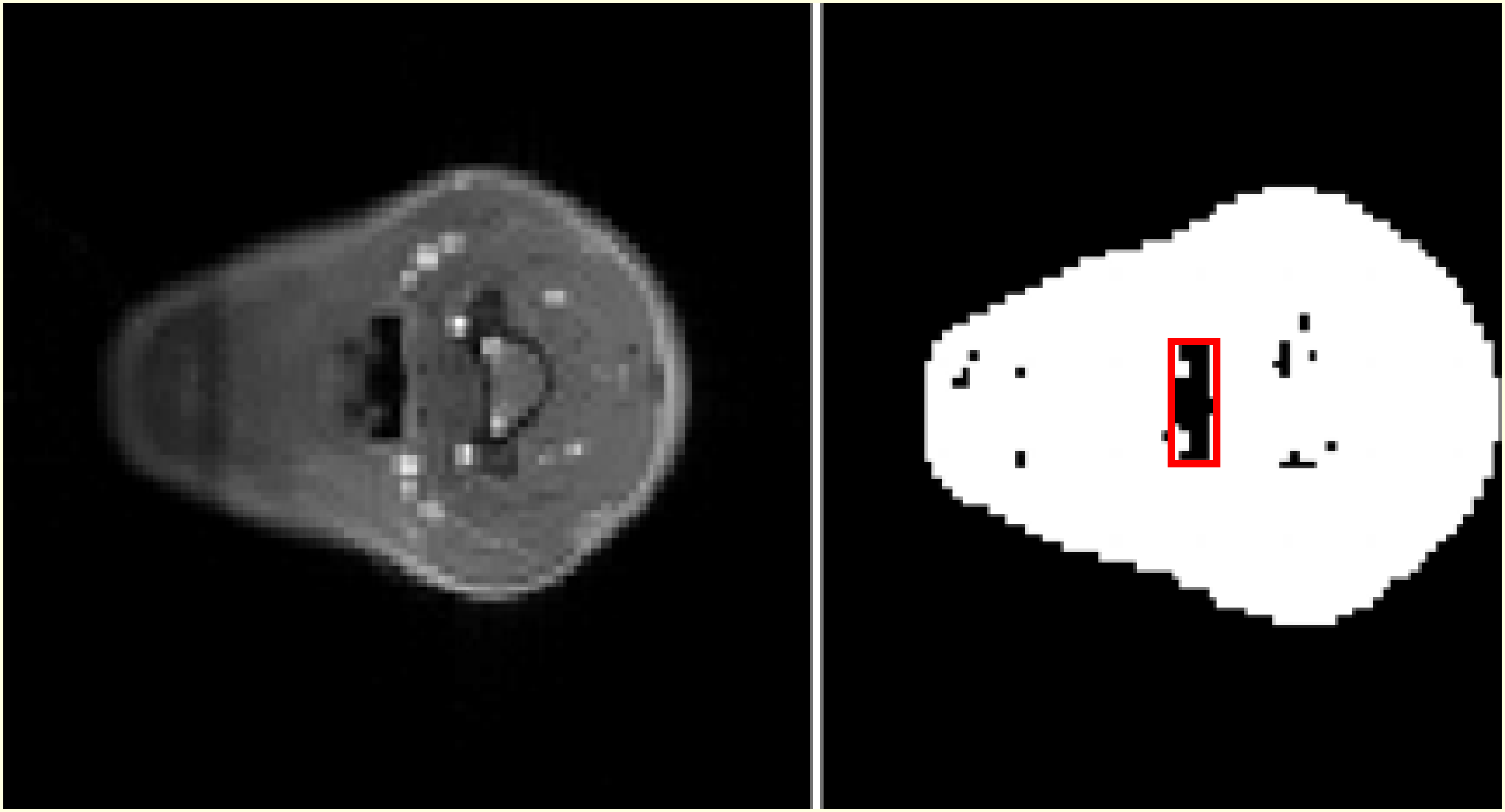
Methodology: rotation and ROI

- ← Example: Average coronal slice for NMF01.
- ROI represents the maximal coordinates of the air cavity observed for the six vowels (e.g., for the coronal slice, [ɑ̃], the lowest vowel).
- Image represents the average MR image for all six vowel sets (used for rotation and translation).

Measure 1: thArea analysis

- The cavity of interest in each MR slice was delineated by hand.
- The intensity values in the air cavity were measured in 8-bit space (values 0-255), and the maximum of the range for each slice was logged as the threshold (τ) for that slice.
- τ was used to convert each MR image into binary space: black (0) for each pixel value at or below τ, and white (1) for each pixel value above τ.
- thArea: sum of number of black pixels in ROI, multiplied by in-plane resolution (2.2 mm^2)

Measure 1: thArea analysis



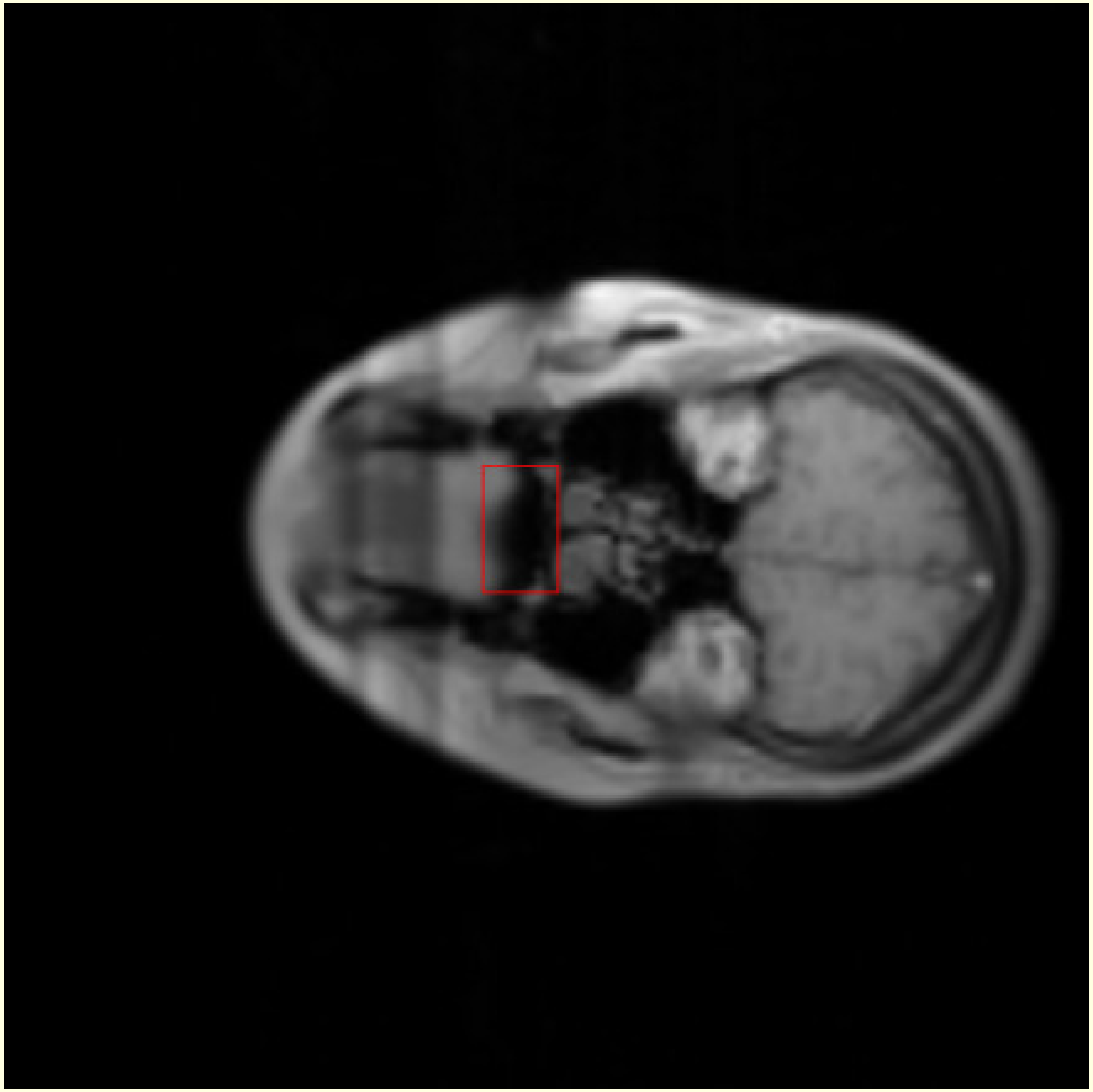
Measure 2: pixel-articulator PCA

- ROI is determined for each vowel.
- Principal Component Analysis (PCA) is used.
- The intensity value of each pixel in the ROI is included as an input the PCA model.
- Reminder: high intensity values are interpreted as flesh, low intensity values are interpreted as air.
- Thus, positive loadings for PCs are interpreted as flesh entering the frame, and negative loadings for PCs are interpreted as flesh exiting the frame.
- Result: provides a method of reliably interpreting PCs in articulatory terms (what is important?).

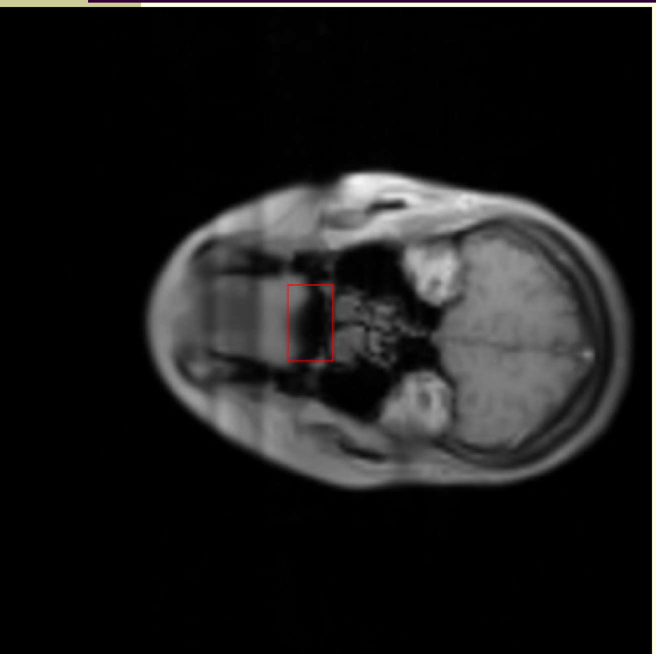
Measure 2: pixel-articulator PCA

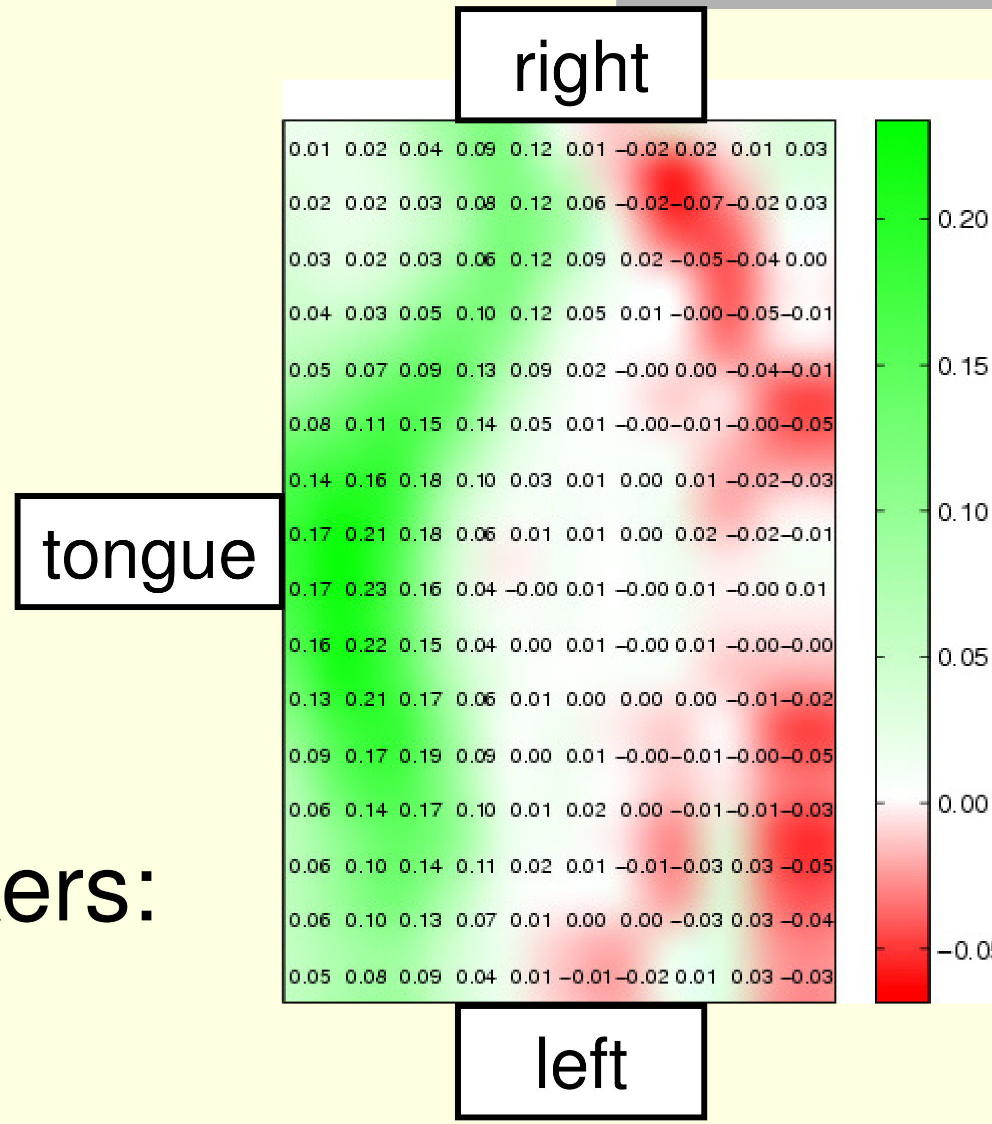
- The method of using PCA, and subsequent analysis of PC1, is sufficient for explaining well-known differences between oral and nasal vowels for the velopharyngeal slice (i.e., closing of the velopharyngeal port for oral vowels).
  - Aside: PC2 also captures opening of the velopharyngeal port and drag of the posterior wall.
- This presentation:
  - PC1 analyses for coronal, hyperpharyngeal slices
  - thArea analysis for hypopharyngeal slice

Coronal slice



Coronal slice, PC1 heatmap





Interpretation all speakers:
<u>tongue raising</u>

Coronal slice, PC1 results

- PC1 interpretation for all speakers:

  tongue raising

1: /ɛ/

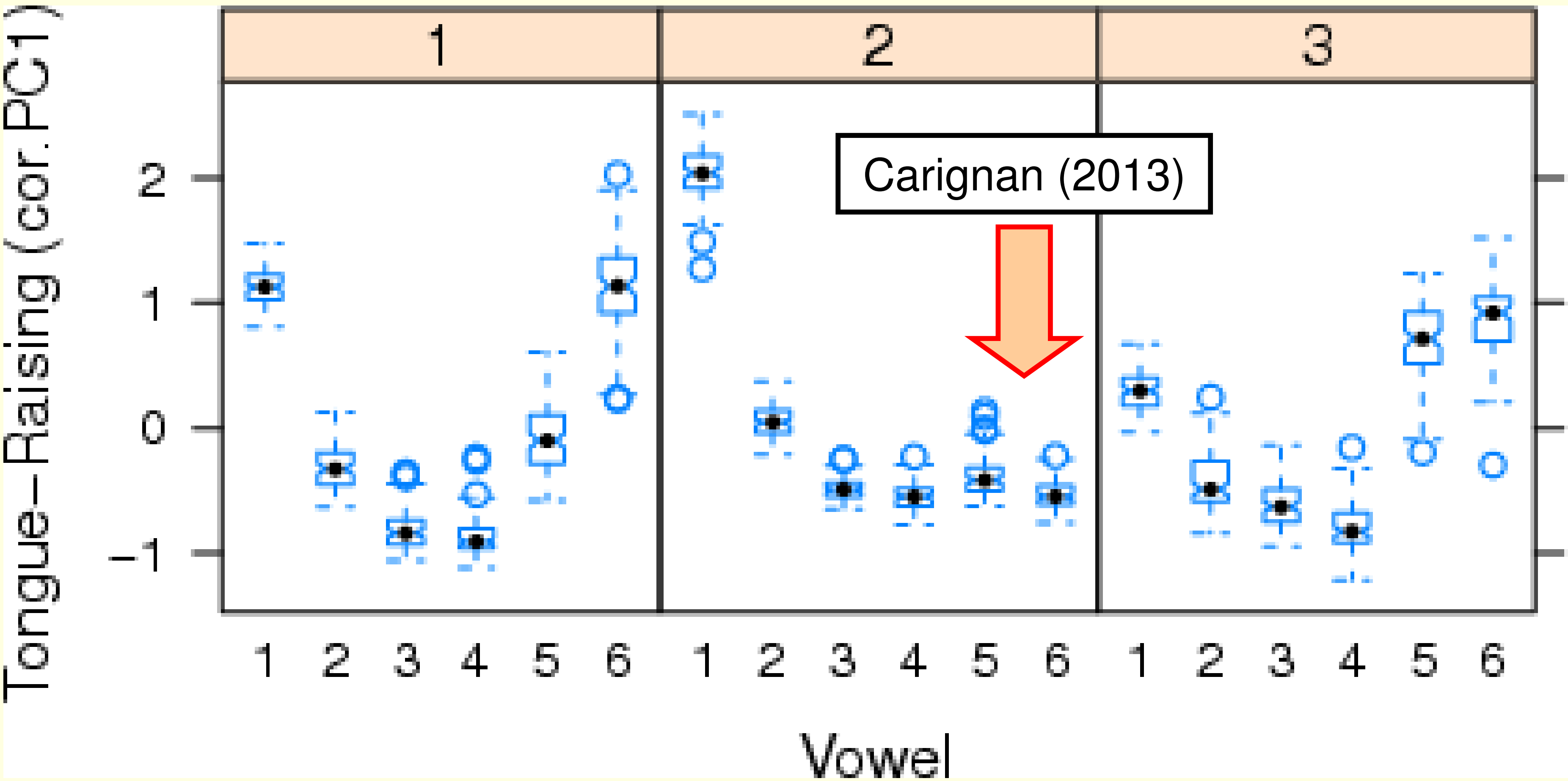
2: /ɛ̃/

3: /a/

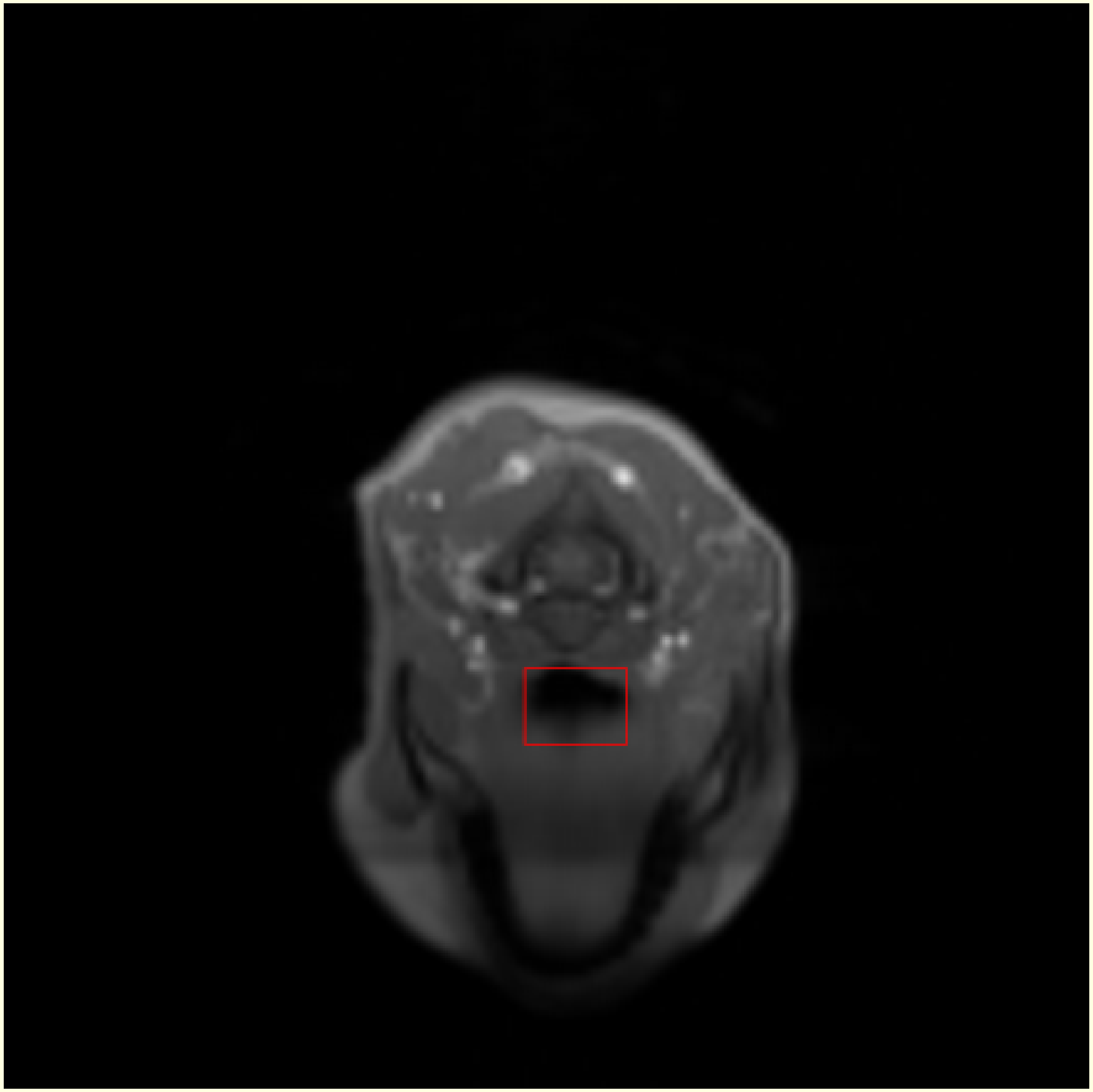
4: /ɑ̃/

5: /o/

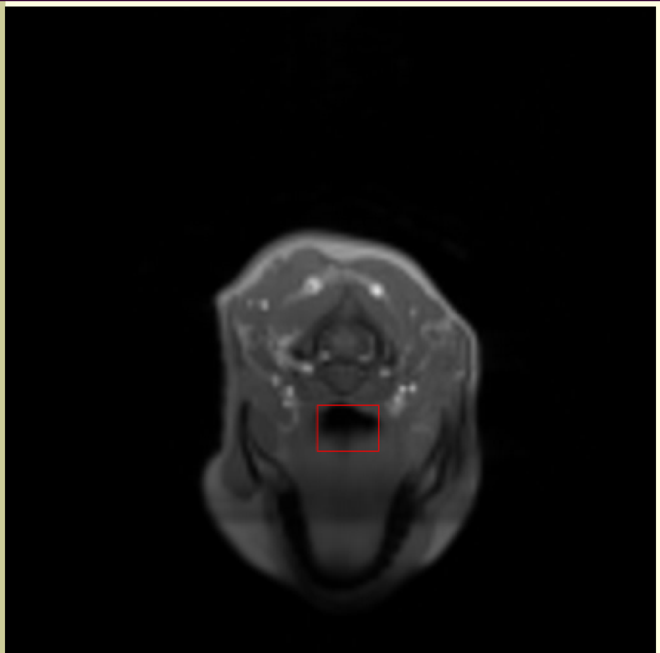
6: /ɔ̃/

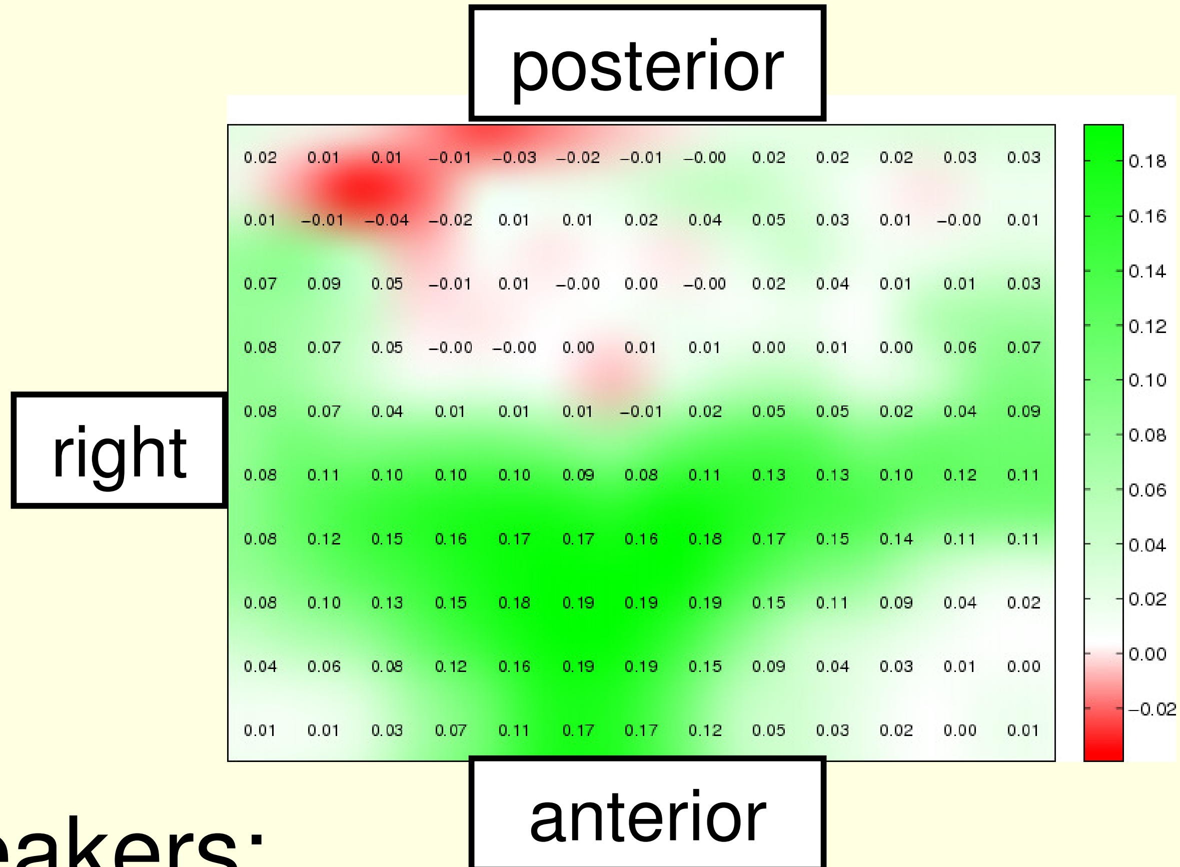


Hyperpharyngeal slice



Hyperpharyngeal slice, PC1 heatmap





Interpretation, all speakers:
tongue retraction

Hyperpharyngeal slice, PC1 results

- PC1 interpretation for all speakers: tongue retraction

1: /ɛ/

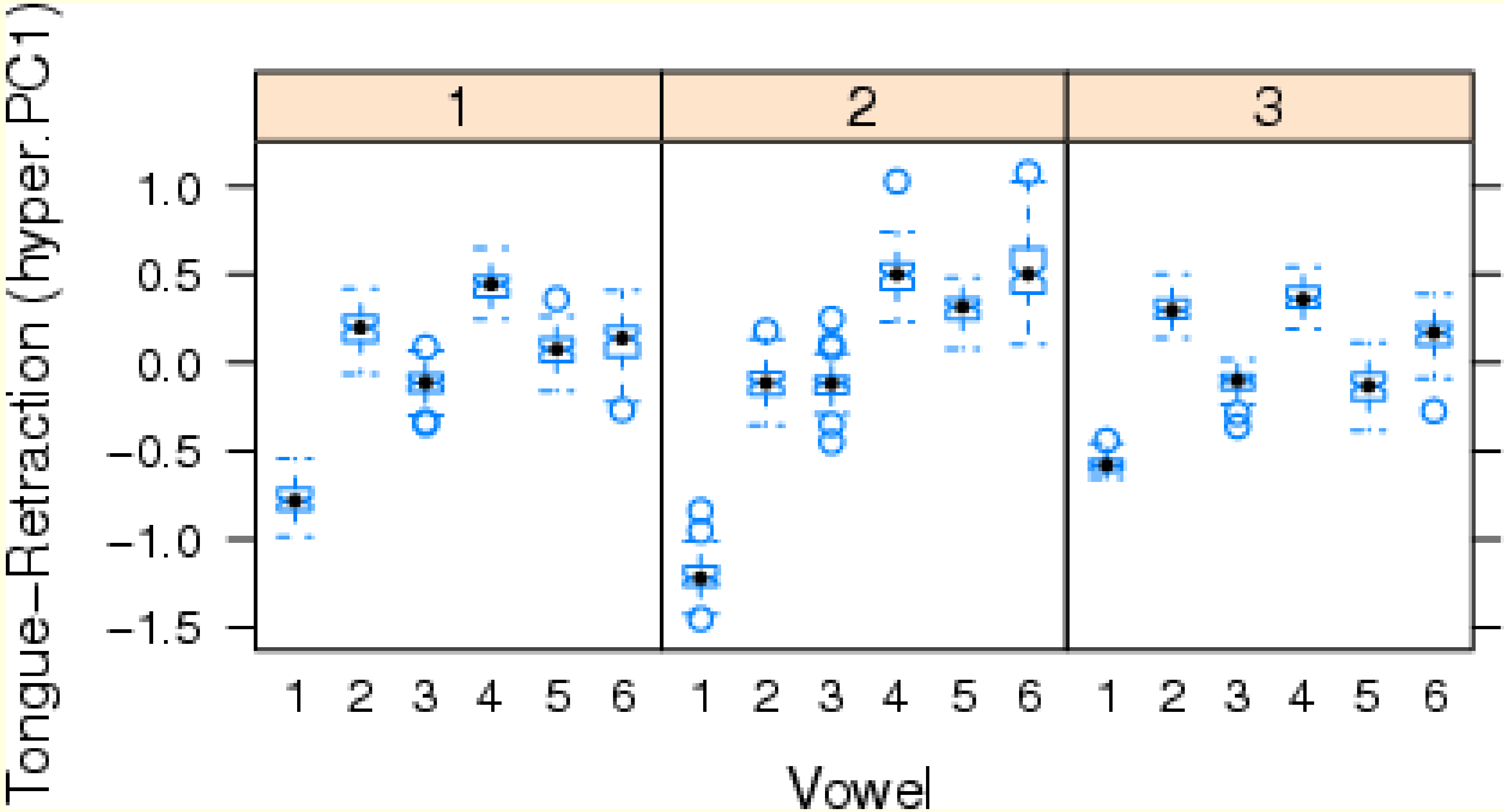
2: /ɛ̃/

3: /a/

4: /ã/

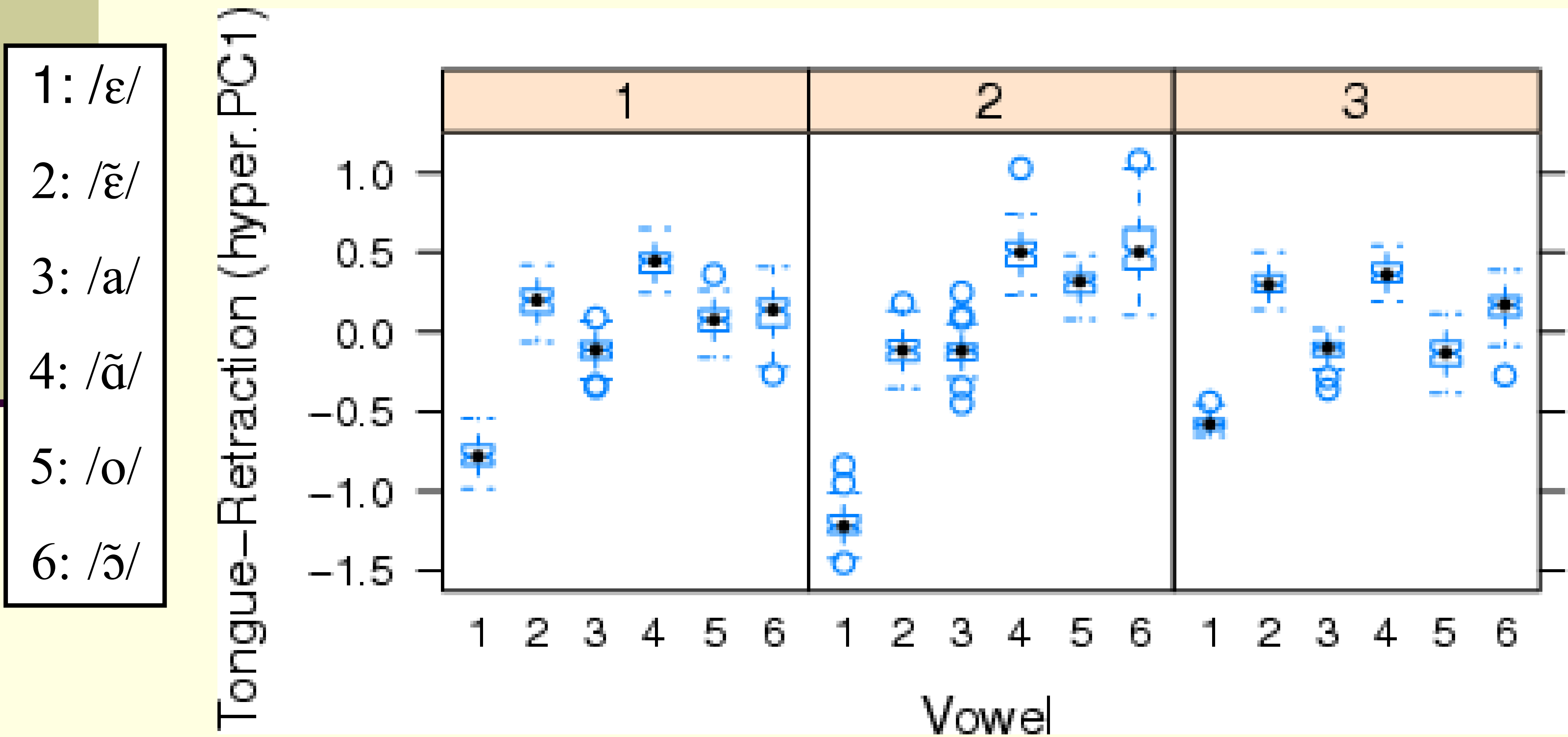
5: /o/

6: /ɔ̃/

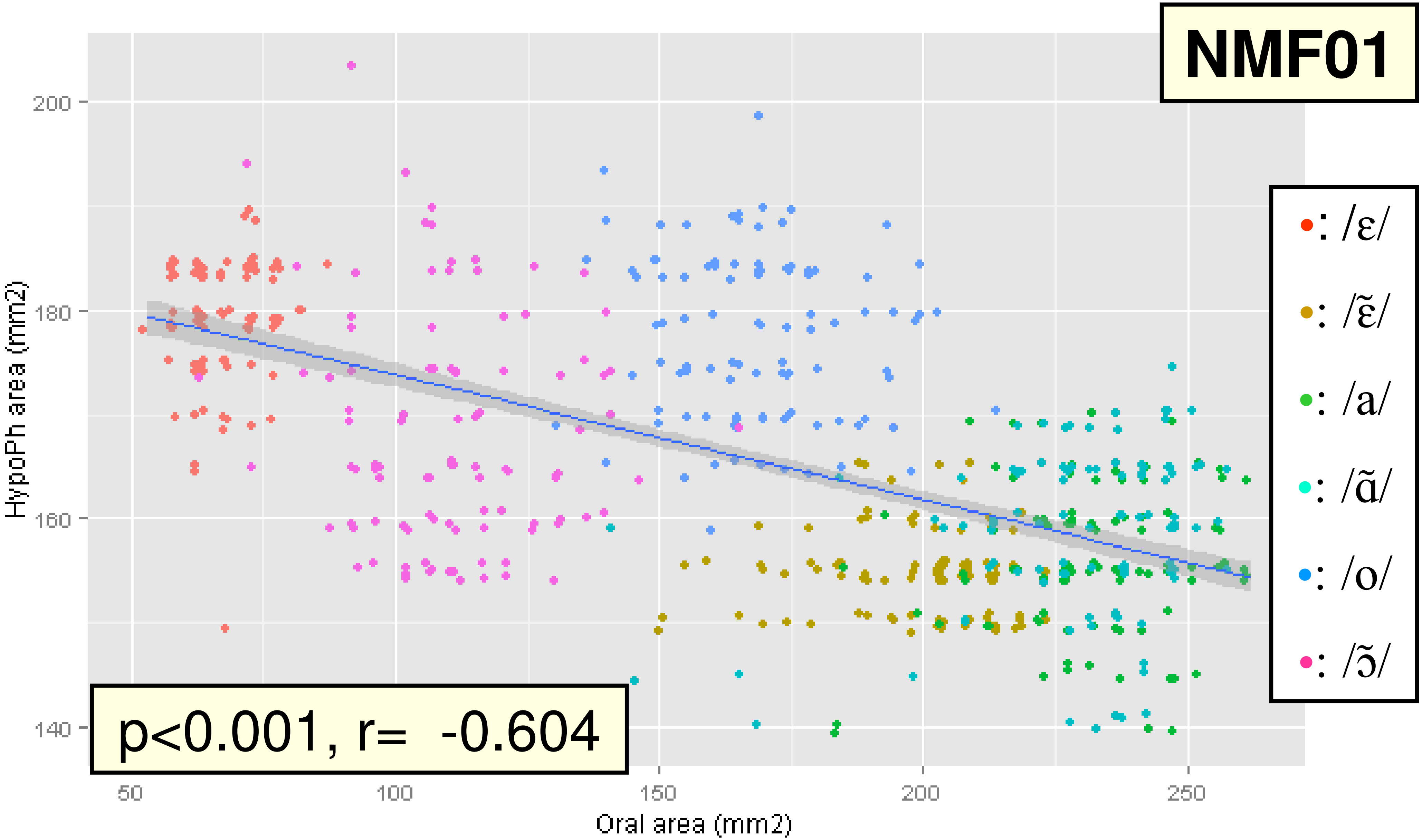


Hyperpharyngeal slice, PC1 results

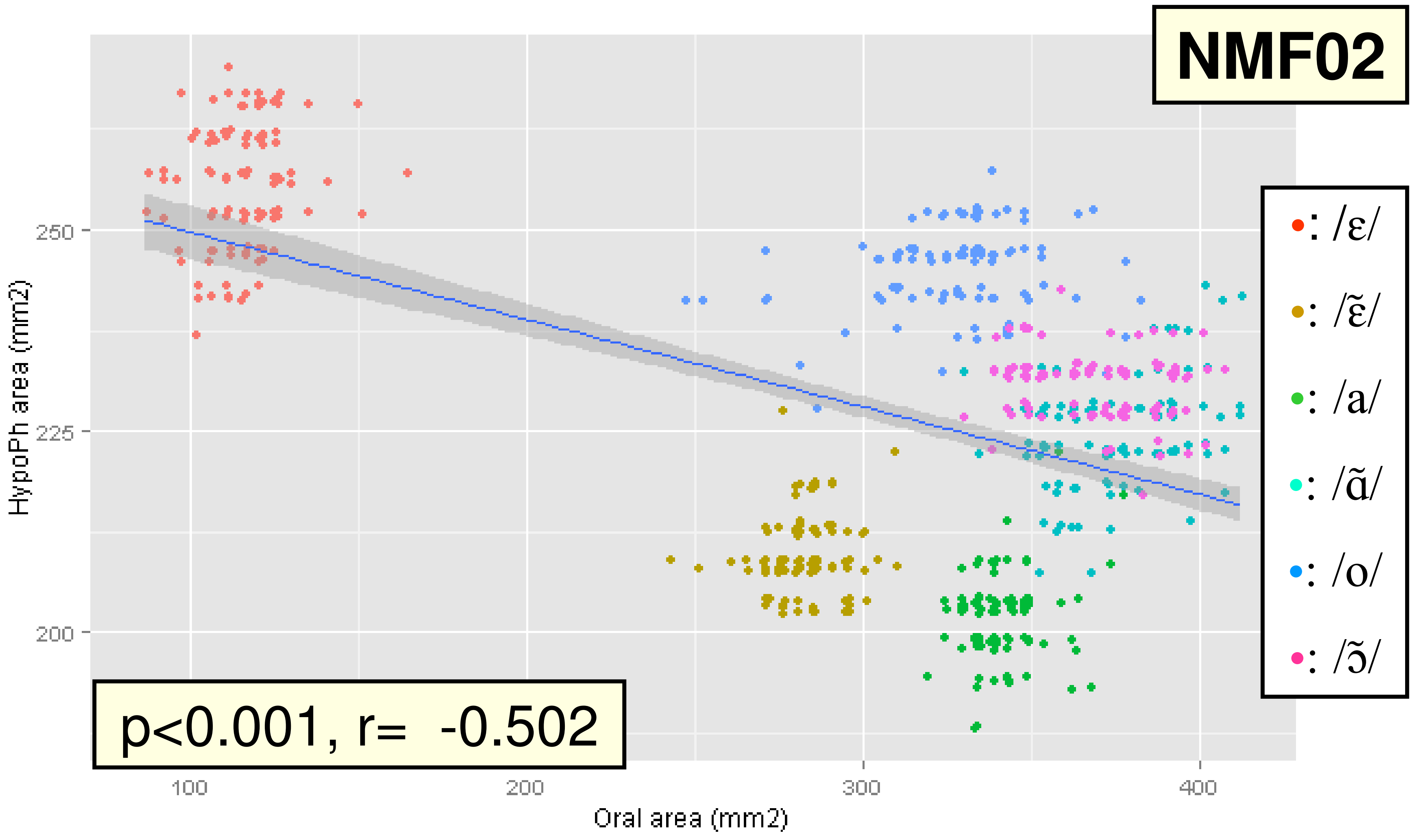
- Horizontal tongue position patterns corroborate EMA data (Carignan, 2013)



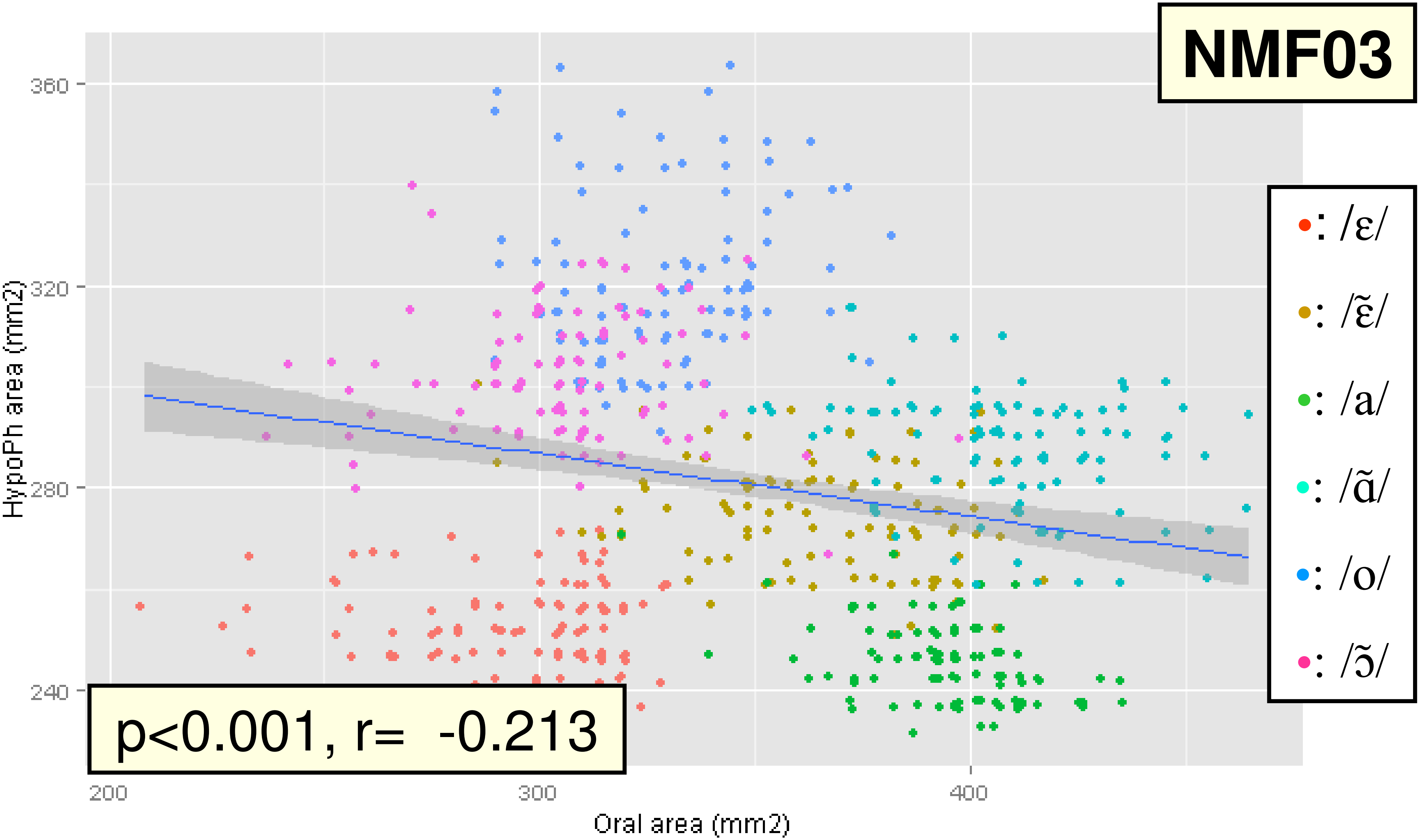
Correlation: cor. thArea/hypo. thArea



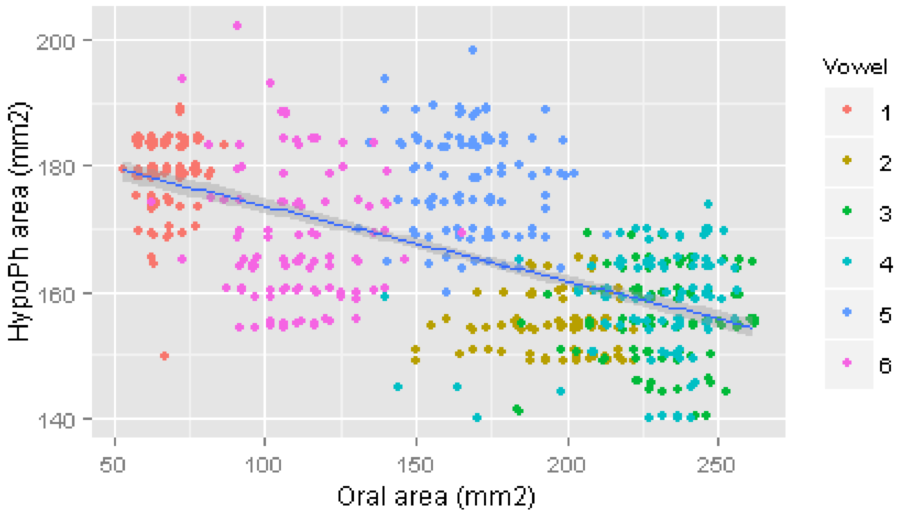
Correlation: cor. thArea/hypo. thArea

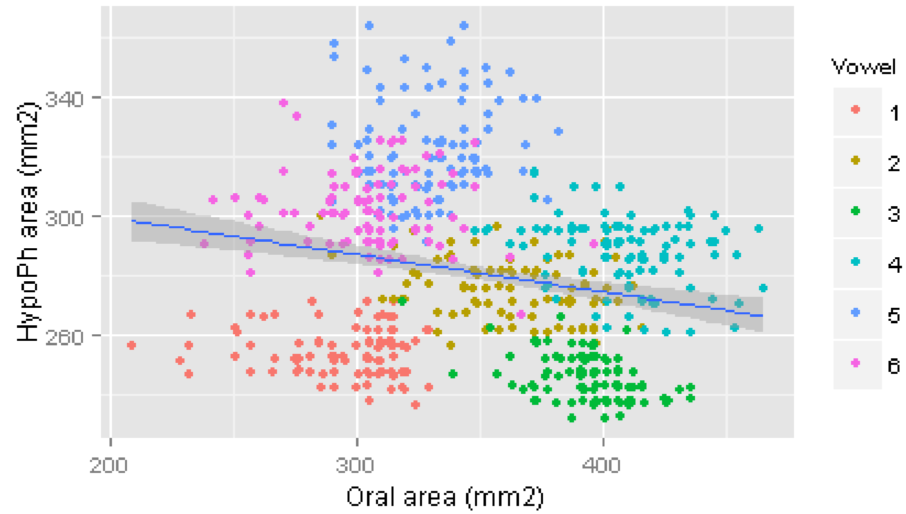


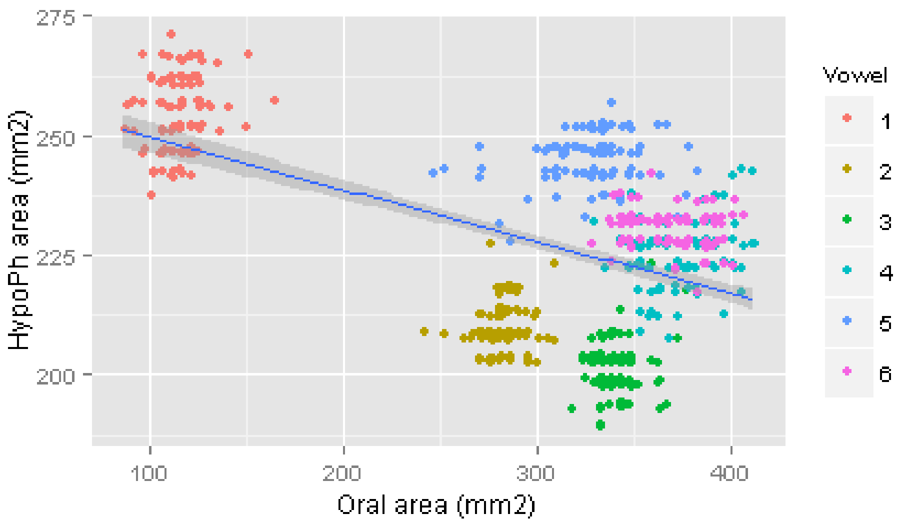
Correlation: cor. thArea/hypo. thArea



Correlation: cor. thArea/hypo. thArea



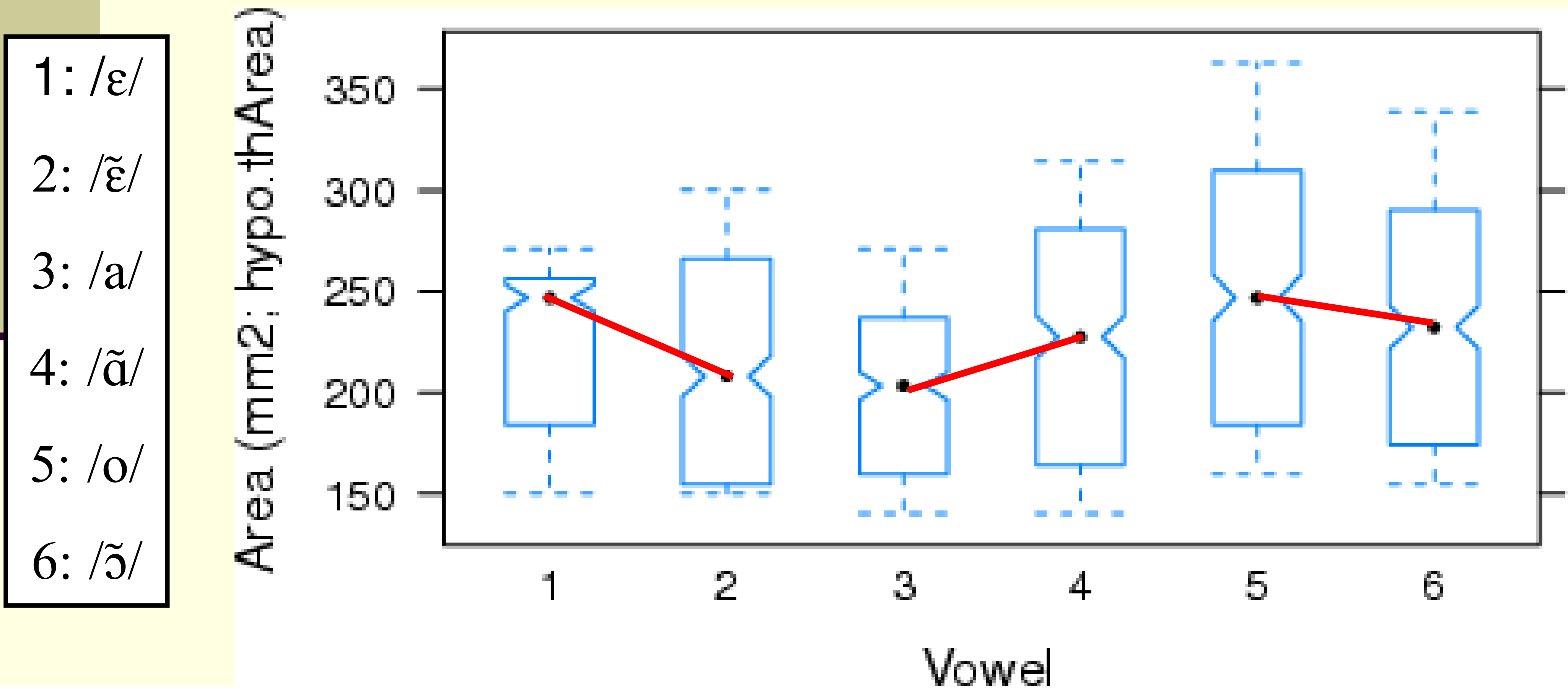




- Negative correlation between coronal thArea and hypopharyngeal thArea.
- Corroborates that low vowels, generally, have greater pharyngeal constriction.

Pharyngeal constriction of NMF nasal vowels

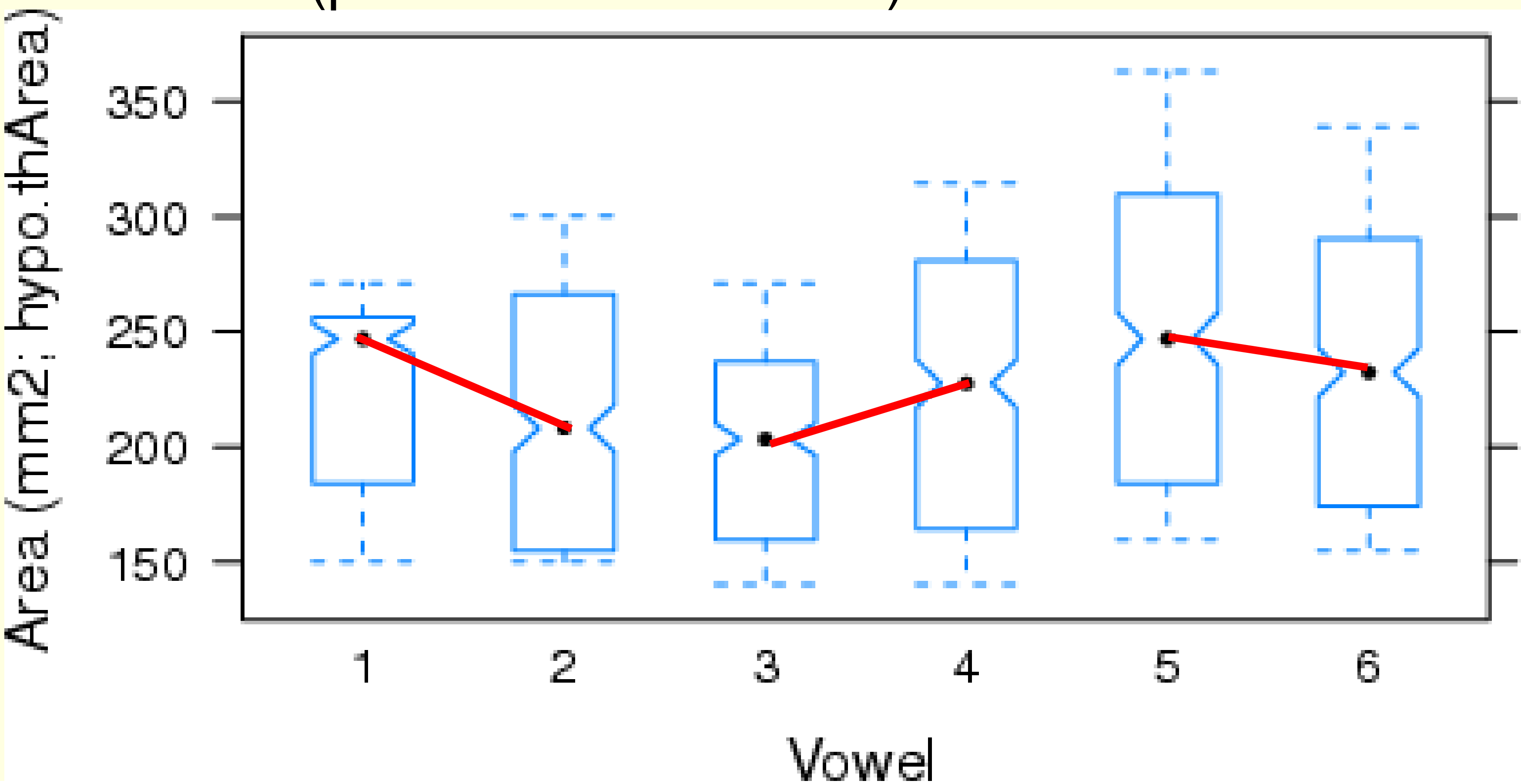
- Hypopharngyeal thArea measure.
- LME model with speaker as random effect.
- All oral-nasal differences: $p<0.001$



Pharyngeal constriction of NMF nasal vowels

- Low vowel pair: less pharyngeal constriction for nasal vowel (predicted to lower F1)
- Non-low vowel pairs: greater pharyngeal constriction for nasal vowels (predicted to raise F1)

1: /ε/
2: /ε̃/
3: /a/
4: /ã/
5: /o/
6: /ɔ̃/

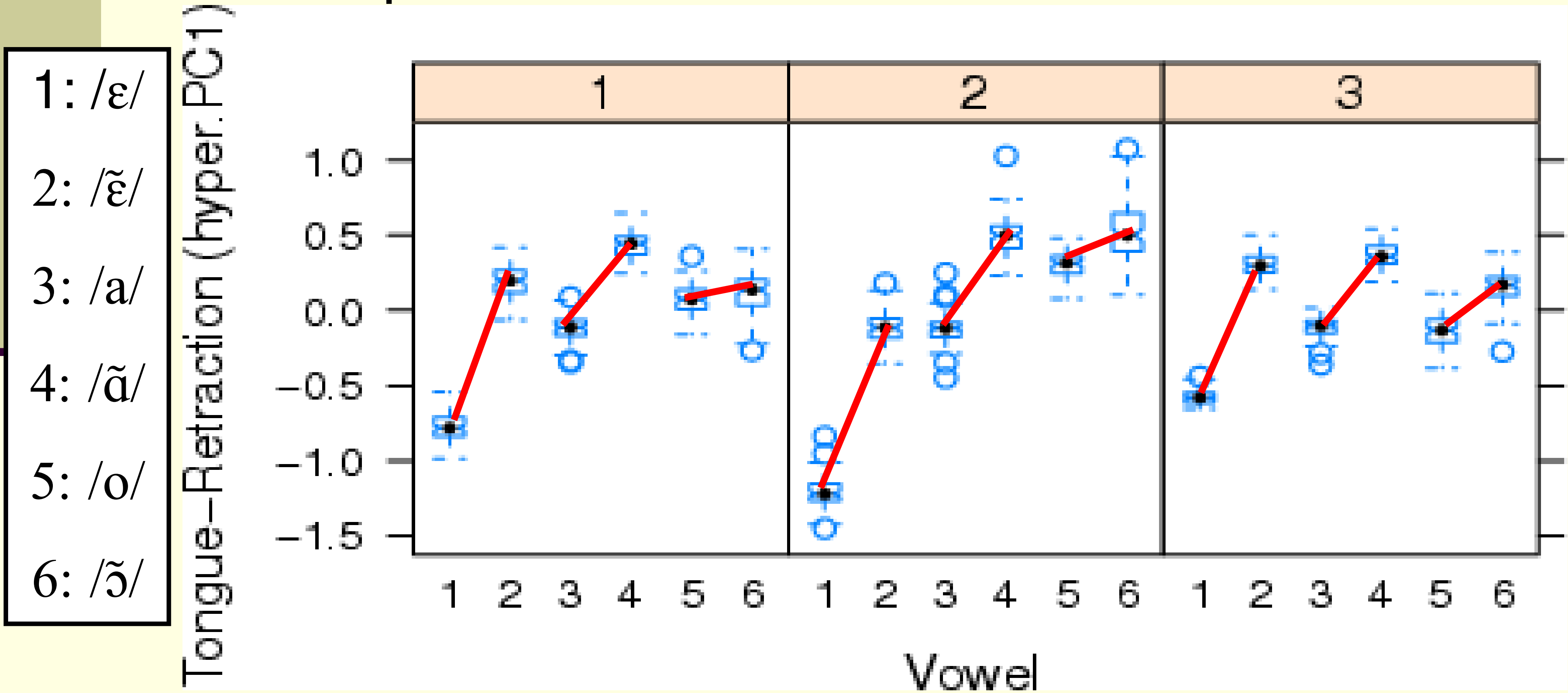


Pharyngeal constriction of NMF nasal vowels

- Remember: F1 dimension is centralized under the effect of nasalization.
- A constriction near the glottis will raise F1.
- Pharyngeal constriction observed for the three NMF oral/nasal vowel pairs is predicted to centralize the F1 dimension for the nasal vowels.
- This finding suggests that hypopharyngeal aperture enhances the acoustic effect of nasalization on F1 frequency.

Lingual retraction for all nasals

- Hyperpharyngeal PC1 (i.e., tongue retraction) is greater for all nasals than their oral counterparts, for all speakers.



Lingual retraction for all nasals (cont.)

- Hyperpharyngeal thArea is smaller for all nasals than their oral counterparts, for all speakers.

1: /ɛ/

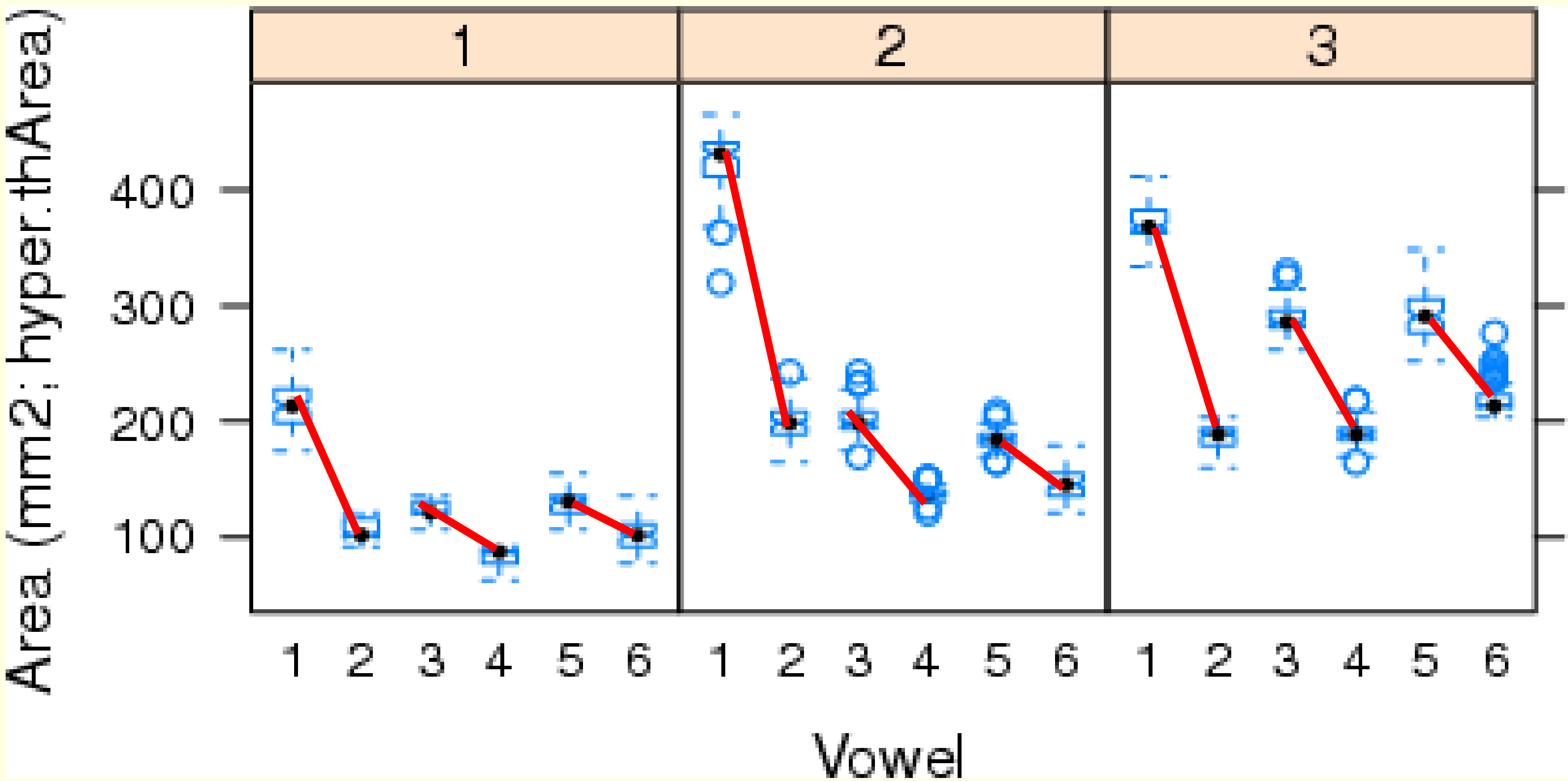
2: /ɛ̃/

3: /a/

4: /ã/

5: /o/

6: /õ/



Tongue retraction, F2 and nasalization in NMF

- Generally, global retraction has been observed for NMF nasal vowels compared to their oral counterparts using EMA (Carignan, 2013)
- Remember: F2 is lowered for non-back vowels under the effect of nasalization.
- "Passive" effect of nasalization
  - Lowered velum → "velic" constriction
    - Shosted et al. (2012)
  - Near an anti-node of F2
    - Constriction: lower F2

Tongue retraction, F2 and nasalization in NMF

- Lingual retraction observed for the three NMF nasal vowel is predicted to lower F2.
- This finding suggests that horizontal tongue position enhances the acoustic effect of nasalization on F2 frequency.
- May help explain perceptual finding from Delvaux (2009), and modeling findings from Serrurier & Badin (2008) and Feng & Castelli (1996).

Conclusion

- Our findings suggest that oral articulatory configurations enhance the effect of nasalization on F1/F2 frequencies in the production of NMF nasal vowels:
  - lingual articulation
  - hypopharyngeal constriction
  - labial rounding/protrusion (EMA: Carignan, 2013)
- The oral articualtion of NMF nasal vowels may be due (at least in part) to misperception of the articulatory source of changes in F1/F2 over time, rather than to mere chance.

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