# Revealing covert articulation in s-retraction

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# Introduction



- We investigate the realisation of the sibilant in the word-initial clusters **/stɹ/** and **/stj/**, which is often more **[ʃ]**-like, using both acoustic and articulatory data
- We address the following questions:
  - Categoricity v. gradience in *s*-retraction, i.e. is the surface realisation of **/s/** in **/stɹ/** and **/stj/** identical to an underlying **/ʃ/**?
    - not just with respect to acoustics but also articulation
  - What degree of inter-speaker variation do we find? To what extent do we find different "systems" of *s*-retraction?
  - What happens in **/stj/** (e.g. *stupid*) and how comparable is it to **/stɹ/** (e.g. *street*)?
  - What does this suggest about the mechanisms that trigger this process?

# BACKGROUND

- Attested in various varieties of English (see e.g. Shapiro 1995, Lawrence 2000, Durian 2007, Bass 2009, Sollgan 2013, Phillips 2016, Wilbanks 2016, 2017, Wilson 2018)
- Focus has often been sociolinguistic rather than phonetic aspect
    - But see Stevens & Harrington (2016) for work on the phonetic origins
- Well-studied with **/stɹ/** in AmE but relatively under-studied in BrE
- BrE also has **/stj/**, which is absent in AmE (at least in these contexts)
- Has been characterised as **retraction**, based primarily on acoustic data
    - Notable exceptions being ultrasound studies by Mielke et al. (2010) and Baker et al. (2011)
- However, acoustics doesn't necessarily have a one-to-one mapping with articulation
    - See e.g. Mielke et al. (2016) on covert articulation of **/ɹ/**

# Phonetic motivations

- The rôle of **/ɹ/** has been foregrounded in many studies:
  - Shapiro (1995) claims *s*-retraction is triggered non-locally by **/ɹ/**
  - Baker et al. (2011) find that even “non-retractors” show coarticulatory bias towards retraction in clusters containing **/ɹ/**, e.g. **/spɹ/**
- However, some have argued that **/ɹ/**’s influence may be more indirect:
  - Lawrence (2000) claims that this is local assimilation with **/ɹ/** causing affrication of **/t/** to **/tʃ/** leading to the retraction of **/s/**
  - This could be particularly appropriate for BrE where **/t/** undergoes a similar process before **/j/** for most speakers
    - e.g. *tune* /tjʉːn/ > [tʃʉːn]    *stupid* /stjʉːpɪd/ > [ʃtʃʉːpɪd]?
  - But Magloughlin & Wilbanks (2016) suggest otherwise for Raleigh English

# METHODOLOGY

# DESIGN OF STIMULI

- 9 word-initial contexts embedded in the carrier sentence **'I know [...] is a word'**

Baselines for comparison:
underlying /s, ʃ/

/s/
e.g. *seep*

/ʃ/
e.g. *sheep*

Retracting environments:

/stɹ/
e.g. *street*

/stj/
e.g. *stupid*

\+ /st/
e.g. *steep*
?

Pseudo distractors:

/tʃ/
e.g. *cheap*

/ɹ/
e.g. *read*

/tɹ/
e.g. *treat*

/tj/
e.g. *tune*

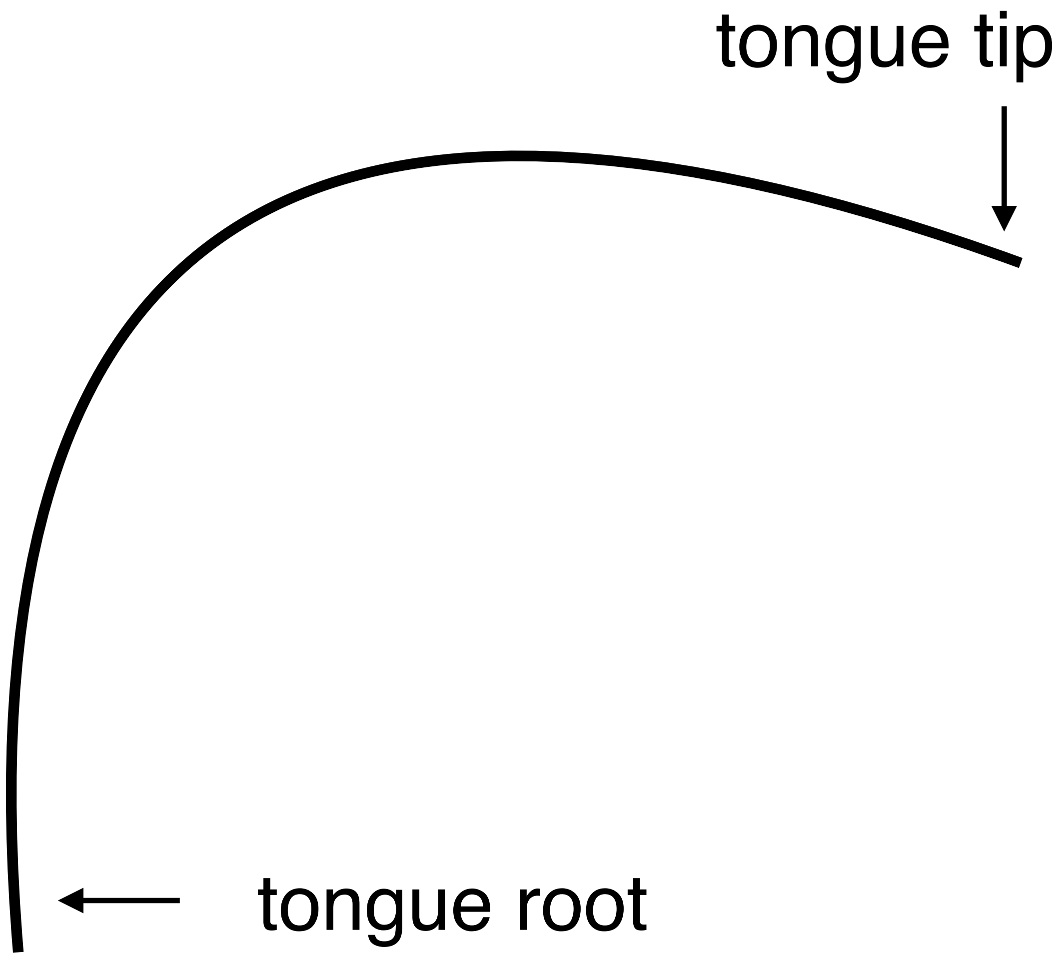
Useful for independent evidence of what happens to /tɹ/ and /tj/ outside of post-/s/ environments

- All contexts precede **[iː]**, **[ʉː]** and **[ɒ]** (except **/stj/**, which only occurs before **[ʉː]**)
- 5 repetitions per token giving a total of 130 sentences per speaker

# DATA COLLECTION

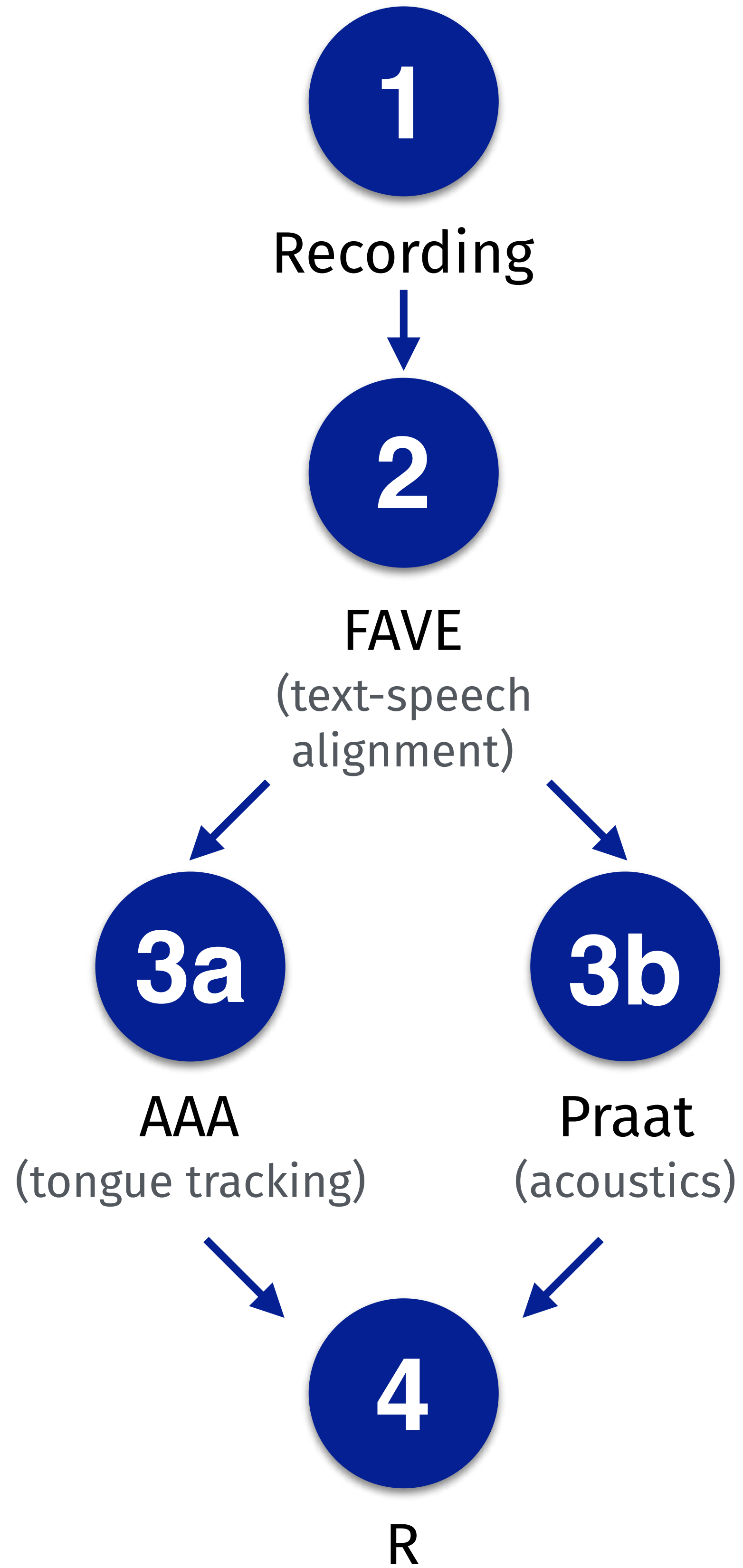


- Synchronised UTI (60fps) and audio recording (lavalier mic)
- Mid-sagittal view
- Stabilised with headcage
- Currently 8 speakers (3M; 5F) aged 18-26
  - All born (or at least raised from age 4) in Greater Manchester, but in some cases parents aren't from Manchester (or even England)



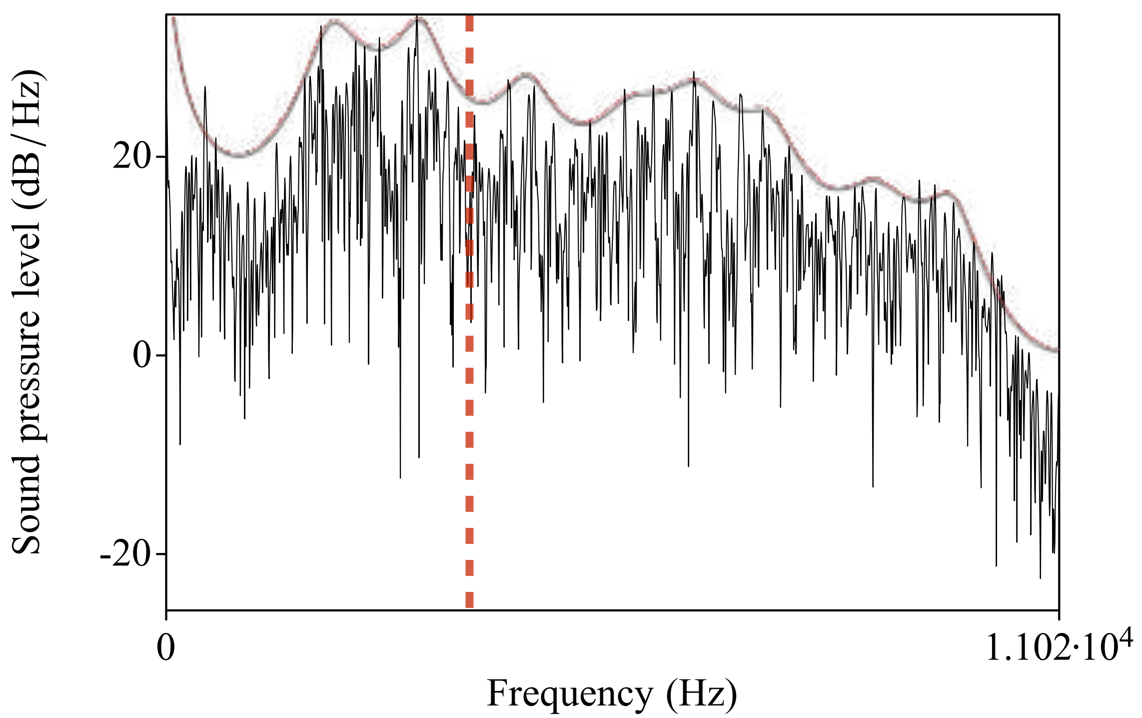
# DATA ANALYSIS

- Forced-alignment using FAVE (Rosenfelder et al. 2011)
  - Manually-corrected, with further sub-segmentation
    - e.g. *tree* T R IY1 > T CH R IY1
- Tongue splines tracked and exported using AAA (Articulate Instruments Ltd. 2011)
  - 3 keyframes per segment - analysis conducted on keyframe 2 (segment mid-point)
  - Data read into R with `rticulate` (Coretta 2017) package

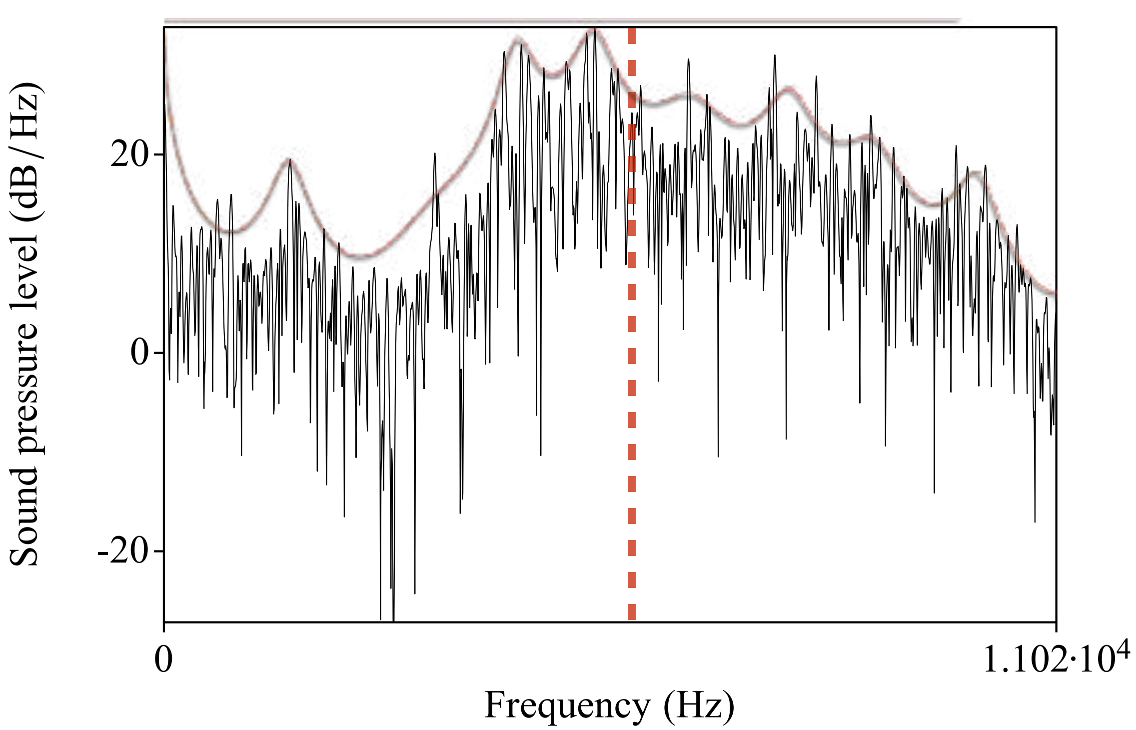


# DATA ANALYSIS

- To complement ultrasound data, acoustic analysis was performed in Praat using two scripts adapted from DiCanio (2017)
- For each fricative (and affricate), we extract:
  - **Centre of gravity (CoG)**
    - lower value = more /ʃ/-like; higher value = more /s/-like (Jongman et al. 2000, Baker et al. 2011)
  - **LPC-smoothed spectral slice**
    - 10 peaks




/ʃ/ CoG: 3749 Hz




/s/ CoG: 5743 Hz

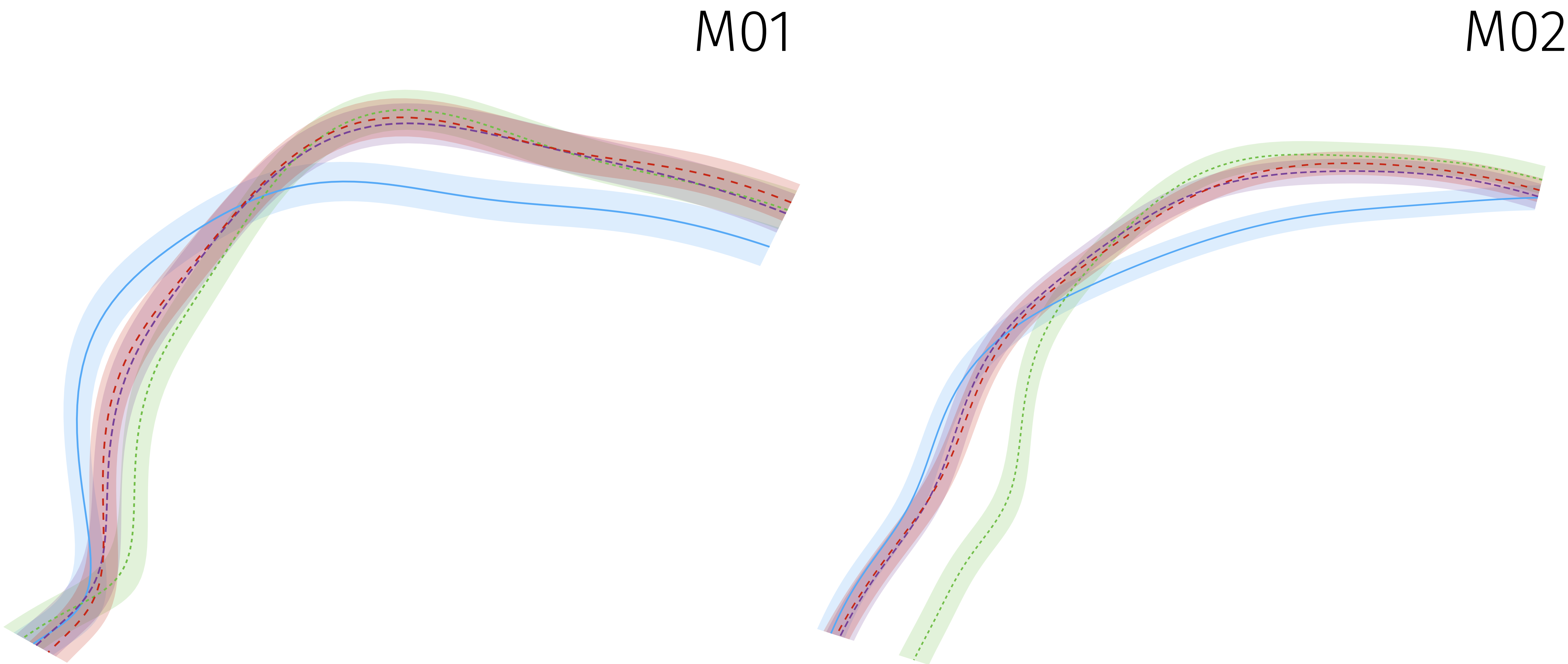
# Statistical methods

- **Ultrasound**
  - Modelled with *GAMMs* (*generalised additive mixed models*) using `tidymv` and `rticulate` packages (Coretta 2017, 2018)
  - Ideal for modelling non-linear effects in dynamic (time/space) data (see Sóskuthy 2017 and references therein)
- **Acoustics**
  - *Mixed-effects linear regression* for CoG measures with `lme4` package (Bates et al. 2015)
  - Supplemented with *functional principle components analysis* for LPC-smoothed spectral slices using `fda` package (Ramsay et al. 2013)
    - see Appendix

# RESULTS

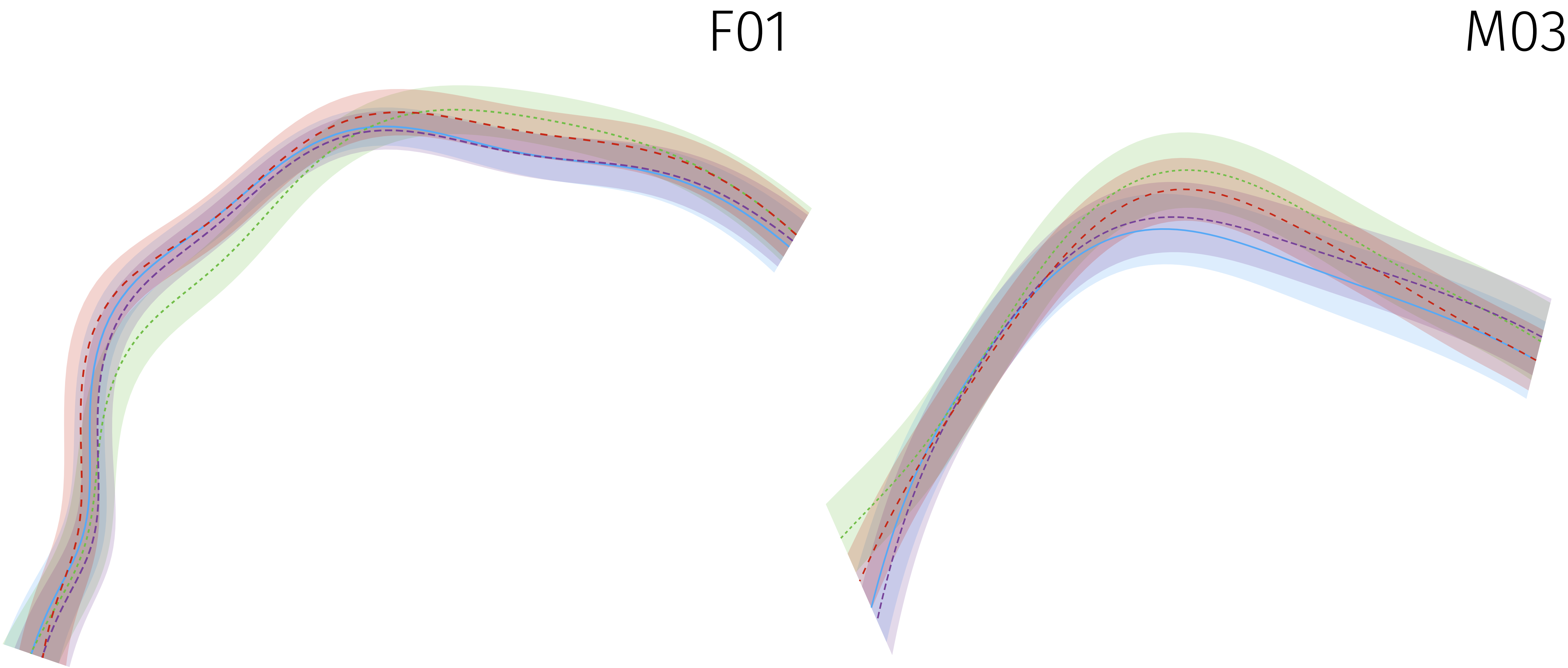
## ARTICULATION

# Articulation




- Clear bimodality for tongue body: **/ʃ/**-**/stɹ/**-**/stj/** v. **/s/**

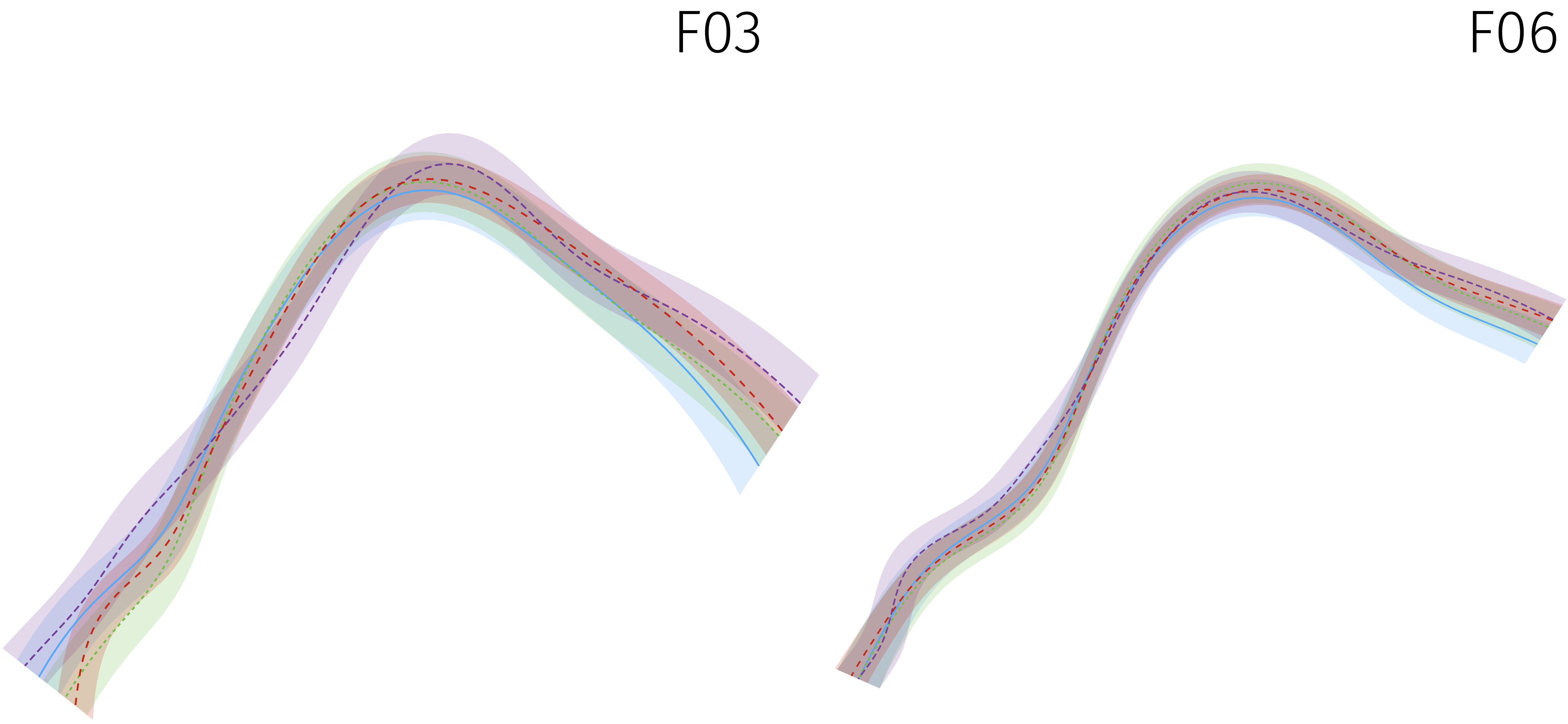
# Articulation




- Tongue body for **/stj/** largely overlapping with **/ʃ/**
- But **/stɹ/** much more similar to **/s/** than **/ʃ/**

# Articulation

(also F07 and F08)



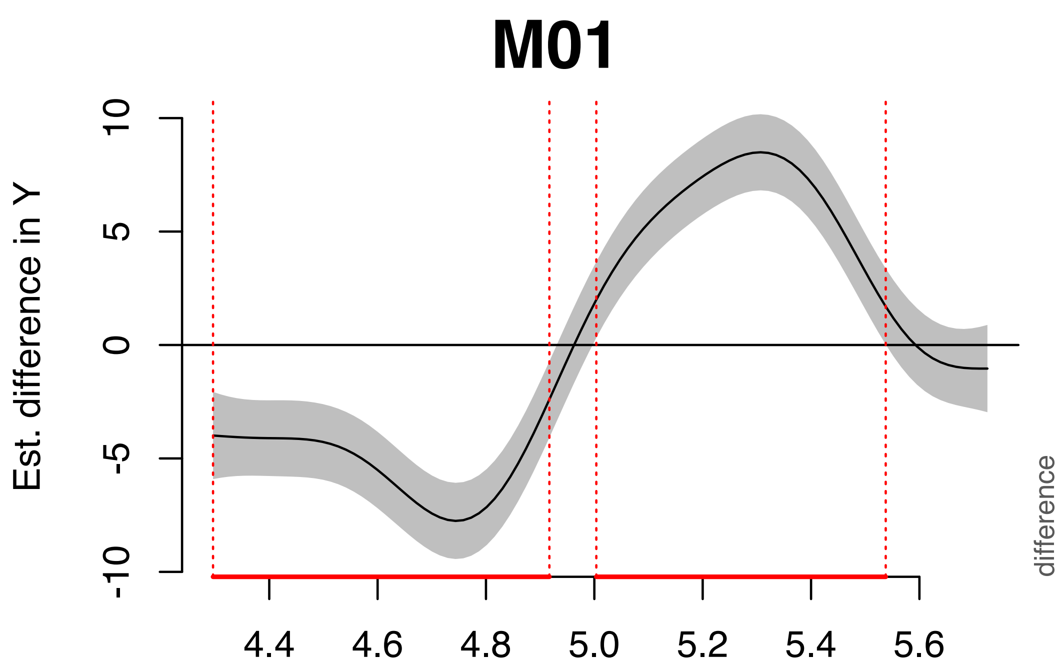

- Almost complete overlap between all four contexts, even **/s/** and **/ʃ/**
- More differentiation at tongue tip (but confidence intervals also wider)

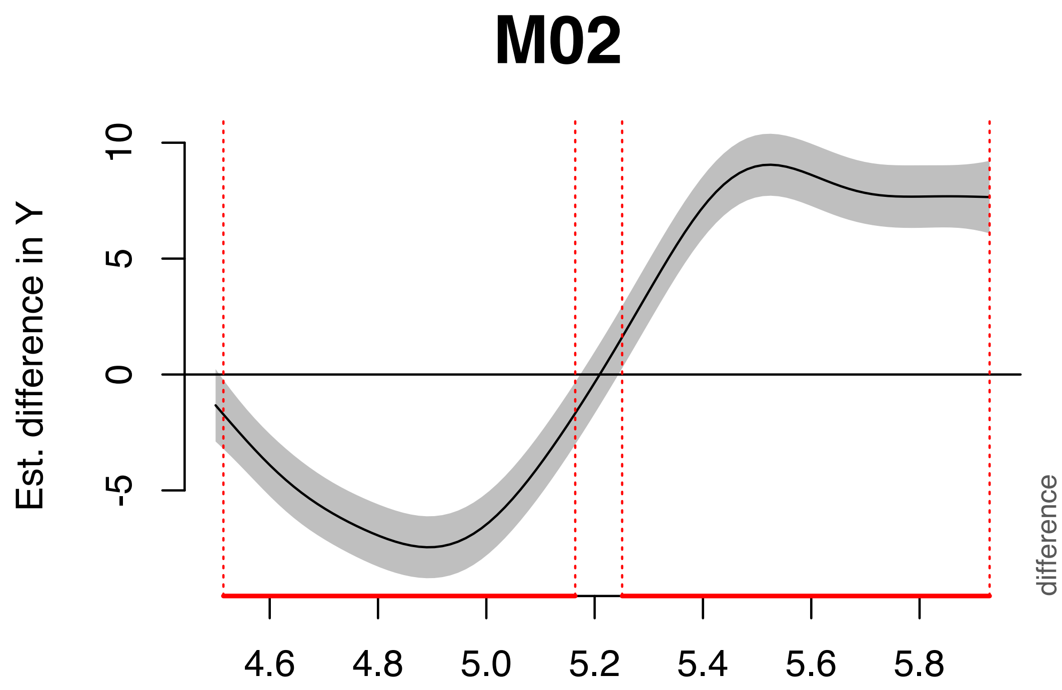
# INTERIM SUMMARY: ARTICULATION

- Some speakers exhibit clear tongue body retraction, such that there are two groups:
  - /s/ v. /ʃ/-/stɹ/-/stj/
- Others show a more intermediate pattern where /stj/ is closer to /ʃ/ but /stɹ/ is more similar to /s/
- Finally, other speakers have no apparent lingual difference, even between /s/ and /ʃ/

# Difference smooths

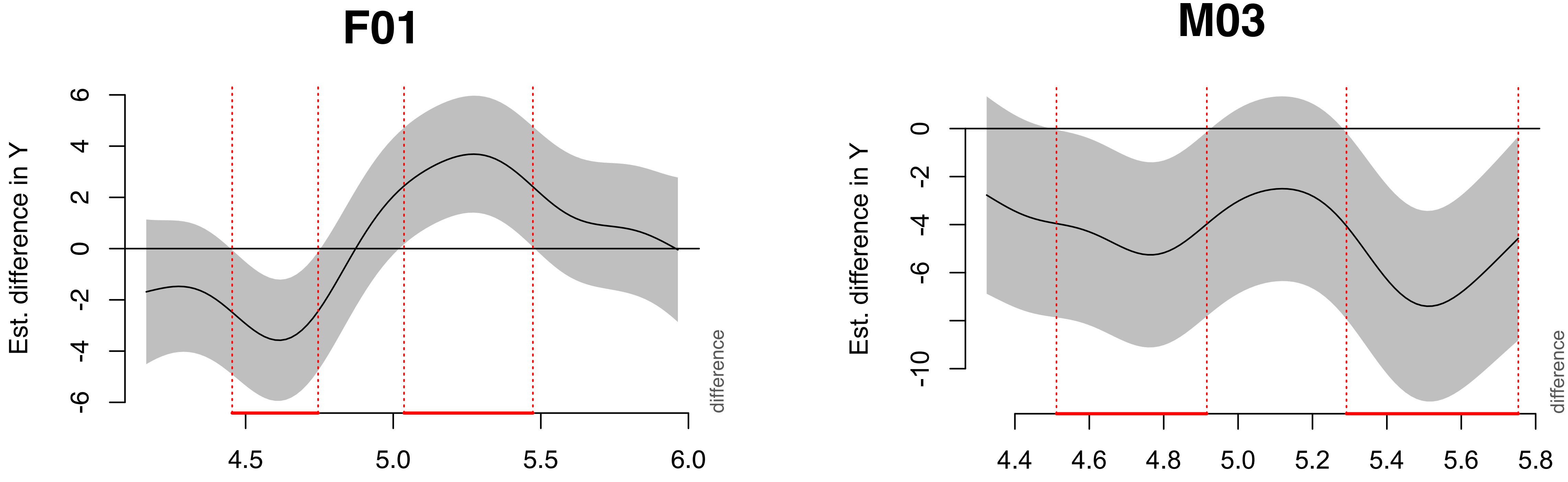
- In addition to visual inspection of the splines, difference smooths can be used for pairwise comparisons of tongue shapes
  - Differences between the two curves are highlighted in red (where confidence interval of difference smooth does not contain 0)
  - More red = more differentiation in tongue shape
  - /s/ and /ʃ/ completely different for M01 and M02



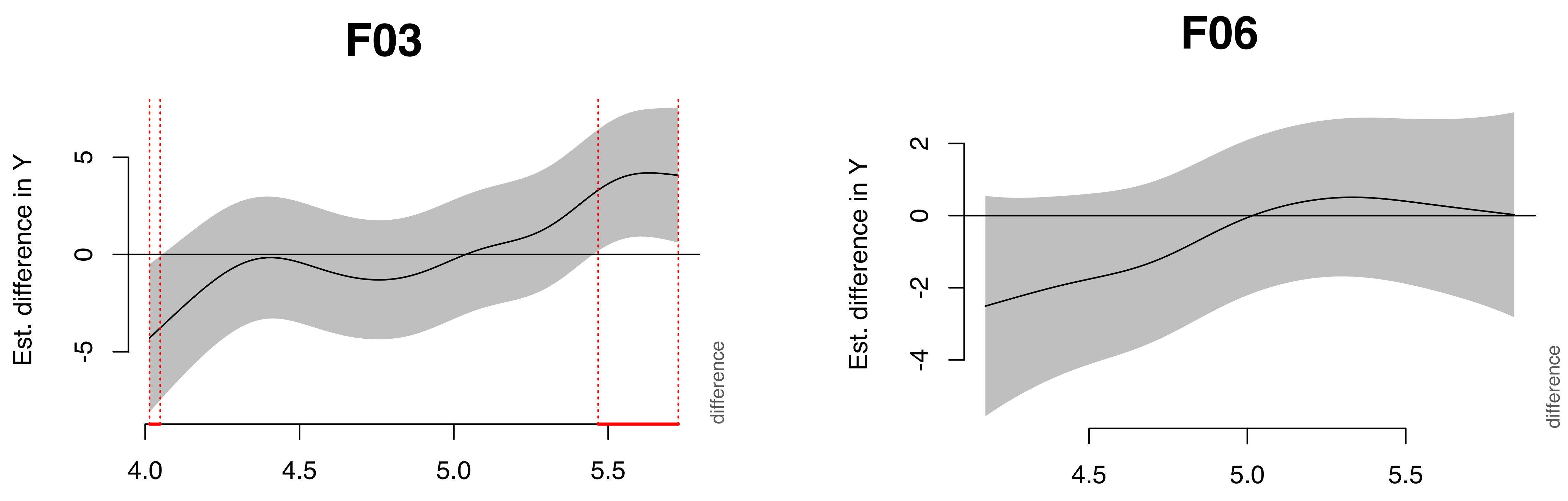
# Difference smooths

- In addition to visual inspection of the splines, difference smooths can be used for pairwise comparisons of tongue shapes
    - Differences between the two curves are highlighted in red (where confidence interval of difference smooth does not contain 0)
    - More red = more differentiation in tongue shape
    - /s/ and /ʃ/ largely distinct (but to a lesser extent) for F01 and M03



# Difference smooths

- In addition to visual inspection of the splines, difference smooths can be used for pairwise comparisons of tongue shapes
  - Differences between the two curves are highlighted in red (where confidence interval of difference smooth does not contain 0)
  - More red = more differentiation in tongue shape
  - /s/ and /ʃ/ not at all different for F03 and F06 (as well as F07 and F08)

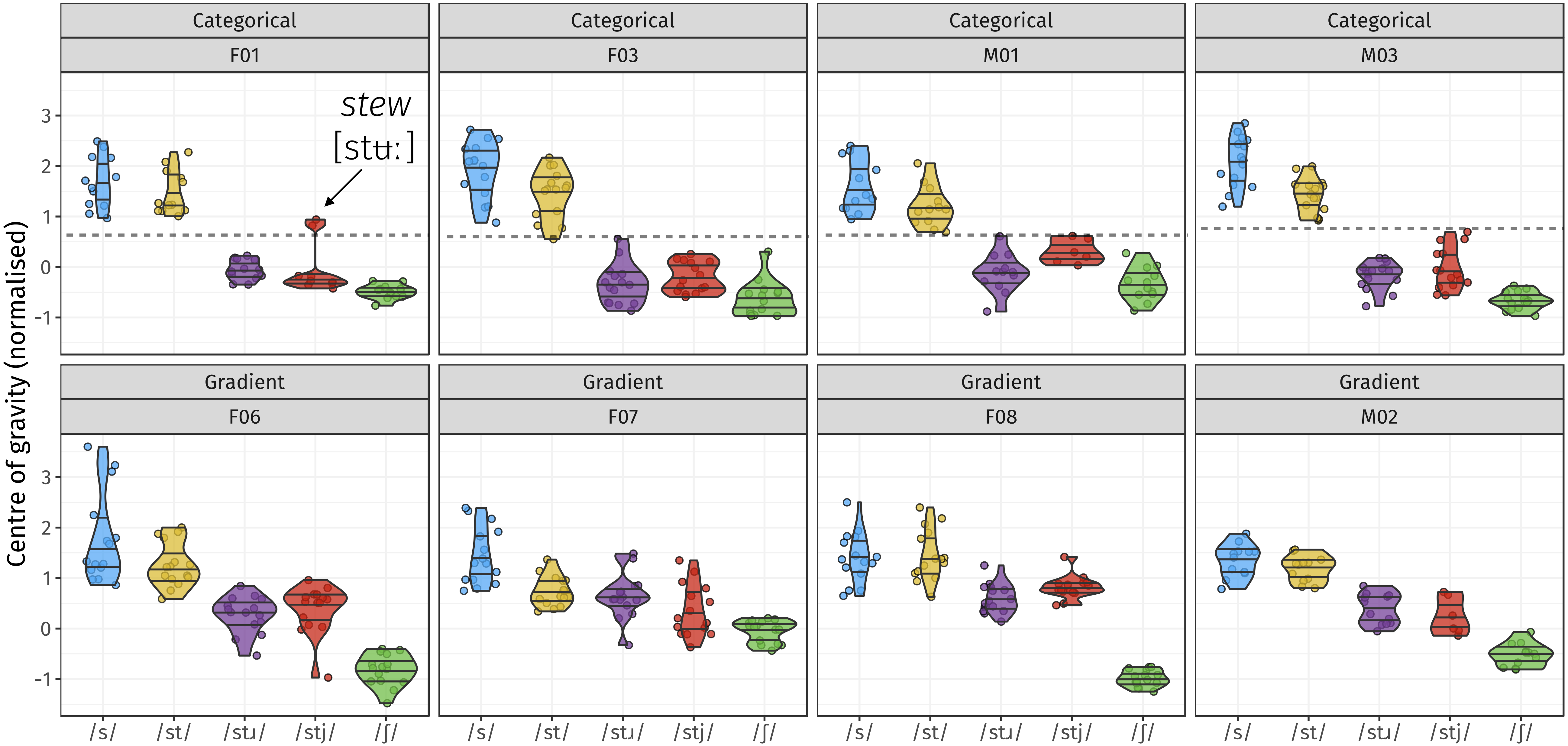


# RESULTS

## ACOUSTICS

# Centre of gravity






- **All** speakers maintain an acoustic contrast between /s/ and /ʃ/
- Categoricity/gradience determined by Tukey contrasts for post-hoc pairwise significance tests in linear regression models (i.e. whether or not /stɹ/ or /stj/ are significantly different from /ʃ/)

# Centre of Gravity

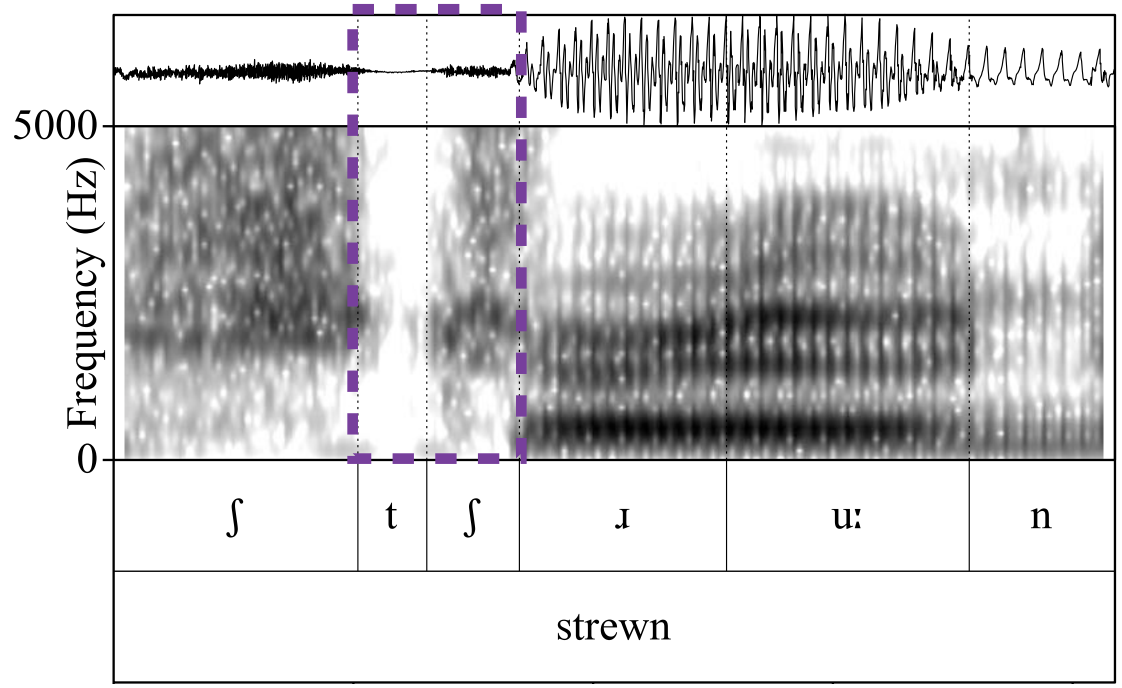
- The acoustic analysis reveals that:

  1. **All** speakers do have an acoustic contrast between **/s/** and **/ʃ/**
  2. **All** speakers exhibit some degree of acoustic "retraction" in **/stɹ/** and **/stj/**

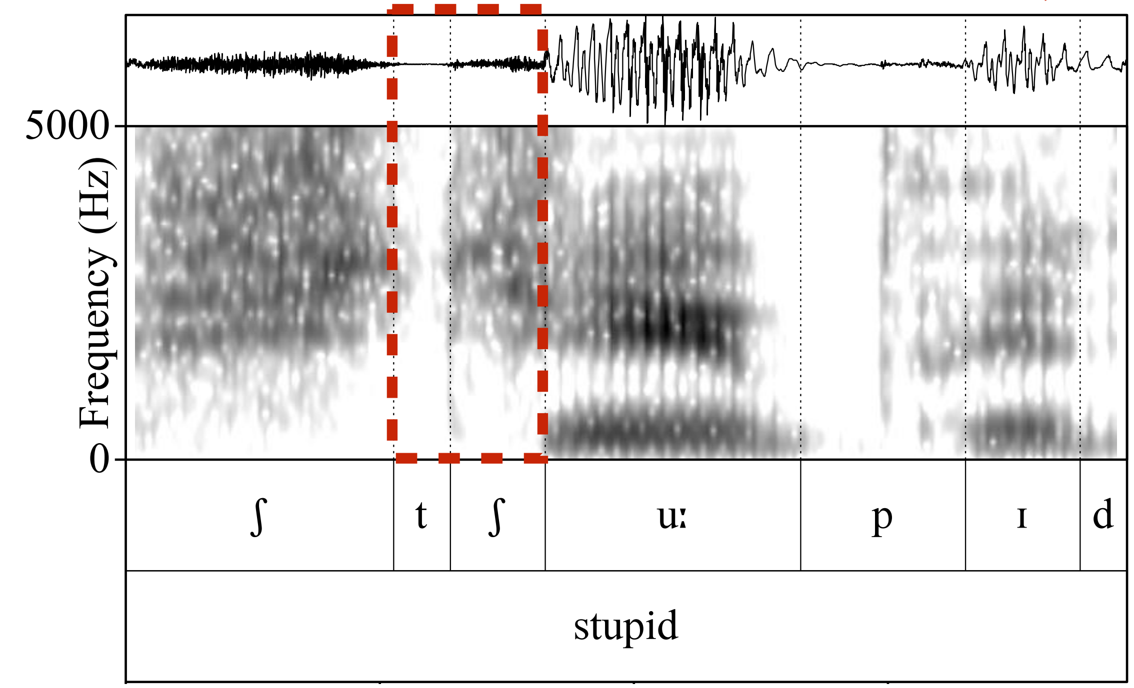
- This may be categorical for some and gradient for others but crucially:
  - Speakers are either categorical in both or gradient in both - there is no evidence that for a single speaker retraction is more advanced in one than the other
  - Suggests that retraction in both environments is governed by the same underlying process, or at least the same phonetic motivations

# AFFRICATION?

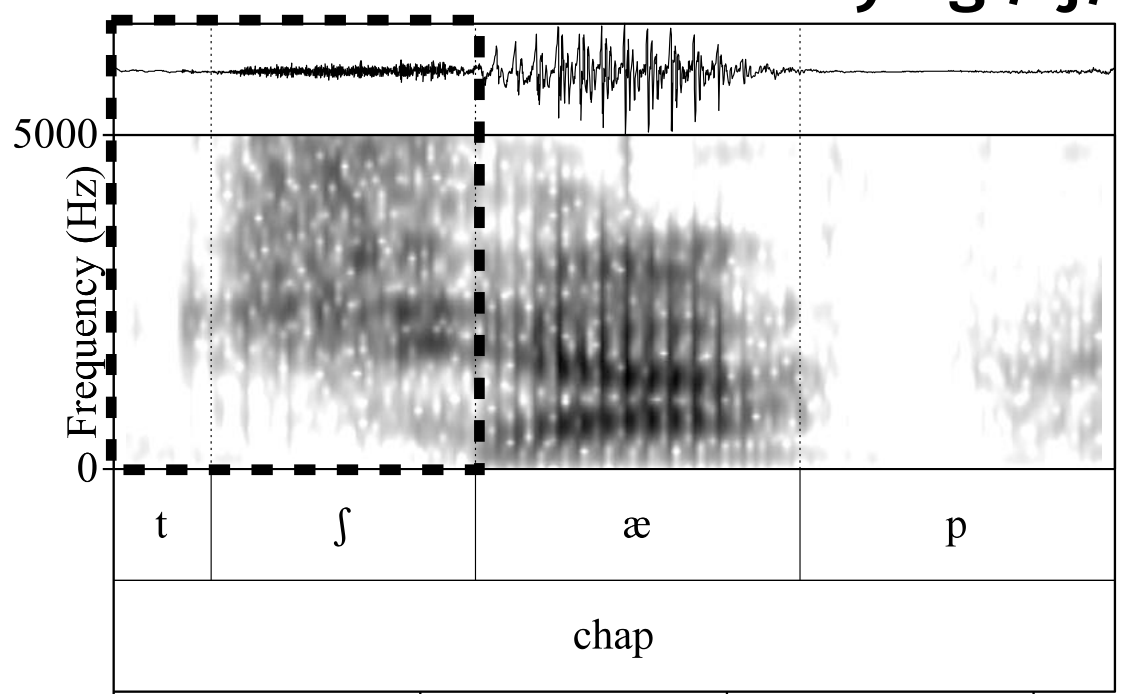
M01: /stɹ/




M01: /stj/




M01: underlying /tʃ/




- Comparable affrication of **/t/** across both **/stɹ/** and **/stj/** environments
- Phonetically similar to underlying **/tʃ/** (just shorter in duration)
- **Some** speakers do differentiate the affricated **/t/** (w.r.t. CoG) depending on whether it is followed by **/j/** or **/ɹ/** (see Appendix)

# Affrication?



- Crucially, **all** speakers affricate **/t/** - it's only the spectral properties of the fricated portion that are variable

- Some evidence that a speaker can affricate **/t/** with only minimal retraction of **/s/** (e.g. F08)

    - But no evidence that speakers retract **/s/** without affricating **/t/**

        - e.g. *[ʃtɹiːt], *[ʃtjʉːpɪd]

# DISCUSSION

## THE ARTICULATION-ACOUSTICS MAPPING

# COVERT ARTICULATION

- Even though some speakers show no apparent articulatory difference even between underlying /s/ and /ʃ/, the acoustic contrast is still maintained
- Rutter (2011) highlights the three phonetic parameters that define the /s/-/ʃ/ contrast:
  - **TONGUE PLACEMENT** - alveolar for /s/, post-alveolar for /ʃ/
  - **TONGUE SHAPE** - grooved for /s/, slit/flat for /ʃ/
  - **LIP SHAPE** - slight labialisation for /s/, strong labialisation for /ʃ/

**'It is also worth noting that changes in one of the phonetic parameters discussed above may not necessarily co-occur with changes in the other two' (Rutter 2011:31)**

  - **TONGUE TIP** - laminal vs. apical constriction
- Speakers achieving the same acoustic output through different articulatory means?
  - Similar to covert articulation in /ɹ/ (Delattre & Freeman 1968, Mielke et al. 2016)

# The articulation-acoustics mapping



| | articulation (UTI) | | acoustics (CoG) |
|---|---|---|---|
| M01 | categorical | ↔ | categorical |
| M02 | categorical | ↔ | gradient |
| M03 | gradient | ↔ | categorical |
| F01 | gradient | ↔ | categorical |
| F03 | none | ↔ | categorical |
| F06 | none | ↔ | gradient |
| F07 | none | ↔ | gradient |
| F08 | none | ↔ | gradient |

# The articulation-acoustics mapping

- No one-to-one mapping between articulation (ultrasound) and acoustics (CoG)
- We find all but one of the six possible mappings (using these categories)
  - With a larger sample size we would likely find examples of this

- **categorical ↔ categorical**
  - M01
- **categorical ↔ gradient**
  - M02
- **gradient ↔ categorical**
  - F01, M03
- **none ↔ categorical**
  - F06, F07, F08
- **none ↔ gradient**
  - F03
- **gradient ↔ gradient**
  - ...

# CONCLUSIONS

# Conclusions

- The **/stɹ/** and **/stj/** contexts behave similarly in terms of acoustic *s*-retraction and *t*-affrication
- This lends support to the idea that retraction is triggered by affrication and not by **/ɹ/** directly
- Evidence that the articulatory mechanisms behind the **/s/**-**/ʃ/** contrast are more complicated than a simple retraction of the place of articulation
    - highlights the need for a more nuanced approach to the articulation of "retraction"
    - and calls into question the suitability of "retraction" as a label for this phenomenon:
        - *s*-hushing? (i.e. hissing **/s/** > hushing **/ʃ/**)
- Speakers could be hitting an acoustic target rather than articulatory target (Boersma 2011:§4)
- Lends support to the older idea that distinctive features should be defined primarily in acoustic terms (Jakobson et al. 1952, Durand 1990:§2.5)
- Highlights importance of (ideally simultaneous) articulatory **and** acoustic studies
- Although, in this case, even capturing midsagittal ultrasound does not tell the whole story

# FUTURE WORK

- **Further avenues for articulatory exploration:**
  - Look more closely at the tongue shape of **/ɹ/** with midsagittal UTI
  - Video recording for lip-rounding (rather than using F3-F2 as a proxy)
  - Electropalatography (EPG), electromagnetic articulography (EMA) and parasagittal UTI to investigate the other articulatory mechanisms of sibilant production, e.g. tongue tip, grooving/slitting
- **Acoustic work to be done:**
  - Investigate word-internal retraction and the effect of morpheme boundaries, e.g. *posture, registry* etc.
  - Investigate phrase-level retraction, e.g. *pass treats*, and the effect of prosodic boundaries and speech rate
  - Collect **/ʃɹ/** data (e.g. *shriek*, *shrew*, *shrapnel*) to compare with **/stɹ/**
  - Look at pre-**[p]** and pre-**[k]** environments, e.g. *spoon, spring; school, screw*
  - Perform acoustic analysis on conversational data (existing corpus of 32 sociolinguistic interviews from Manchester and other North West cities)

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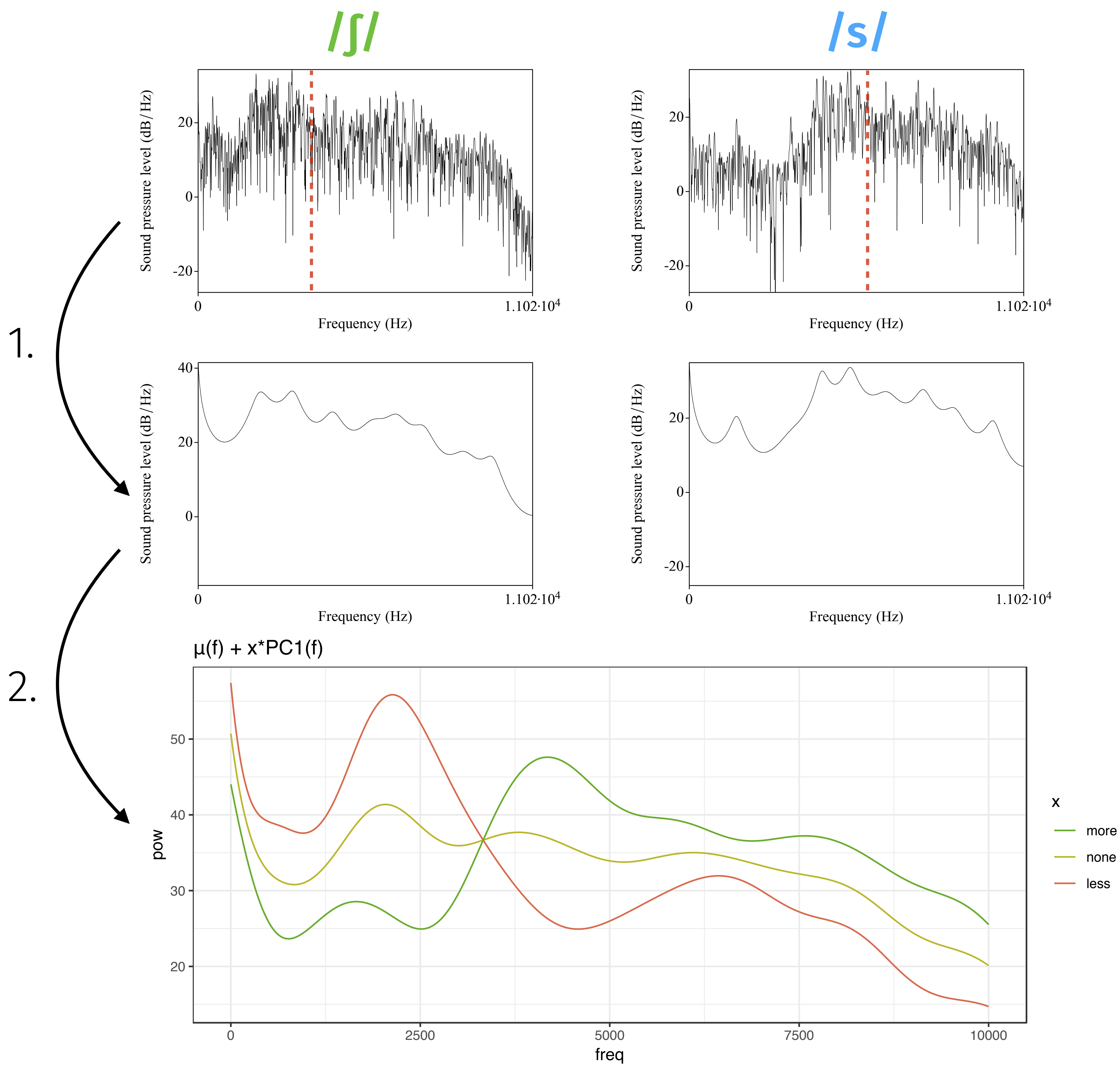
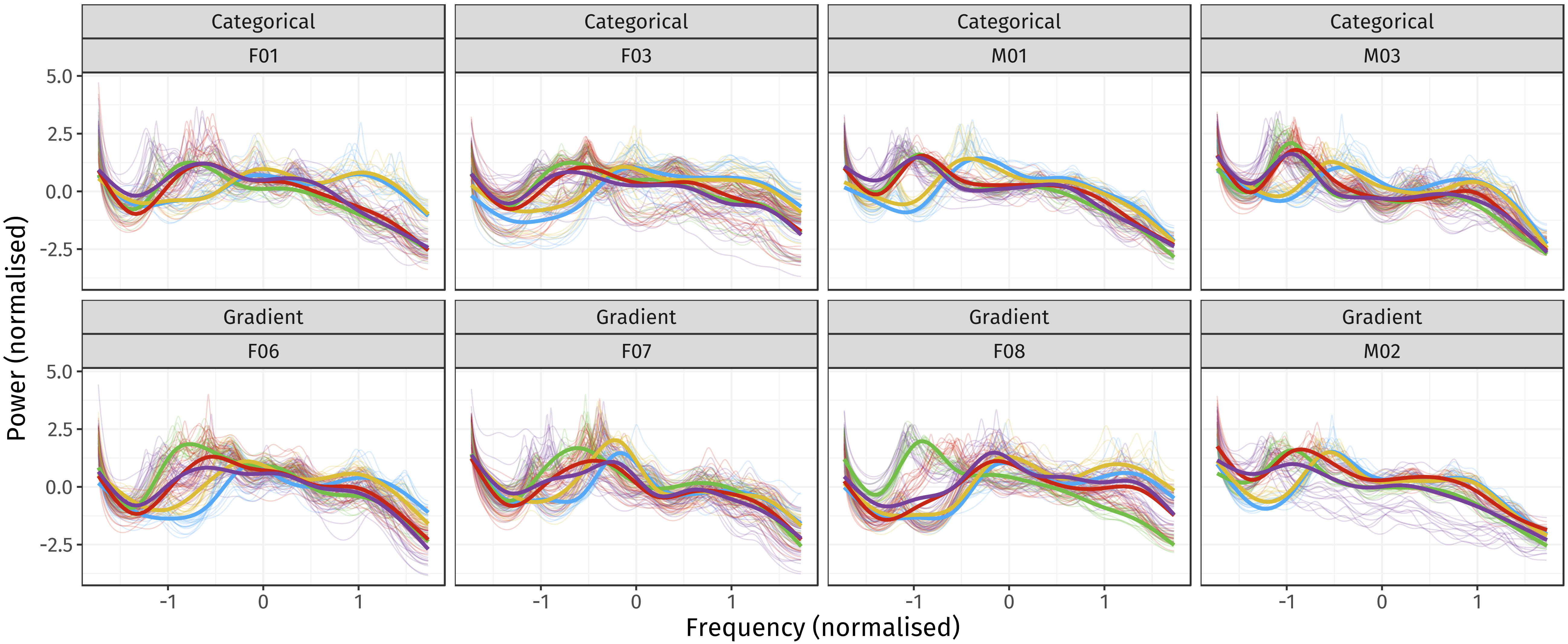
# APPENDICES

# FUNCTIONAL PRINCIPLE COMPONENTS ANALYSIS (FPCA)

- Single spectral moments (e.g. CoG, skew, kurtosis) often used to distinguish sibilants (Haley et al. 2010:548-9)
- But this is an over-simplification of a complex acoustic signal
- We also analyse the entire curve:
  1. LPC smoothing of spectral slice
  2. Use FPCA to reduce dimensionality and describe curve shapes using two or three principle components (PCs)

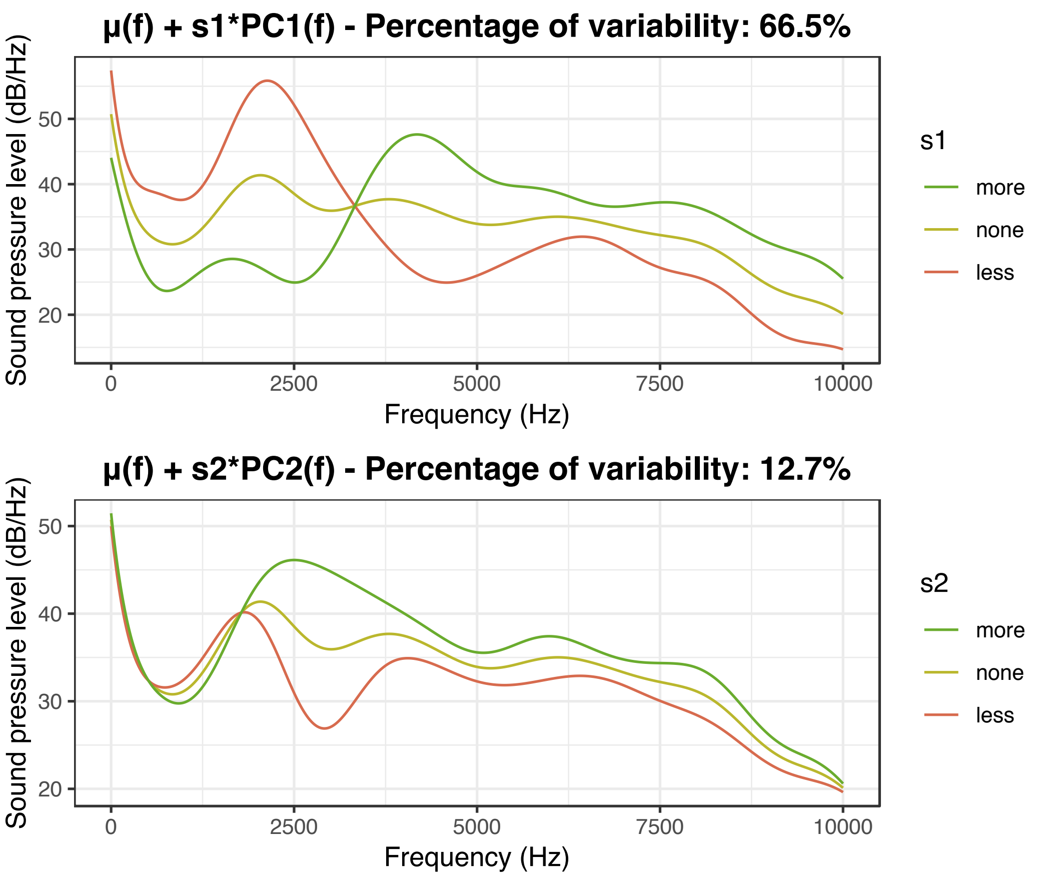


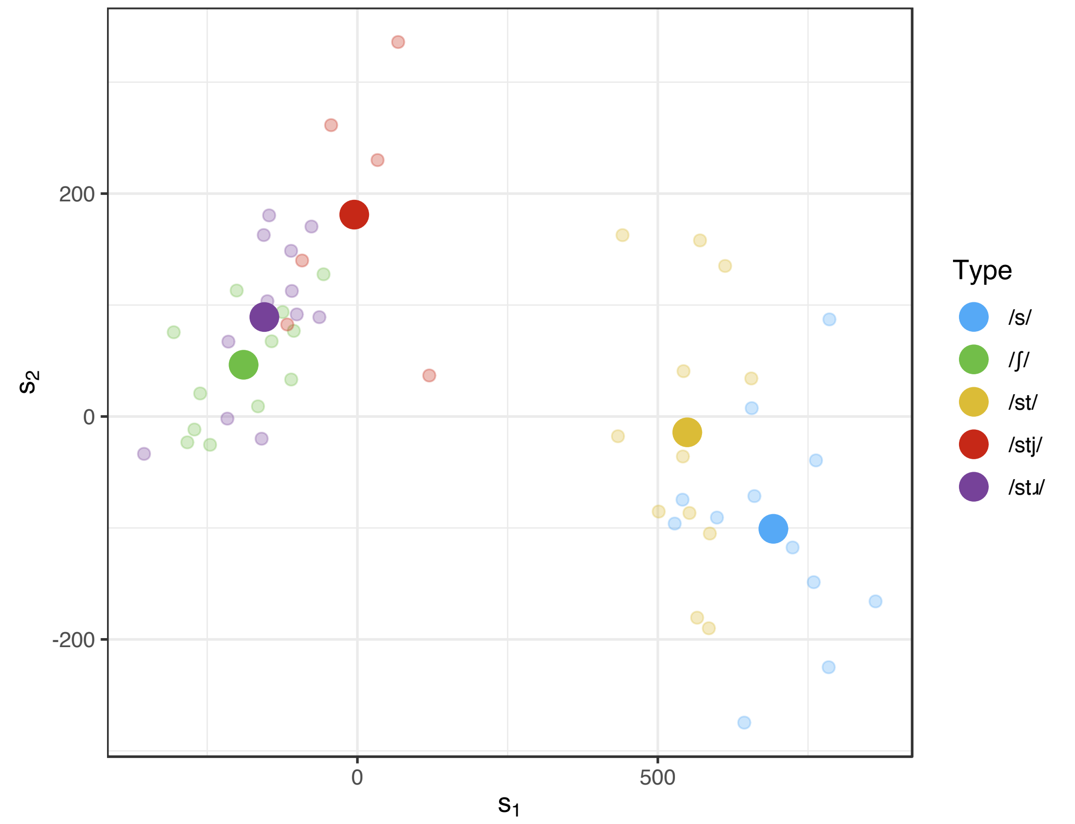
# LPC-SMOOTHED SPECTRAL SLICES




- Looking at the entire spectral profile, the same two patterns emerge as with CoG:
  - “Categorical” speakers, where /stɹ/ and /stj/ patterns with /ʃ/
  - “Gradient” speakers, where /stɹ/ and /stj/ are intermediate between /s/ and /ʃ/

# FUNCTIONAL PRINCIPLE COMPONENTS ANALYSIS (FPCA)



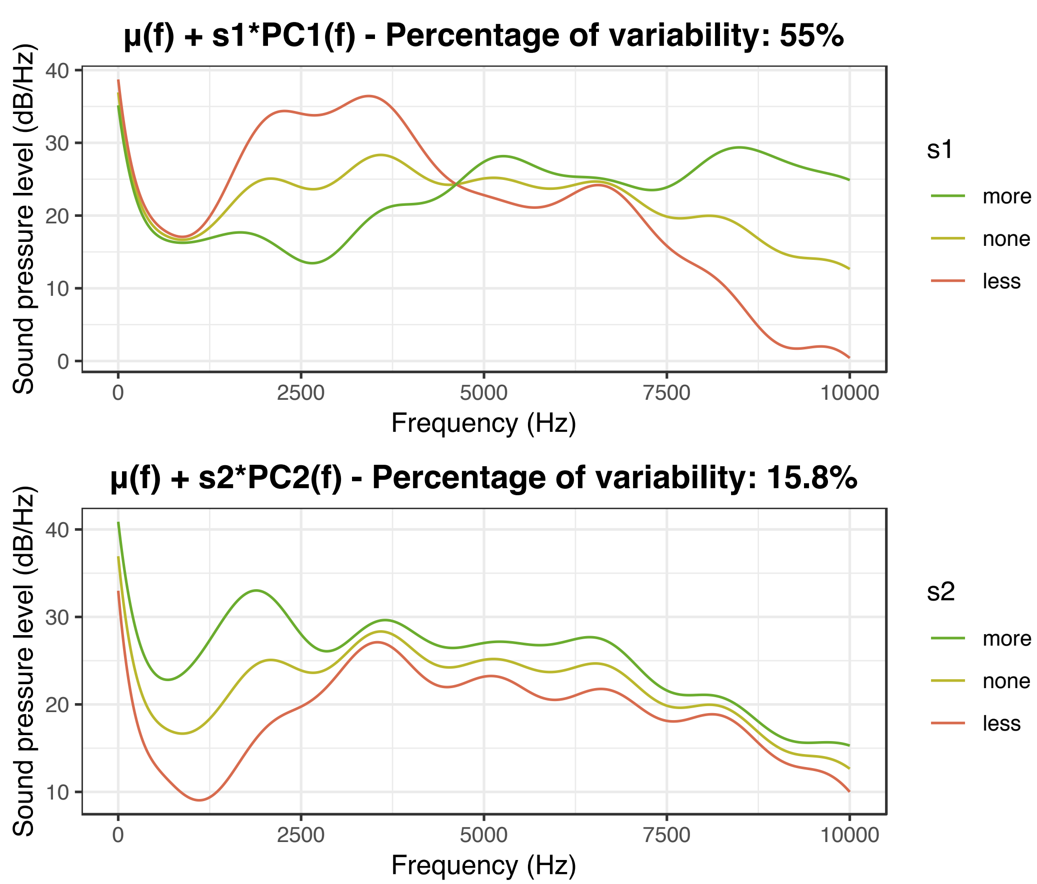



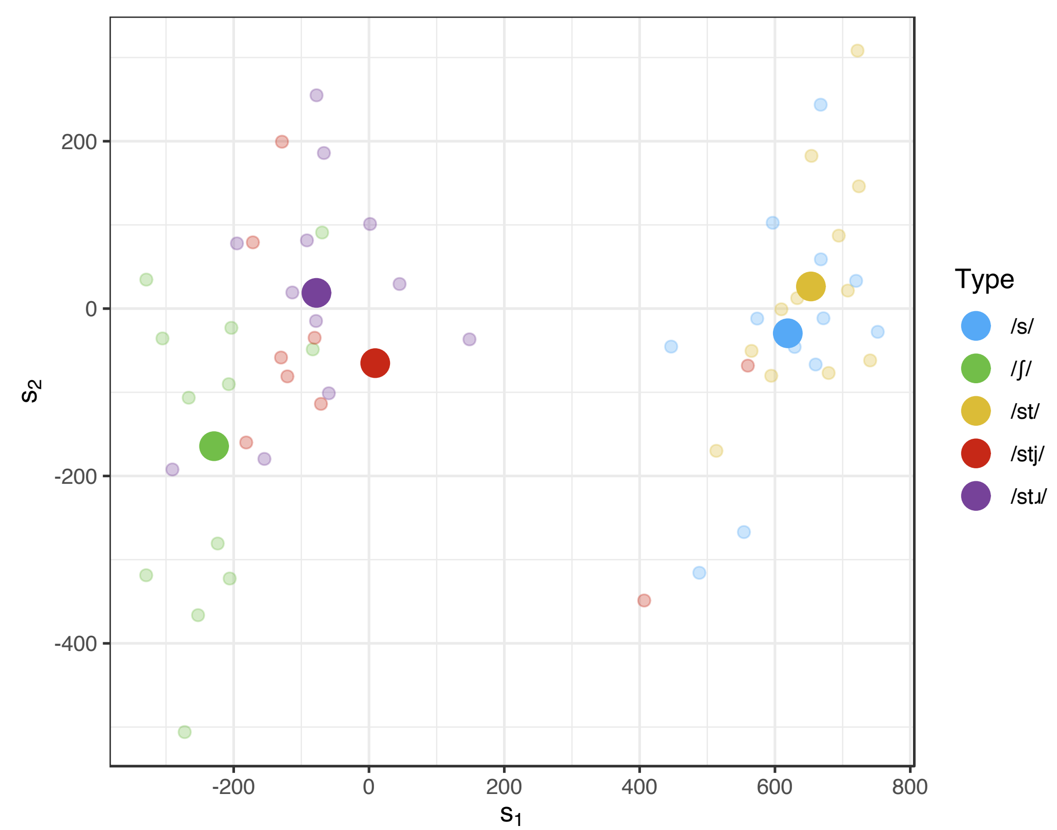

**M01**

categorical

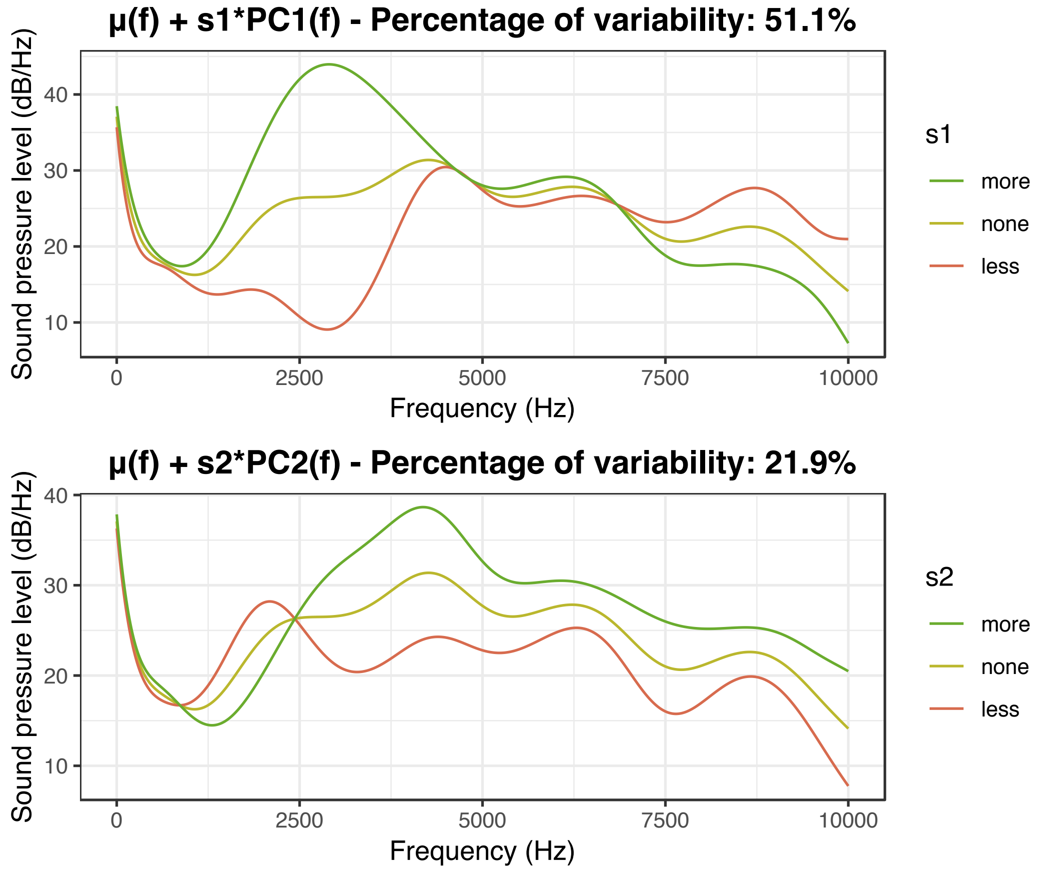
**F01**

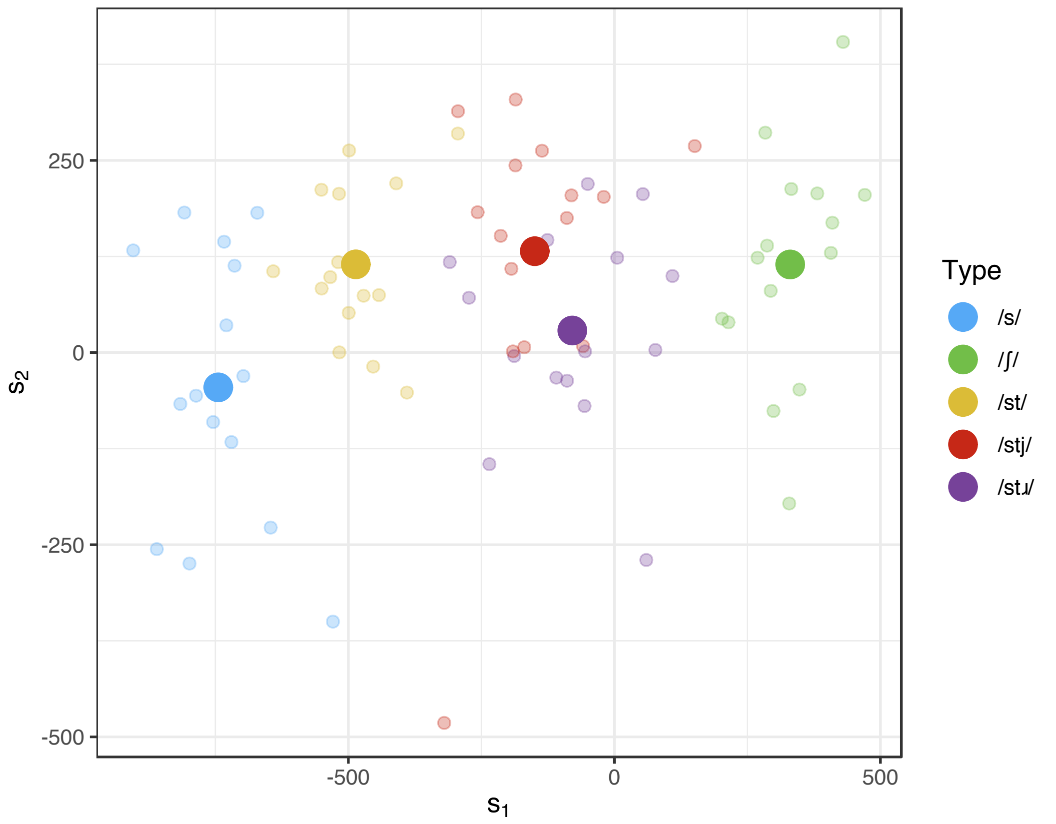
categorical



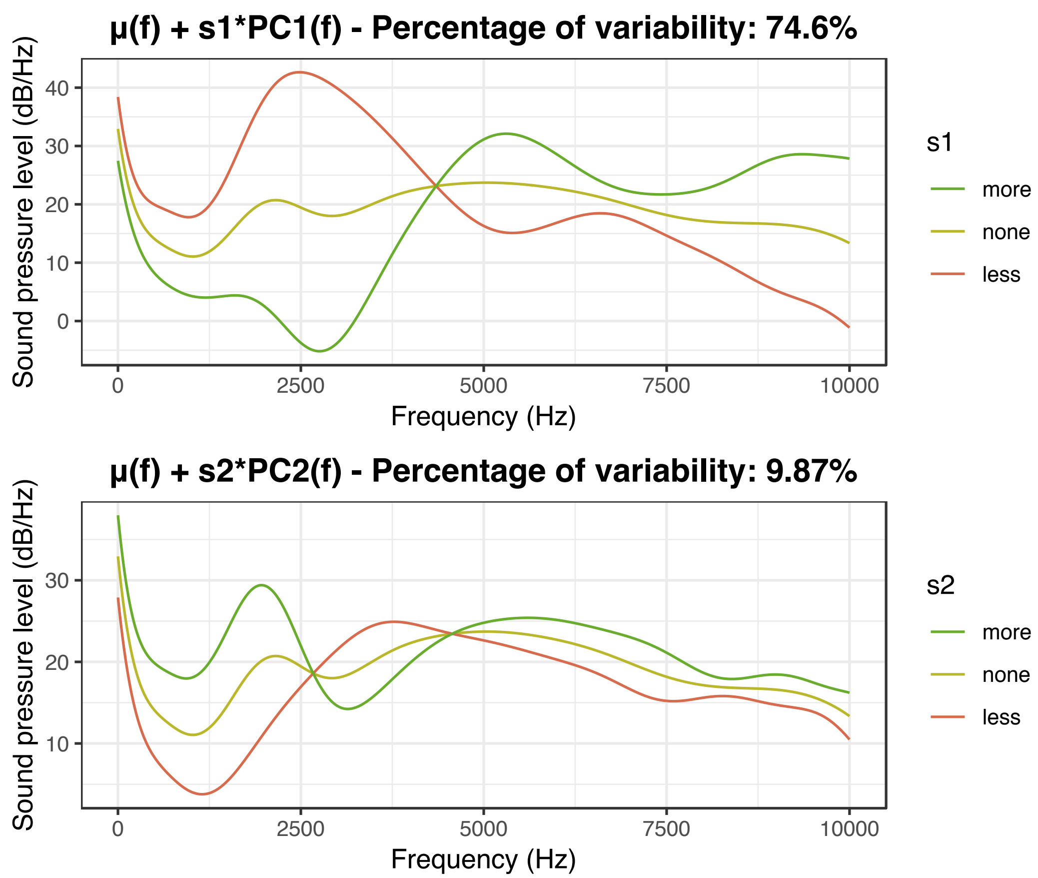
# FUNCTIONAL PRINCIPLE COMPONENTS ANALYSIS (FPCA)

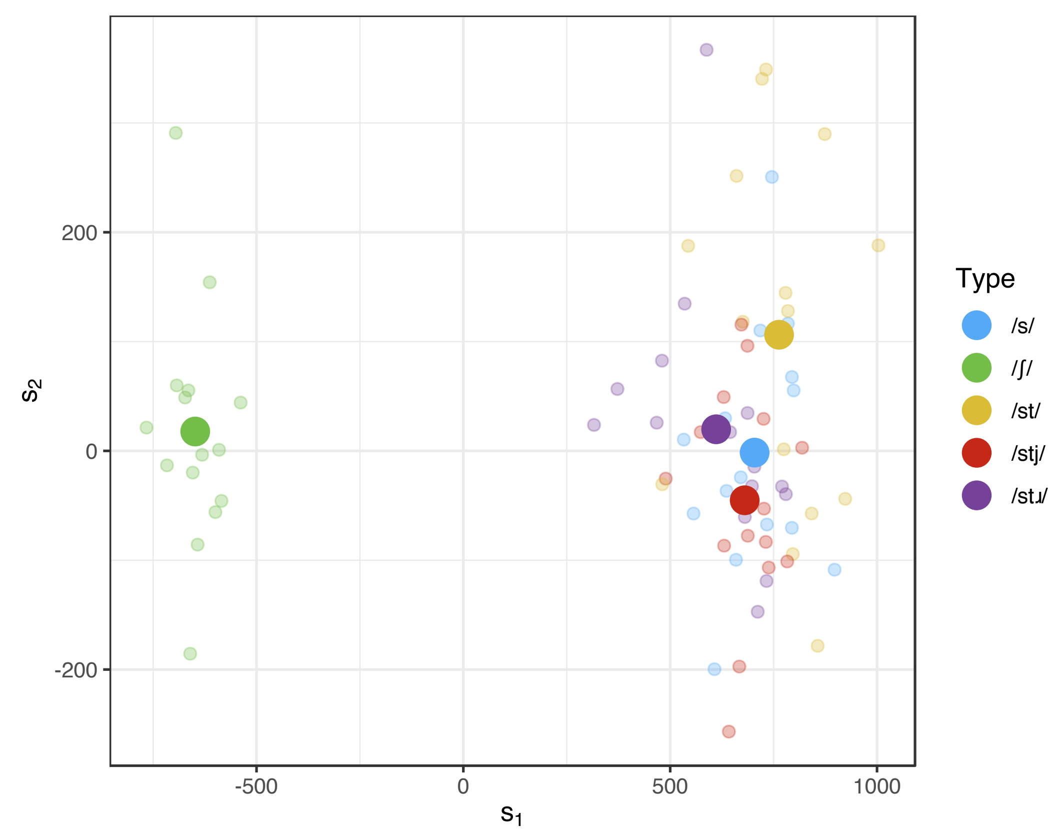



**F06**

gradient

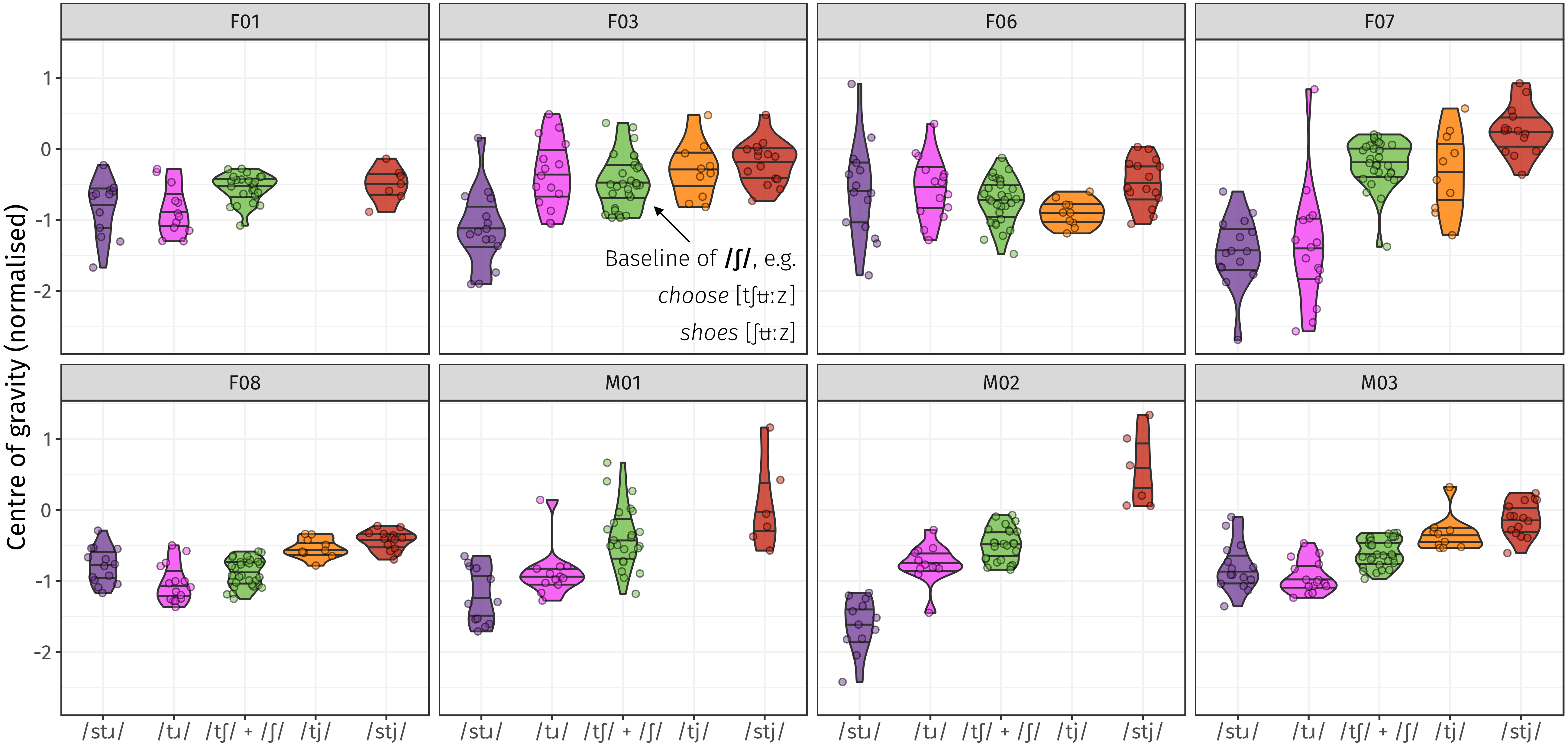



**F08**

gradient
(none)

# AFFRICATION?




- For most speakers, the fricated portions of pre-**/ɹ/** affrication and **/tj/**-coalescence are identical both to each other and to underlying **/tʃ/**
- But **some** speakers do differentiate the affricated **/t/** depending on whether it is followed by **/j/** or **/ɹ/** (see F07, M01, M02)