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Variability of North American English /r/ Production in response to Palatal Perturbation

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rle AT MIT

a production of

Acoustics of Vocal Tract Shapes for Liquids

(NIH DC05250)

with colleagues

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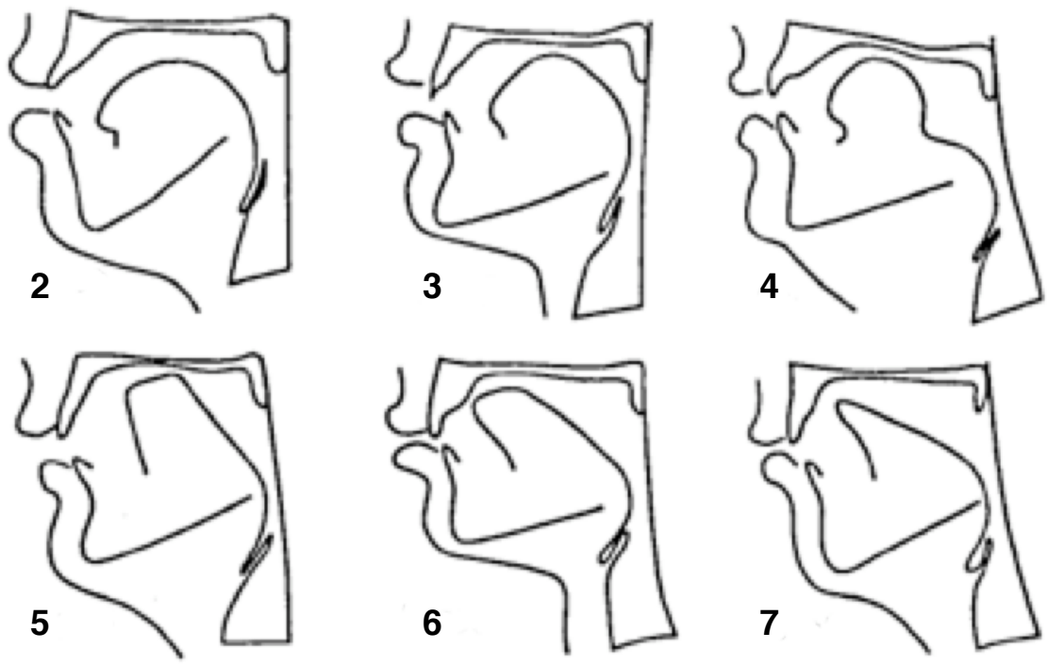
and thanks to

Vincent Gracco

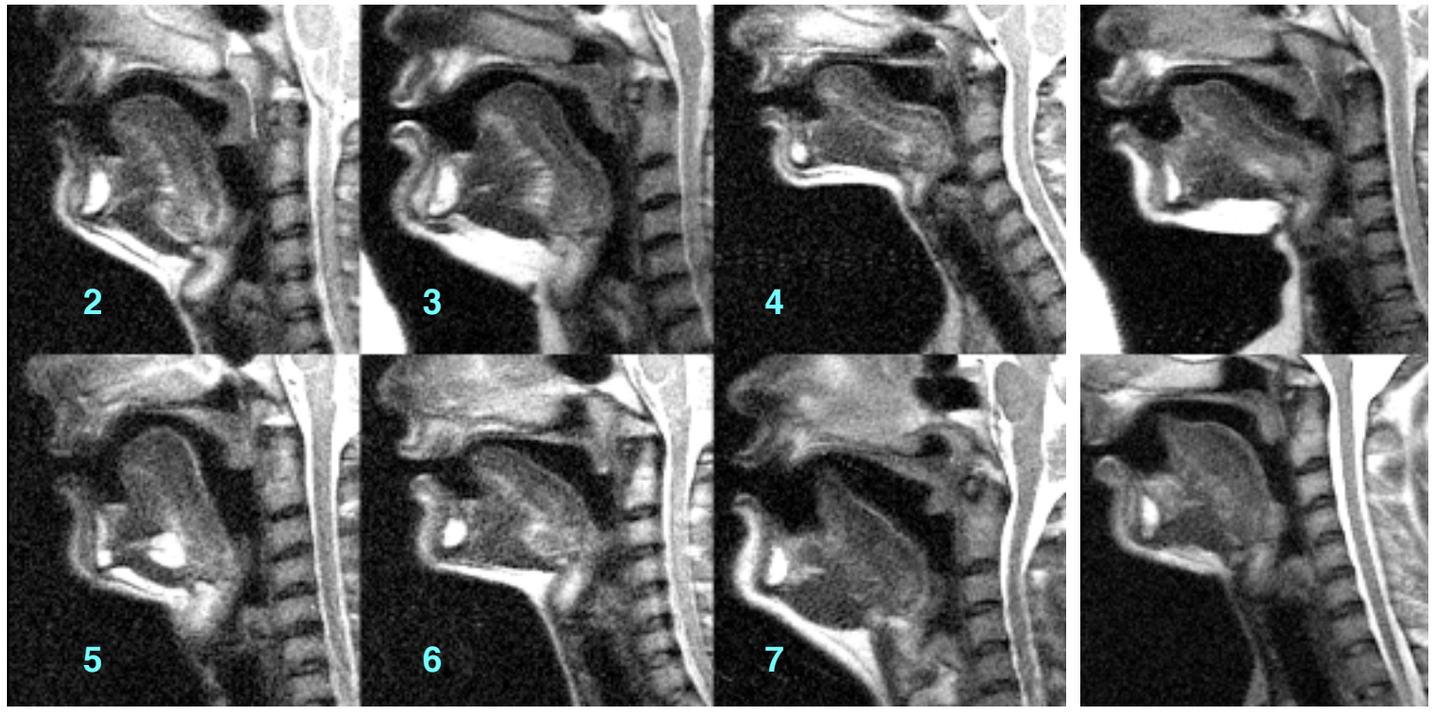
Douglas Shiller

AE /r/ is produced with different tongue shapes

- Delattre & Freeman (1968); cineradiography
- Westbury *et al*. (1998); X-ray microbeam



Tongue configuration types for AE /r/ as identified from cineradiographs by Delattre & Freeman (1968). *Adapted from Hagiwara (1985)*.



Examples of corresponding AE tongue configuration types for sustained /r/ as identified from MRI by Tiede *et al*. (2004).

Broadly speaking two categories:

"**bunched**" (dorsal constriction)

"**retroflex**" (apical constriction)

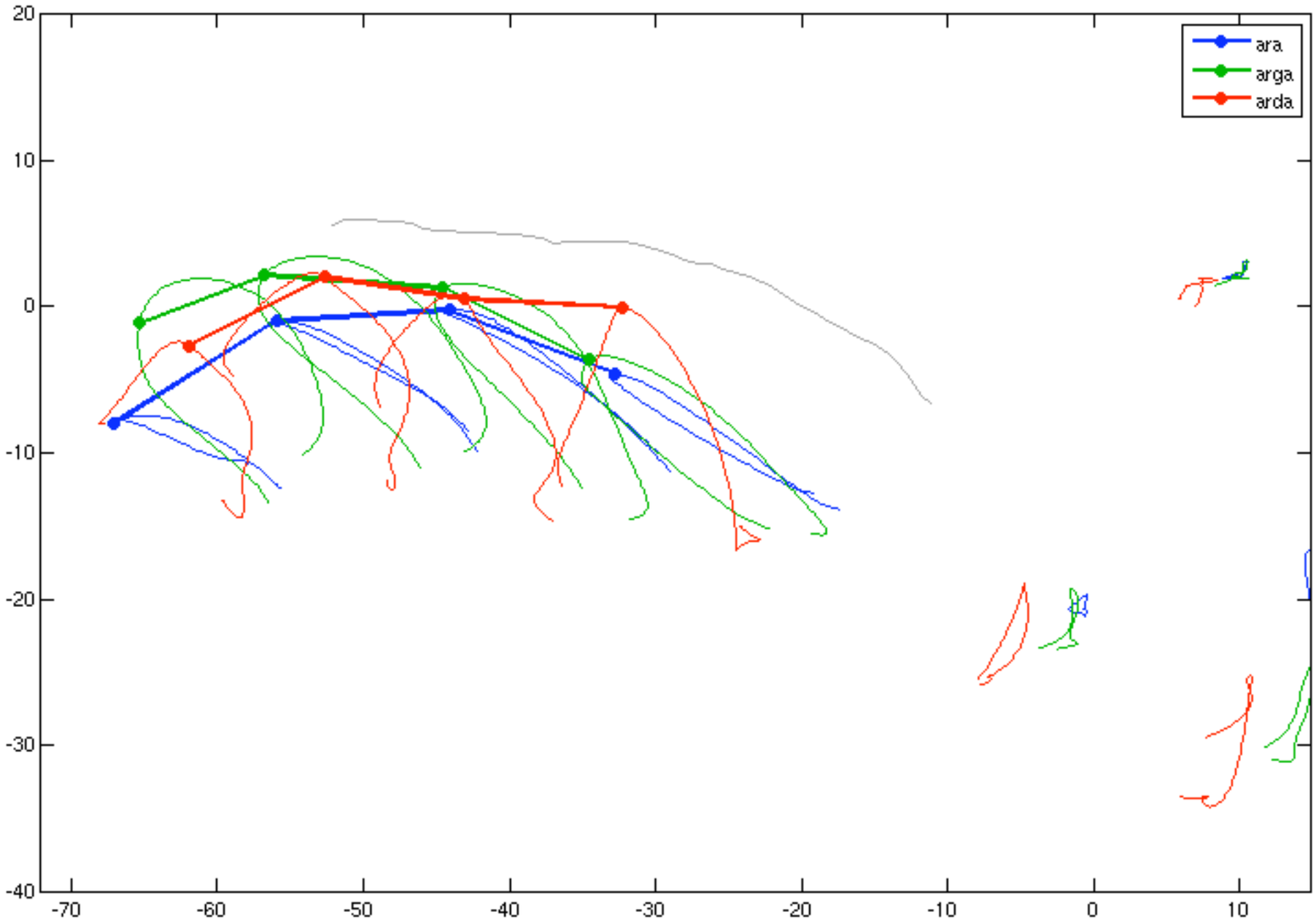
Question: Does an individual AE speaker produce /r/ with more than one of these articulation strategies?

• X-ray tracings of /prV/ clusters (Shriberg & Kent 1995) show in general
  – bunched tongue when V is high, front
  – retroflex when V is low, back

• EMMA study (Guenther *et al.* 1999) showed for two of five subjects
  – bunched postures in *wadrav*, *wagrav* contexts
  – retroflex in *warav*, *wabrav*, *wavrav*

Example 1: synchronized phase-shifted (pseudo-cine) MRI (Masaki et al. 1999); *warav*, *wabrav*, *wavrav* from one subject

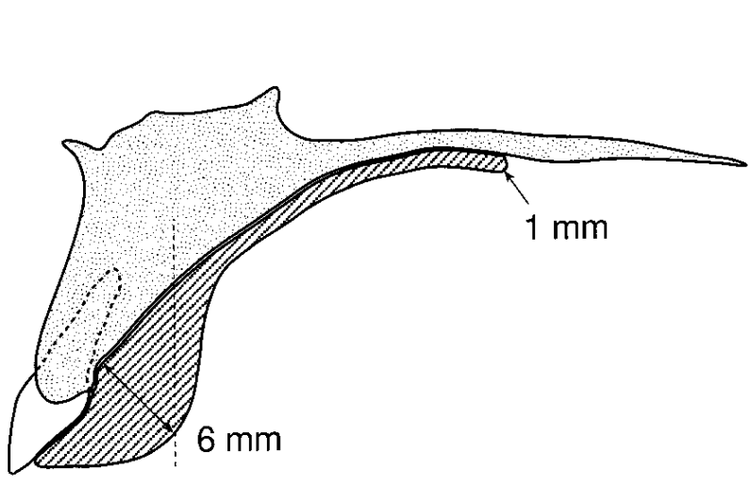
Example 2: EMA showing *ara*, *arda*, *arga* from one subject

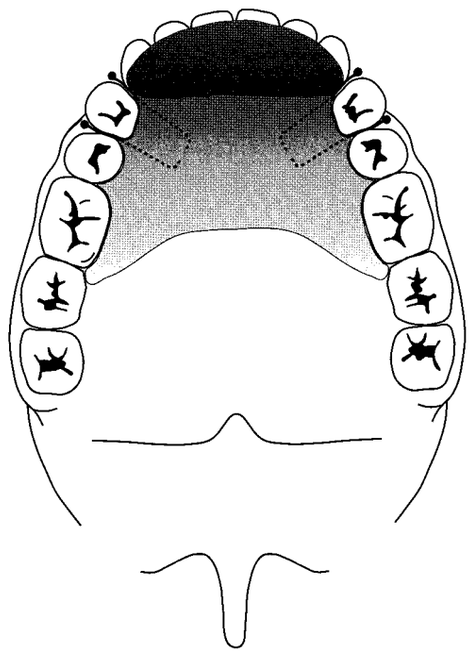


Coproeduction effects suggest speakers can achieve /r/ with more than one /r/ posture – can this production variability be induced by perturbing palatal shape?

Perturbation (follows Baum & McFarland 1997)

- subject-specific palatal prosthesis
- dental acrylic with retaining ball clasps
- 6 mm at alveolar ridge tapering to 1 mm

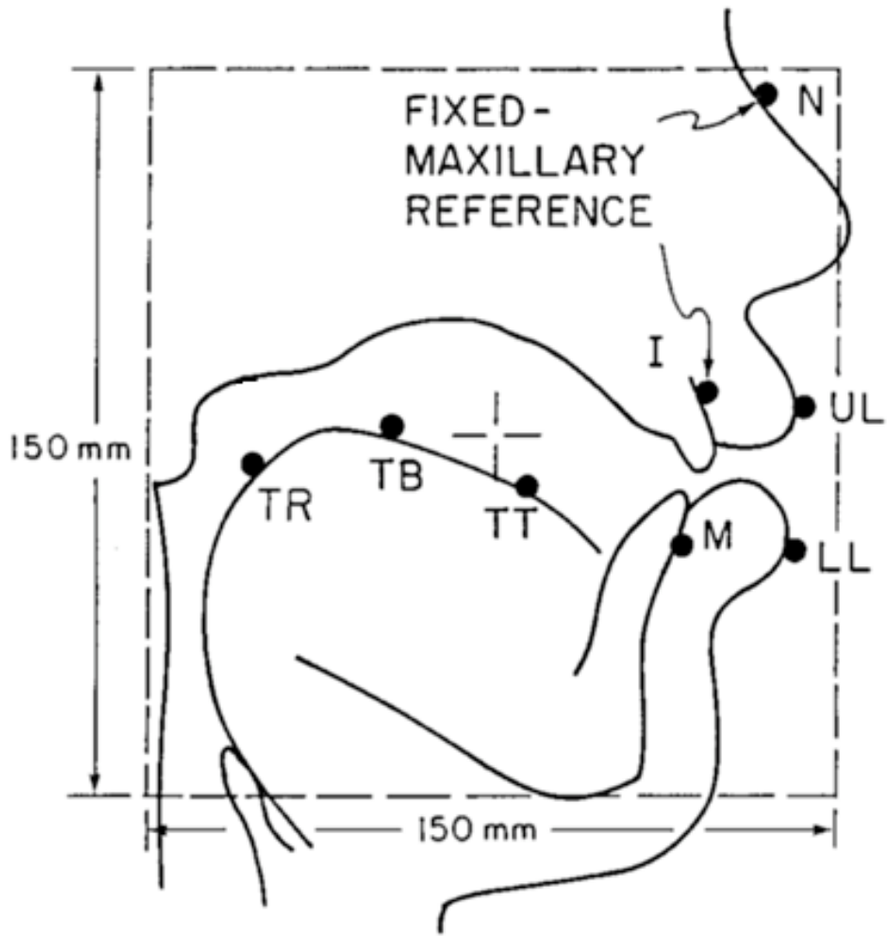




Inferior and midsagittal views of palatal prosthesis (from Baum & McFarland 1997)

Stimuli

- /ara/, /iri/, /uru/; produced in isolation
- 10 repetitions / condition (final condition 5 reps only)
- randomized within a larger study observing obstruents in VCV contexts (by Gracco at McGill)



EMA transducer arrangement

Subjects

- 1 male, 2 female
- native speakers of North American English

Data

- audio recorded @ 16 kHz
- EMA recorded @ 200 Hz (Carstens AG200)

Conditions

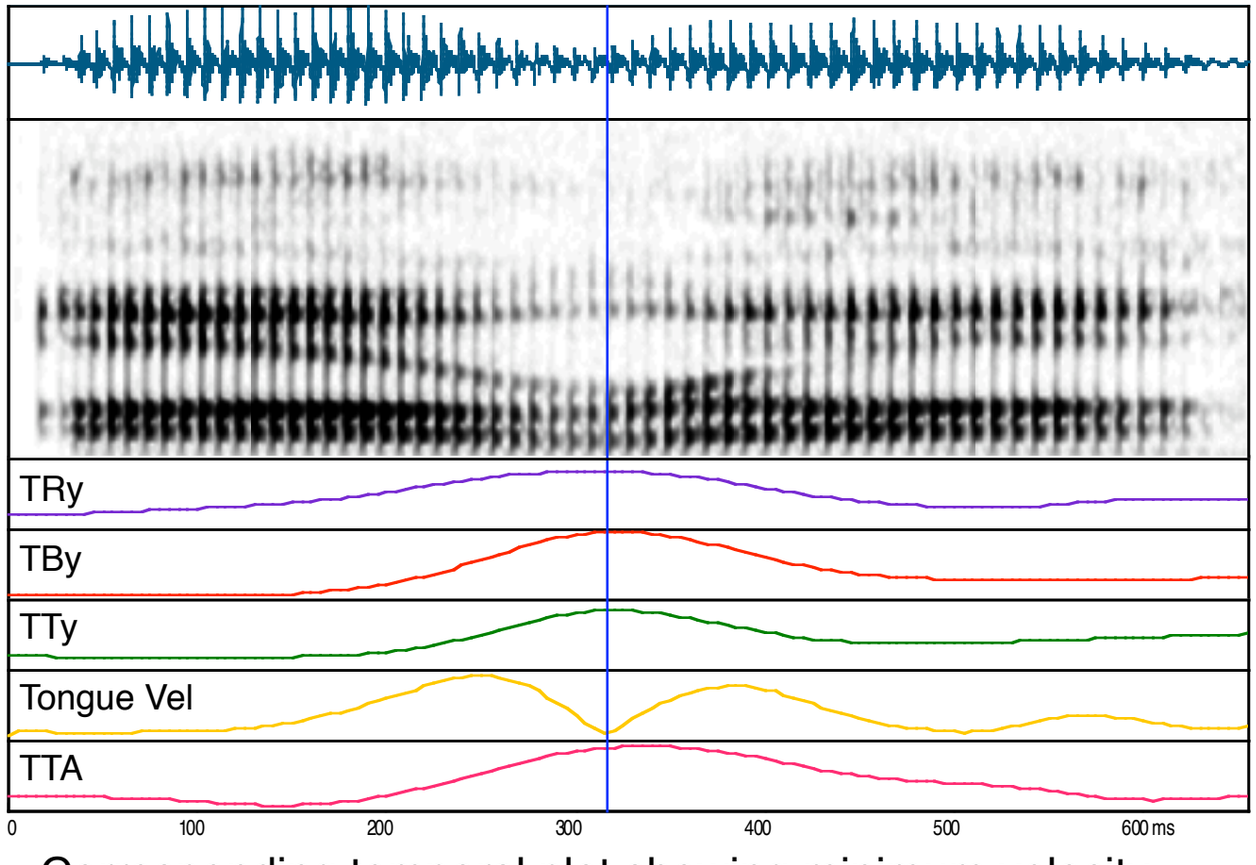
- Block 1: pre-perturbation
- Block 2: immediately following prosthesis insertion

An intervening 20 minute adaptation period during which subjects read aloud with prosthesis in place was not recorded

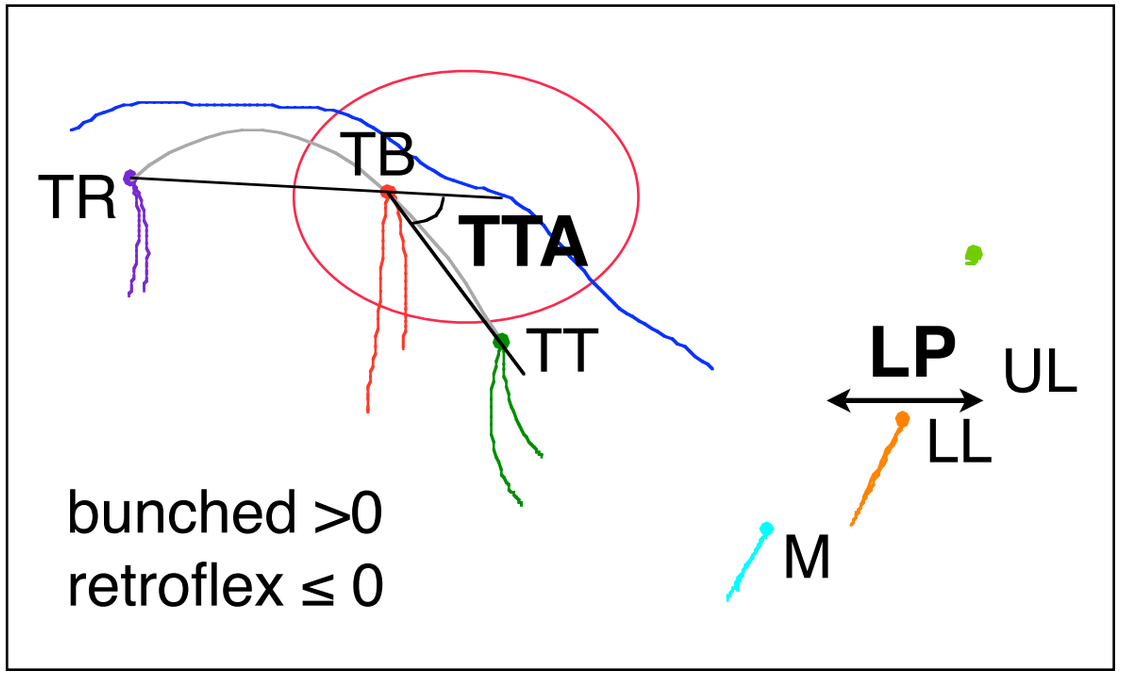
- Block 3: post-adaptation, prosthesis still in place
- Block 4: immediately following prosthesis removal

Articulatory measure: TTA

- temporal measurement offset determined by minimum velocity computed across all tongue transducers
- tongue posture at that offset characterized by Tongue Tip Angle (TTA), subtended by lines between TR:TB and TB:TT



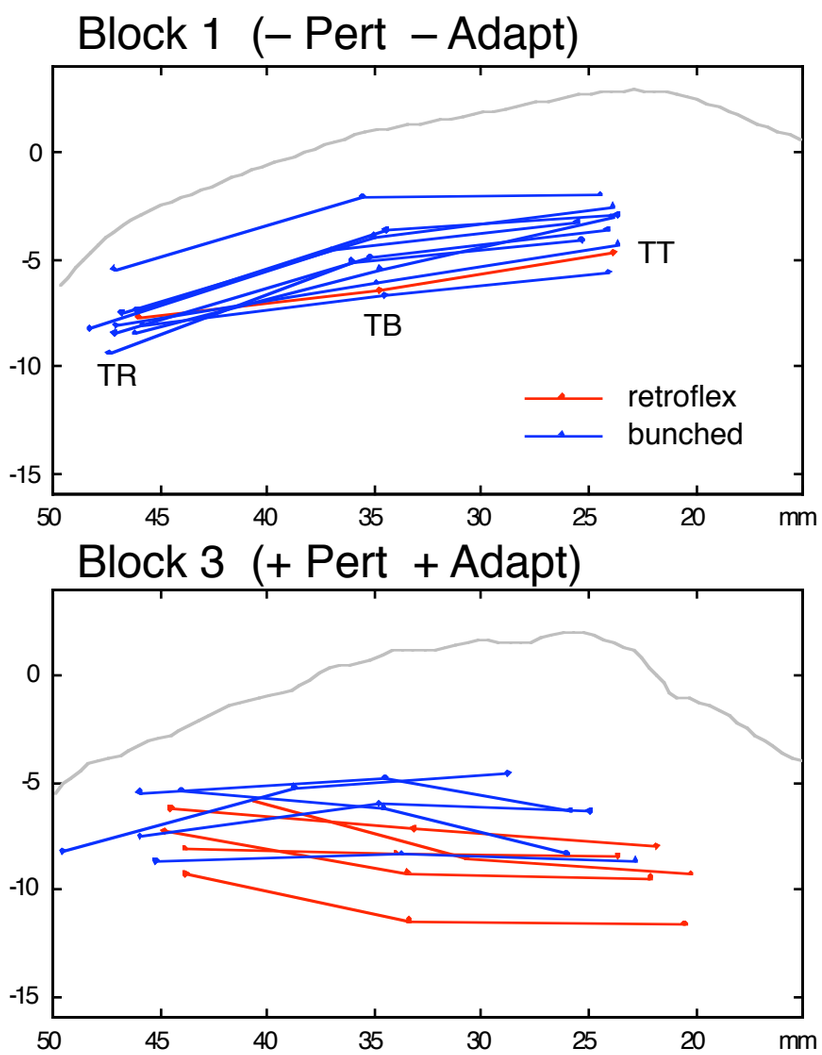
Corresponding temporal plot showing minimum velocity measurement offset

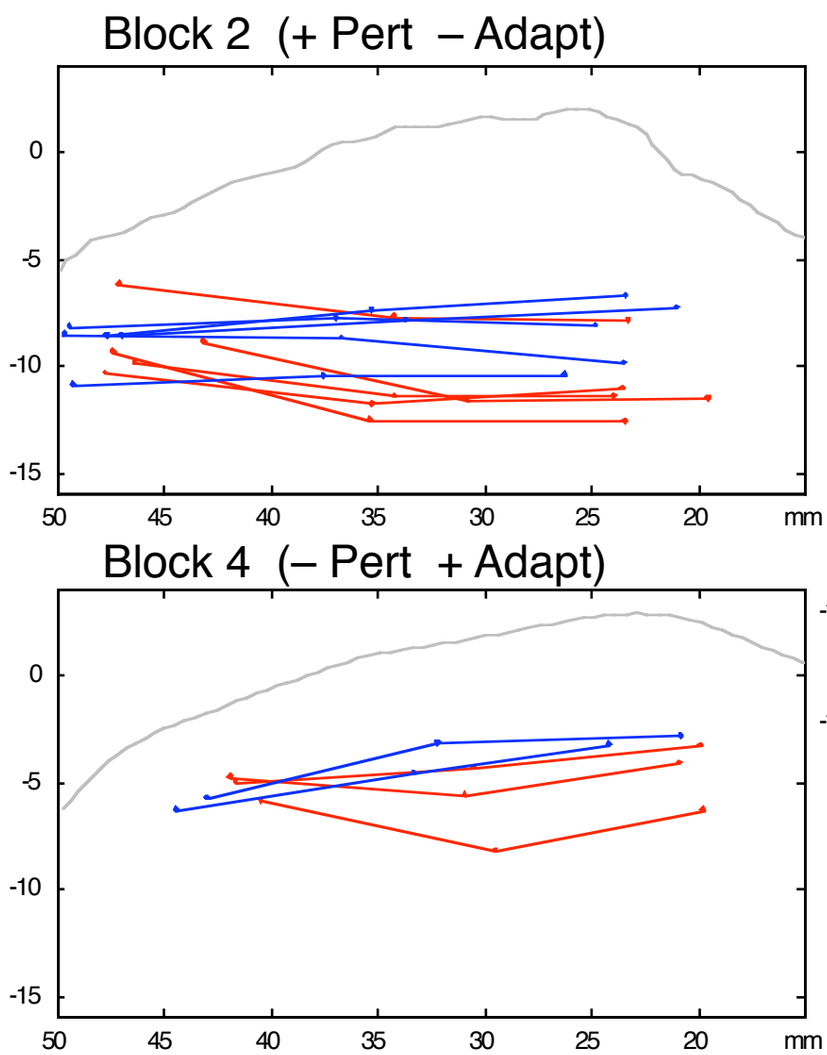


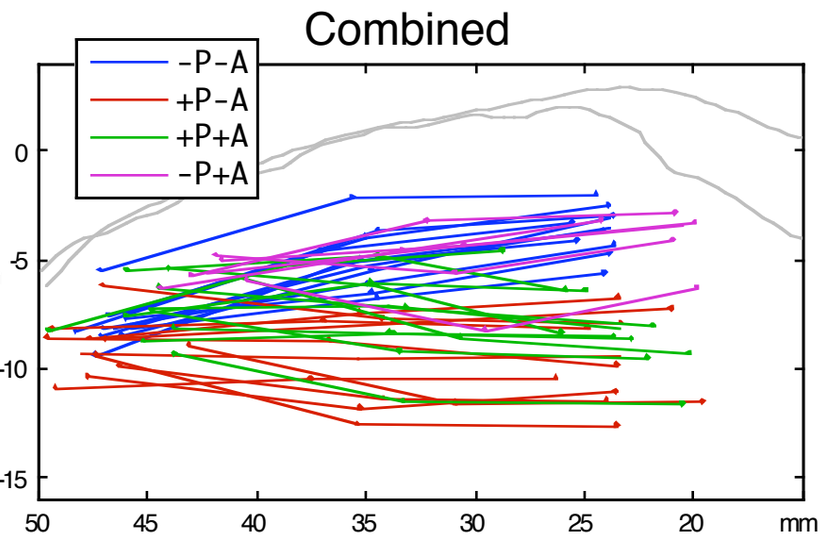
Example token of unperturbed bunched posture /ara/ showing Tongue Tip Angle measure (TTA).
Lip Protrusion (LP) characterized using horizontal position of lower lip

Example Response to Perturbation

Subject F1 /uru/



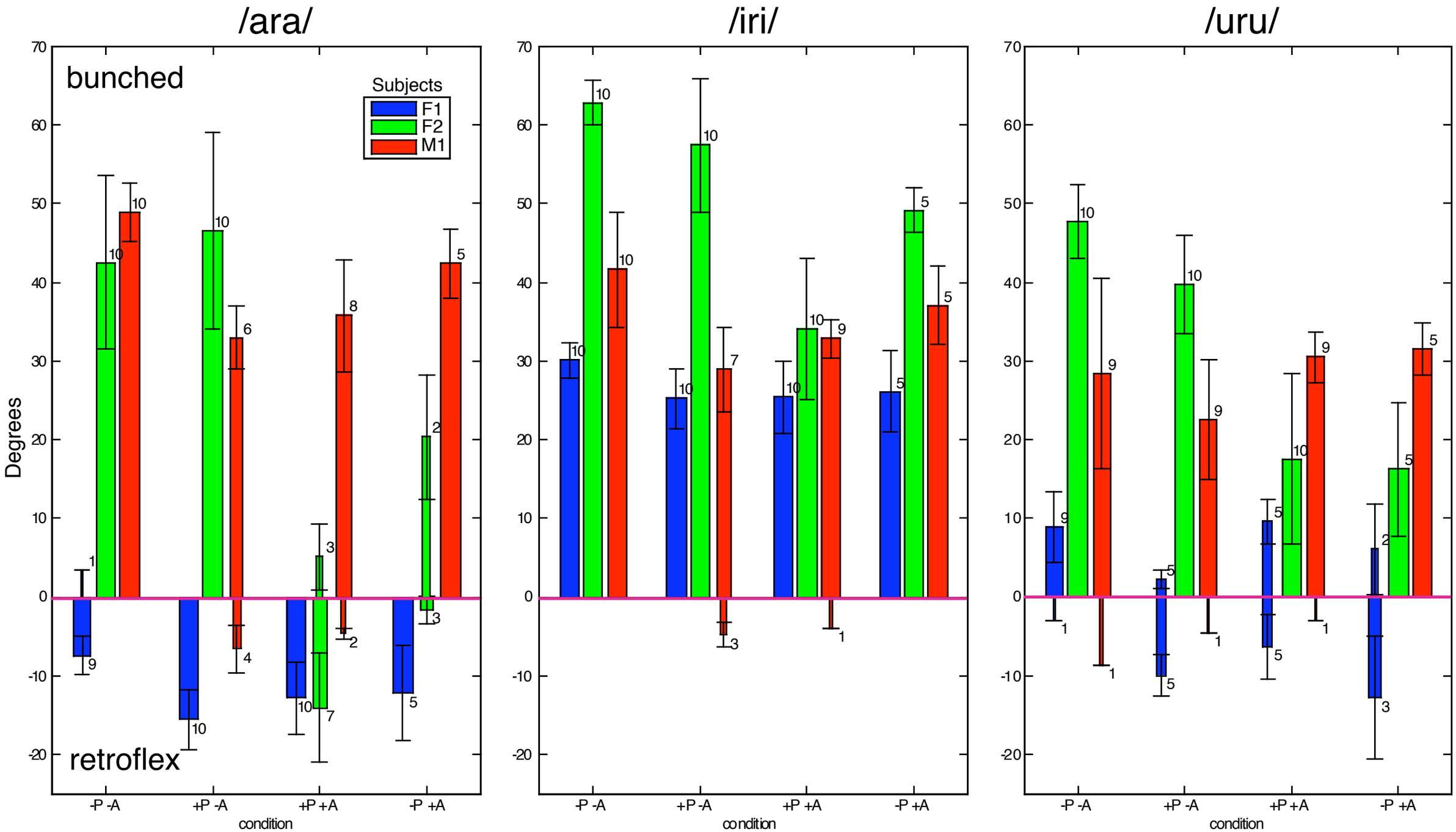




Blocks 1 through 4

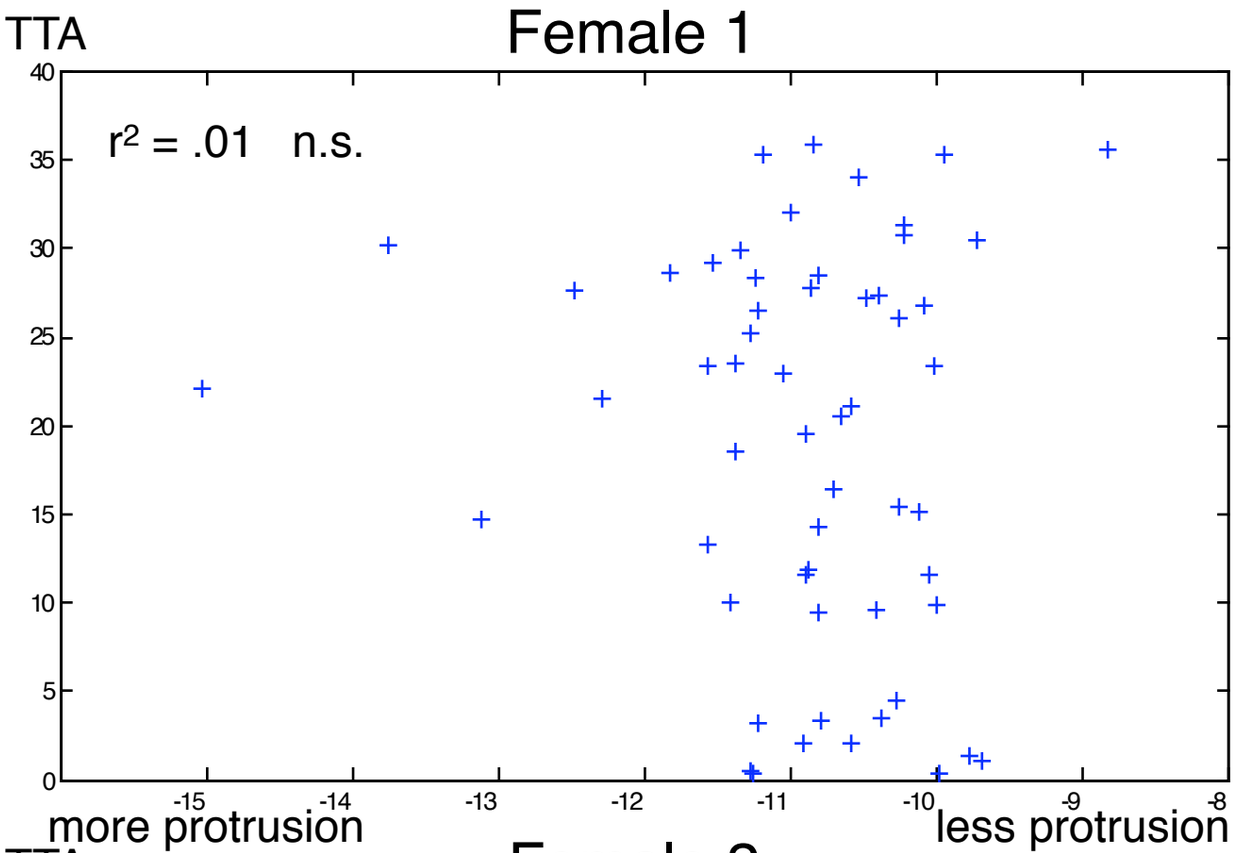
Tongue postures at velocity (F3) minimum

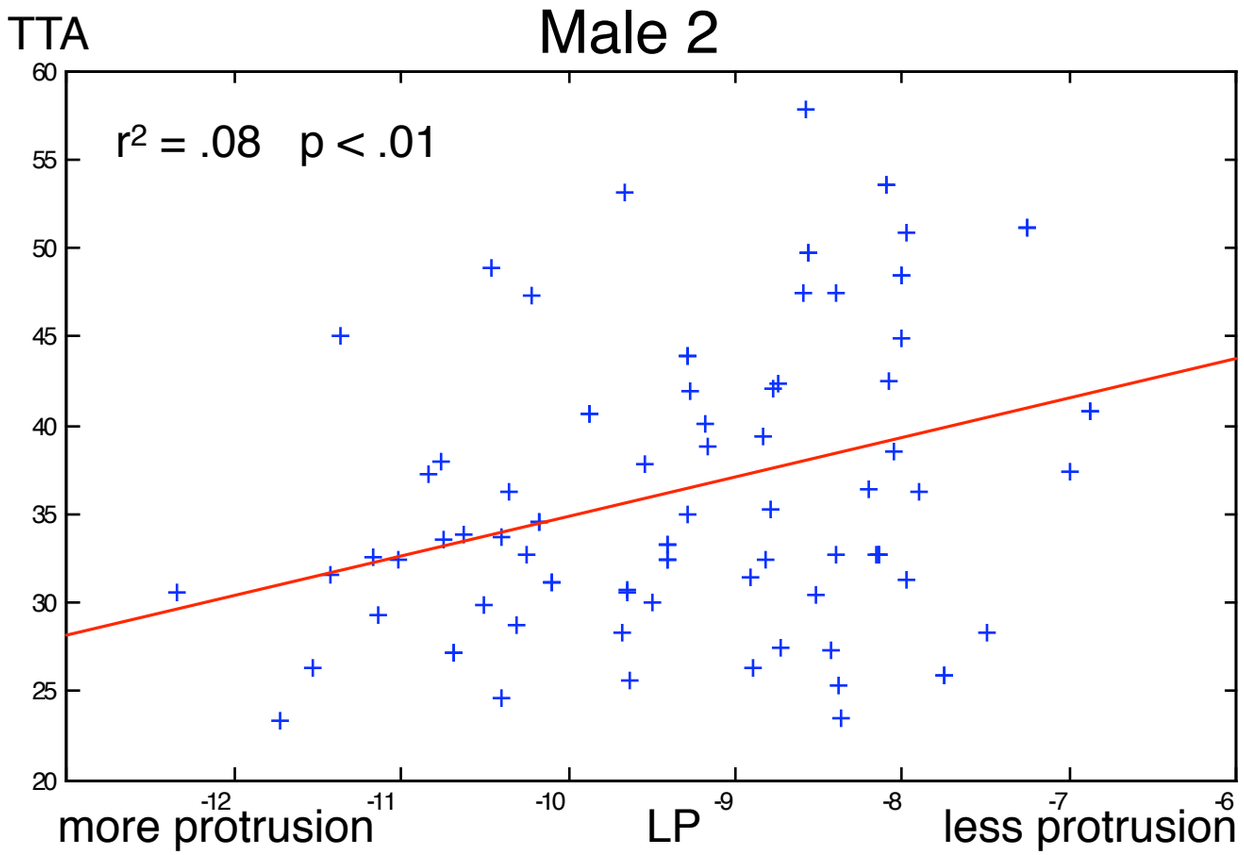
Articulatory Results

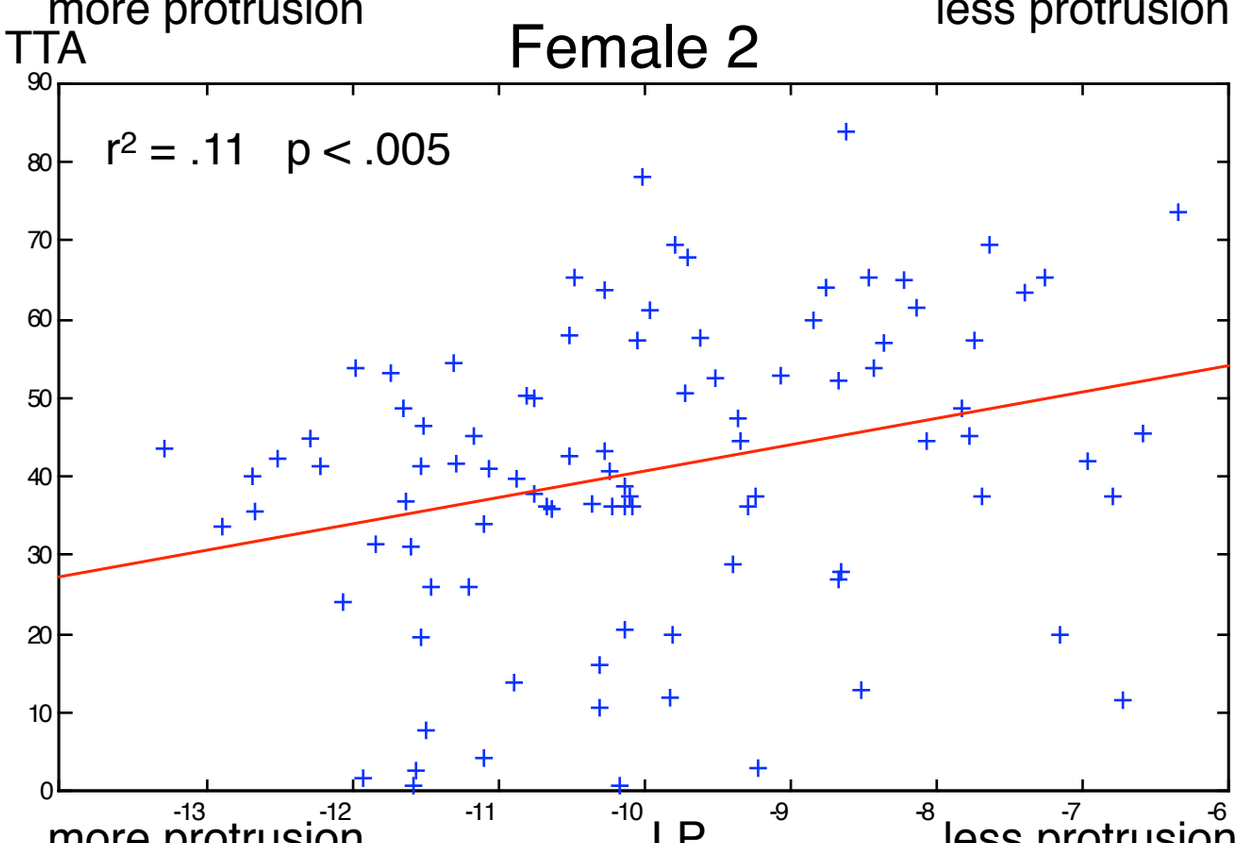


Tongue Tip Angle (TTA) measured in degrees at tongue velocity (F3) minimum, by condition and vowel context. Positive angles indicate bunched production posture; negative angles indicate retroflex. The width of each bar is proportional to the number of bunched or retroflex trials for that condition (the final –Pert +Adapt block had only five repetitions per condition). Error bars show 95% confidence intervals.

Relationship between TTA and Lip Protrusion (LP)







Moderate correlation for 2 subjects holds only for bunched posture:

- increased tongue convexity associated with less lip protrusion (an example of motor equivalence; Perkell *et al*. 1993)

Summary of Articulatory Results

In general, subjects

- showed distinct pre-perturbation postural preferences
- in response to perturbation decreased TTA; produced a mix of bunched and retroflex production postures
- preferred bunched postures for /iri/
- were most susceptible to perturbation for /ara/

Subject-specific:

- M1 least affected by perturbation
  - after initial (block 2) TTA decrease returned to near original posture
  - same-sized perturbation might have smaller effect on larger male vocal tract
- F1 most affected by perturbation
  - changed preferred bunched posture to majority retroflex for /uru/
- F2 reacted least to initial perturbation; adapted most
  - post-adaptation showed greatest difference from original posture

Aftereffects (final contrary to initial preferred posture):

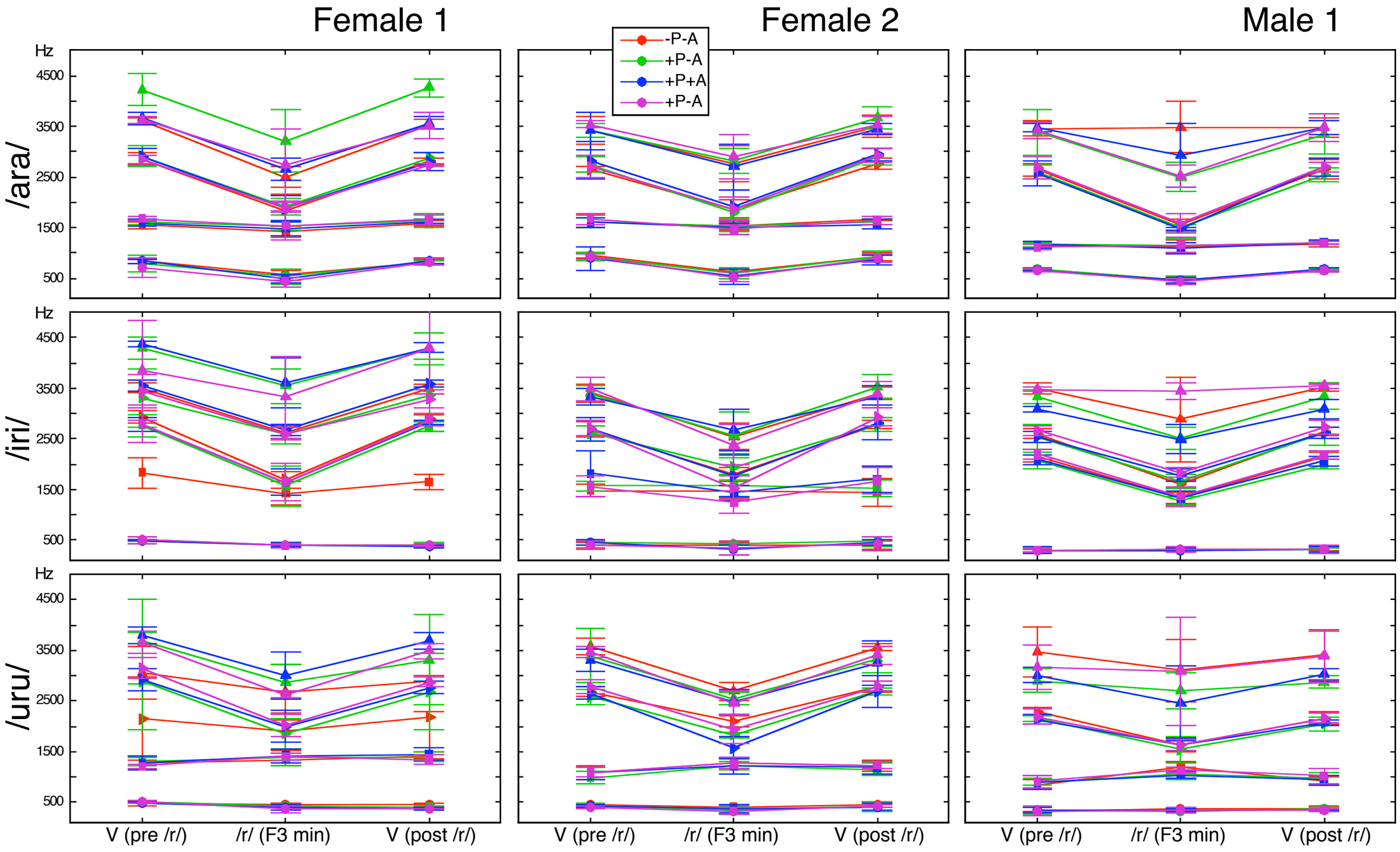
- F1 /uru/, F2 /ara/, M1 (none)

Acoustic Measures

Question: Do alternative production strategies have discernible acoustic consequences?

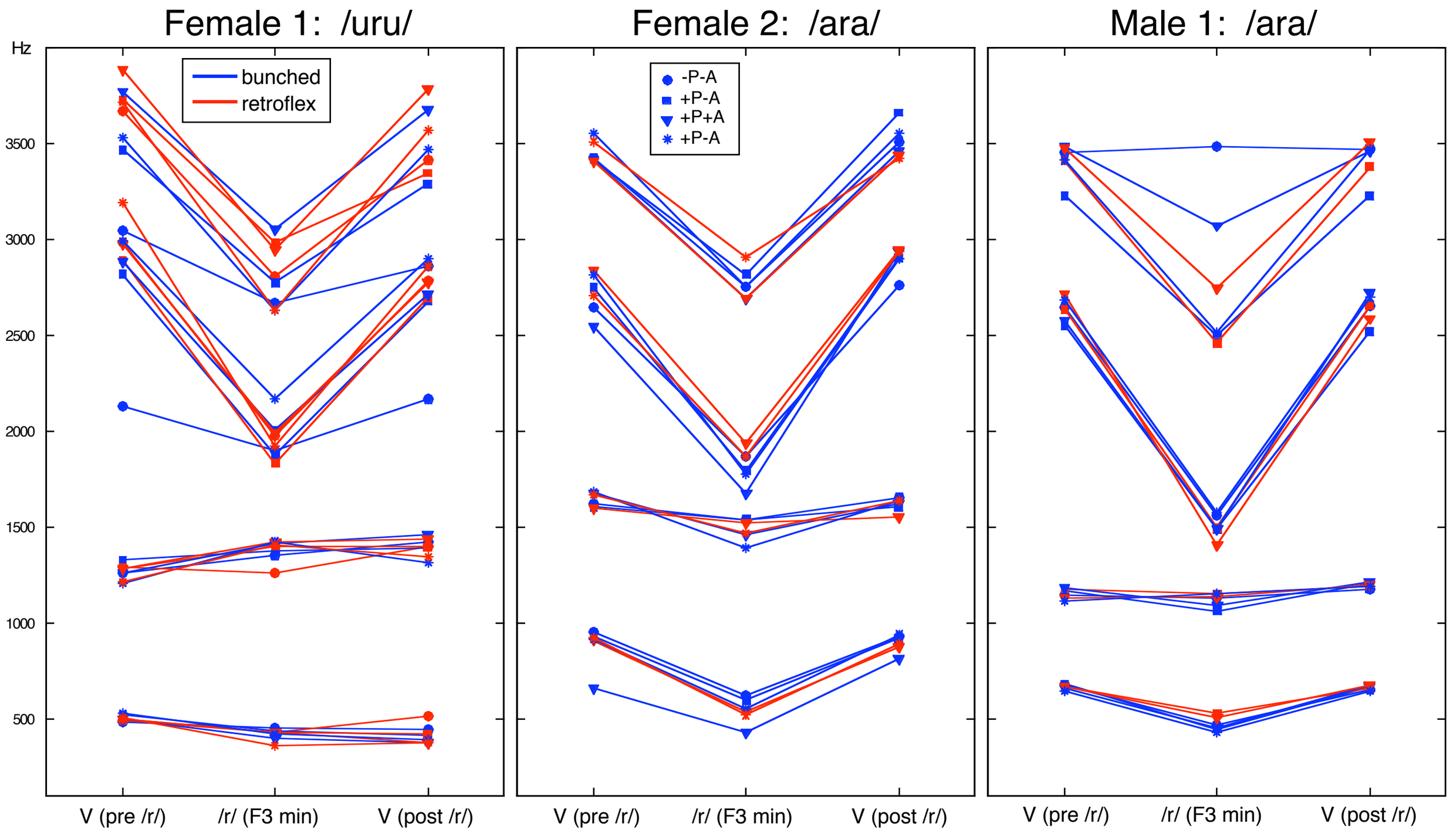
- first four formants computed using order 20 LPC (25 ms Hanning window)
- evaluated at F3 minimum, and within preceding and following vowel (before/after F3 inflection)

Acoustic Results



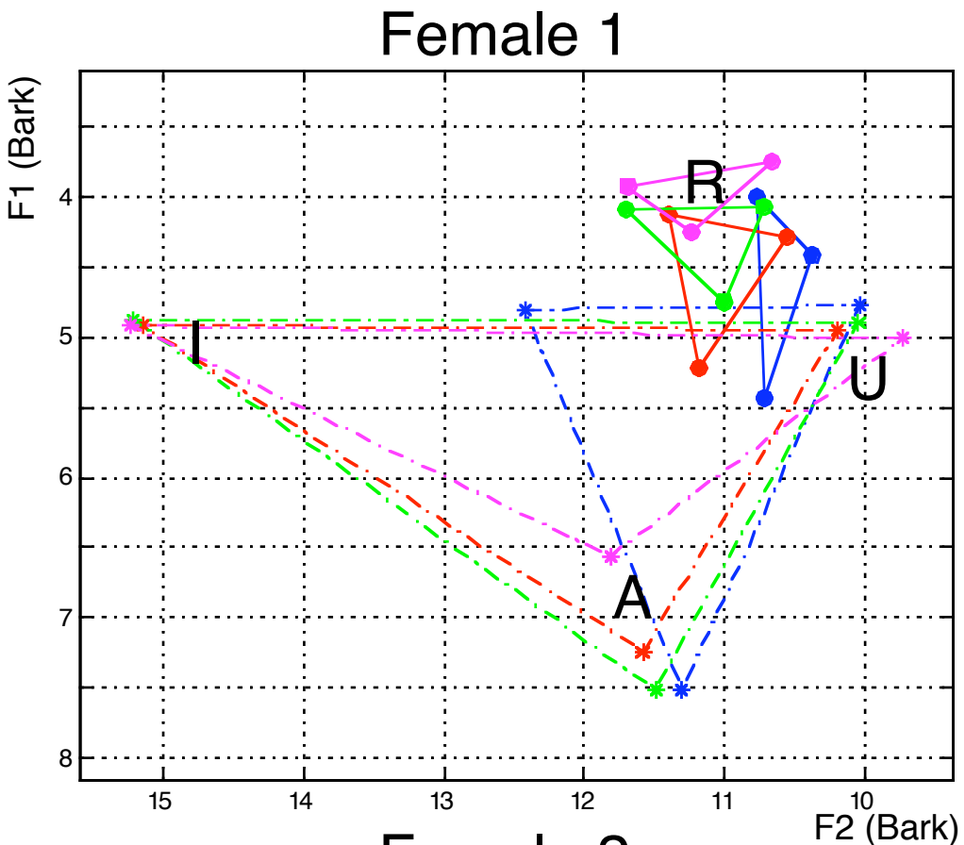
The first four formants showing transition into and away from /r/ target, plotted by condition. Marker shown at median value of repetitions for that formant/condition, with error bars determined by inter-quartile range.

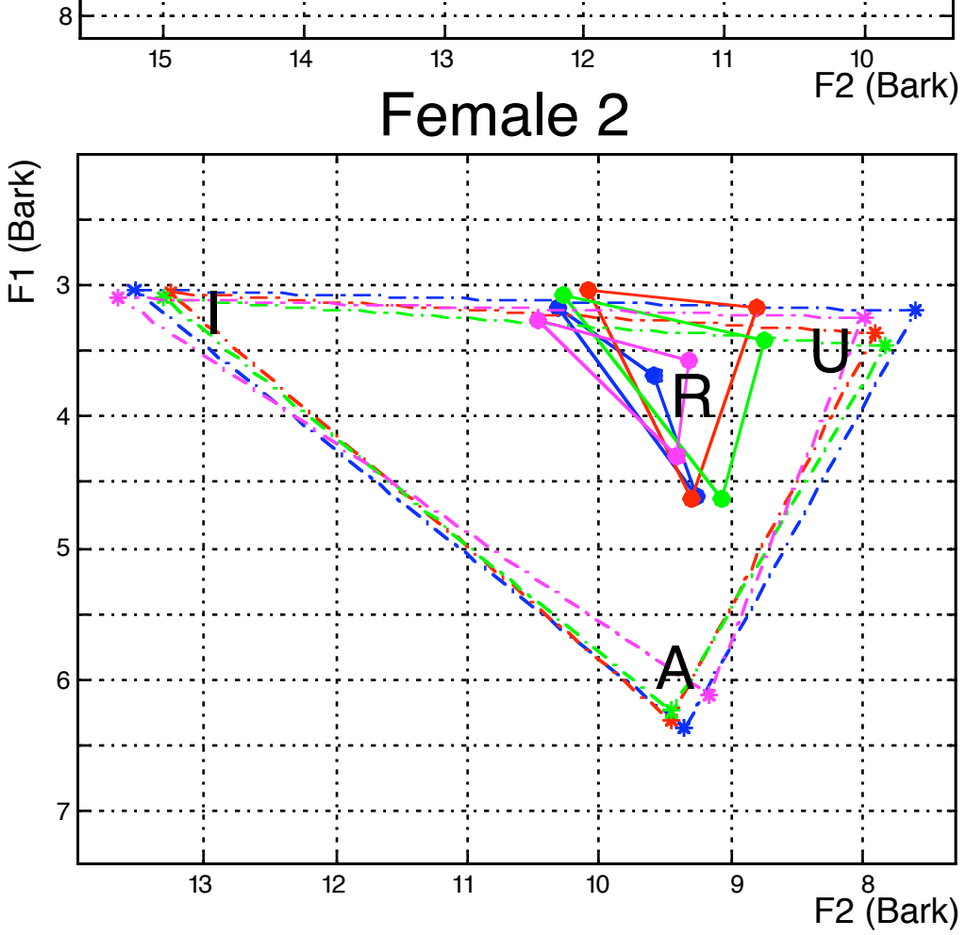
Acoustic Results (mixed postures only)

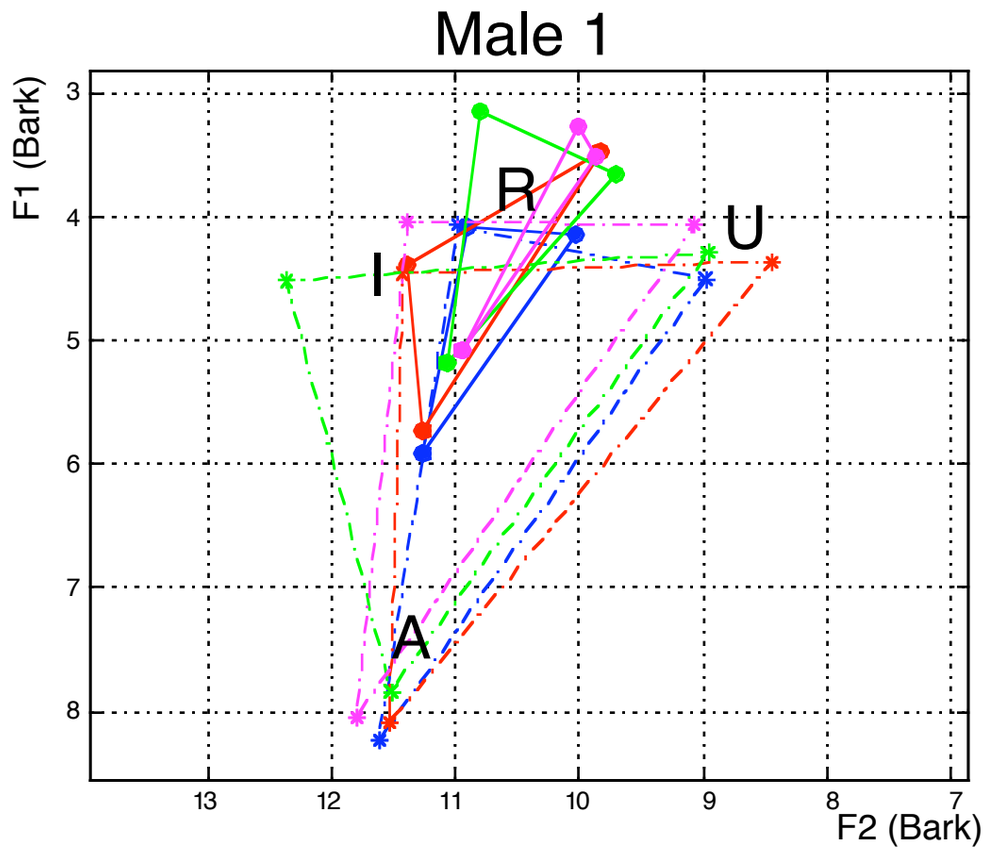


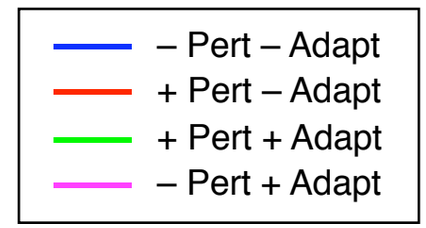
Plotted here are those instances for which subjects showed a mix of tongue postures. The marker shows the median value of repetitions for that formant/condition. Note the lack of systematic effects of tongue production posture.

Acoustic Results (vowel spacing)









F2 x F1 plots of median formants by condition, showing preceding vowel (dotted line) and F3 minimum associated with /r/. Note that the reduced formant spacing for /r/ nonetheless preserves the separate identity of each context vowel.

In general, subjects

- ***did*** show effects of perturbation on formants
- ***did not*** show any systematic acoustic effects of tongue posture
- **preserved** vowel identity during /r/

Summary

Effects of a palatal perturbation prosthesis on /r/ production were observed using EMA:

- each subject showed distinct, vowel context-specific pre-perturbation tongue postural preferences
- in response to perturbation the tongue tip angle (TTA) decreased; that is, the tongue became less bunched / more retroflexed
- some trials after exposure to perturbation were produced with production postures distinct from the subject's original preference (bunched => retroflex)
- low vowel (/ara/) contexts were most affected; high front vowel (/iri/) contexts the least
- bunched /r/ TTA moderately correlated with lip protrusion
- no systematic acoustic effects of production posture were observed

Conclusions

Fluent speakers of AE have more than one strategy accessible for /r/ production, and these strategies succeed equally well in shaping the formant structure perceived as /r/.

The need to master two viable and potentially competitive production strategies may be a a reason why /r/ is among the last sounds to be mastered in AE language acquisition.

Speech pathologists make use of prosthetic devices similar to that described here as a means of facilitating production in school-age children with persistent difficulties in mastering /r/ (the “R-appliance”; cf. Clark *et al*. 1993)

For proficient speakers of North American English, selection of tongue posture in /r/ production is likely made at a motor planning level conditioned by some least effort principle: Under perturbation or coproduction constraints, speakers employ an alternative tongue posture to shape /r/ target formants if that choice is easier to produce.

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