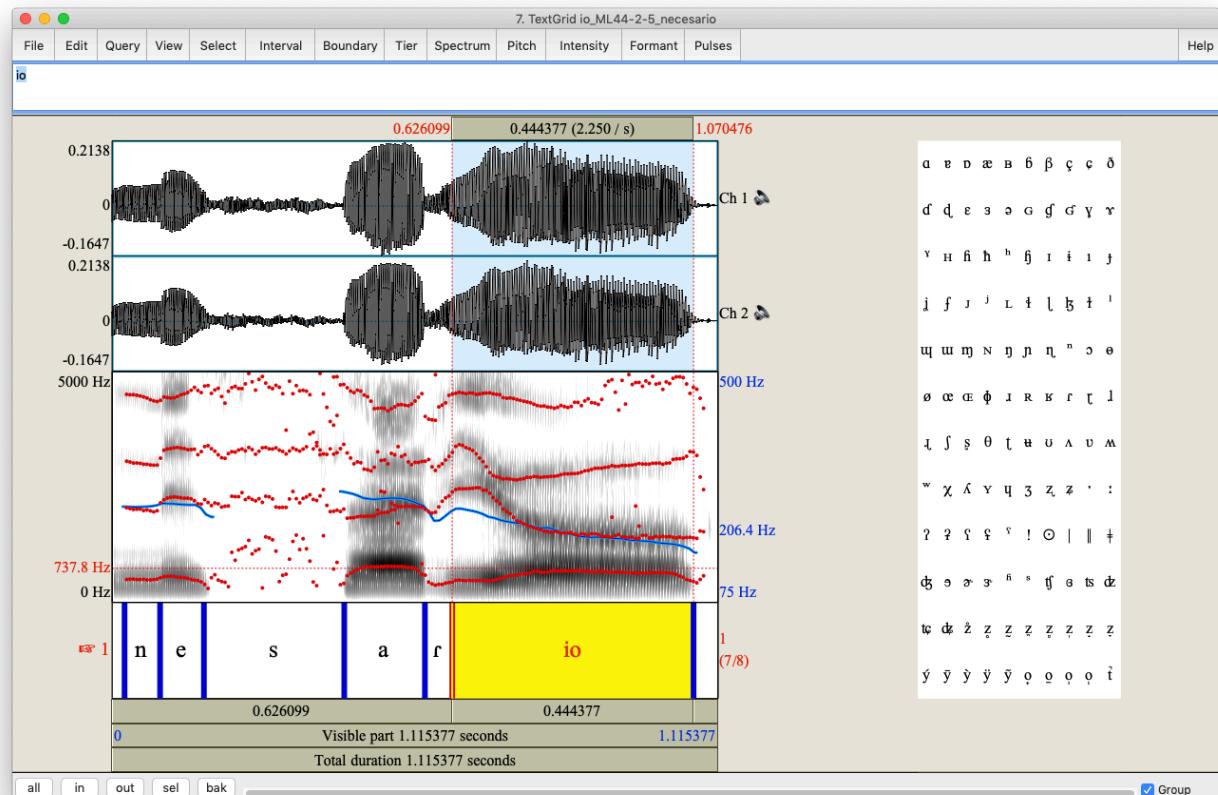


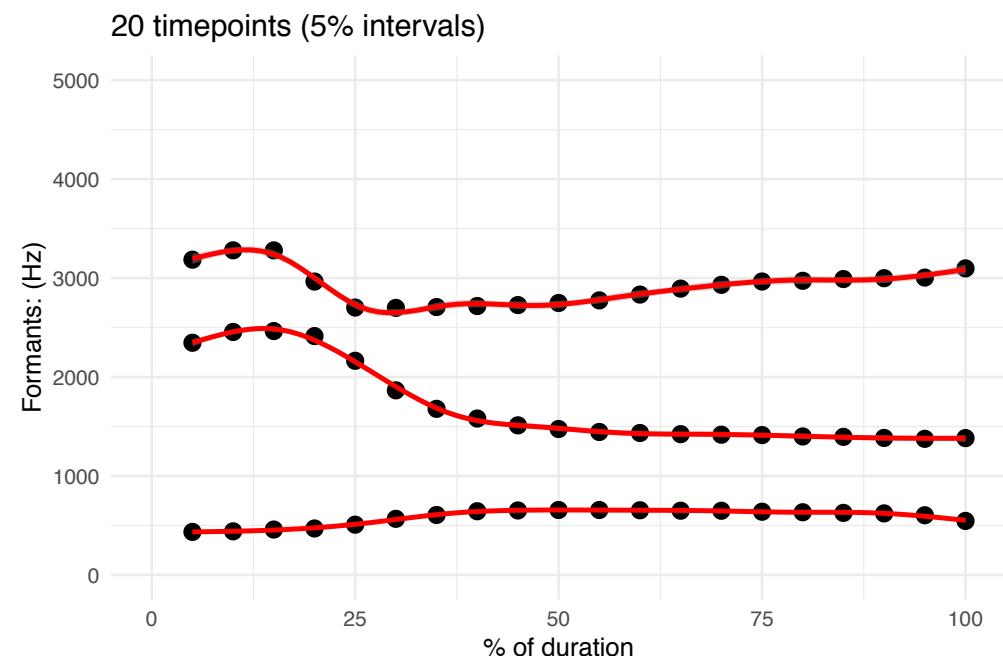
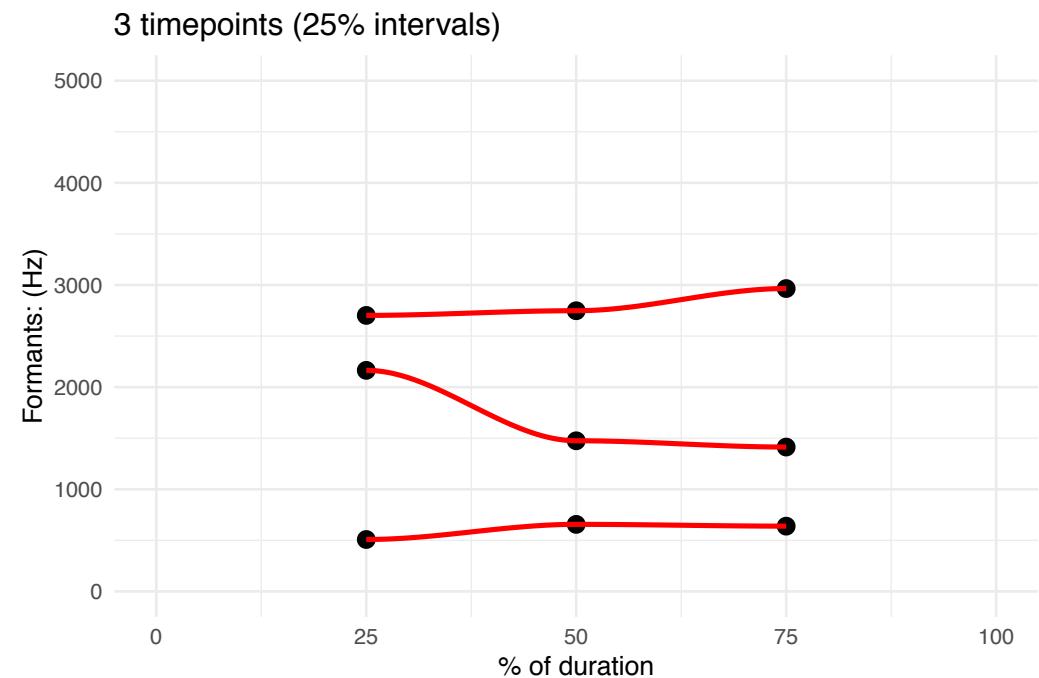
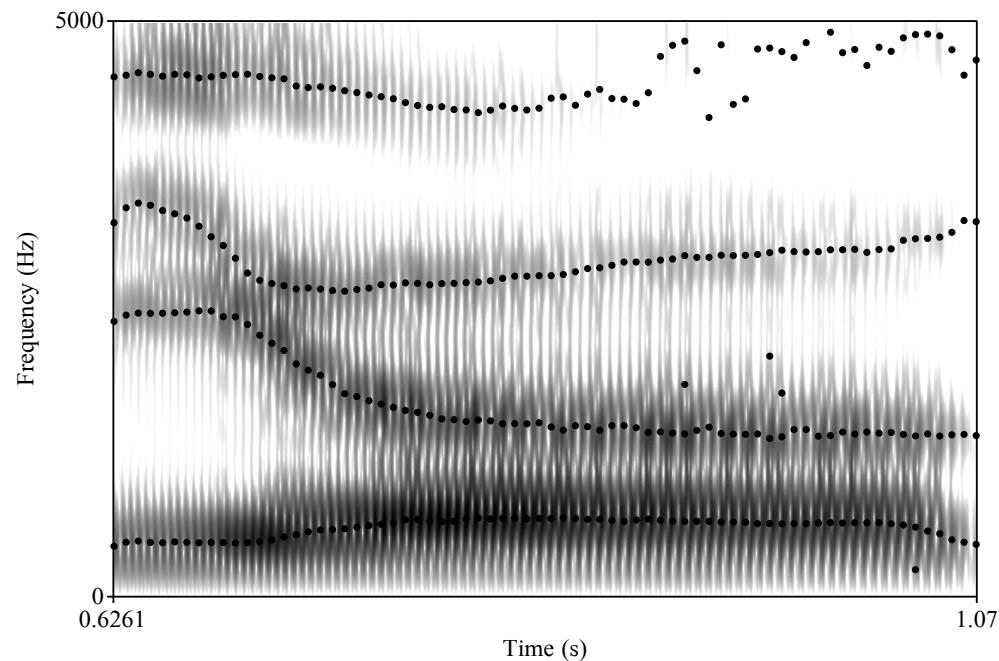
Acoustic Measurement

- Tokens of diphthong-containing words isolated in Praat and manually segmented
- *FormantPro* script (Xu & Gao, 2018) used to extract formant measurements for F1, F2, F3 at 5% intervals across vowel duration



Acoustic Analysis

- Formant measurements taken at 5% intervals (20 points) permit high-fidelity replication of original formant contours with minimal errors, versus more commonplace 25% intervals (3 points)

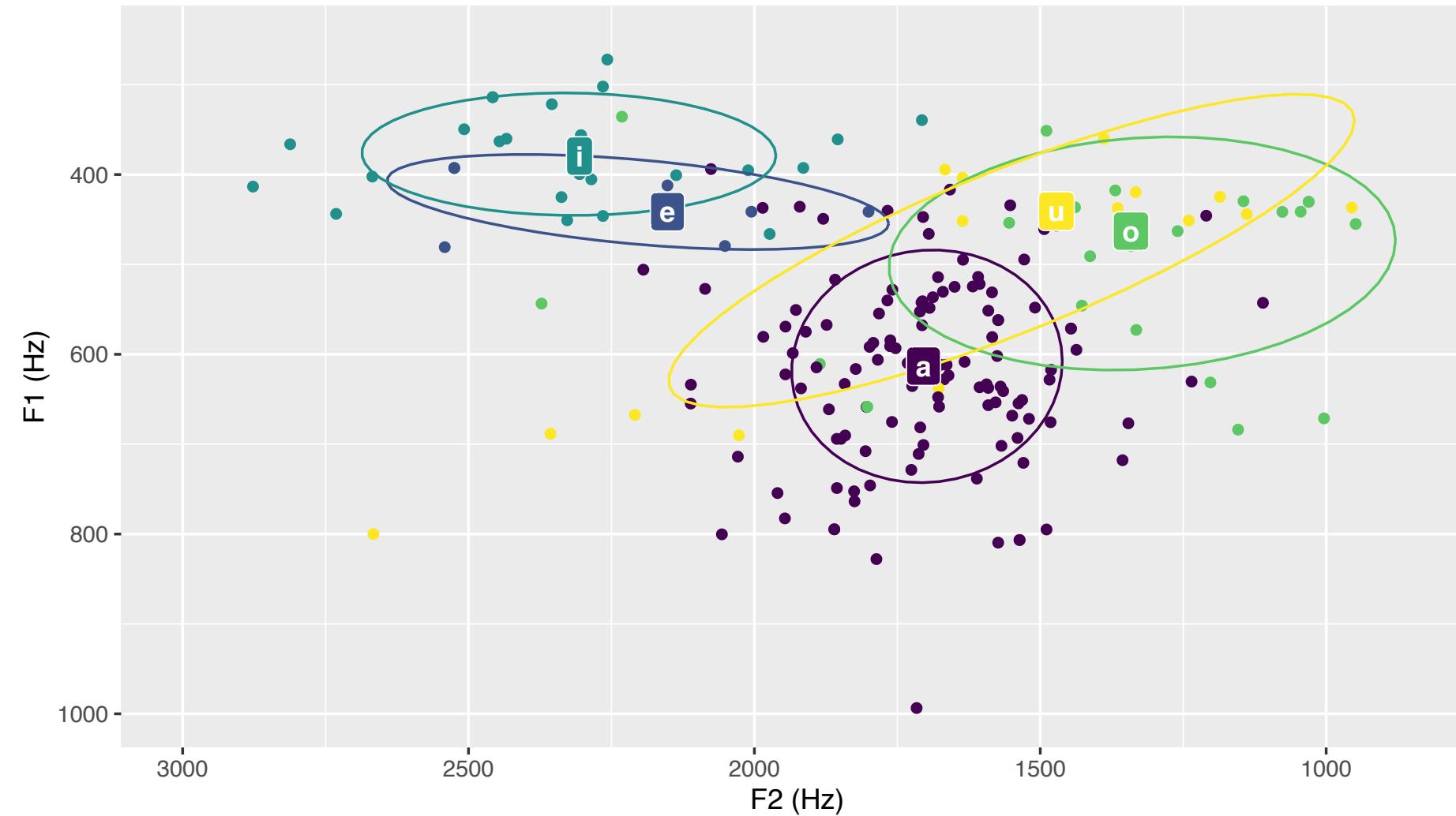


GAMMs comparisons

- Generalized Additive Mixed Models (GAMMs; Hastie & Tibshirani, 1990; Wood, 2017; Sóskuthy, 2017) for comparison of non-linear data:
 - E.g. comparisons of formant trajectories across different conditions:
 - Vowel A vs. vowel B
 - Vowel A before segment X and segment Y
 - Vowel A by L1 vs. L2 speakers (Onosson & Bird, 2019)
- Applied within our dataset to compare:
 - Production of the same diphthong across Media Lengua, Quichua, and Spanish
 - Production of Quichua- and Spanish-derived diphthongs within Media Lengua

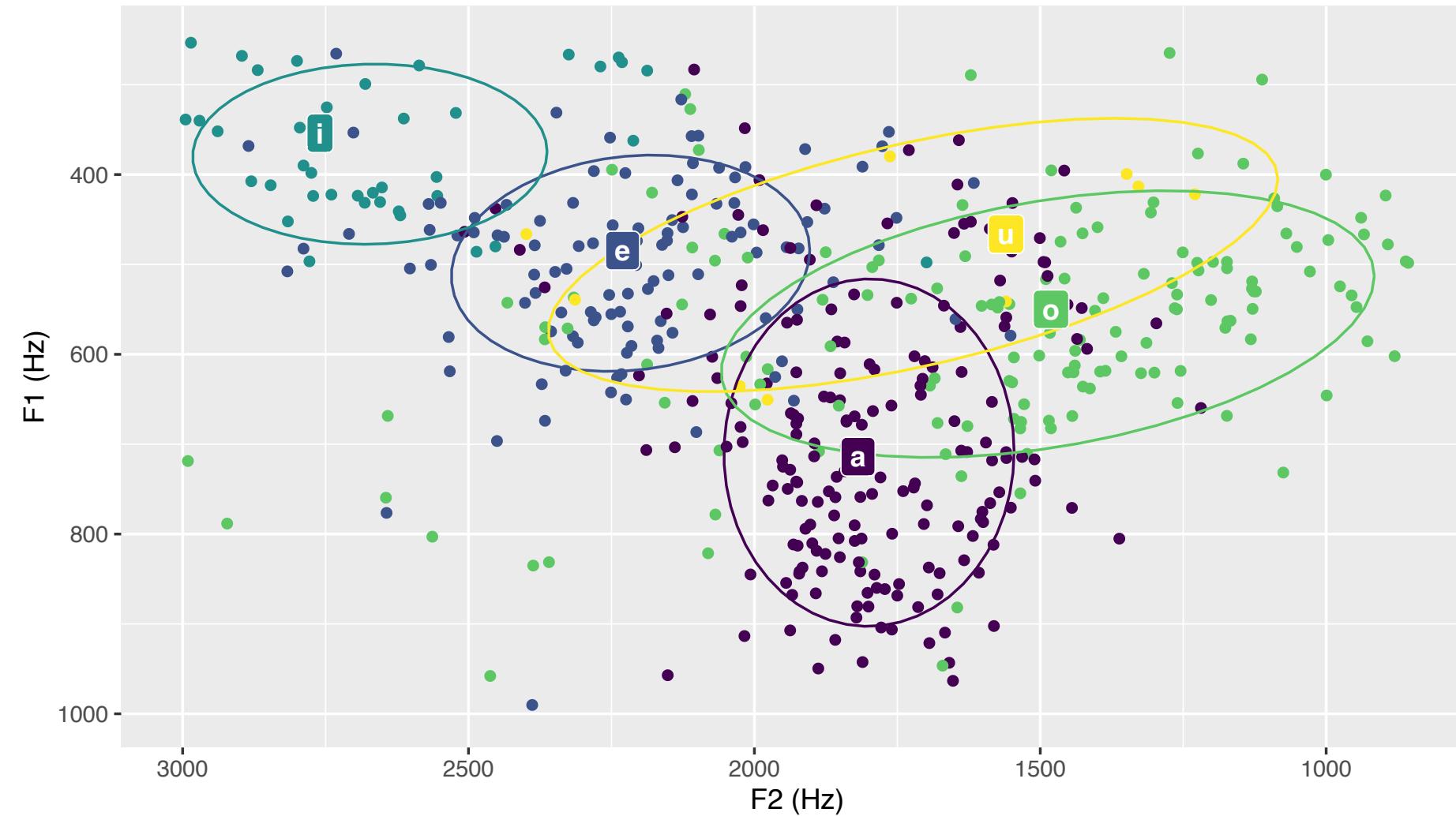
Quichua vowel space

Ellipses indicate 2 standard deviations; monophthong n = 634



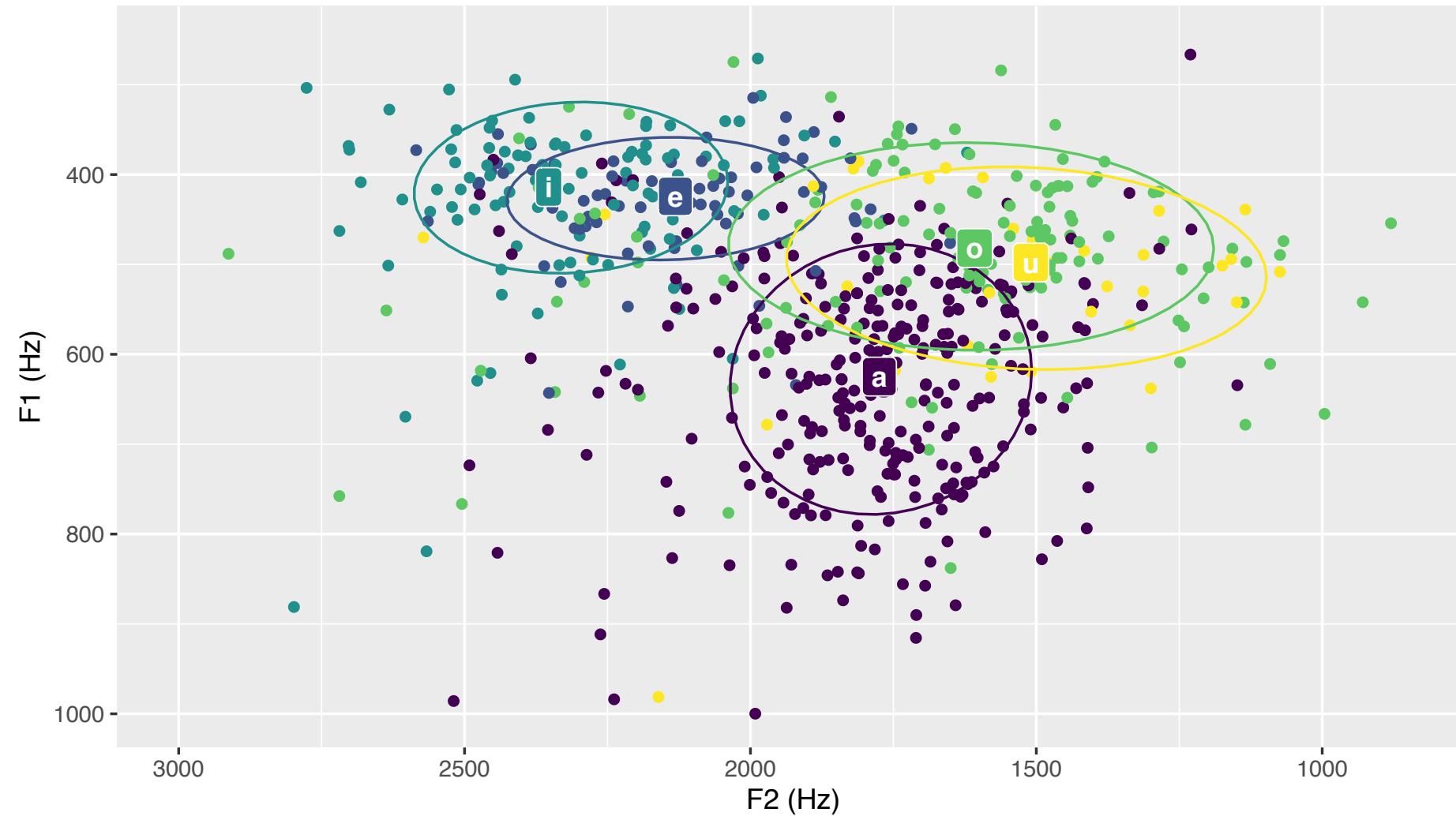
Spanish vowel space

Ellipses indicate 2 standard deviations; monophthong n = 1929



Media Lengua vowel space

Ellipses indicate 2 standard deviations; monophthong n = 2040



Cross-Language Diphthong Comparisons

- Per-diphthong, per-formant GAMMs comparisons:
 - Dependent variable: – F1 or F2
 - Main independent/fixed effect: – Language (M.L. vs. Quichua vs. Spanish)
 - 2 random effects: – Speaker (by Duration)
– Word (by Duration)

Cross-Language Diphthong Comparisons

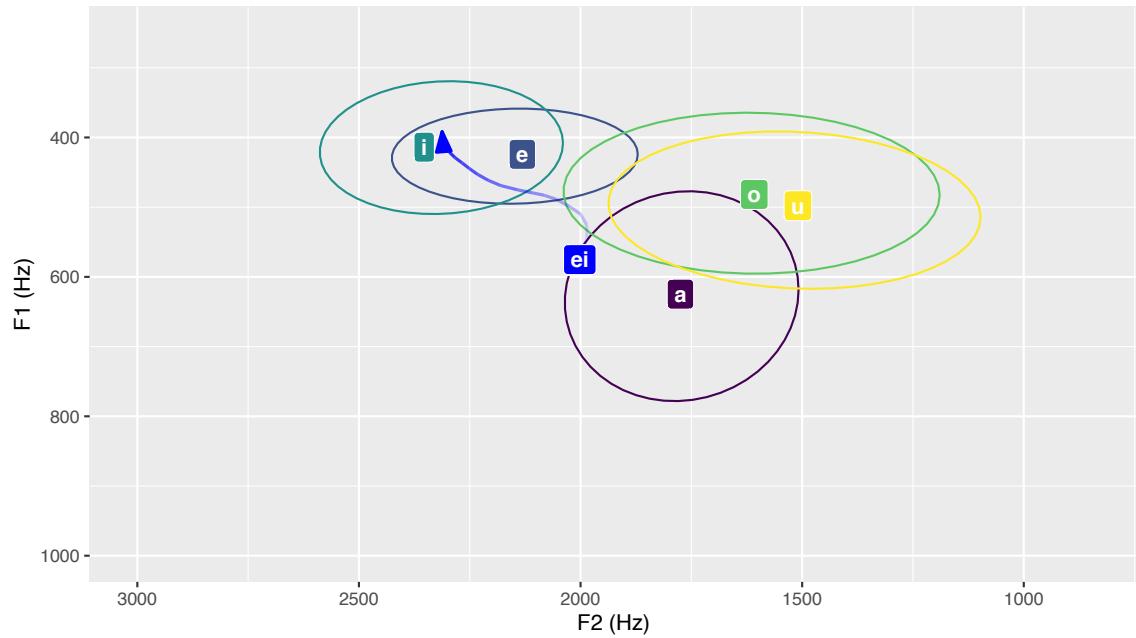
	ae	ai	ao	au	ea	ei	eo	eu
F1	n.s.	n.s.	n.s.	<i>p=0.02</i>	n.s.	<i>p=0.011</i>	n.s.	<i>p=0.005</i>
F2	n.s.	n.s.	n.s.	n.s.	n.s.	<i>p≈0</i>	n.s.	<i>p=0.006</i>
Langs	ML, S	ML, Q, S	ML, S	ML, Q, S	ML, S	ML, S	ML, Q, S	ML, S
	ia	ie	io	oa	ua	ue	ui	uo
F1	<i>p≈0</i>	n.s.	<i>p≈0</i>	n.s.	n.s.	n.s.	n.s.	<i>p=0.002</i>
F2	<i>p≈0</i>	<i>p≈0</i>	<i>p=0.023</i>	n.s.	n.s.	<i>p≈0</i>	n.s.	n.s.
Langs	ML, Q, S	ML, Q, S	ML, S	ML, S	ML, Q, S	ML, Q, S	ML, Q, S	ML, S

Cross-Language Differences in both E1 and E2

- Media Lengua vs. Spanish: /ei, eu, io/
- Media Lengua vs. Quichua vs. Spanish: /ia/

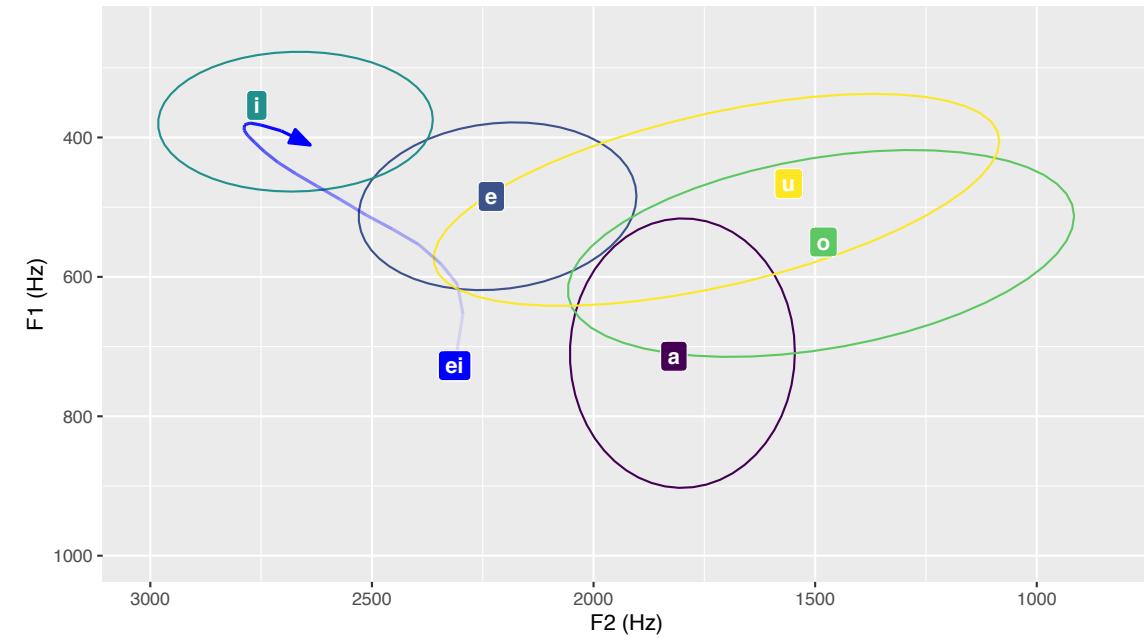
Media Lengua vowel space with /ei/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 2040

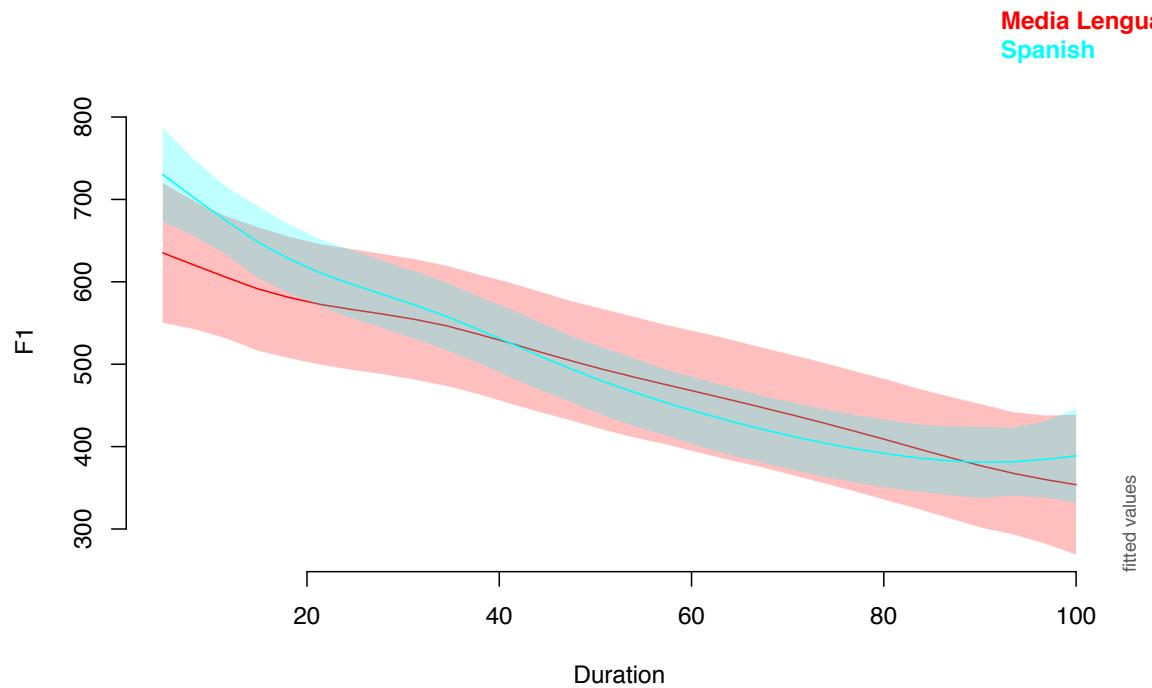


Spanish vowel space with /ei/ trajectory

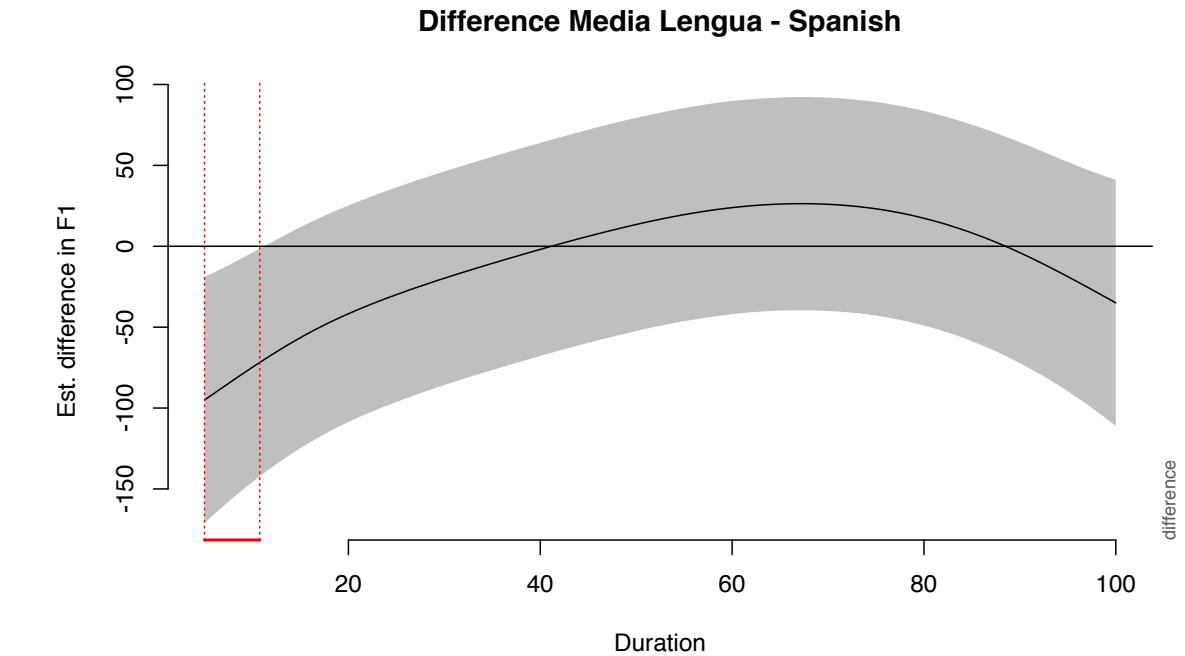
Ellipses indicate 2 standard deviations; monophthong n = 1929



/ei/: F1 & F2



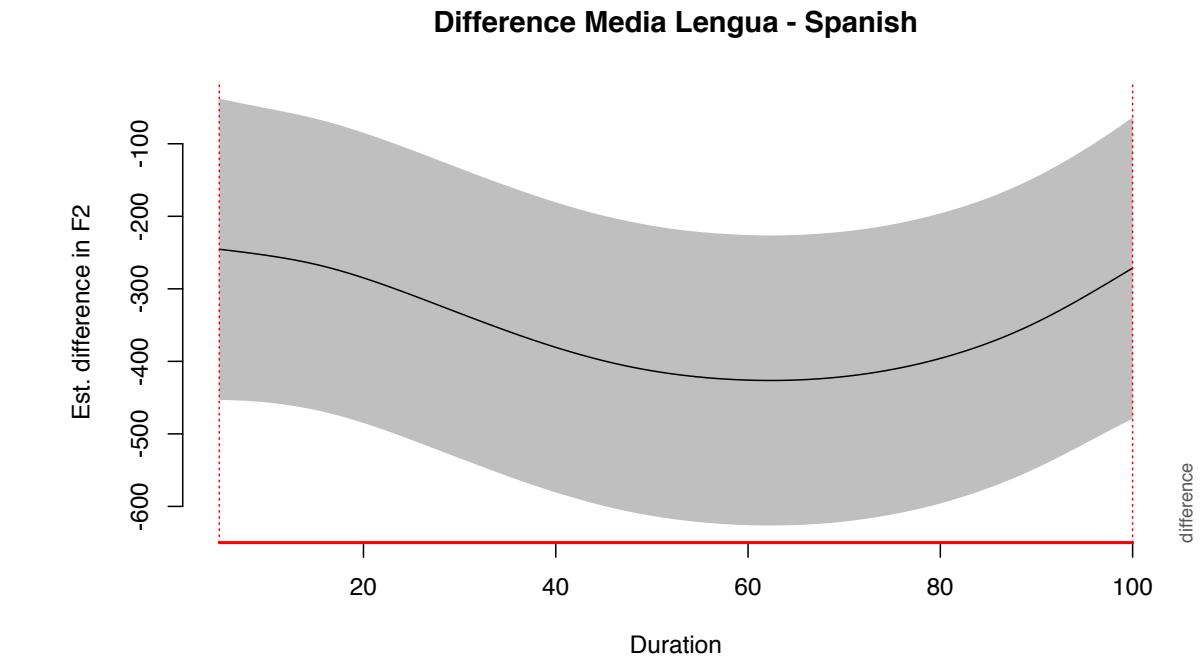
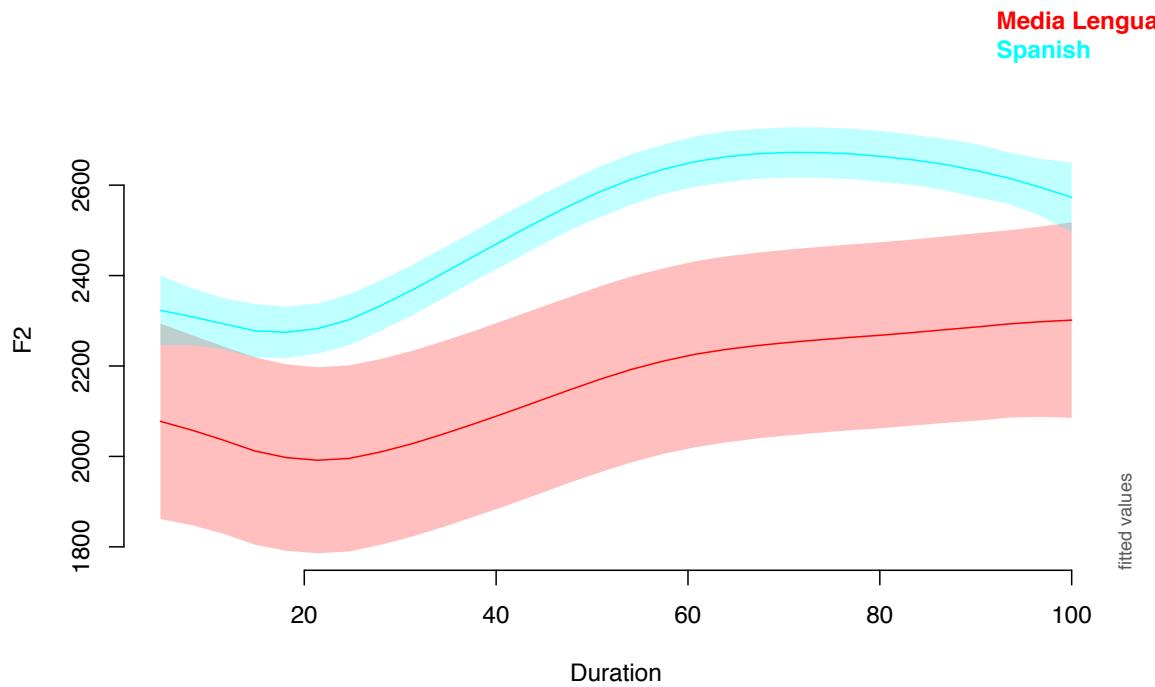
Media Lengua
Spanish



Difference Media Lengua - Spanish

/eɪ/ F1

- Very small differences, localized to onset
- Media Lengua: lower F1 = higher articulatory position

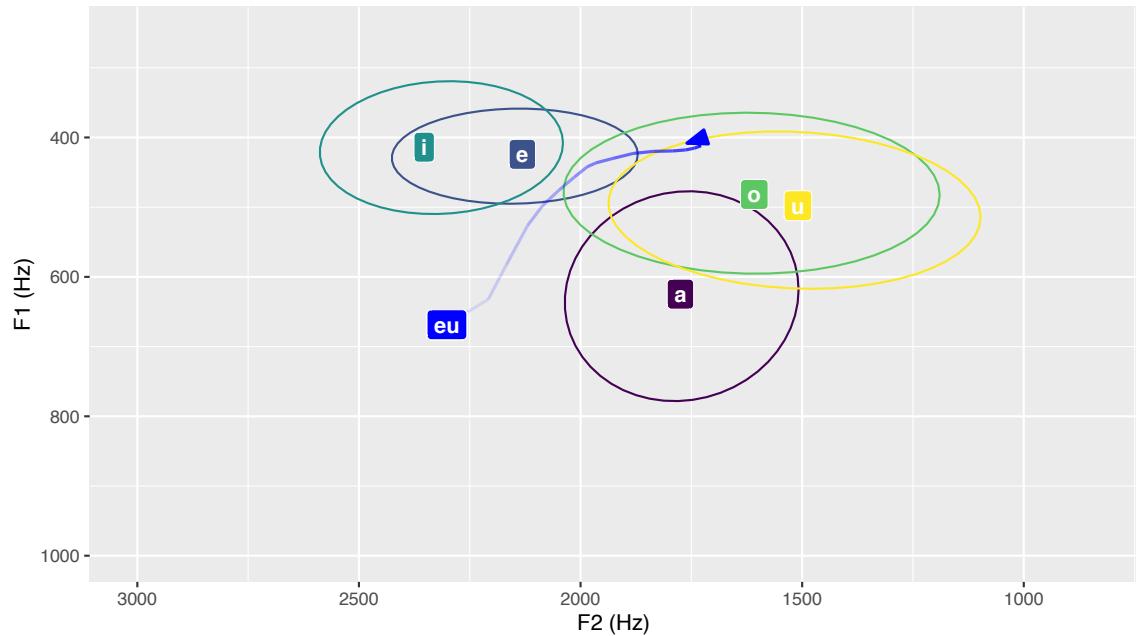


/eɪ/ F2

- Significant differences across full trajectory
- Media Lengua: F2 much lower = retracted position

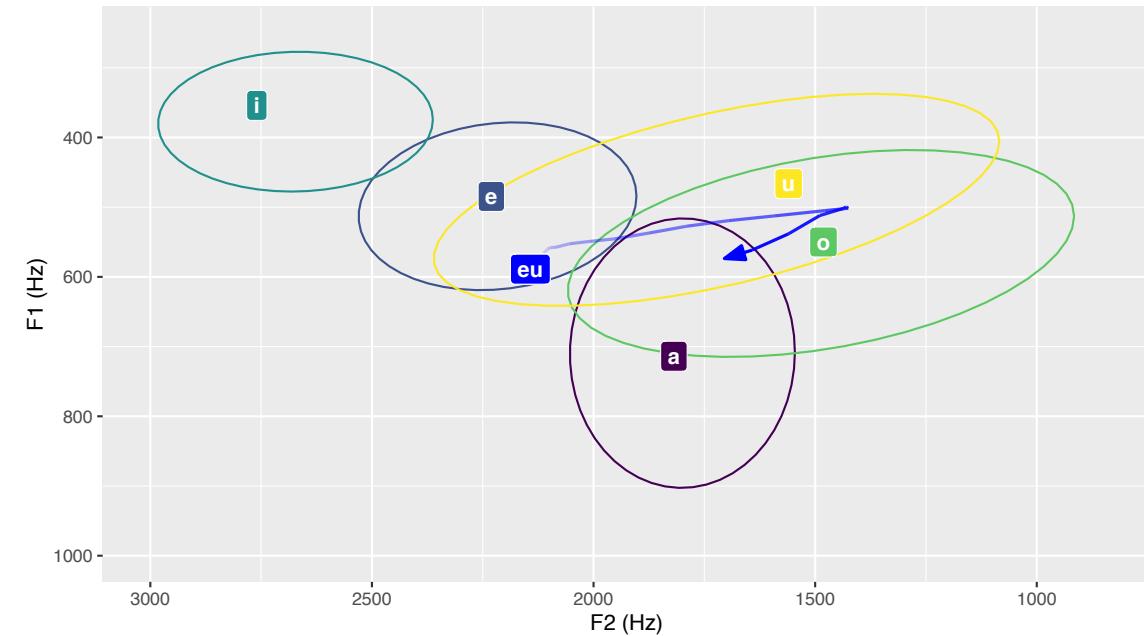
Media Lengua vowel space with /eu/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 2040

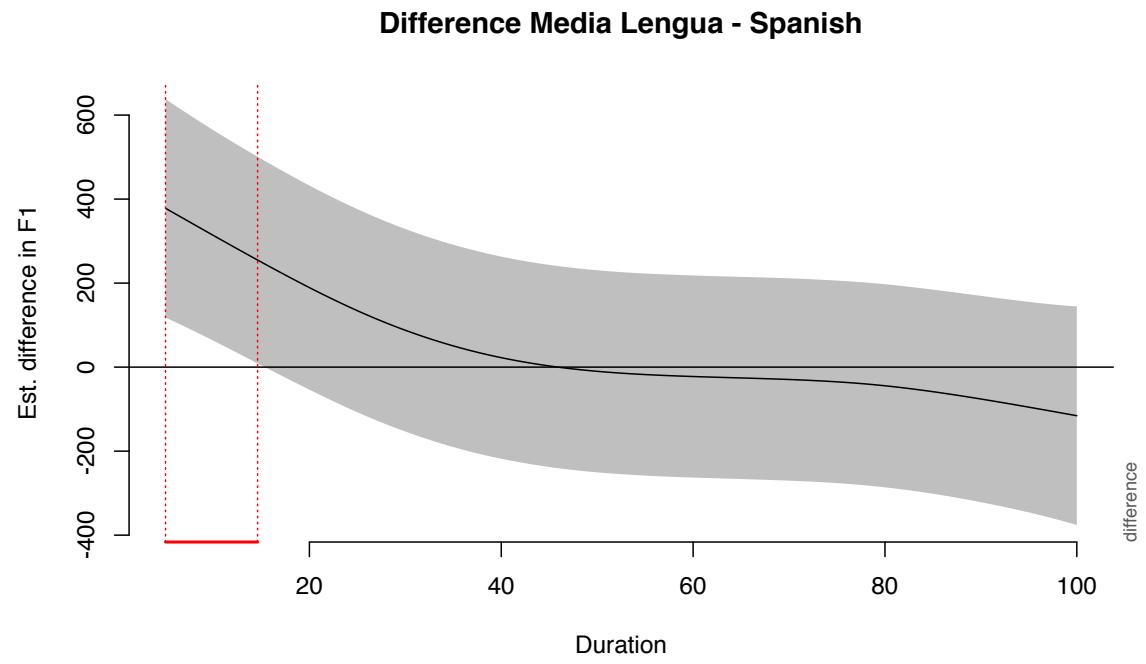
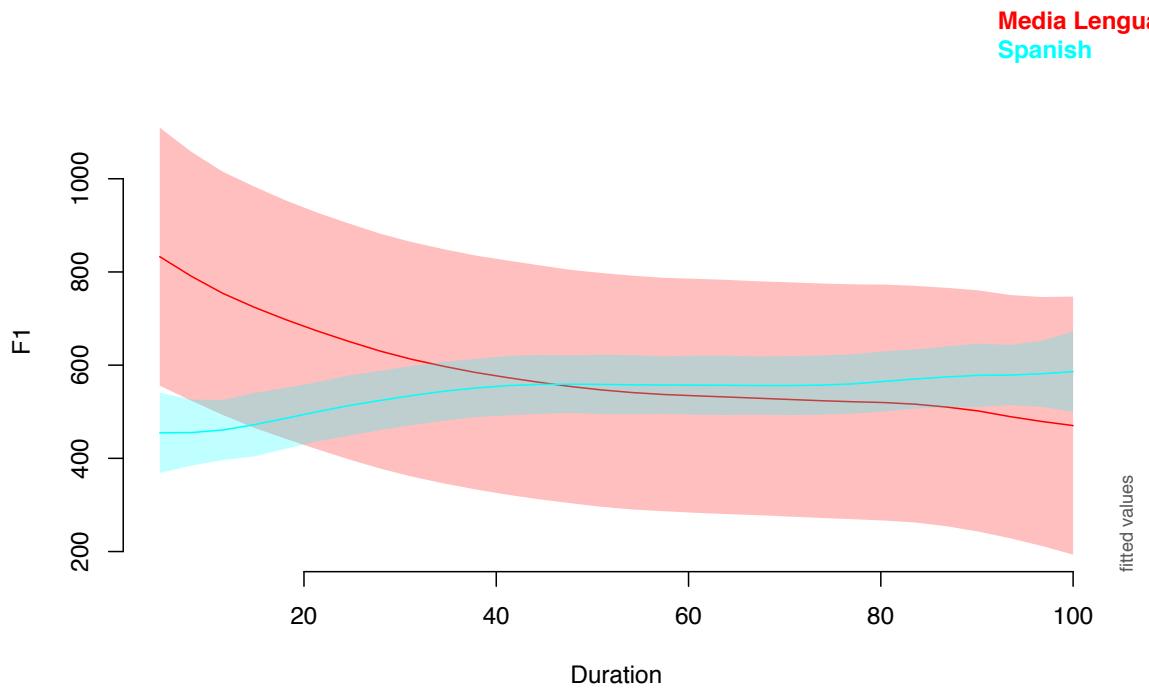


Spanish vowel space with /eu/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 1929

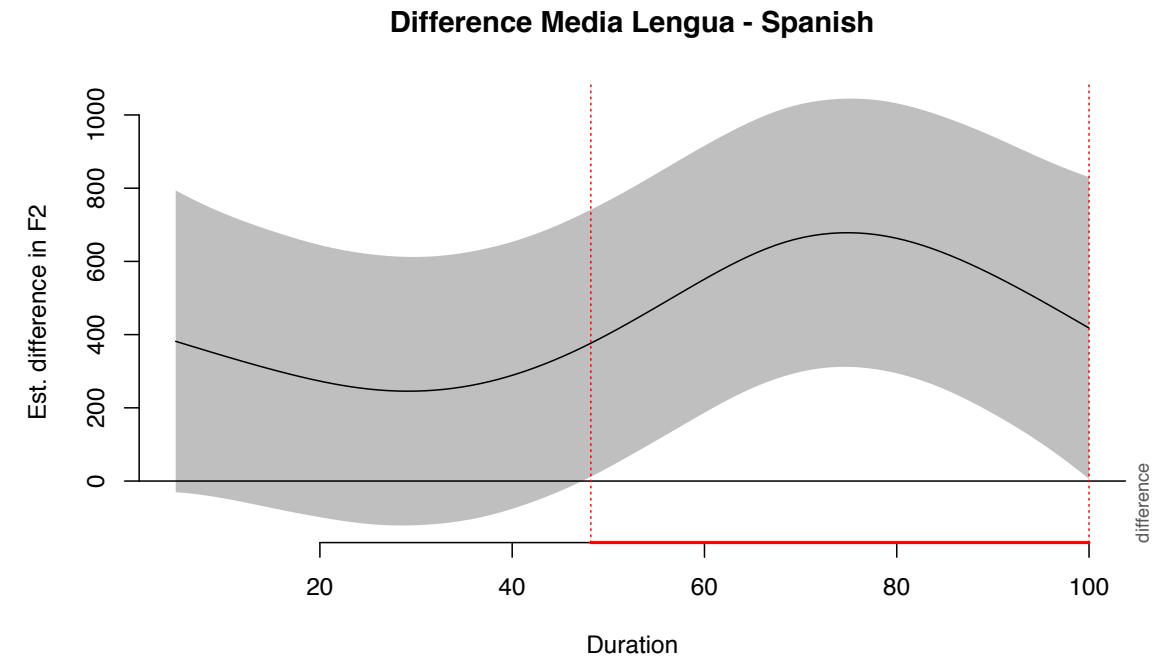
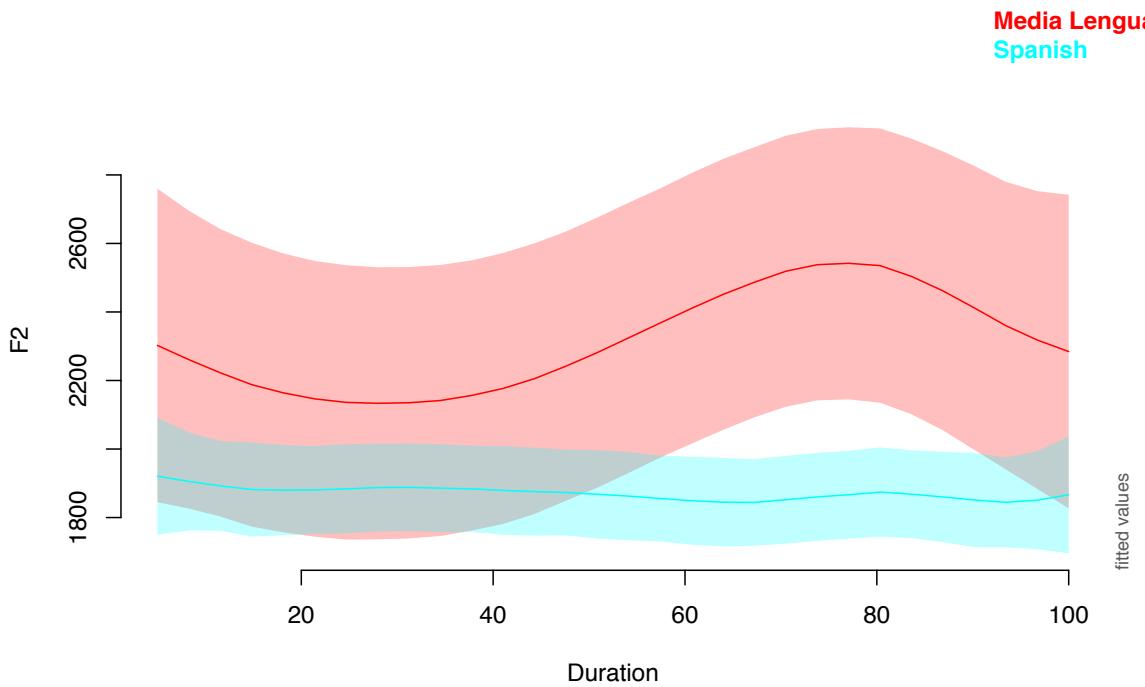


/eu/: F1 & F2



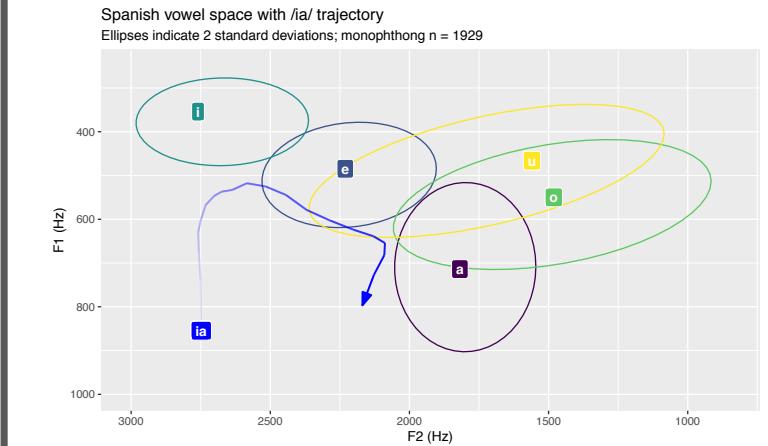
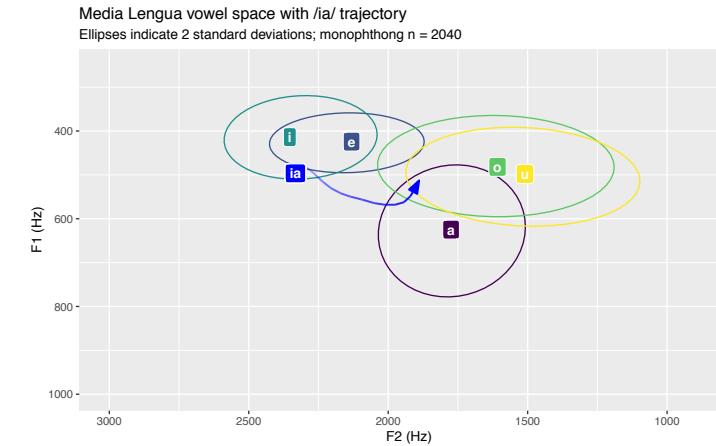
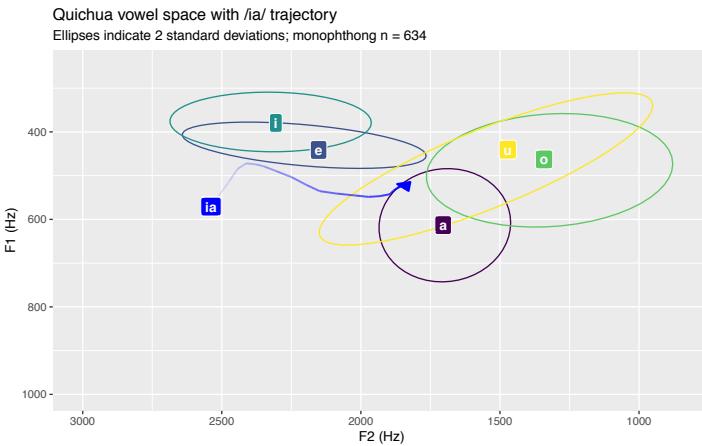
/eu/ F1

- Small, localized difference in onset
- Media Lengua: higher F1 = lower articulation

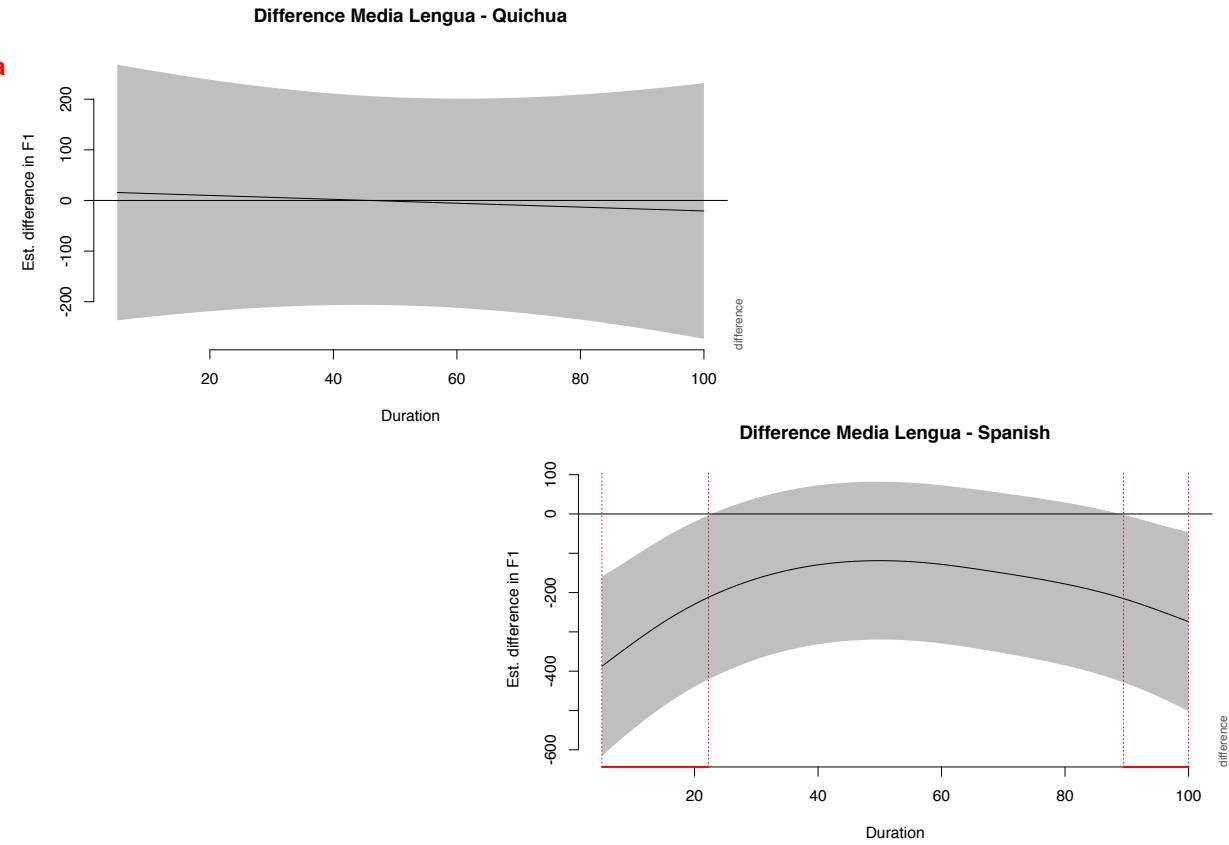
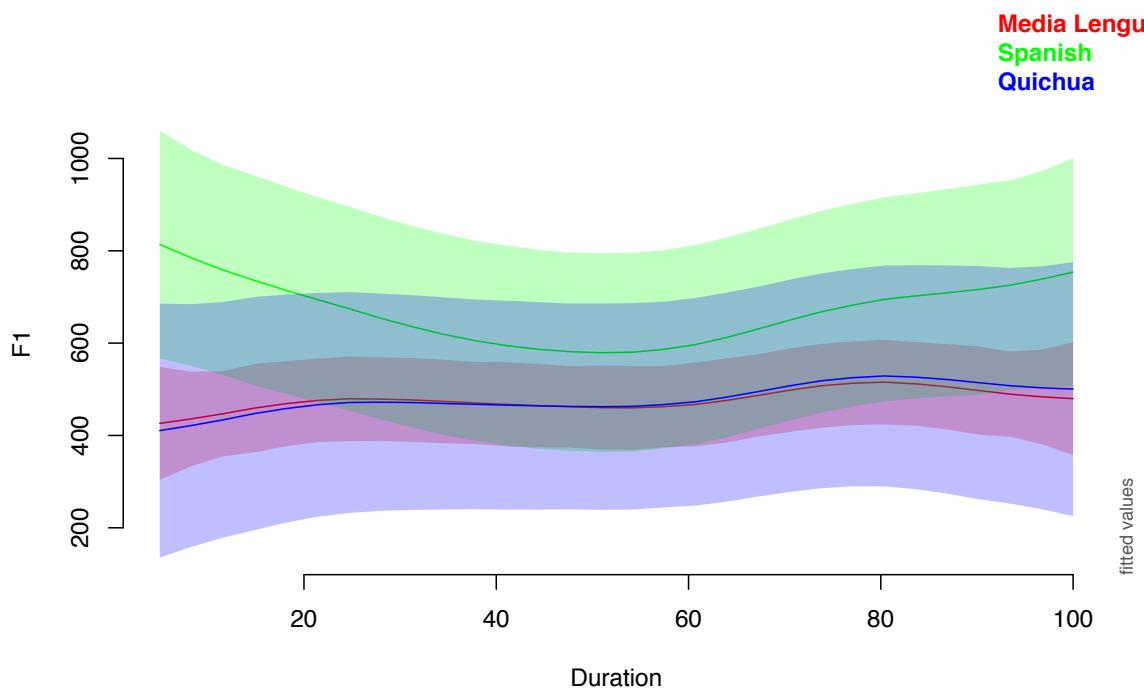


/eu/ F2

- Sig. F2 differences across >50% of trajectory
- Media Lengua: F2 higher (advanced position) and generally more dynamic
- Spanish: F2 very flat, little front-to-back movement

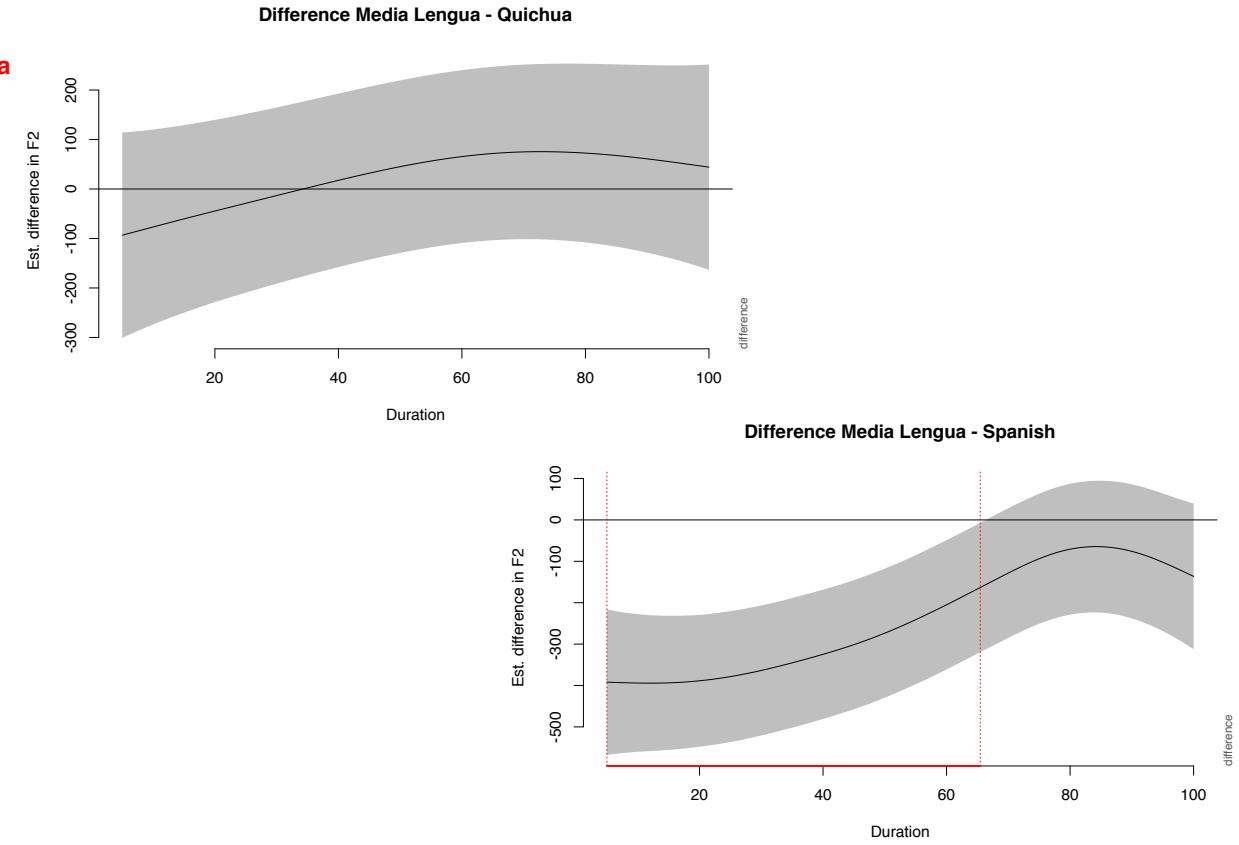
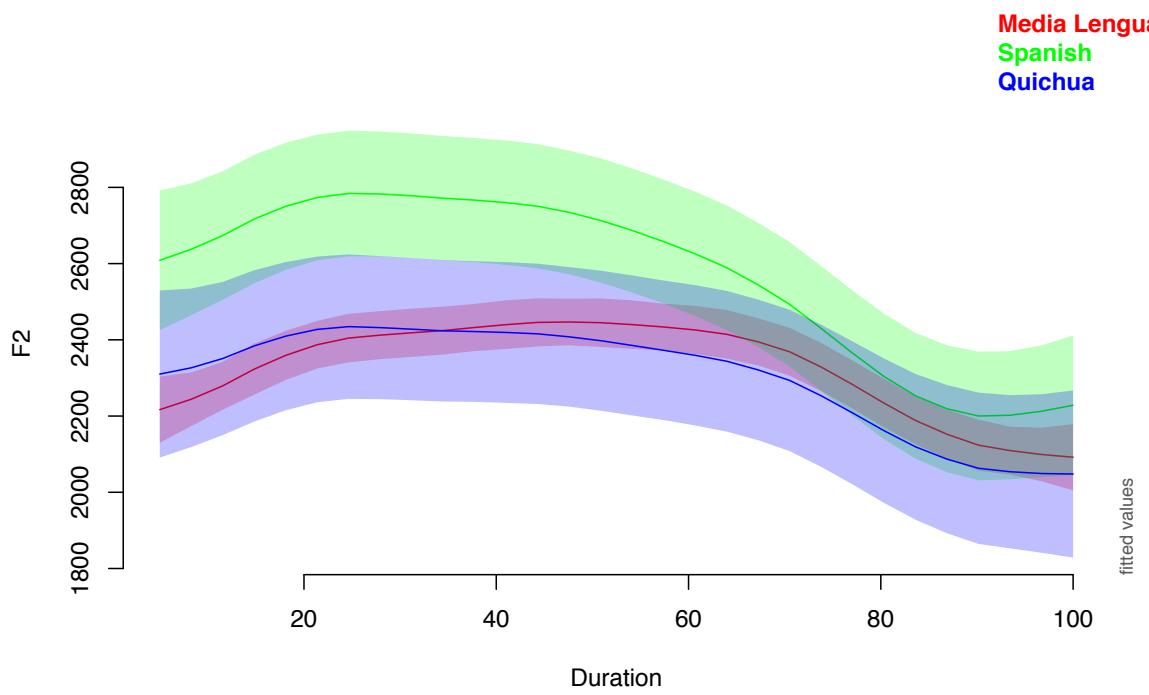


/ia/: F1 & F2



/ia/ F1

- Media Lengua vs. Quichua: no sig. difference
- Spanish: somewhat higher F1 = lower articulation, sig. difference at onset and offset

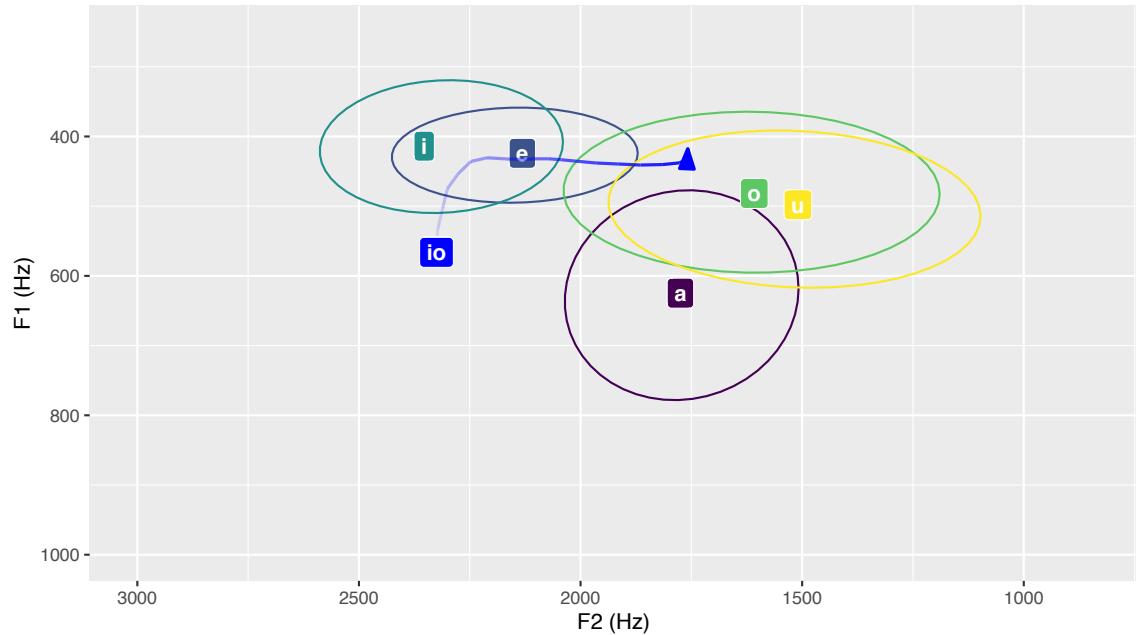


/ia/ F2

- Media Lengua vs. Quichua: no sig. difference
- Spanish: higher F2 = advanced articulation, over initial 2/3 of duration

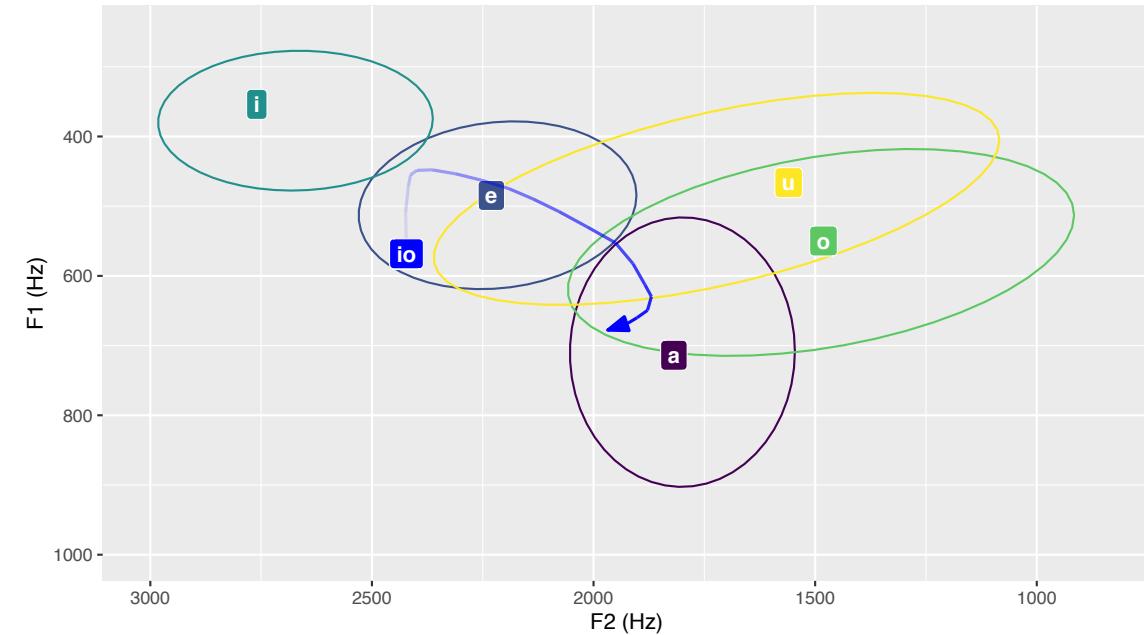
Media Lengua vowel space with /io/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 2040

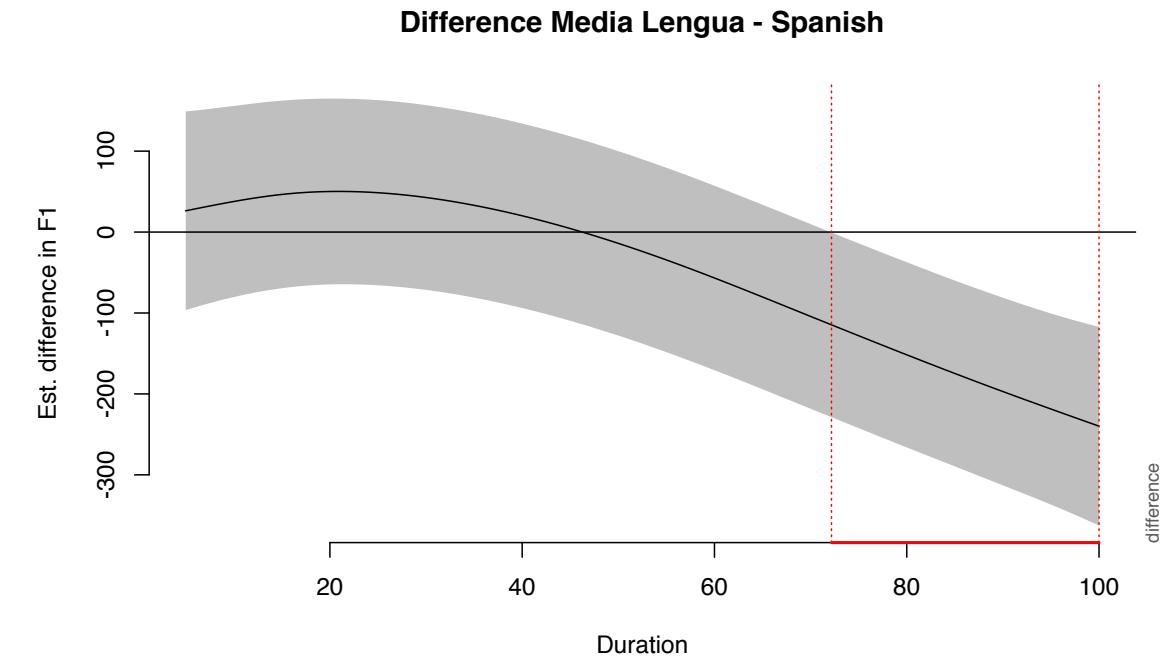
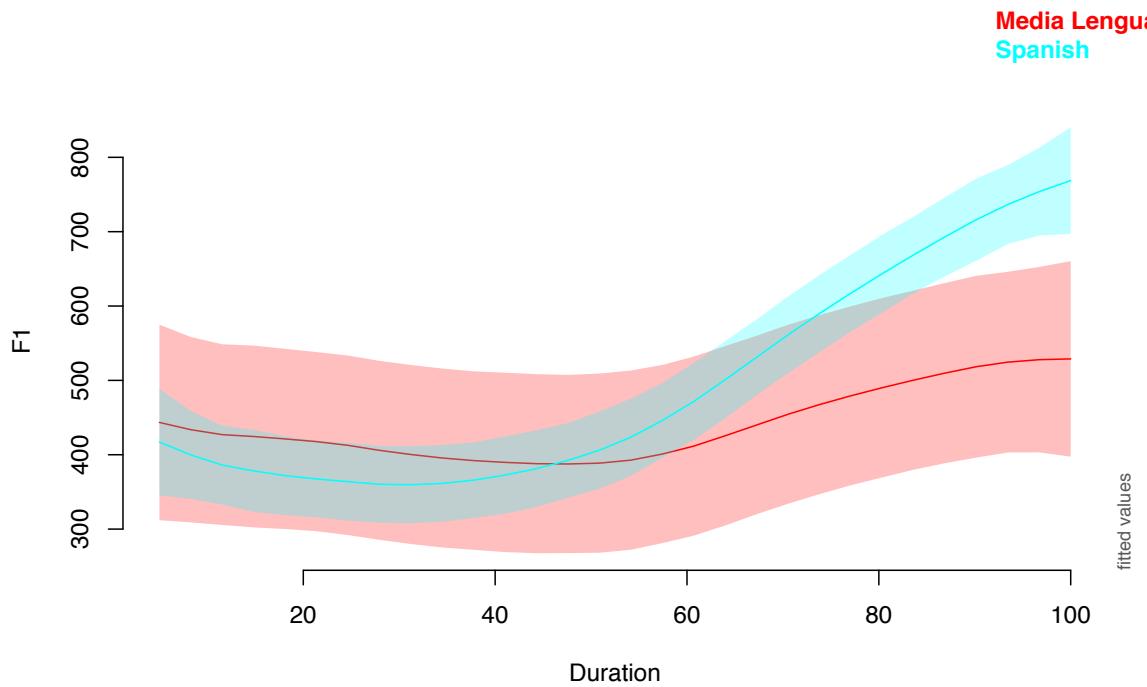


Spanish vowel space with /io/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 1929

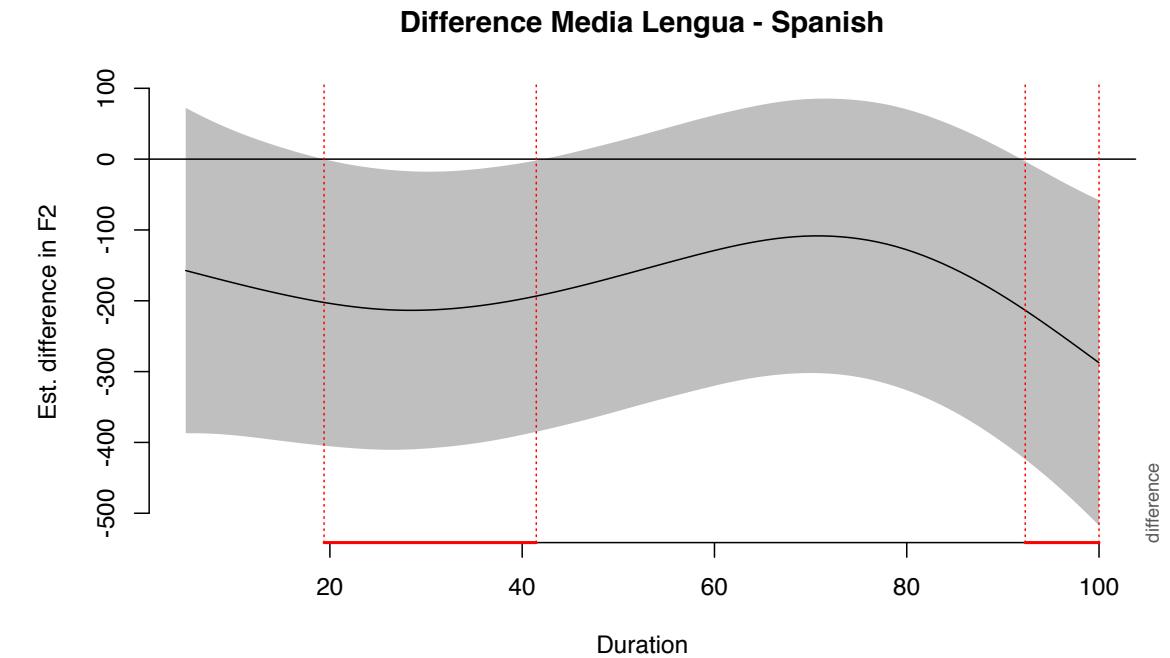
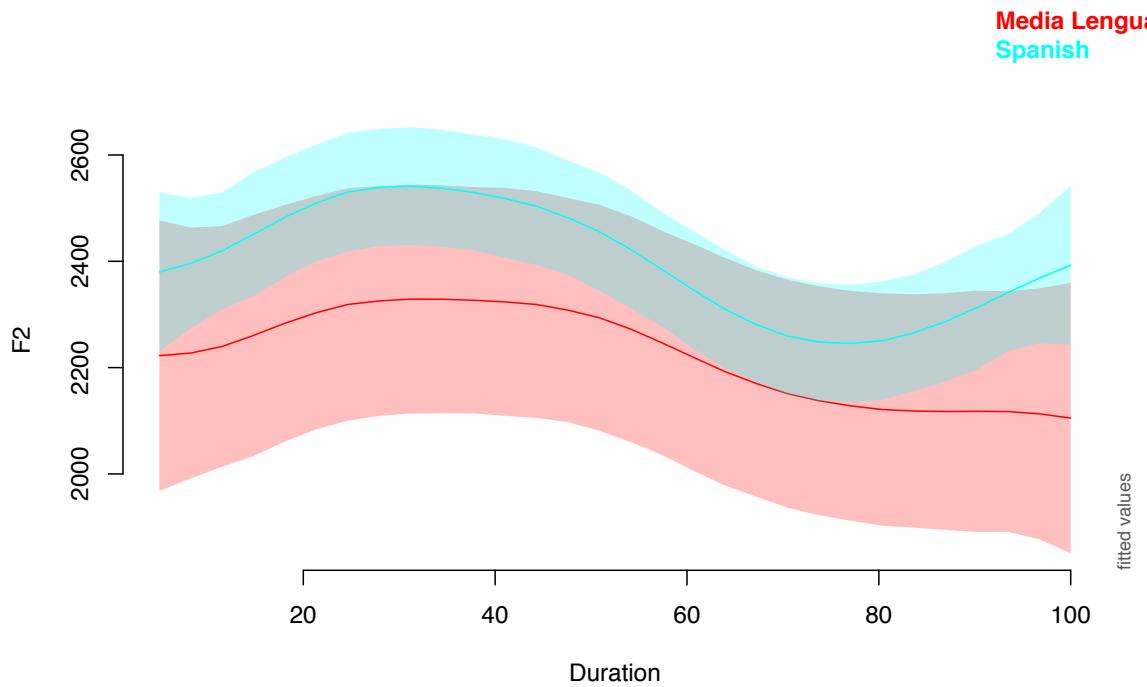


/io/: F₁ & F₂



/io/ F1

- Media Lengua: F1 lower (higher articulation) during final 25% of duration

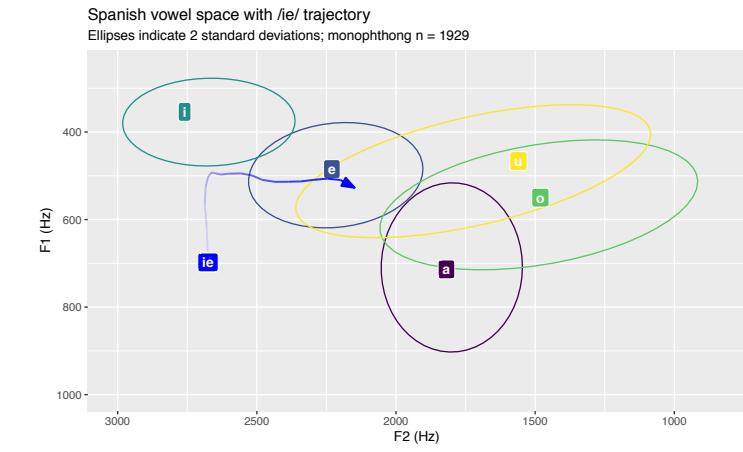
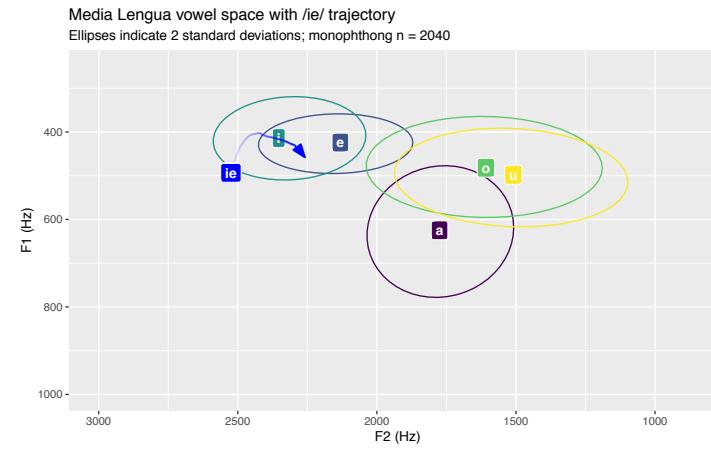
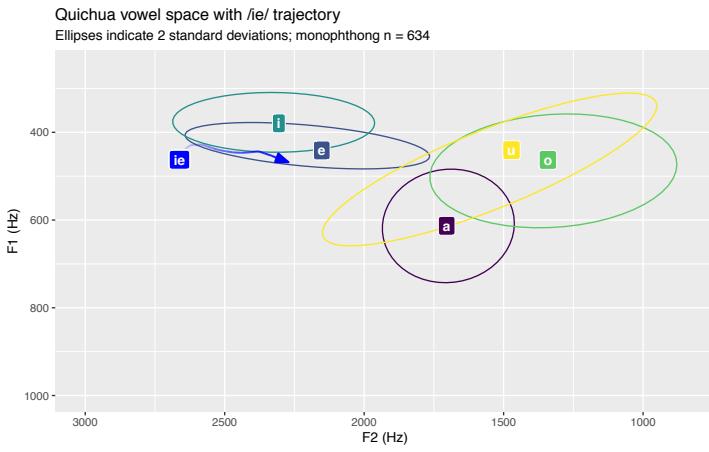


/io/ F2

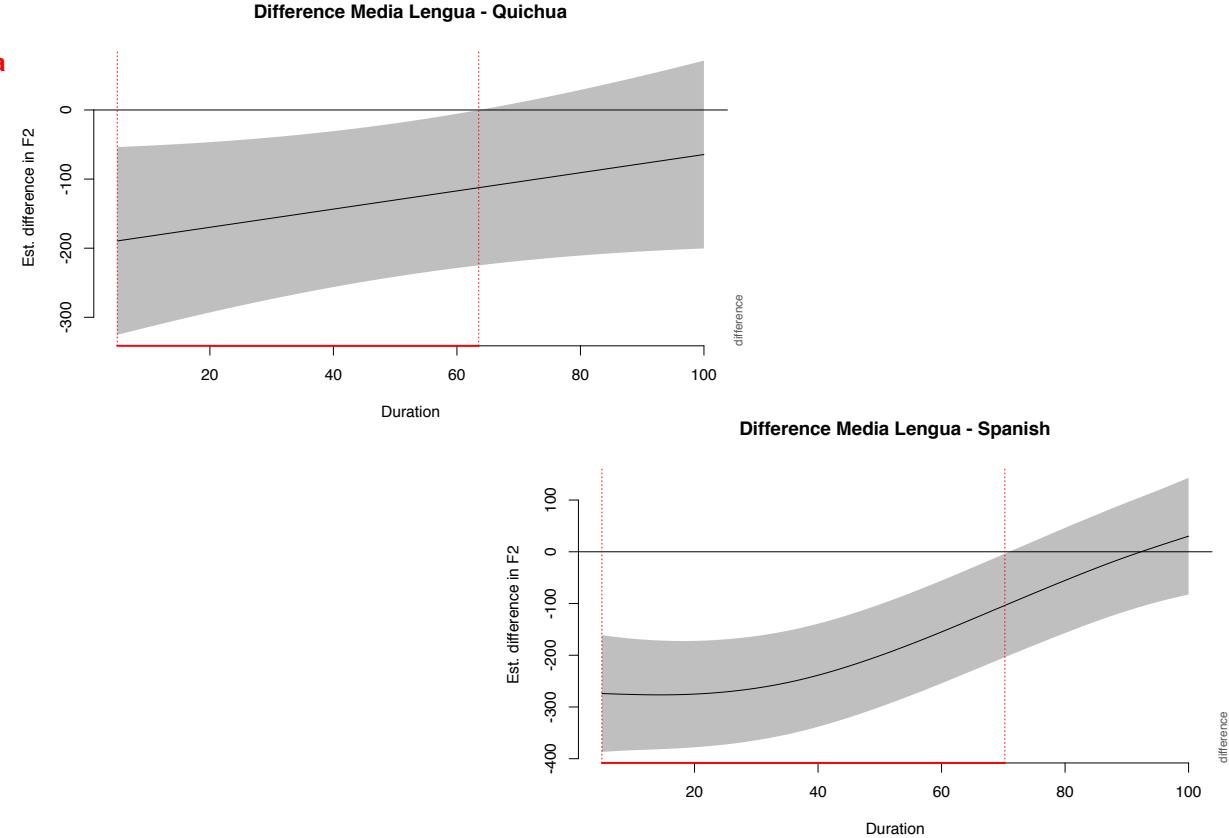
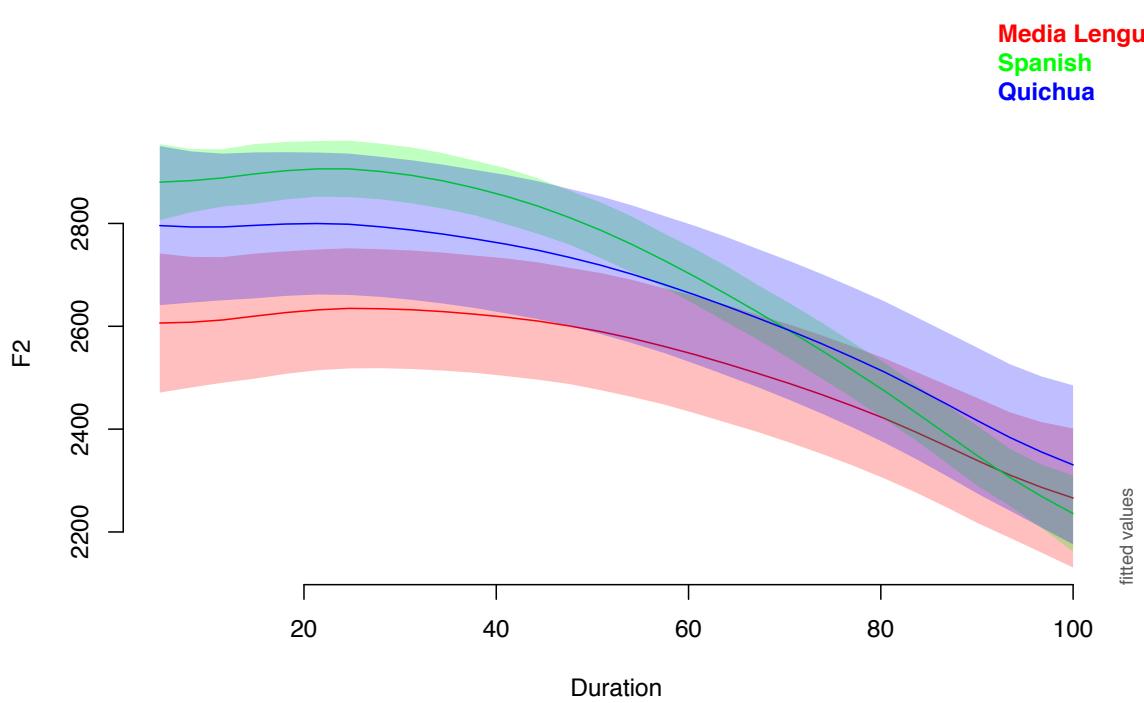
- Spanish: slightly higher F2 = advanced articulation, from 20–40% duration and at offset

Cross-Language Differences in only F1 or F2

- F1:
 - Media Lengua vs. Spanish: /uo/
 - Media Lengua vs. Quichua vs. Spanish: /au/
- F2:
 - Media Lengua vs. Quichua vs. Spanish: /ie, ue/

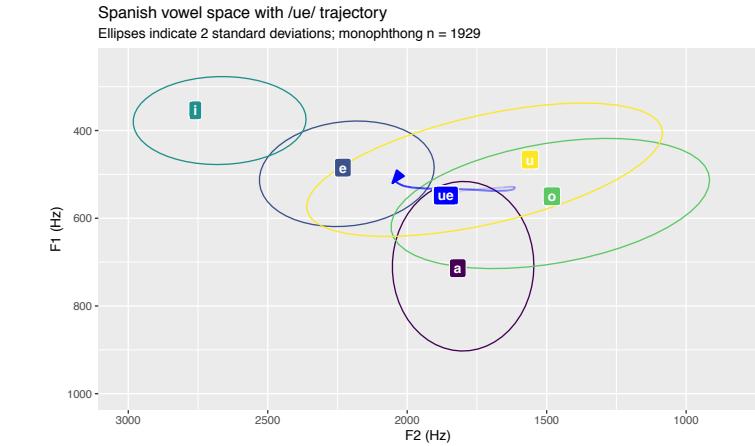
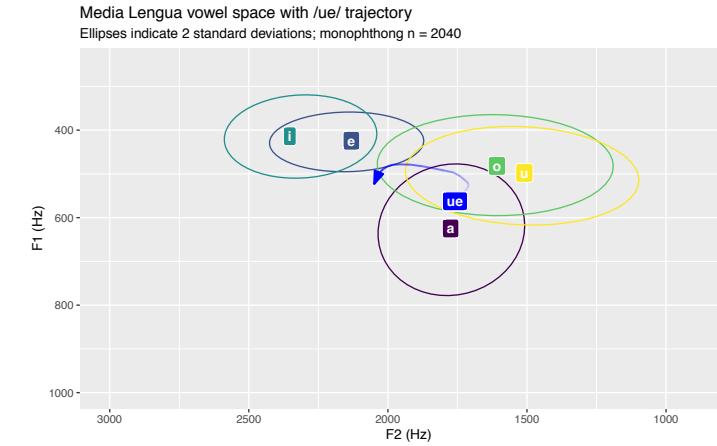
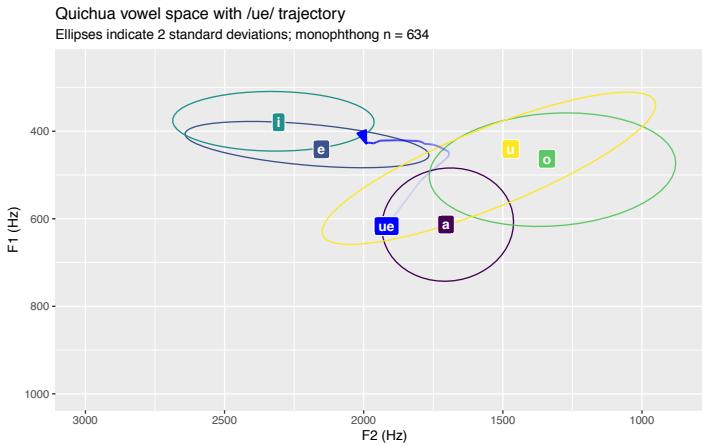


/ie/: F2

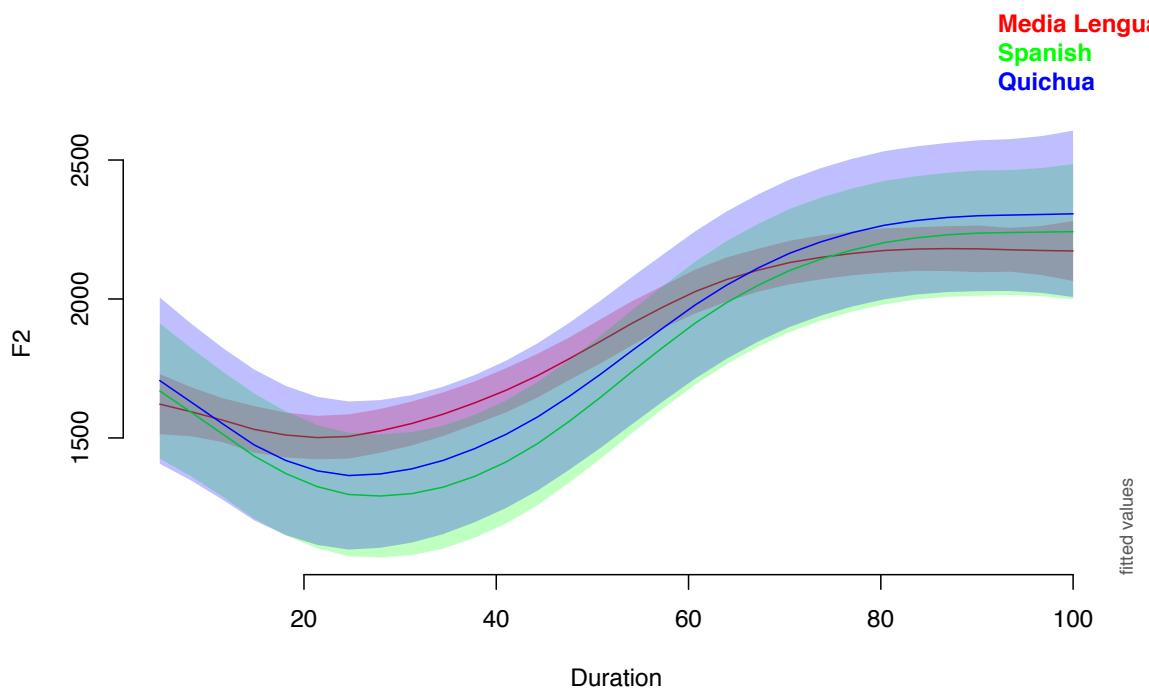


/ie/ F2

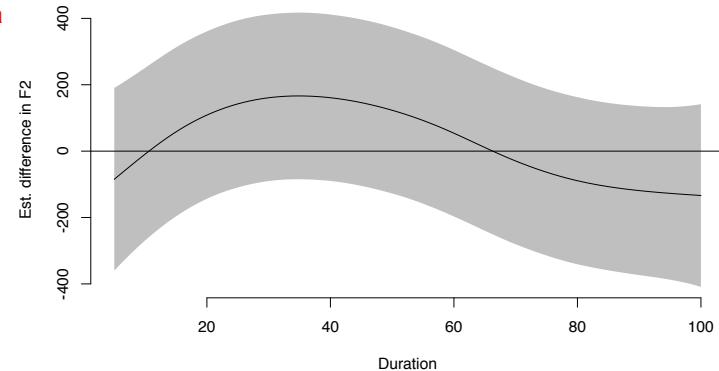
- Media Lengua distinct from *both* Quichua & Spanish; lower F2 (retracted) over initial 2/3 duration
- Quichua: F2 slightly higher = advanced position
- Spanish: F2 substantially higher with steeper trajectory



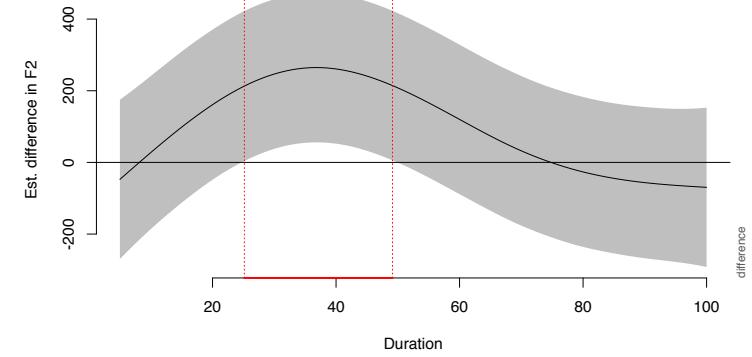
/ue/: F2



Difference Media Lengua - Quichua



Difference Media Lengua - Spanish



/ue/ F2

- Media Lengua vs. Quichua: no sig. diff.
- Spanish: lower F2 = retracted position, during approx. 30-50% of duration

Cross-Language Comparisons

- Spanish diphthongs generally show less internal variability:
 - Confidence intervals typically much narrower than other languages
 - Lower variation can't be attributed to either speaker n , which is notably higher than Quichua, nor token n which is the largest among all three languages
- Media Lengua vs. Quichua typically non-contrasting
 - Single identified contrast between ML~Q is F2 of /ie/; ML~Sp /ie/ F2 difference is even greater
 - *In general, Media Lengua production matches Quichua production*

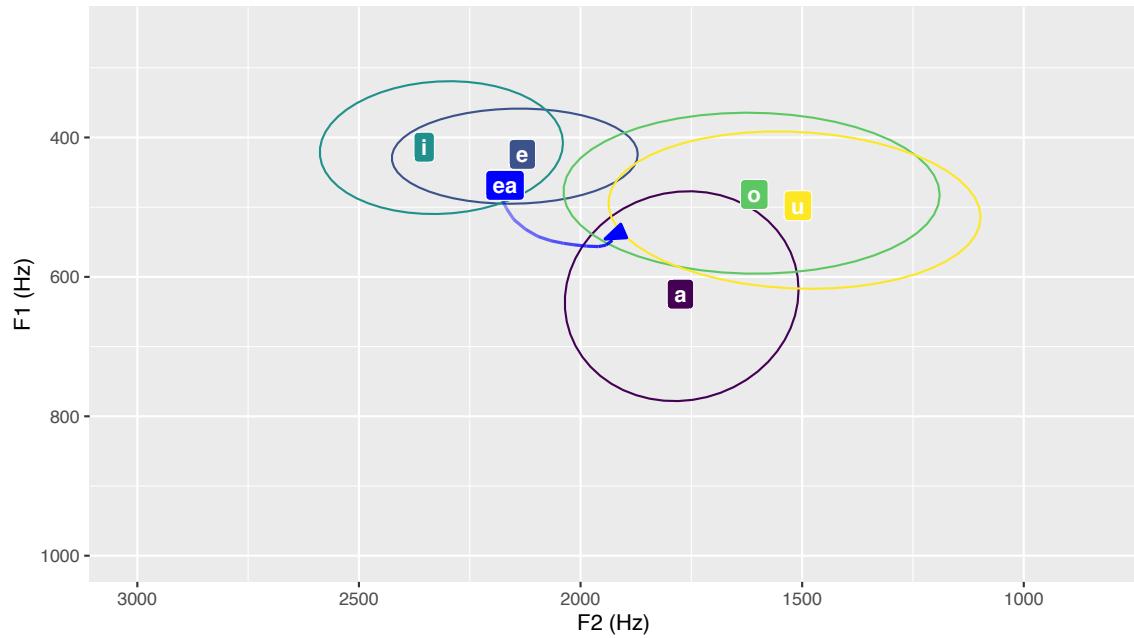
Media Lengua-Internal Diphthong Comparisons

- Pairs of Media Lengua diphthongs selected for cross-comparison
 - /ai ~ ei/ /ea ~ ia/ /eo ~ eu/ /ue ~ ui/
- GAMMs model uses main fixed effect of Vowel instead of Language
- ANOVA comparison of GAMM *null* vs. *non-null* models identifies where formant trajectories differ significantly between diphthongs

	ai vs. ei	ea vs. ia	eo vs. eu	ue vs. ui
F1	$p \approx 0$	n.s.	$p \approx 0$	$p = 0.008$
F2	$p \approx 0$	$p \approx 0$	$p \approx 0$	$p = 0.002$

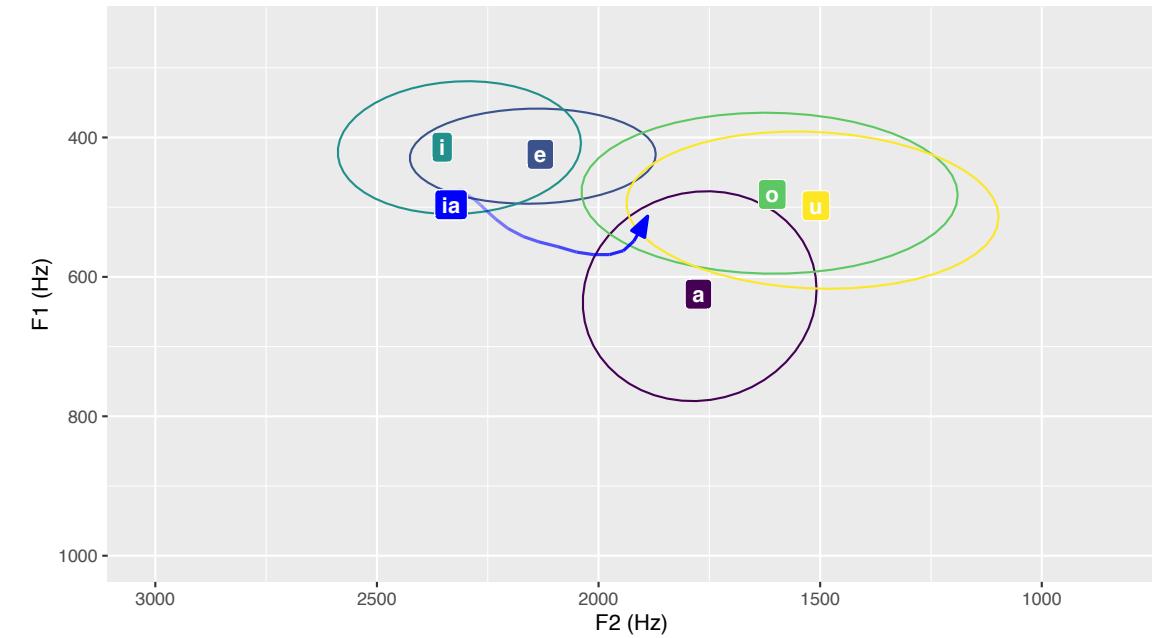
Media Lengua vowel space with /ea/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 2040

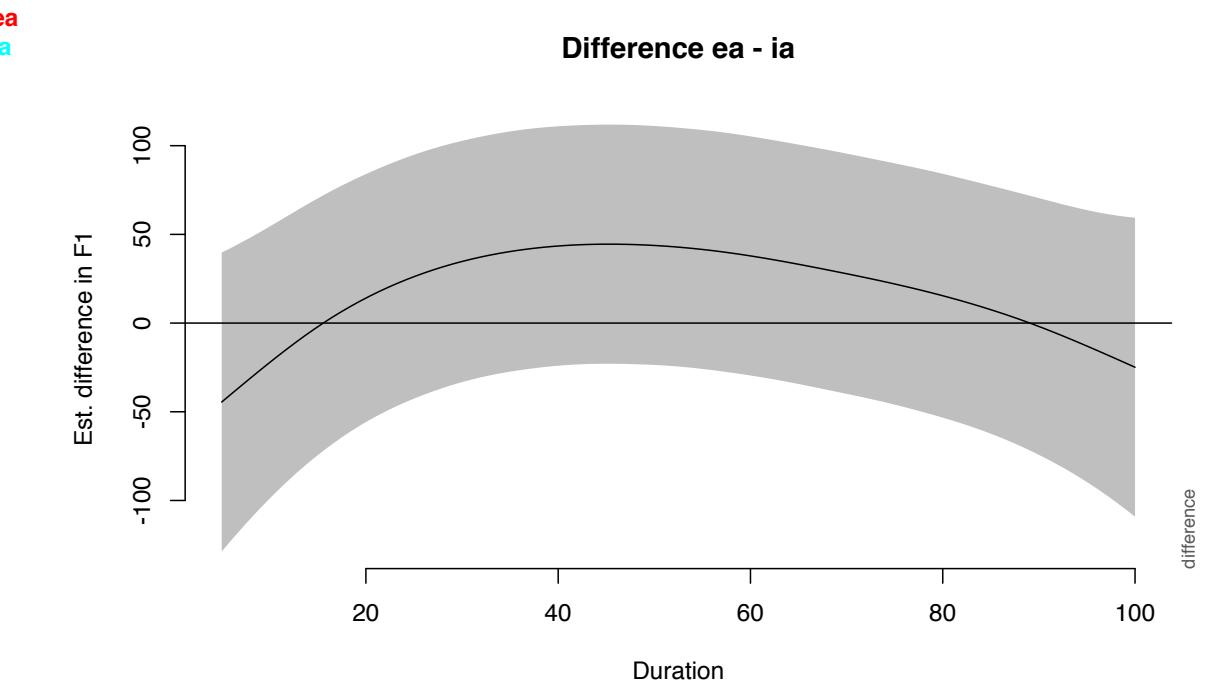
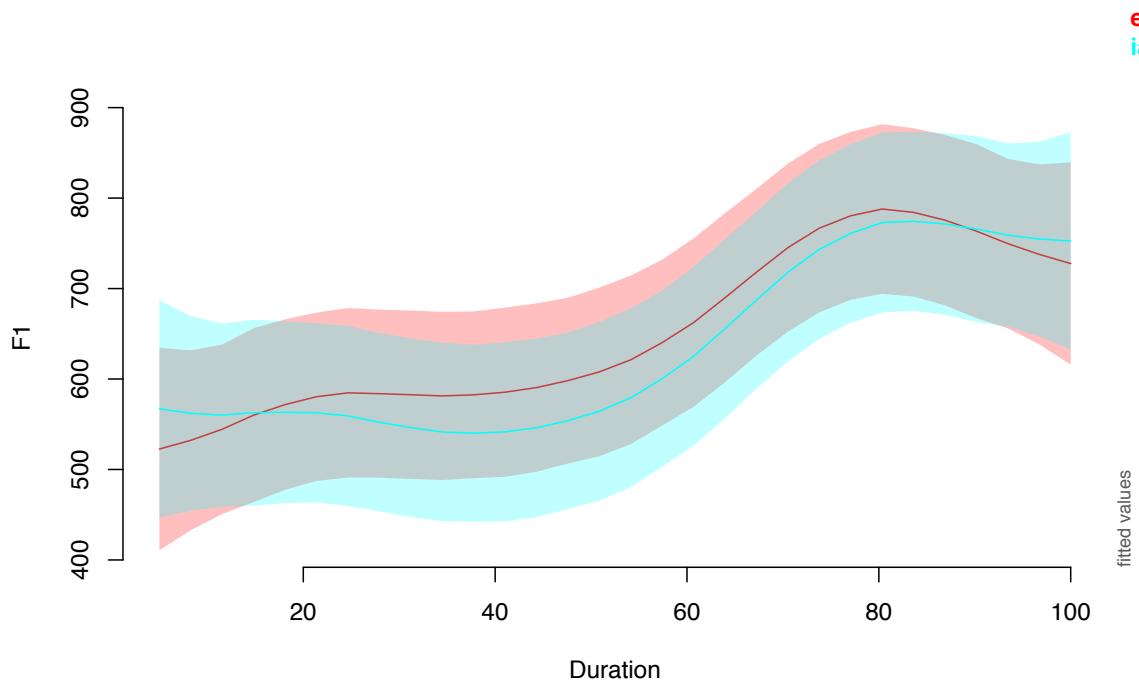


Media Lengua vowel space with /ia/ trajectory

Ellipses indicate 2 standard deviations; monophthong n = 2040

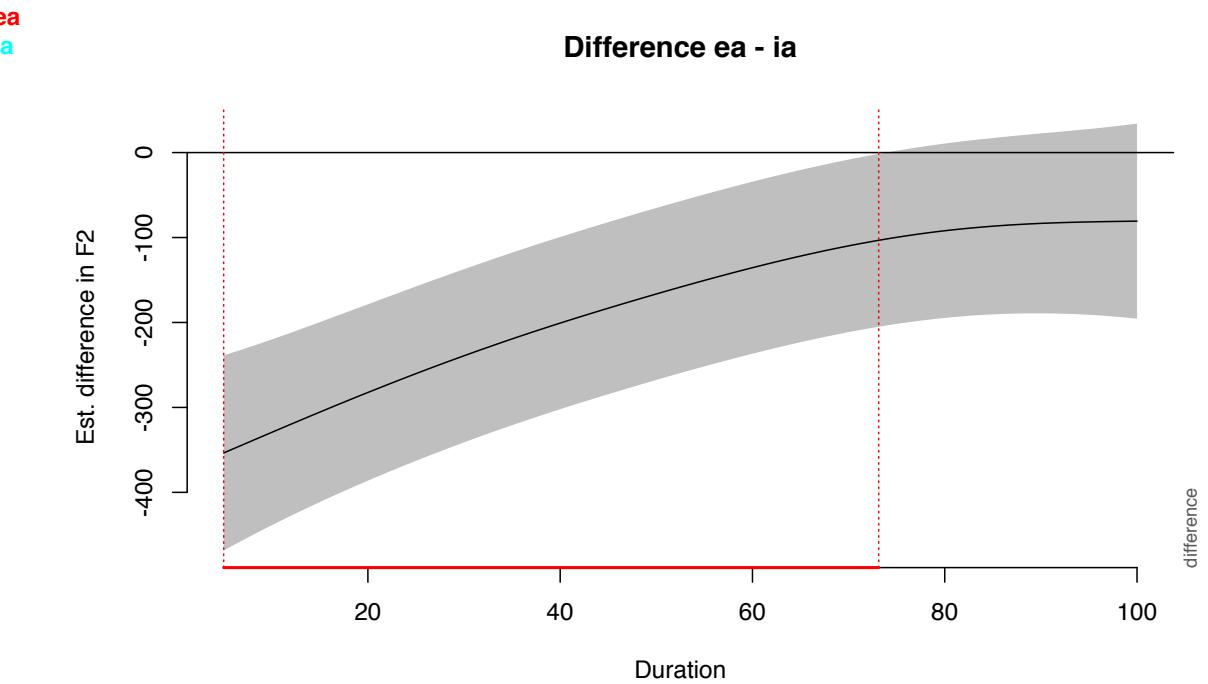
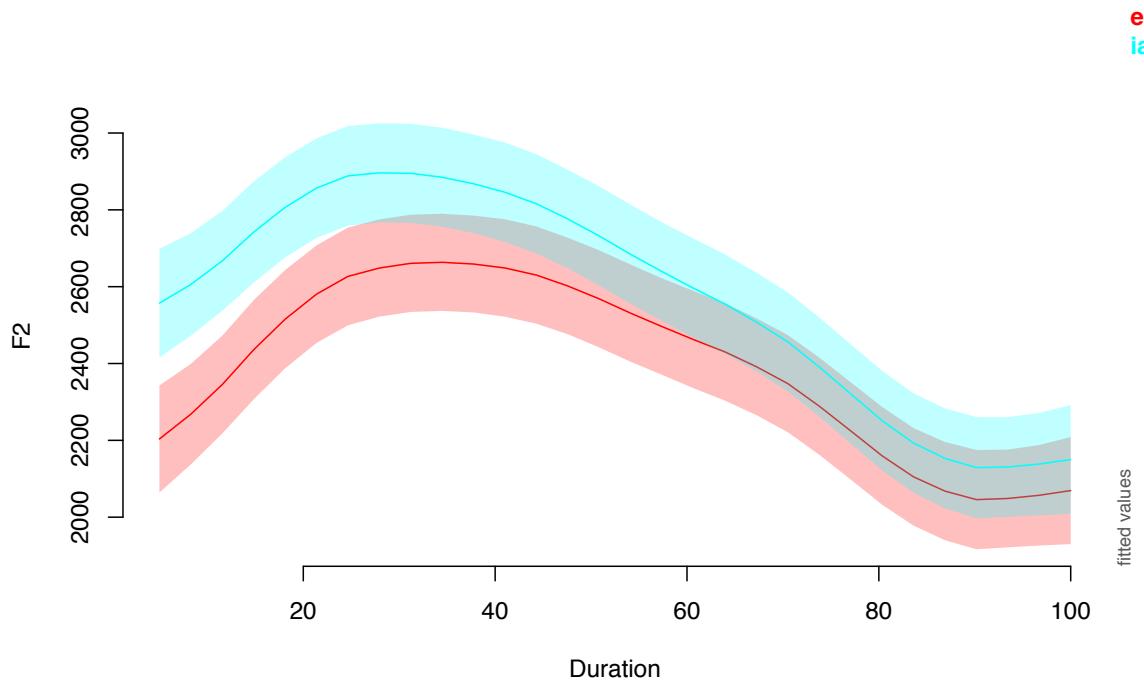


Media Lengua /ea/ vs. /ia/



Media Lengua
/ea, ia/ F1

- Substantial overlap in F1 confidence intervals = no significant difference in vowel height across entire trajectory



Media Lengua
/ea, ia/ F2

- /ia/ F2 higher (advanced) until ~70% duration

Media Lengua-Internal Diphthong Comparisons

- Most diphthong pairs differ significantly across both F1 & F2
 - /ea, ia/ do *not* differ in F1, leaving F2 (i.e. front-back position) as the sole differentiating factor for this pair
 - Some pairs (e.g. /eo, eu/ and /ue, ui/) exhibit only subtle differences, and not always restricted to the expected portion of the trajectory

Media Lengua Comparisons by Source Language

- Three diphthongs are represented by Media Lengua lexical items of both Quichua and Spanish origin:
 - /ai, au, ui/
- GAMMs comparison conducted for each diphthong using Media Lengua data with a fixed effect of Source Language
- *None* turned out to exhibit significant differences in formant trajectories
 - In other words, different-source-language lexical items are incorporated into a single phonological vowel system (with regards to these particular diphthongs)
 - This aligns with cross-linguistic comparison across diphthong inventory, where vast majority of ML~Q comparisons were non-distinctive