Coarticulation and contrast in static and dynamic models of second formant trajectories

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Introduction

- Acoustic variation in CV production:
  1. Size of the segmental inventory [Manuel, 1990, Manuel, 1999]
  2. Resistance to coarticulation [Recasens and Espinosa, 2009]
- Resultant acoustic variation is a product of two constraints: contrastive and articulatory-motor
- Degree of coarticulatory resistance shapes the spread of coarticulation between neighbouring segments
- Formant transitions are commonly used to categorize consonant place of articulation (POA) and relative coarticulatory resistance in CV contexts
- Questions:
  1. Do models of POA categorization from CV formant transitions operate equivalently in languages of differing inventory densities?
  2. What is the relation between predictions from static (vowel-independent) and dynamic (vowel-dependent) models in this regard?
- Findings:
  - Results from investigations of the dense coronal system in Malayalam (exhibiting an alveolar–dental–retroflex contrast) indicate inconsistencies in categorization outcomes from the two models
  - Coarticulation and contrast-based differentiation of coronal categories are not aligned tasks in present models

Early Investigations of Place Cues in F2 Trajectories

- Critical information as to the place of articulation of a consonant determined to be contained in F2 transition into the following vowel; cues were ambiguous, however, in some CV sequences [Delattre et al., 1955]
- F2 transitions found to follow exponential trajectories which further revealed 'under/overshoot' effects in the acoustic realization of V_2 target formant frequencies [Lindblom, 1963]
- Consonant locus framework temporarily abandoned after [Öhman, 1966] demonstrated lack of acoustic invariance in Swedish VCV sequences

Locus Equations: Consonant Place Categorization

- The linear and POA-dependent relationship between F2 at onset and target (steady-state/midpoint) of the following vowel in CV syllables was proposed by [Sussman et al., 1991] as a viable acoustic invariant in the categorization of plosives /b d g/ in American English
- This model was also shown to be cross-linguistically applicable early-on in a study of Thai, Cairene Arabic, and Urdu; notably the coronal contrasts were not distinguishable in pairwise comparisons [Sussman et al., 1993]

Locus Equations: Coarticulatory Resistance

- Locus equation slopes found in patterned relation to computer-modeled degree of gestural overlap [Chennoukh et al., 1997]
- These results did not obtain in natural language data in [Löfqvist, 1999]
- More robust articulatory measures from X-ray Microbeam (XRMB) and Electromagnetic Midsagittal Articulography (EMMA) data validate the inverse relationship between degree of coarticulatory resistance and LE slope [Iskarous et al., 2010]

Malayalam

- Dravidian language spoken in the state of Kerala, India
- Exhibits a three-way coronal place contrast (alveolar, dental, retroflex); notably this contrast is restricted to intervocalic voiceless geminates [Dart and Nihalani, 1999]
- The dental and alveolar are tongue tip/blade gestures; the retroflex uses an additional tongue dorsum gesture [Bladon and Al-Bamerni, 1976]

Materials and Methods

- Speech data were recorded at the EFLU Phonetics Lab from 6 native speakers of Malayalam (3 female, 3 male) from Malappuram district in Kerala
- Material: Utterance-framed words carrying target voiceless geminate plosives in intervocalic position (V_1C:V_2) for three coronal places of articulation (alveolar, dental, and retroflex)
- 3 places of articulation × 10 target words × 3 repetitions × 6 speakers = 540 total items
- Recorded data were digitized (16 bit, 44.1 kHz), annotated, and analyzed in Praat 5.3 [Boersma, 2001]
- Formants were calculated with Praat's implementation of the Burg algorithm [Childers and Kesler, 1978], optimized per speaker, per vowel using F2/F3 variance minimization as described in [Escudero et al., 2009]
- F2 and F3 values were extracted at intervals of 5% of V_2 duration from onset to midpoint
- The Static Model: First-order Locus Equations (LEs)

$$F2_C = \beta + \alpha F2_V$$

where β is the LE intercept; and $\alpha = \rho\frac{\sigma_C}{\sigma_V}$, which is the LE slope, an index of coarticulatory resistance [Iskarous et al., 2010]
- $F2_C$ is the second formant calculated at CV boundary (offset by 5% of V_2 duration to avoid measurement noise near voiceless plosive release)
- $F2_V$ is the second formant calculated at V_2 midpoint
- Standard (CV) model applicable in VC:V context as demonstrated in [Ghavami, 2002]
- The Dynamic Model: Time-normalized Formant Trajectories

$$F_n(t) = \beta e^{-\alpha t} + \gamma$$

where $\beta = F_{locus} - F_{target}$; and $\gamma = F_{target}$ in the exponential decay model derived from Lindblom (1963) [Lindblom and Sussman, 2012]
- If the formant trajectory is increasing, β is negative and $F_n(t)$ follows an inverted exponential decay

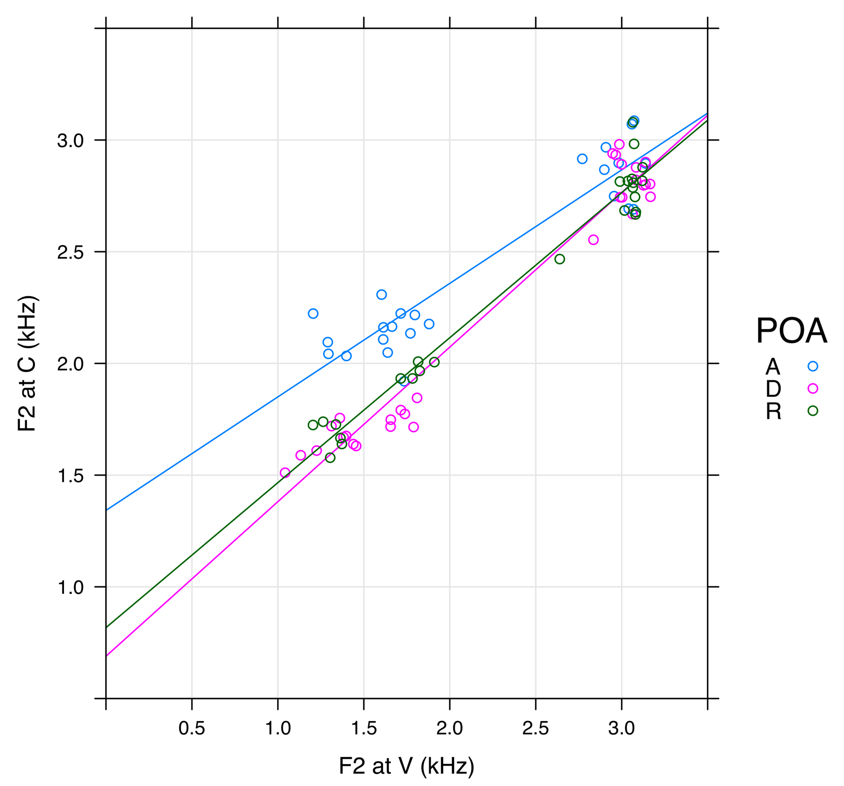

Figure 1: Sample calculation of alveolar (A), dental (D), and retroflex (R) locus equations for speaker F01

Results: F2 Locus Equations

- Permutational (non-parametric) MANOVA (by Sex): Significant main effect of POA on LE parameters in female [F*=25.5, p<0.01] and male [F*=15.5, p<0.01] groups
- Pairwise: $\alpha_A < \alpha_R = \alpha_D$; $\beta_R = \beta_D < \beta_A$
- This slope relation suggests Alveolars are more resistant to coarticulation than Retroflexes, against predictions based on gestural complexity

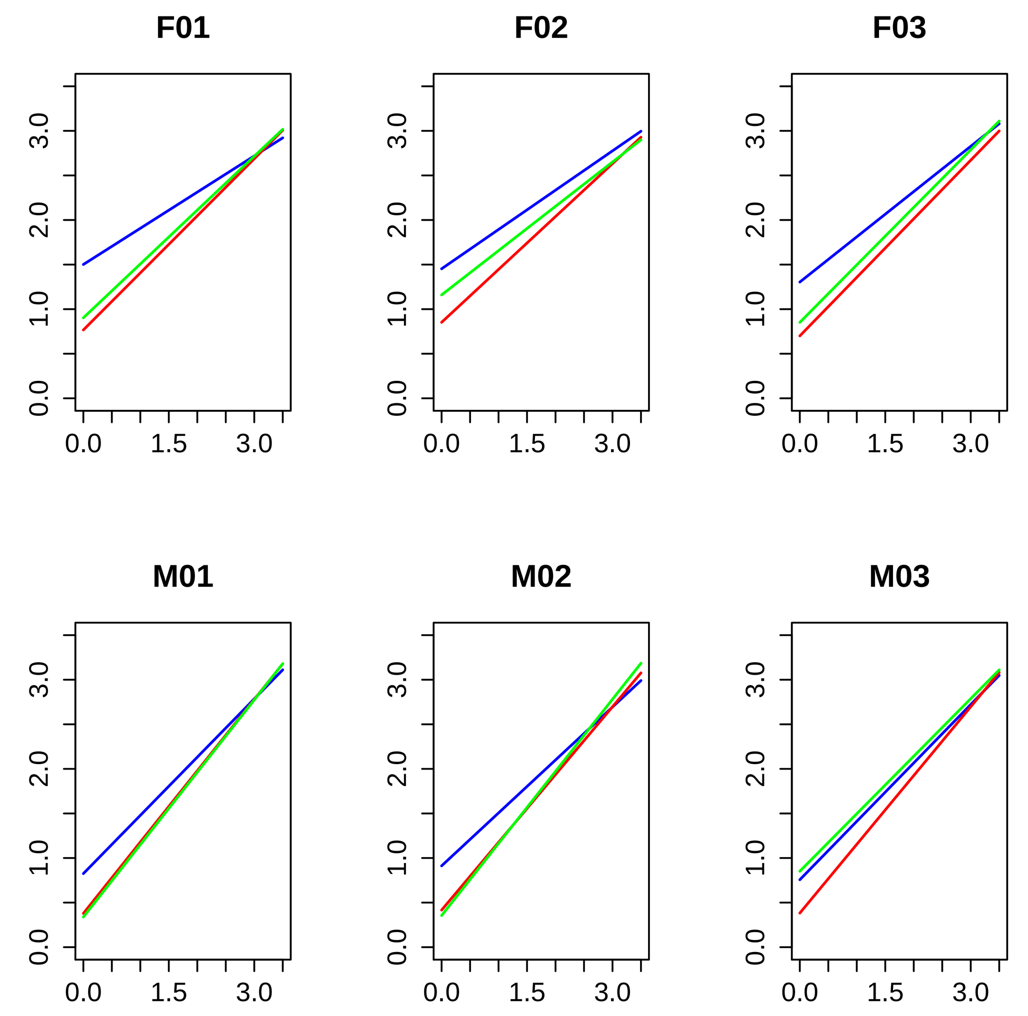

Figure 2: F2 locus equations for alveolar (blue), dental (red), and retroflex (green) places of articulation

Results: F2 and F3 Trajectories

- Permutational MANOVA (by Sex/V_2): Significant main effect of POA on F2 trajectory parameters in 2 out of 6 groups [$p_{F/u}$ <0.01; $p_{M/i}$ <0.05]
  POA significant on joint F2*F3 trajectory parameters in 3 out of 6 groups [$p_{F/a}$ <0.01; $p_{M/a}$,$p_{M/u}$<0.05]
- Thus incorporation of F3 yields a marginal improvement in model categorization of POA contrasts; though neither model is reliable in all vocalic environments

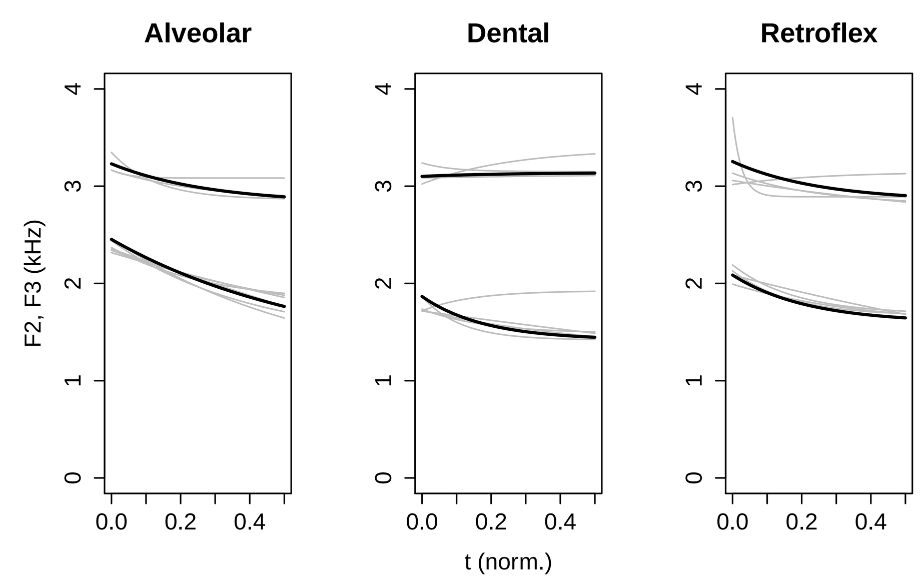

Figure 3: F2 and F3 item (gray) and median (black) trajectories for alveolar, dental, and retroflex C[a] transitions produced by speaker F03

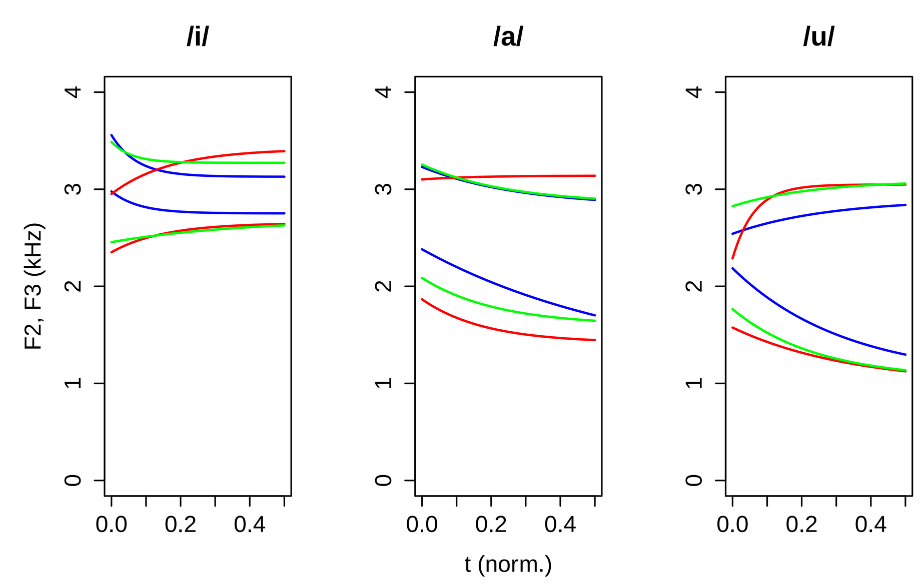

Figure 4: F2 and F3 median trajectories for alveolar (blue), dental (red), and retroflex (green) transitions into vowels /i a u/ produced by speaker F03

Conclusions and Implications

- The reliable separation of consonant place of articulation contrasts in languages of relatively sparse consonantal inventories (the canonical set being labial–alveolar–velar) has been shown to break down in the dense coronal system in Malayalam
- This finding is corroborated in studies of languages with similarly dense inventories [Tabain and Butcher, 1999]
- Results from the dynamic model suggest the incorporation of F3 is necessary in differentiating the coronals in Malayalam, aligning with previous observations on the role of F3 in the acoustics of retroflex productions [Dart and Nihalani, 1999]
- Accounting for the unexpected result that alveolars show flatter slopes and therefore greater coarticulatory resistance than retroflexes or dentals may require appeal to relative lexical frequency, which has been shown to affect coarticulation [Scarborough, 2004]

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