Phonetic implementation of phonologically different high tone plateaus in Luganda

Cerys Hughes, Seung Suk Lee, Alessa Farinella and Kristine M. Yu

University of Massachusetts Amherst

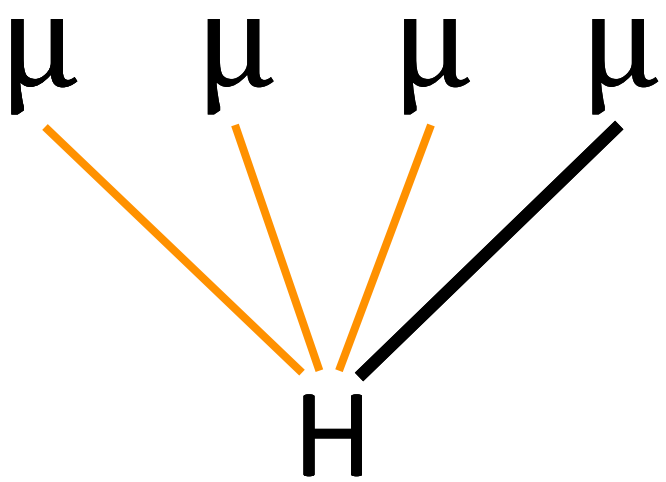
ICPhS 2023

August 7 2023

Luganda high tone spans

LH

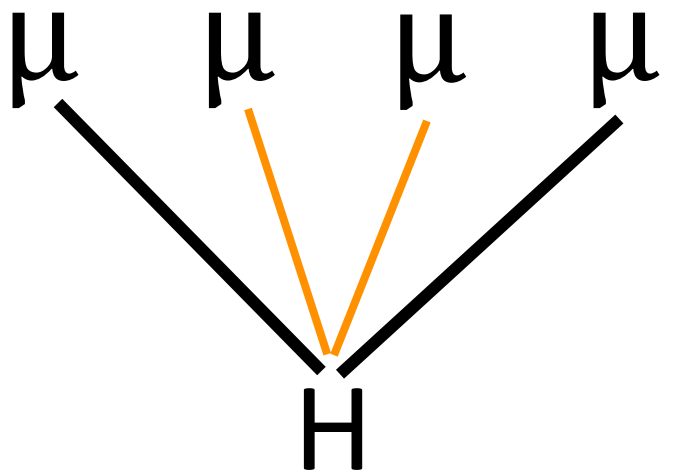
[òmùlà:ŋgìrà:**máɲó**:**múlá**lwò:nò]



Neutralization

HH

[òmùlè:nzìjà**lúmán**:**áwó**lòvù]

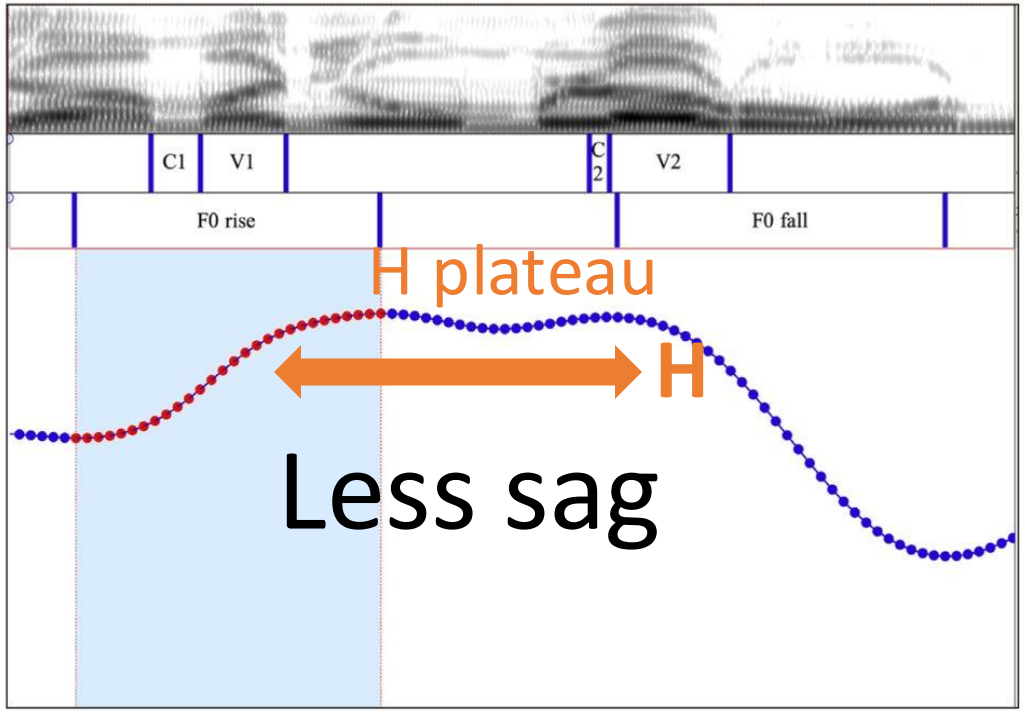


Luganda high tone spans

Do we see a difference in the plateau shape?

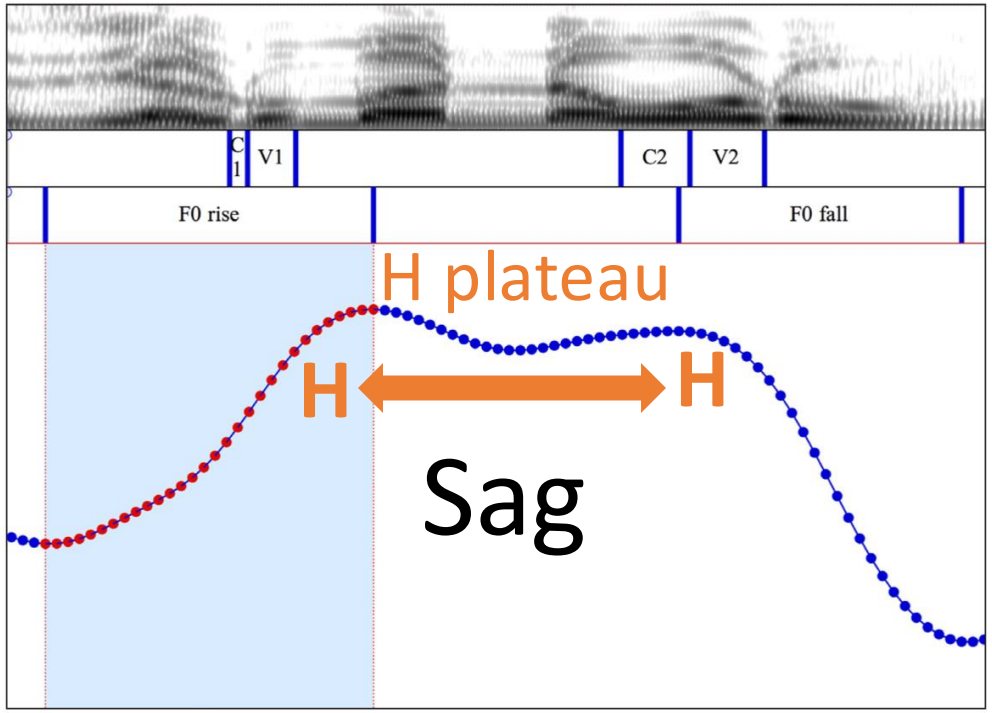
Data from Myers et al. 2018

LH



[òmùlà:ŋgìrà:**máɲó**:**múlá**lwò:nò]
“The prince recognizes this mad person.”

HH

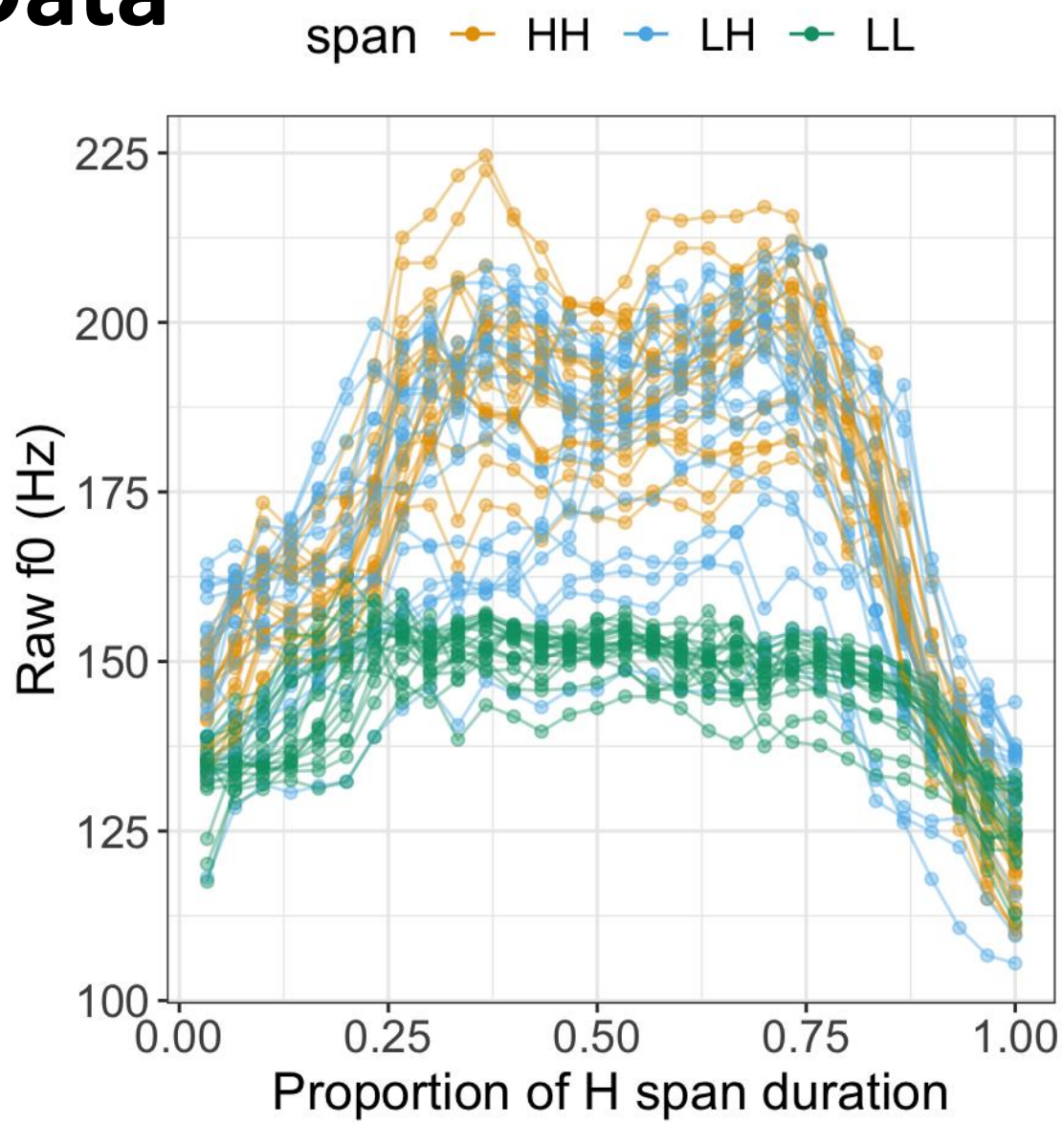


[òmùlè:nzìjà**lúmán**:**áwó**lòvù]
“The boy bit the chameleon.”

Incomplete Neutralization for LH, HH Tones?

- Question: Do LH and HH spans have different degrees of sag in their phonetic implementations?
  - Pierrehumbert 1980 – sag is a function of distance between 2 (intonational) tonal targets
  - Little work on whether there's similar phonetic implementation in lexical/grammatical tonal spreading processes
  - Different underlying specification, good test case for tonal incomplete neutralization
    - A lot of work on incomplete neutralization with segments, not so much on tone (Nicenboim et al. 2018)

Data



- Dataset of 4 Luganda tone spans from Myers et al. 2018
- 793 tokens, 10 speakers
- ~20 sentences per span type
- Differences in phonetic implementation found in previous work (Myers et al. 2018, Lee et al. 2021, Hughes et al. 2022)

Incomplete Neutralization Methodology

- Recent trends to move beyond point-wise measures to take the entire contour into consideration
- Methodological innovations: trajectory shape representations
  - Vowel formant contours (Stanley et al. 2021, Hualde et al. 2021)
  - Liquid formant contours (Simonet et al. 2008)
  - F0 contours (Chen et al. 2013, Gubian et al. 2015, et seq)
- Researcher choices relevant to answering LH vs HH question:
  - Types of **normalization**
  - Methodological innovations:
  - Functional Principal Component Analysis (FPCA)
  - Generalized Additive Mixed-effects Model (GAMM)

Overview of the current study

- Using contour shapes in addition to point measurements can reveal further phonetic implementation differences
- Normalization technique is not just a preprocessing step: different choices can affect analyses of contour shapes
  - Within-speaker vs. Within-token
  - Mean centering vs. Z-scoring
- Different methods of analysis found different shape differences between LH and HH
  - FPCA or GAMM

Previously found implementation difference

- Data from Myers et al. 2018
  - Found difference in f0 rise and fall for some Luganda high tone spans (LL, HL, LH, HH) (Figure 7 from Myers et al. 2018)

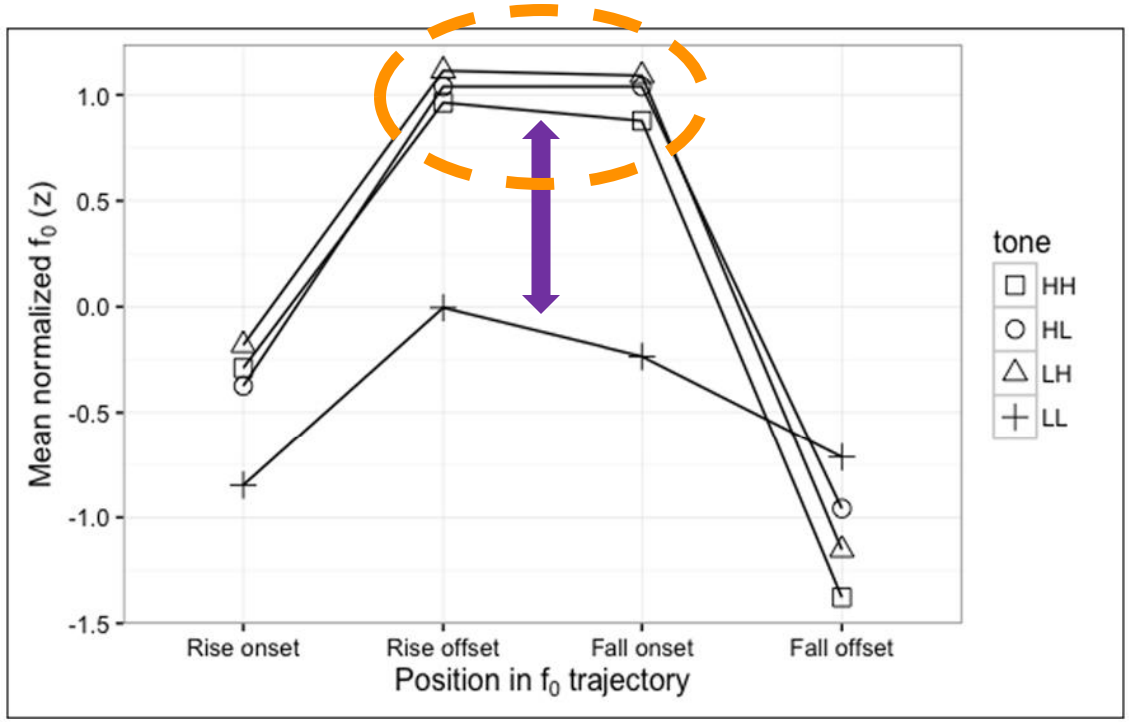
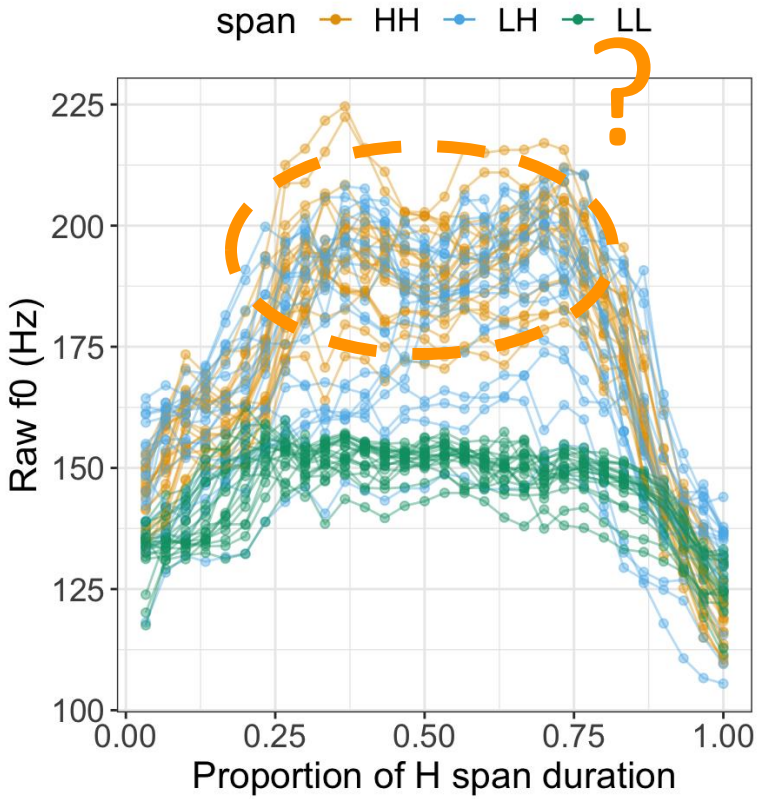
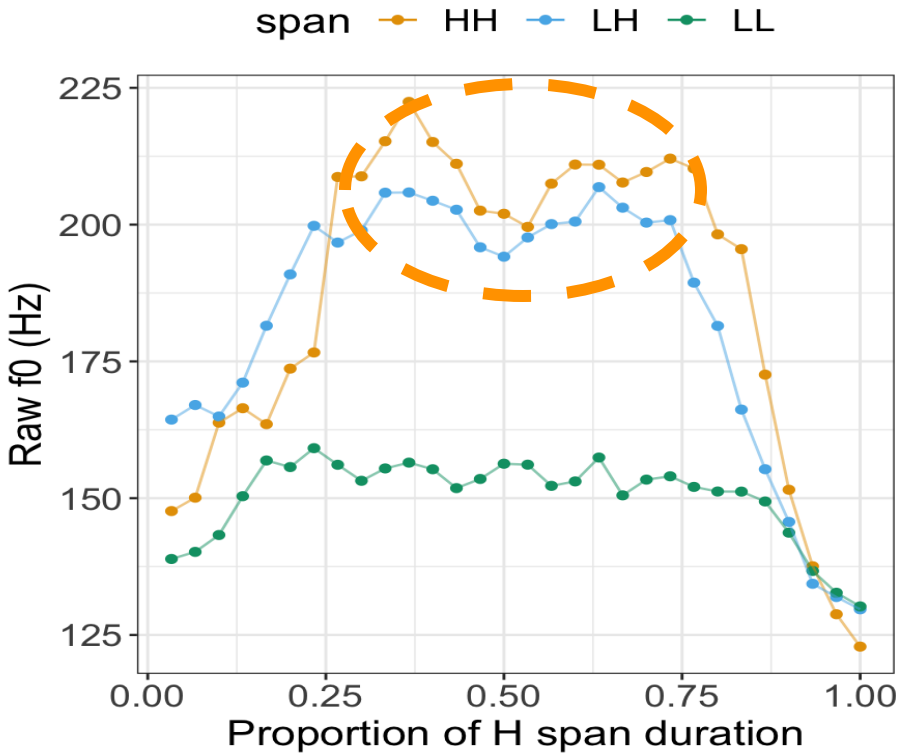


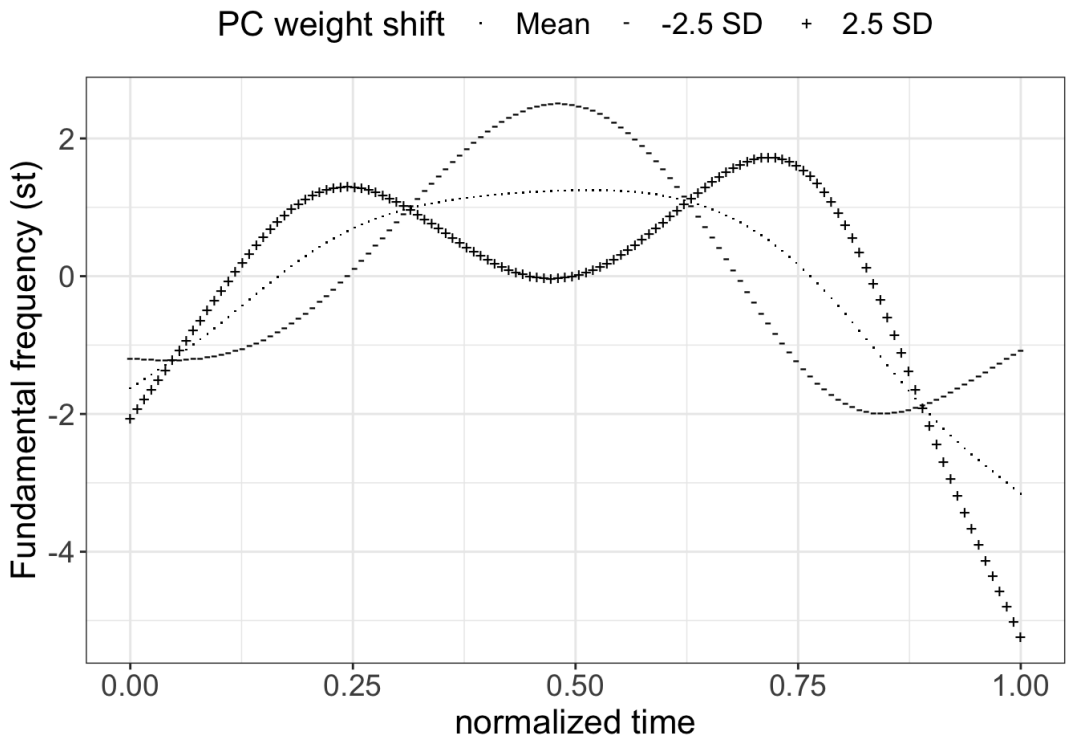
Figure 7: Mean normalized f_0 (z) by tone class and position.



Previously found trajectory shape difference

- Lee et al. 2021, Hughes et al. 2022 found a difference between LH and HH in their trajectory shape using Functional Principal Component Analysis





Researcher choices in previous findings

- Normalization of F0 contours
  - By-speaker z-scoring in Myers et al. 2018
  - Within-token mean centering in Lee et al. 2021, Hughes et al. 2022
- Different methods of analyzing trajectory shapes
  - FPCA in Lee et al. 2021, Hughes et al. 2022
  - GAMM?

Normalization Techniques

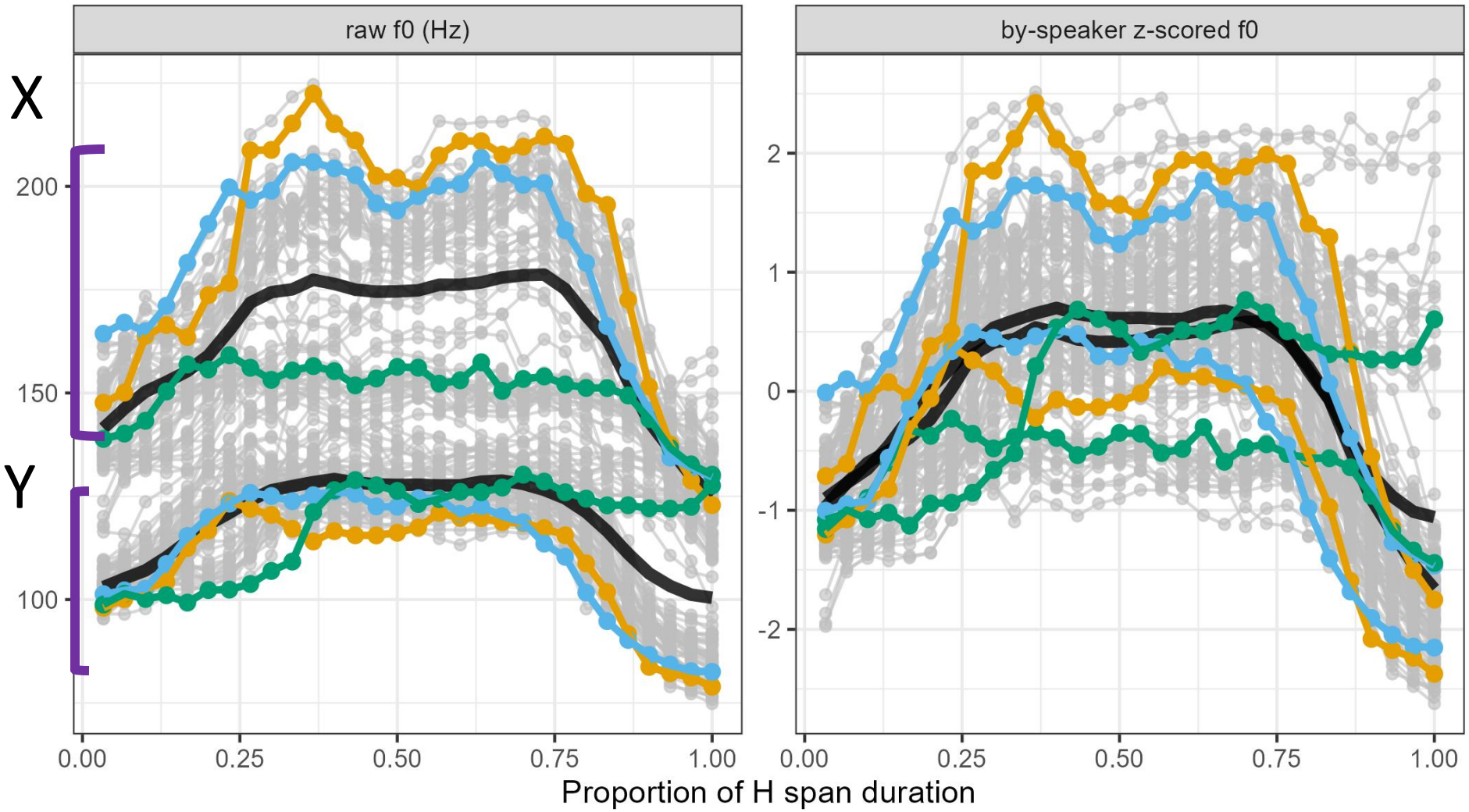
F0 Data-preprocessing approaches

- F0 vs Log-transformed F0 (e.g. semitones)
  - (Zhang 2018 a.o.)
- Mean centering vs scaling (z-scoring)
  - (Cheng et al. 2015, Gubian et al. 2015 a.o.), cf. (Myers et al. 2018, Lohfink et al. 2019, Gryllia et al. 2022 a.o.)
- Within-token vs within-speaker
  - (Cheng et al. 2015, Gubian et al. 2015 a.o.), cf. (Myers et al. 2018 a.o.)
- **Current study:**
  - Within-token mean-centering, within-speaker z-scoring, and within-speaker mean-centering

Within-Speaker z-scoring

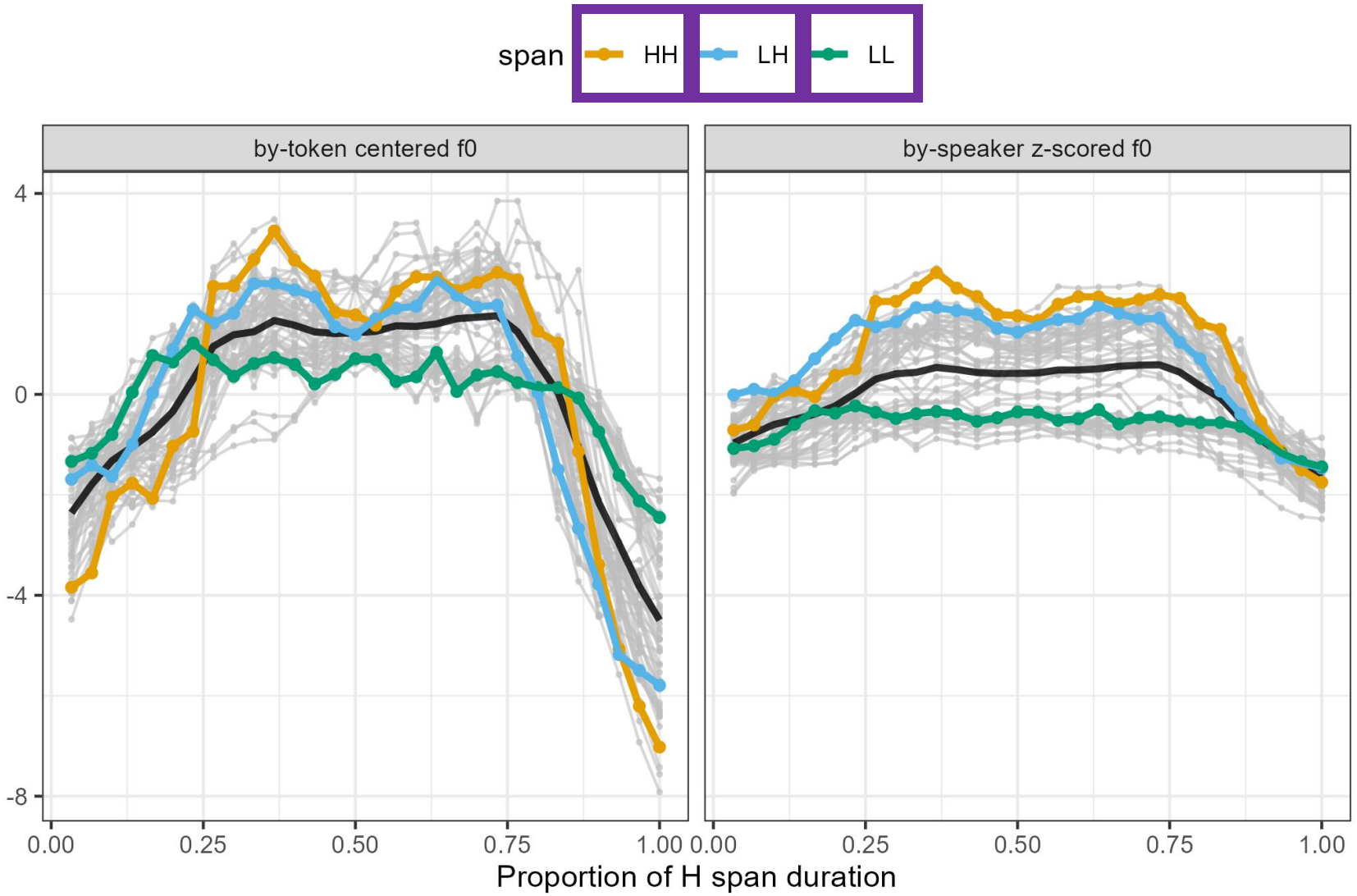
Speaker X

Speaker Y



Within-Token Centering

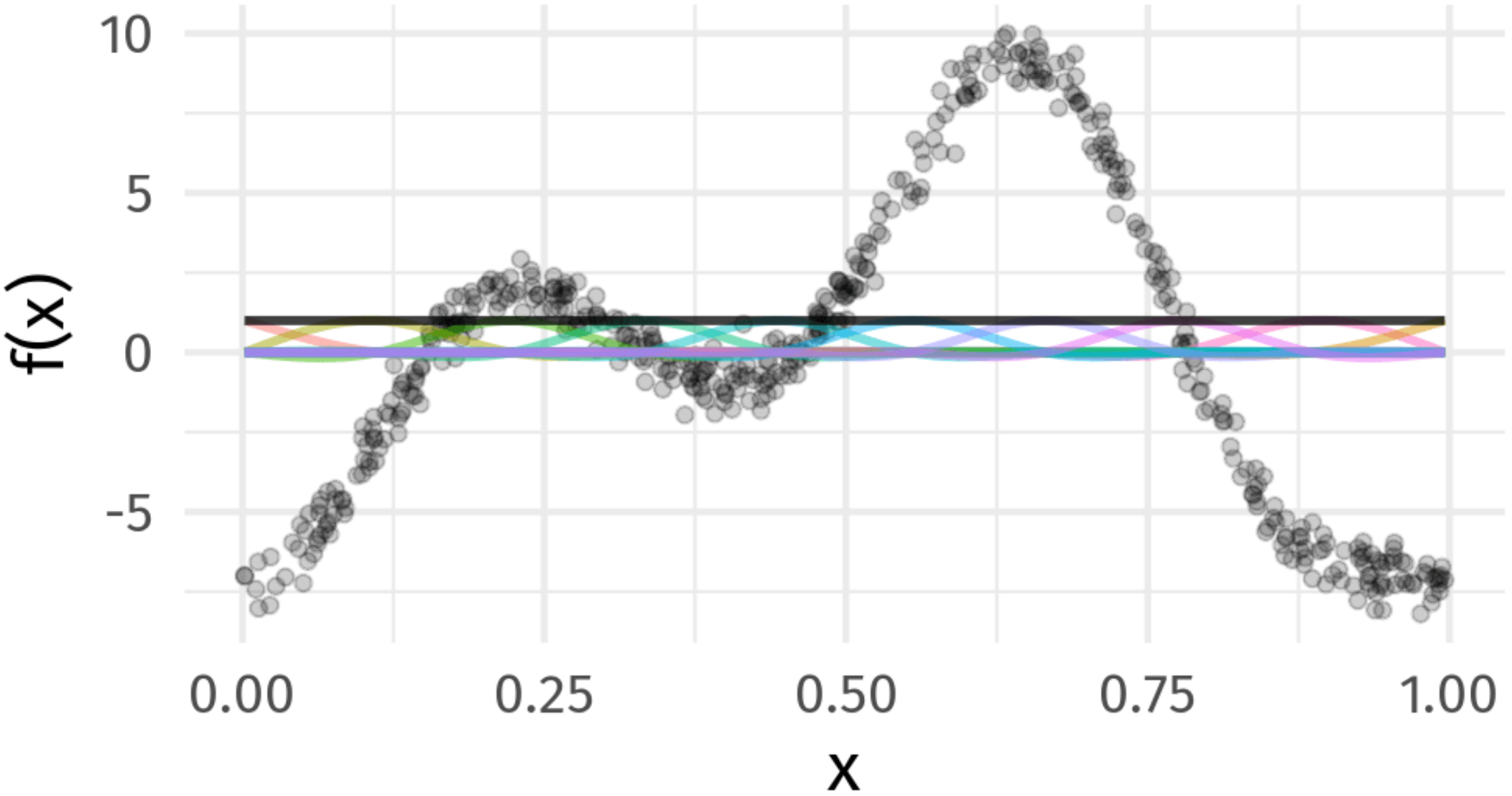
"Sag" defined in terms of token's F0 range (Pierrehumbert 1981)



Analysis Method Choices

FPCA or GAMM

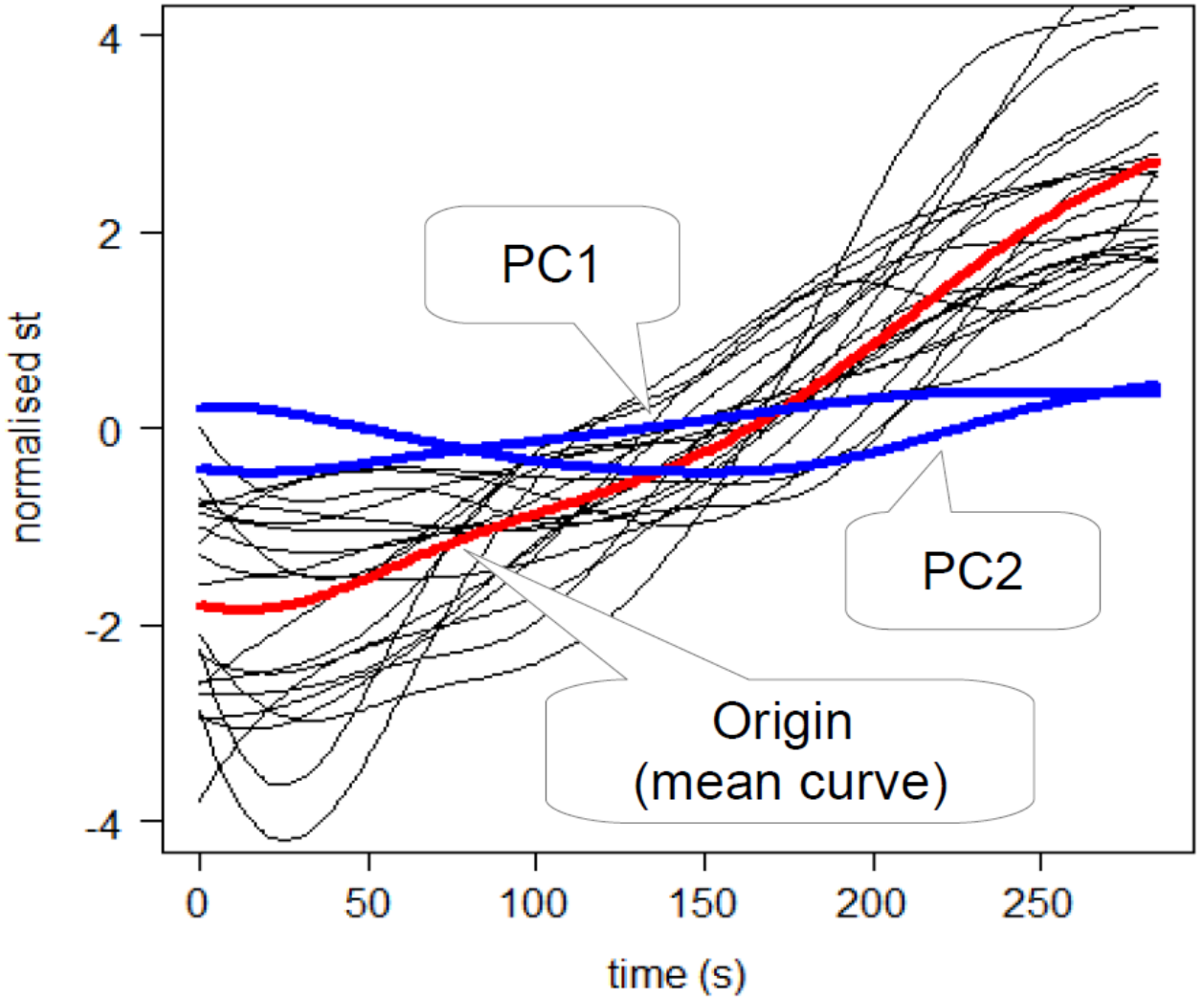
Representing Function Shapes



https://github.com/gavinsimpson/intro-gam-webinar-2020

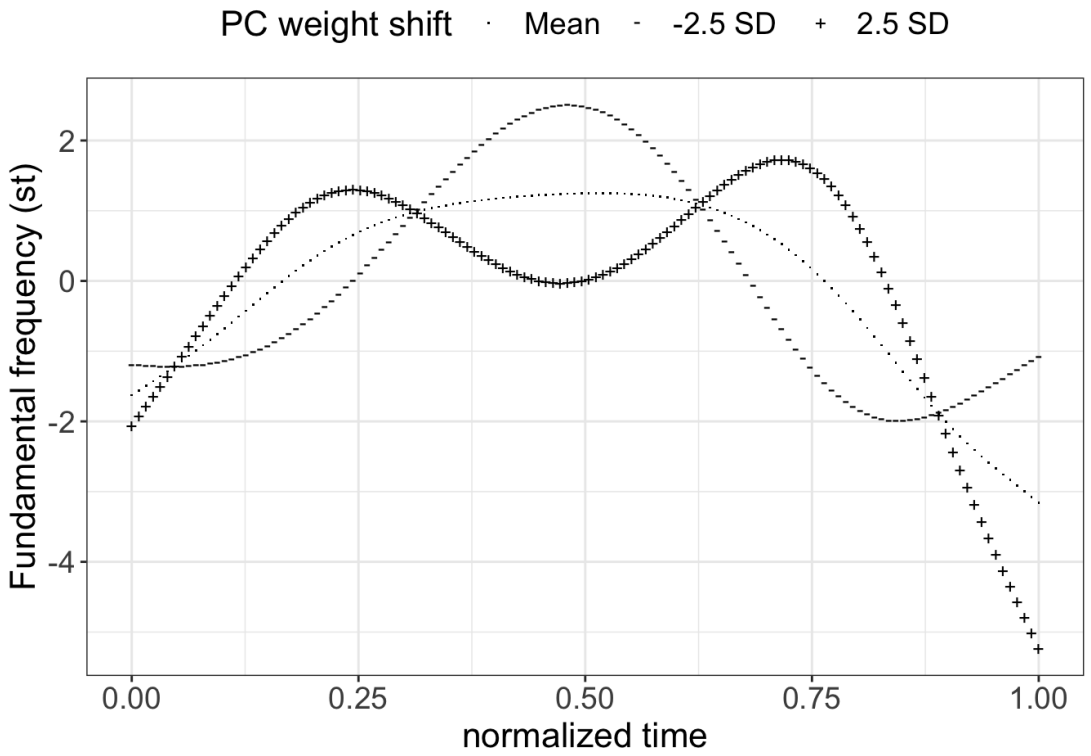
Functional Principal Components Analysis (FPCA)

- Represent F0 contours with function shape weight
- Identify function shapes that F0 contours maximally vary on
- Principal Component Functions (PCs)
- Weighted sum of PCs



Gubian (2020)

One of PCs: Sag shape



More negative sag PC weight = more sag in an f0 contour

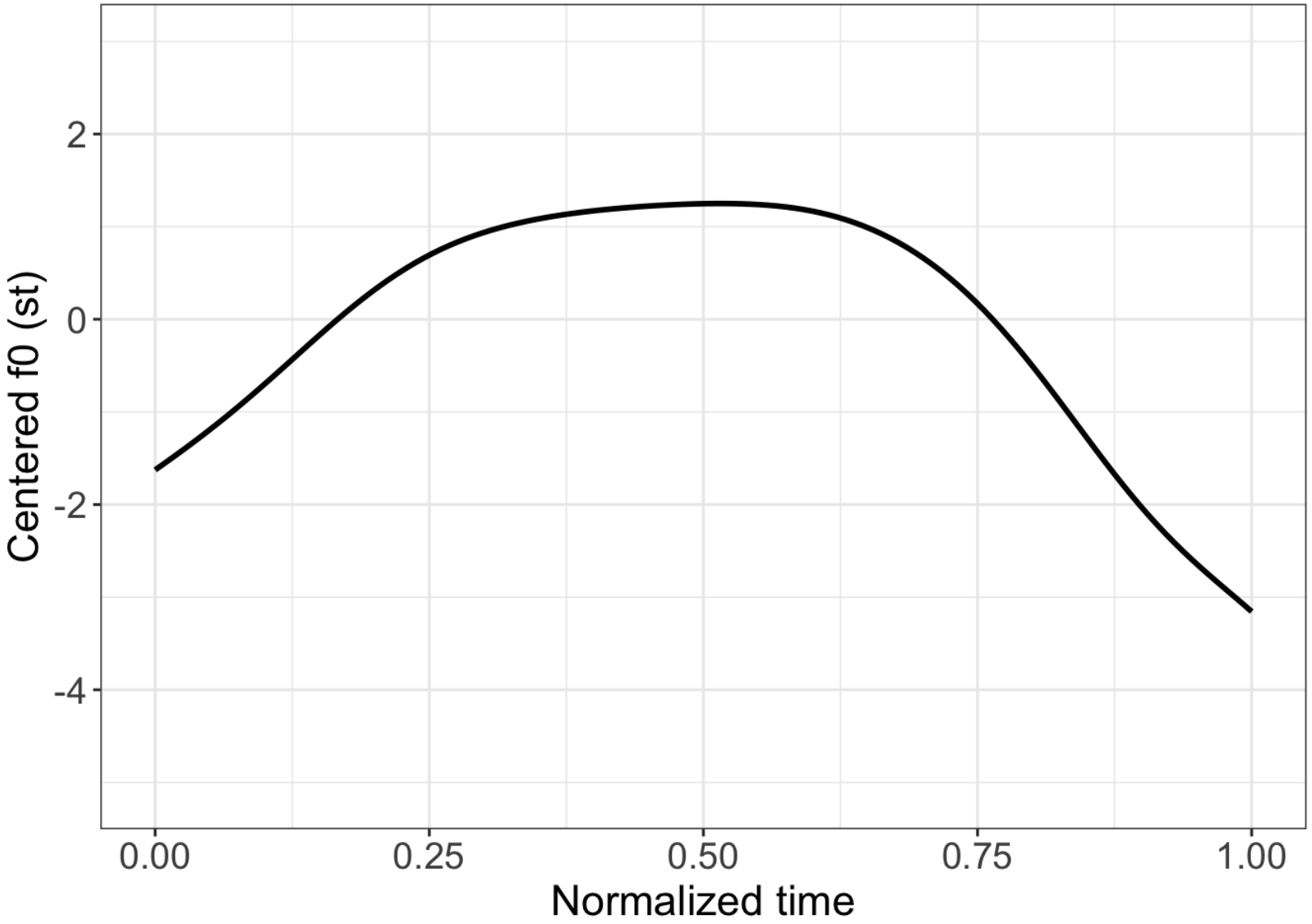
Mixed effects linear regression model:

- Predict sag PC weight from span type (LH or HH)
- By-speaker random intercepts
- Does span type (LH vs HH) have a significant effect on sag PC weight?

Lee et al. 2021, Hughes et al. 2022: difference in sag PC between LH, HH

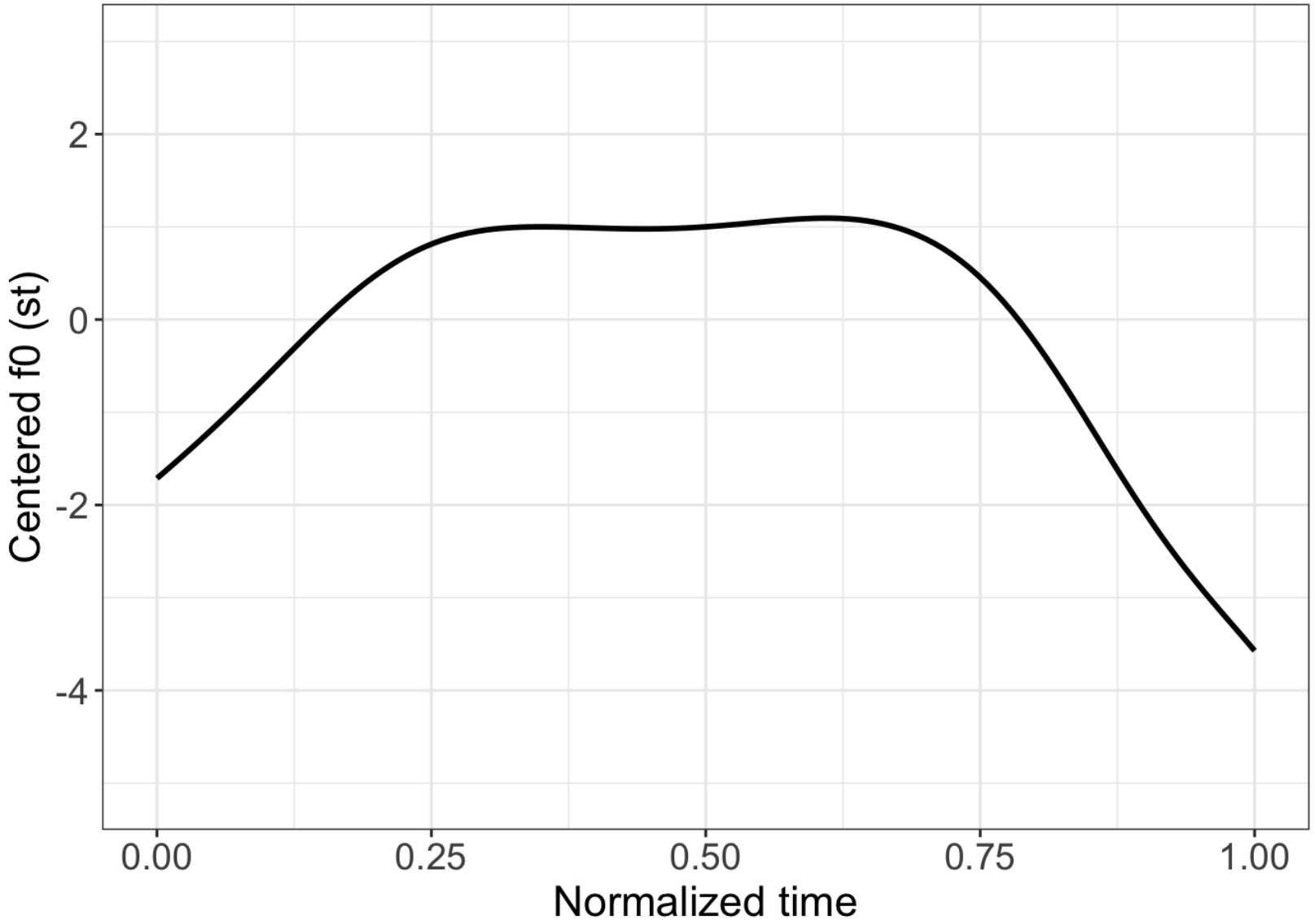
Present work: Replication (+ duration interaction) with small differences from normalization choice

More negative sag PC weight = more sag in f0 contour



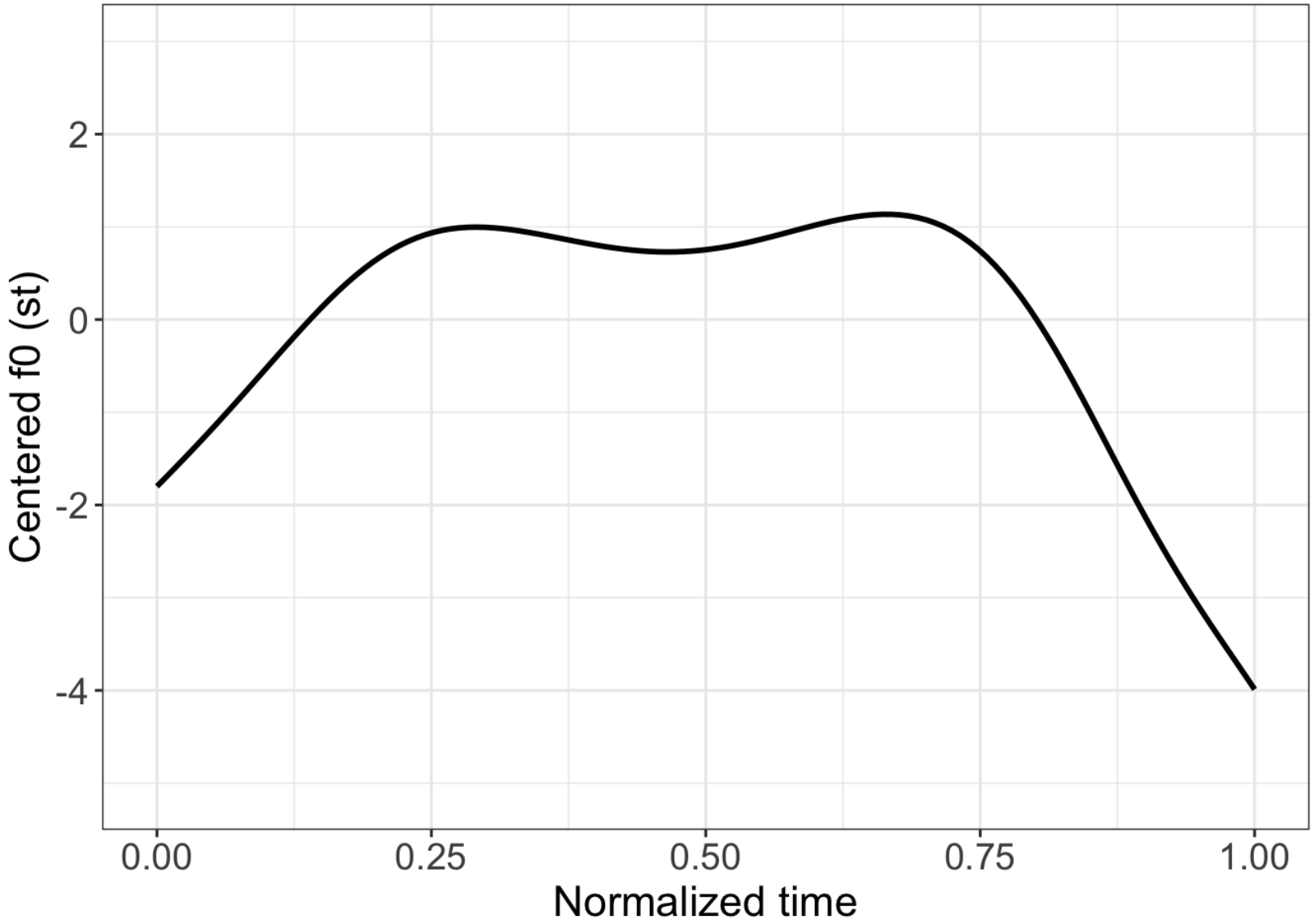
More negative sag PC weight = more sag in f0 contour

Sag PC weight more neg.



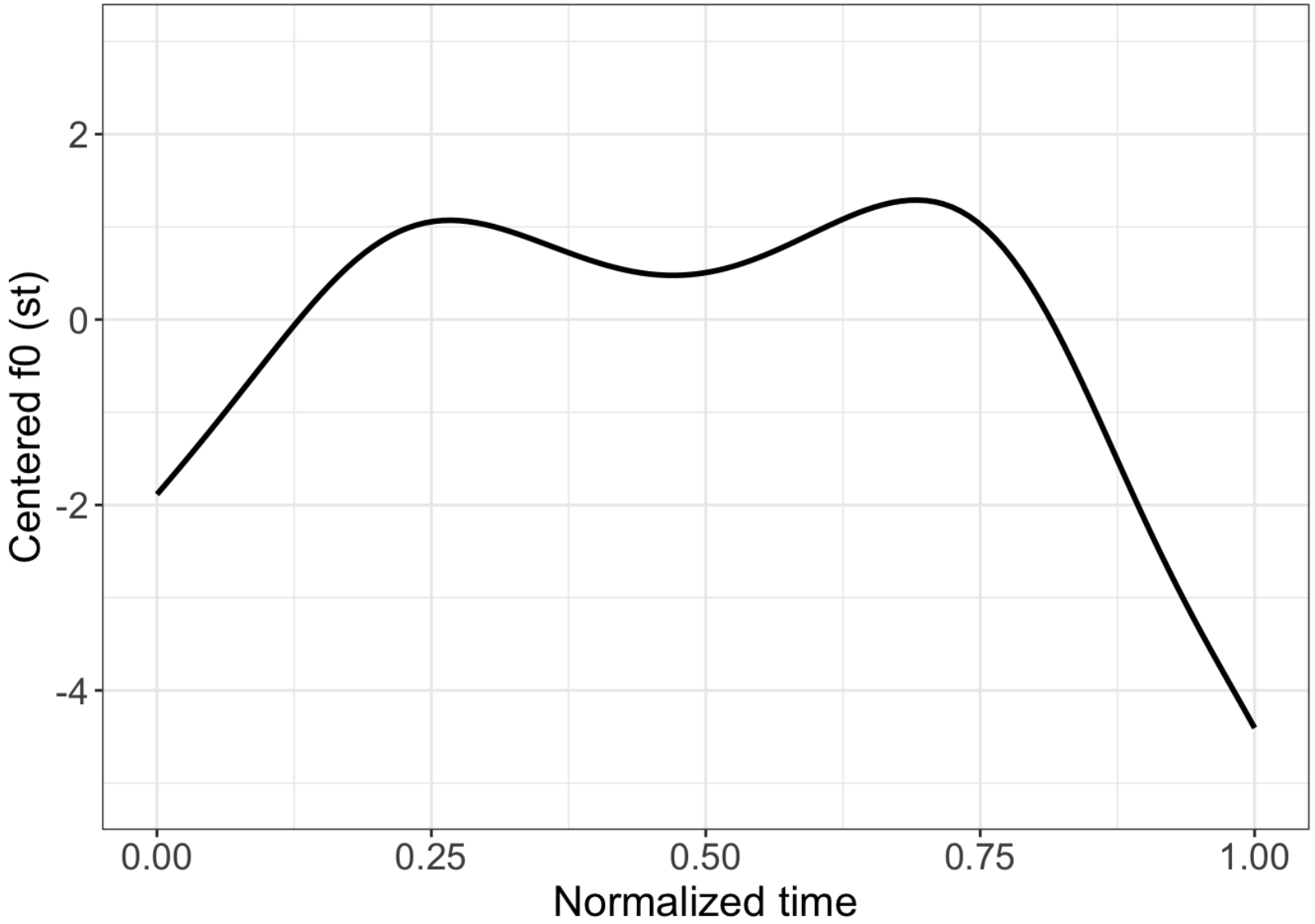
More negative sag PC weight = more sag in f0 contour

Sag PC weight more and more neg.



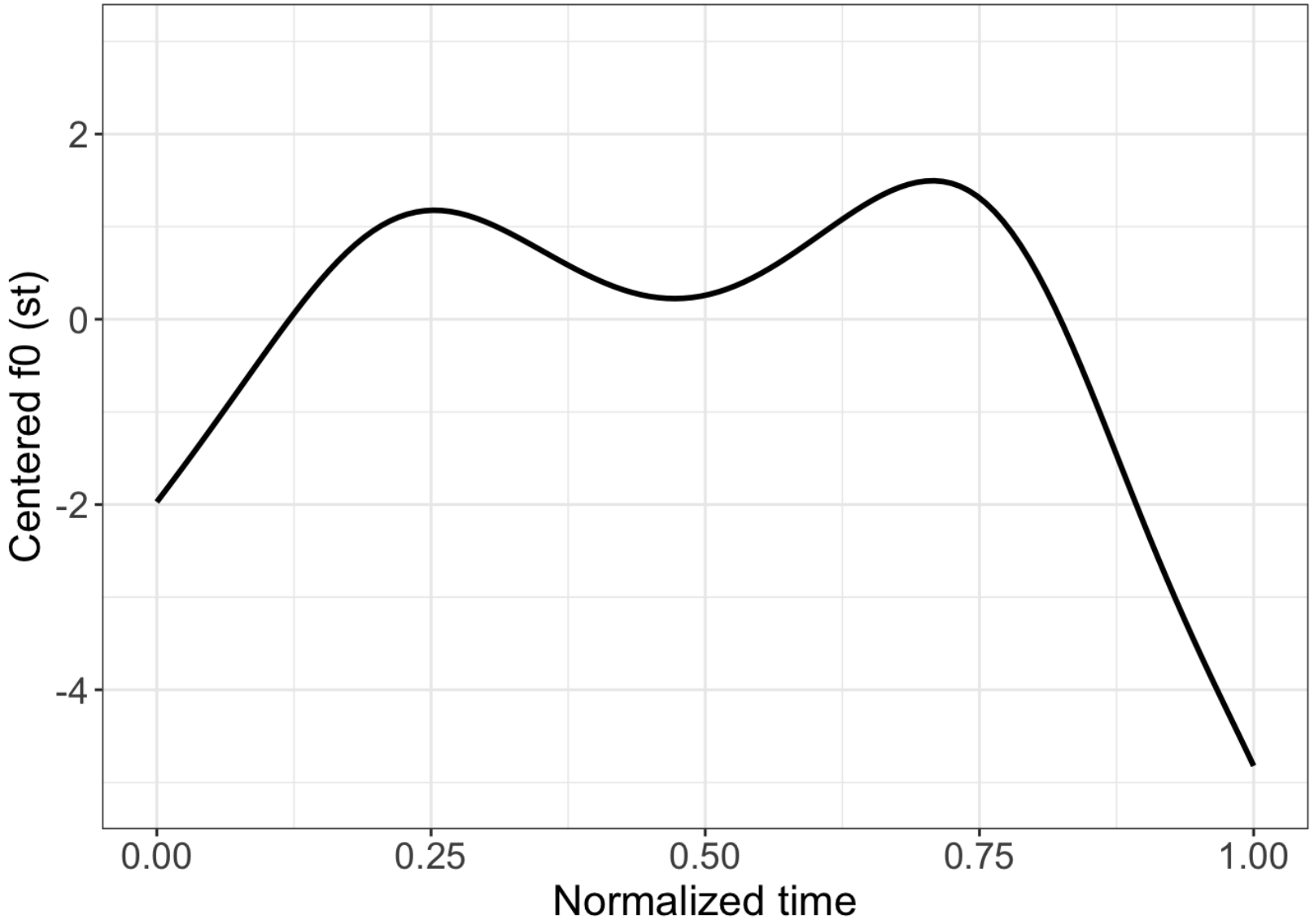
More negative sag PC weight = more sag in f0 contour

Sag PC weight more and more and more neg.



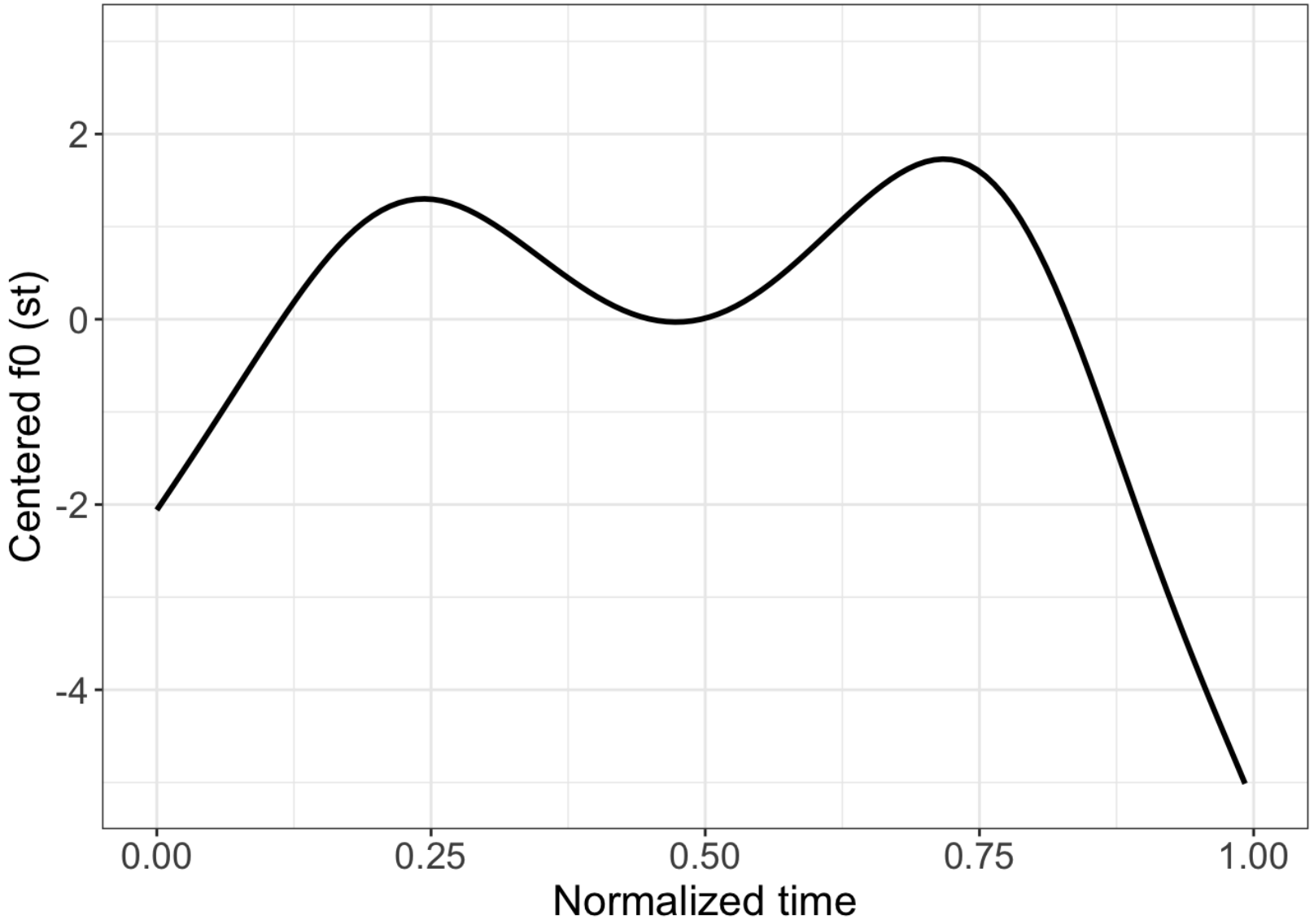
More negative sag PC weight = more sag in f0 contour

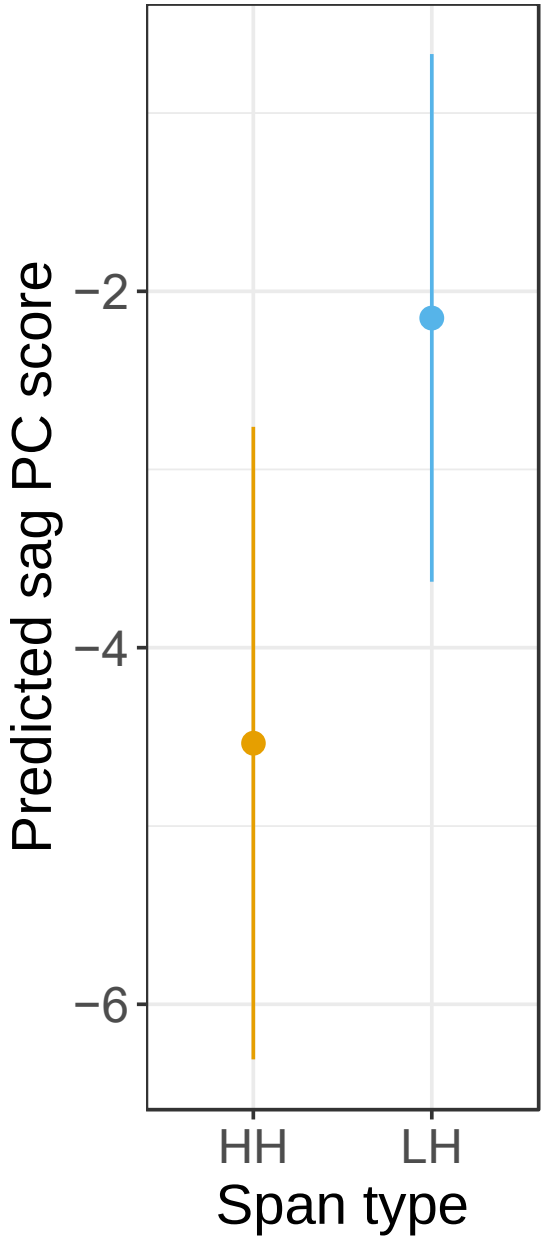
Sag PC weight more and more and more and more neg.



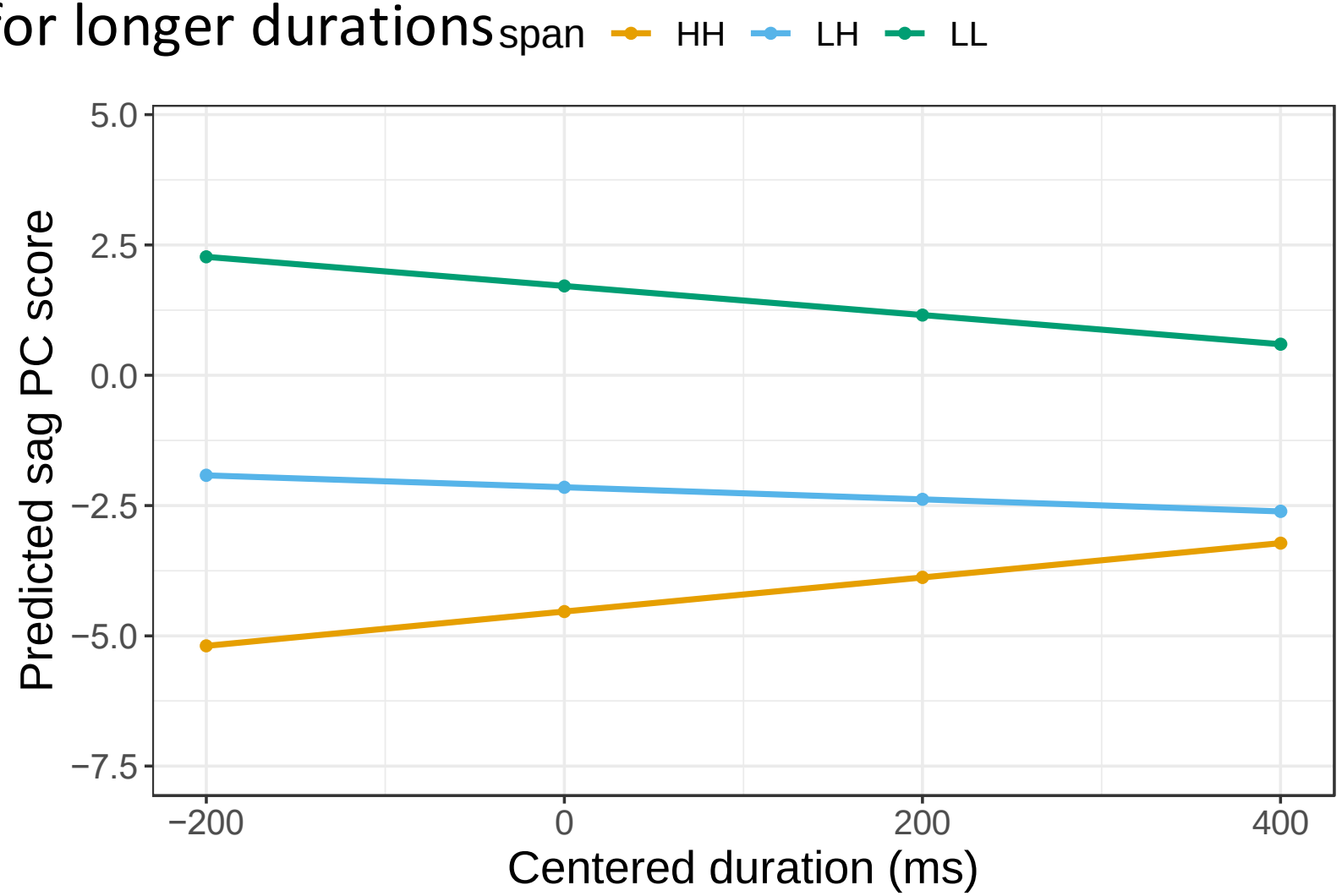
More negative sag PC weight = more sag in f0 contour

Sag PC weight more and more and more and more neg.



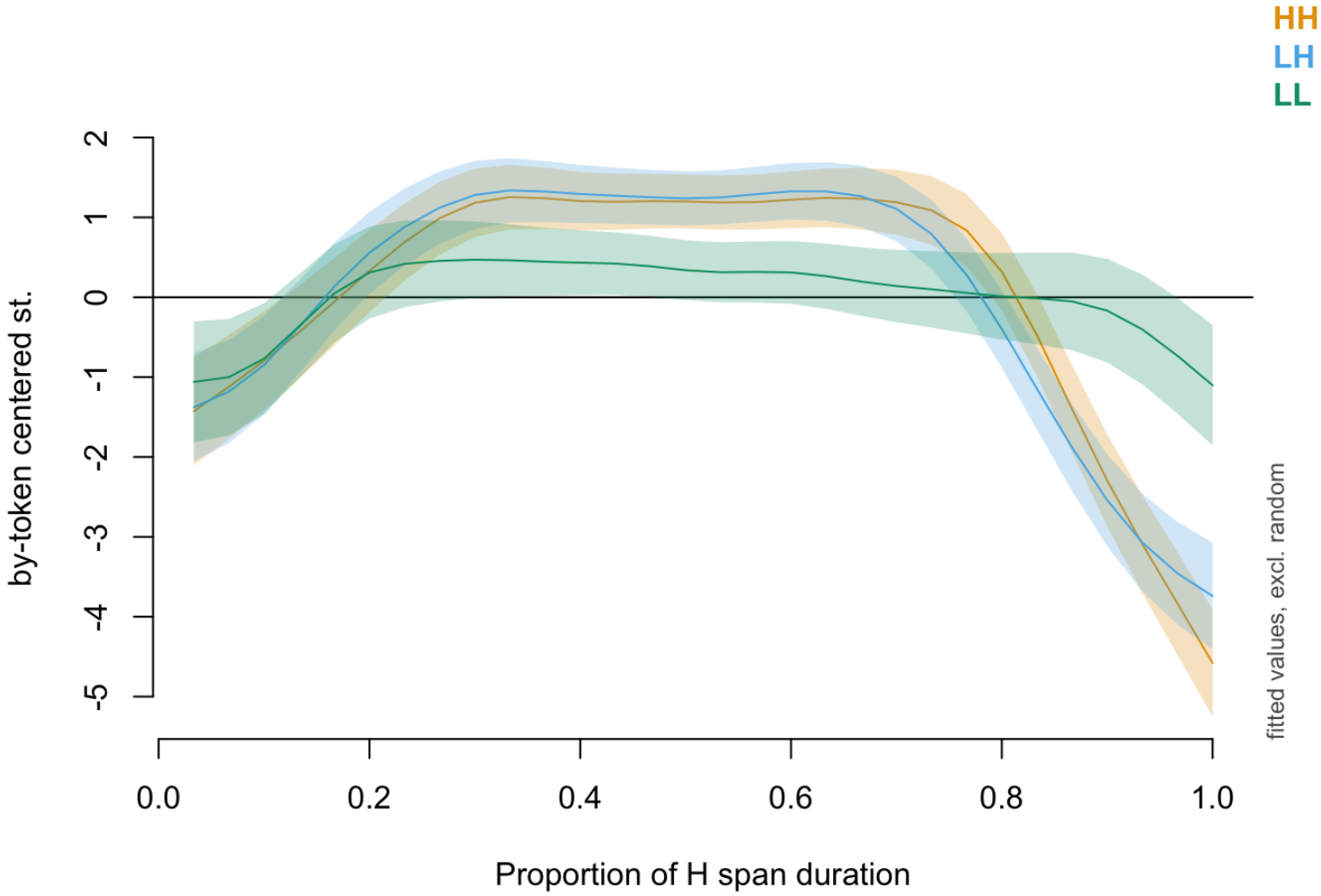


- F0 normalized by speaker z-score
- Span type affects predicted sag PC score
- Duration interaction: Magnitude of difference is smaller for longer durations



Generalized Additive Mixed-Effects Model

- Fit F0 contour over time
  - Model corrections for correlation between timepoints
- Unlike FPCA
  - only produces overall curve, not components like sag
- **No evidence for sag difference between HH, LH curves**

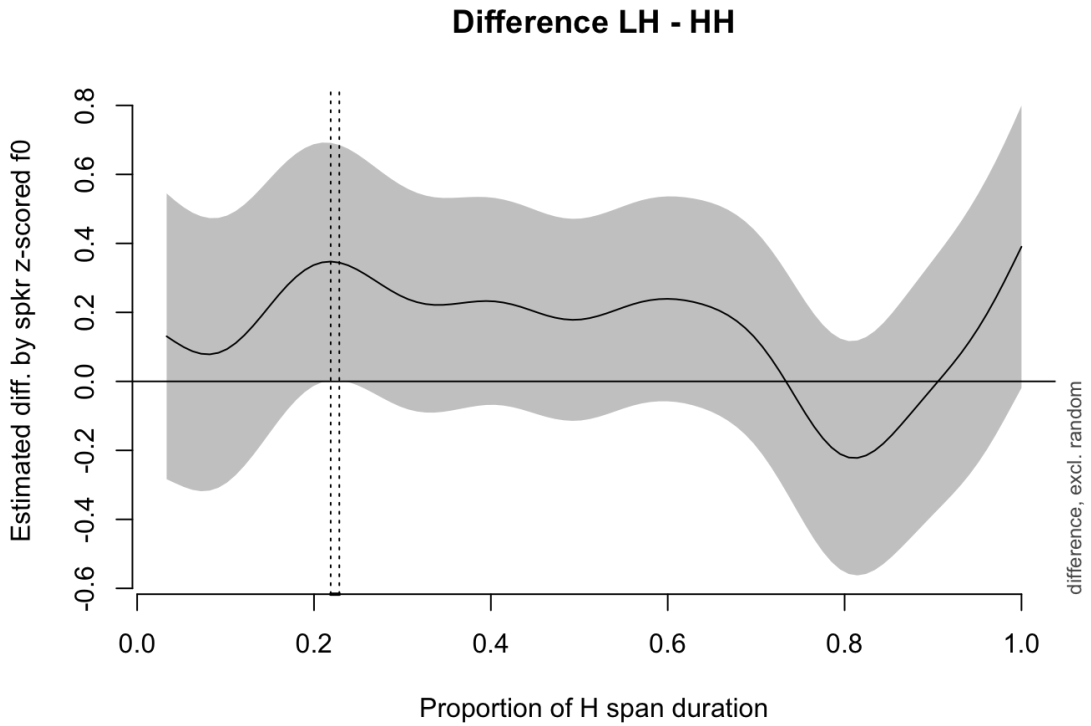


Generalized Additive Mixed-Effects Model

- Differences **besides** sag found depending on F0 normalization choice

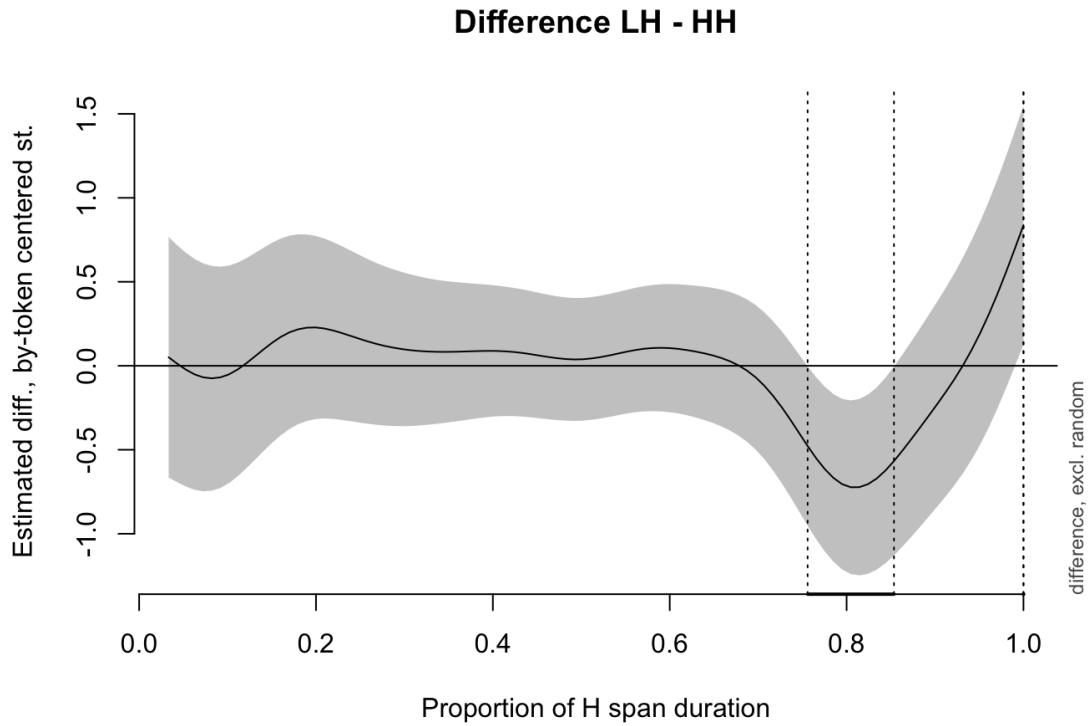
By-speaker normalization:

Rise difference



By-token centering:

Fall difference

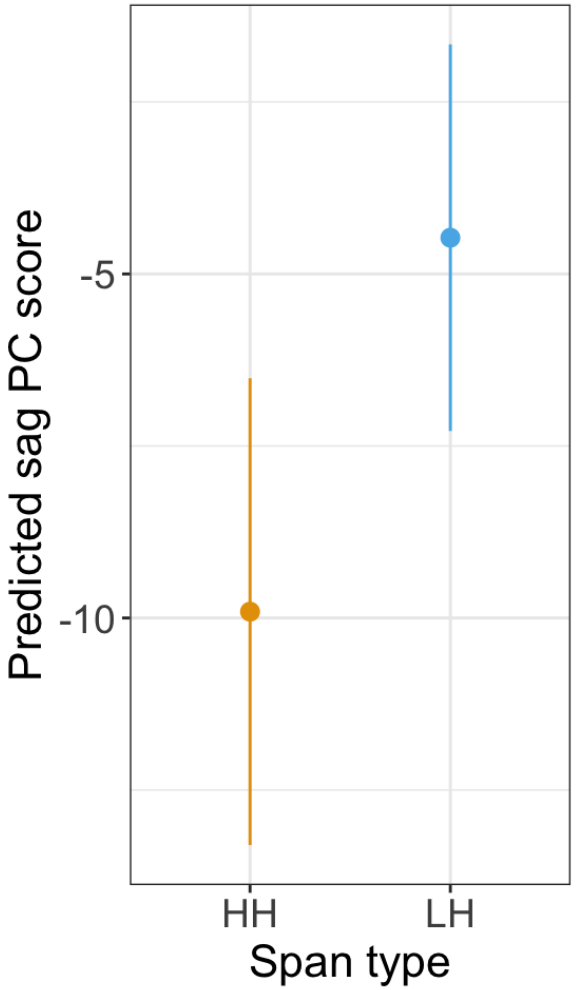


Discussion and Conclusion

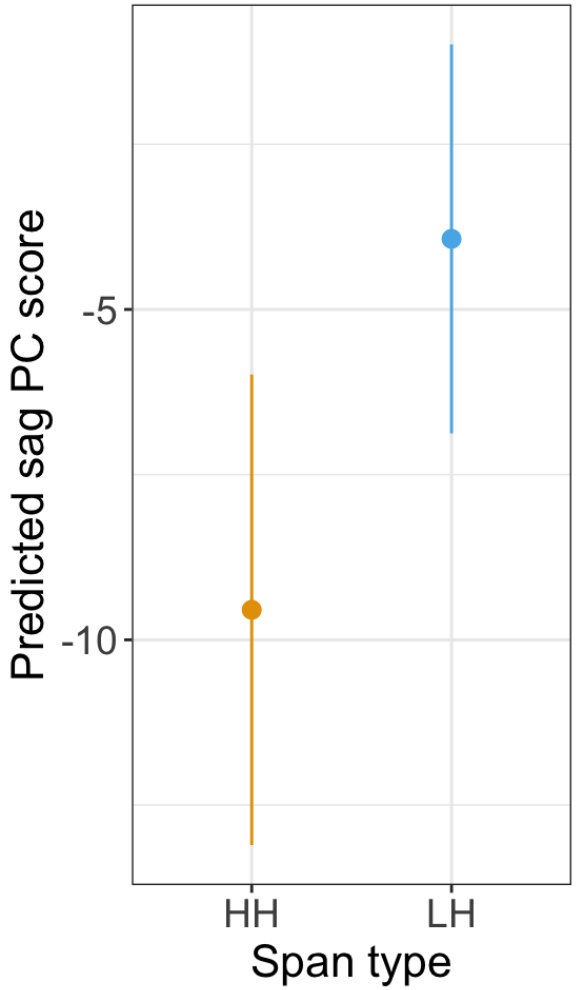
- Understudied: understanding implementation of transition between tonal targets and tonal incomplete neutralization
- Normalization and model choice affect findings
    - Replication of LH, HH sag difference with FPCA
    - No apparent LH, HH sag difference with GAMMs
        - Less control over which component to test: interpretability
        - Small amount of data available
    - Need more work to support one choice over another, e.g. theoretical or perceptual results

Appendix

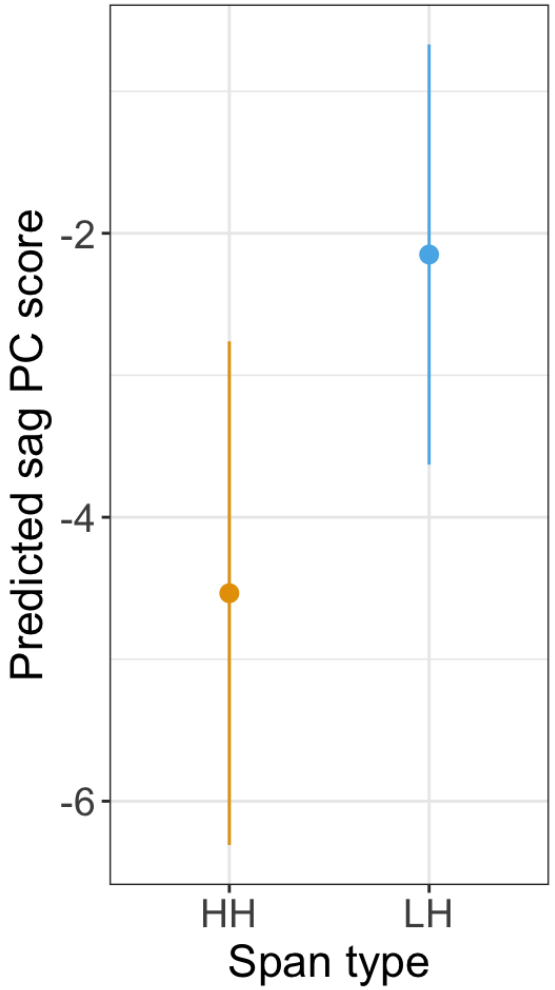
FPCA: HH significantly saggier than LH for all normalizations



By-token centered (st)

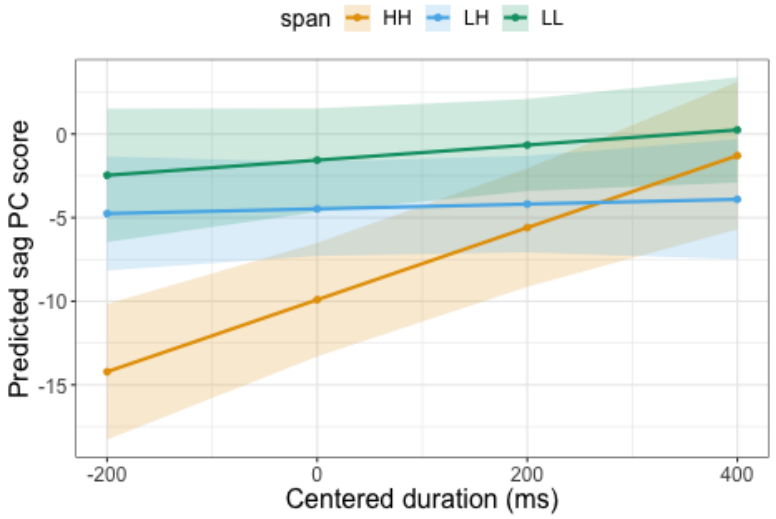


By-speaker centered (st)

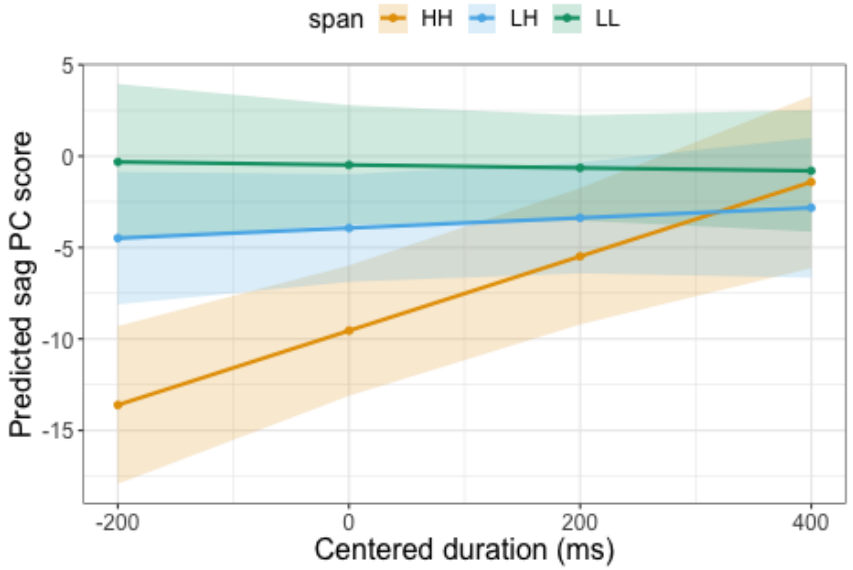


By-speaker z-score (Hz)

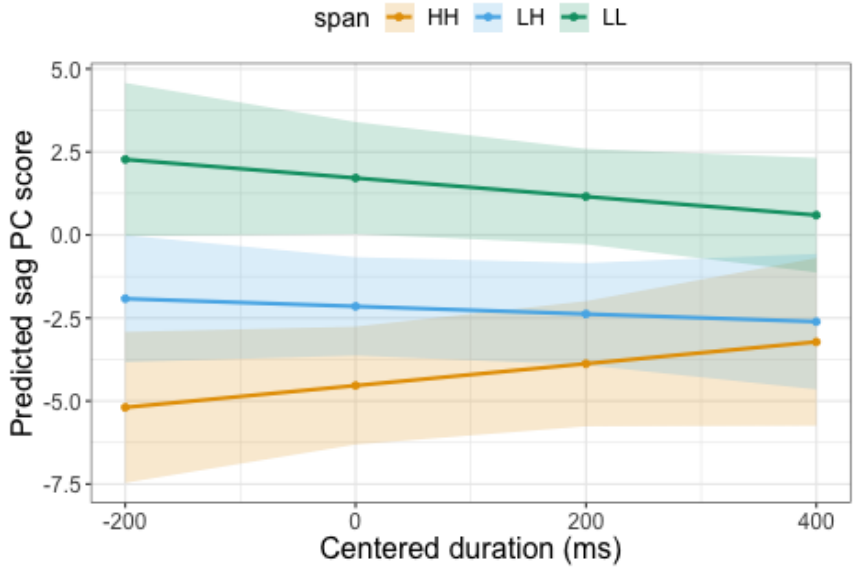
FPCA: Difference in sag between HH and other span types *decreases* with longer durations (all normalizations)



By-token centered (st)



By-speaker centered (st)



By-speaker z-score (Hz): duration interaction not significant for HH vs. LH

FPCA model specification:
sag PC component weight as dependent variable

```
pc.sag.weight ~ span * duration
                + (1|speaker)
                + (1|item)
```

GAMM specification: with autoregressive AR1 structure to take time series dependence in residuals into account

```
# estimate correlation from model
ar1.rho <- start_value_rho(gam.no.ar1)

bam(z.F0 ~ span + duration +
             s(prop.span.dur, by=span, bs="tp",k=15)+
             s(prop.span.dur,speaker,bs="fs",m=1,k=15)+
             s(prop.span.dur,item,bs="fs",m=1,k=15) +
             s(prop.span.dur,speaker, by=span.ord,bs="fs",m=1,k=15),
             rho=ar1.rho, AR.start = start.event,
             discrete = TRUE, family = "scat")
```

FPCA

- Pick function shapes that F0 contours vary the most on
  - Regardless of category
- Can focus on component function shapes of interest (e.g. sag)
- F0 contour shape estimation separate from statistical modeling; regression modeling done on the PC coefficients
- Our case: heavy tails in regression

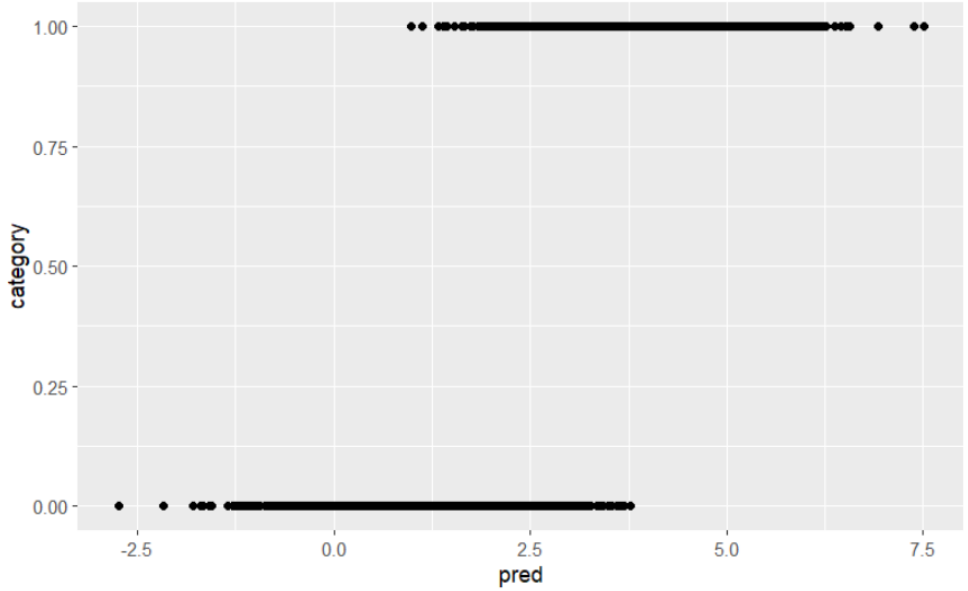
GAMMs

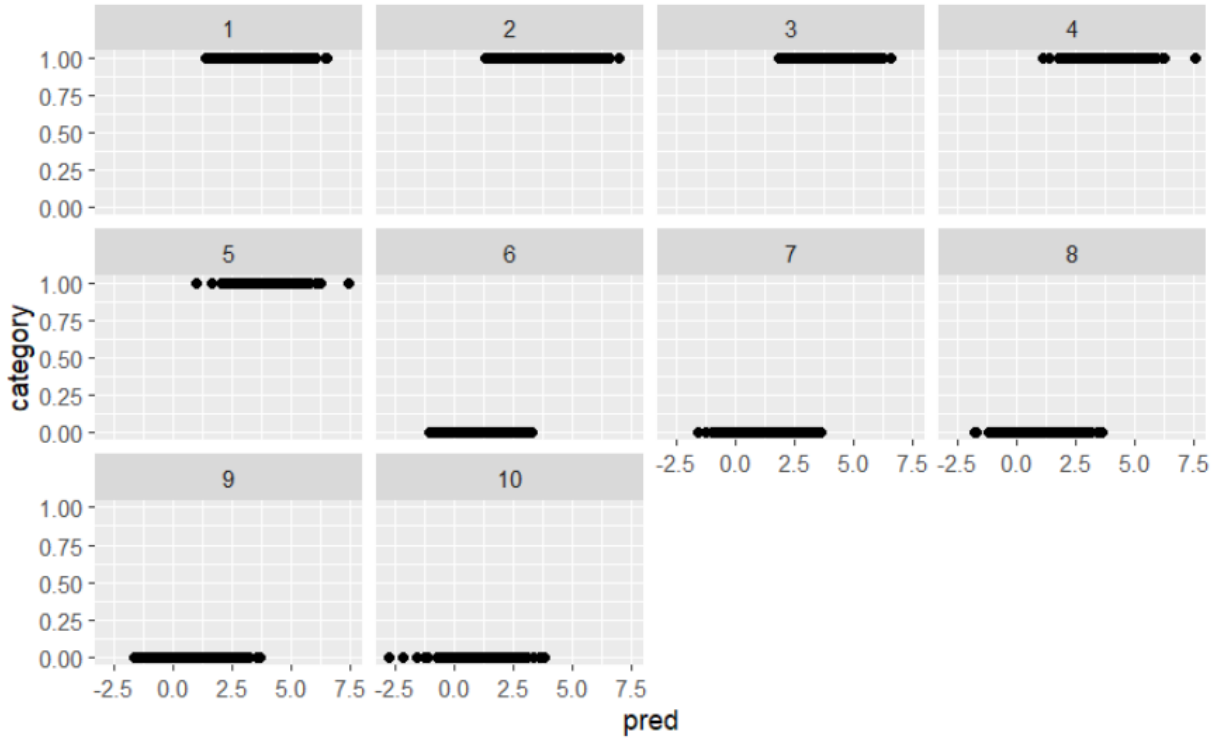
- F0 contour "wiggliness" can be directly conditioned on/interacted with category and other predictors
- Provides quantitative differences in overall contour shape between factor levels
- F0 contour shape estimation and regression modeling done together
  - Regression model requires corrections for correlations in time series data
  - Available tutorials/software for modeling heavy tails

By-Item Random Effects in Logistic Regression: Perfect Predictability

- We originally tried adding by-item intercepts to the FPCA + logistic regression models of Lee et al. (2021) and Hughes et al. 2023
- This led to the LH, HH sag difference being no longer significant
- However, this finding is an artefact of how the Luganda items are defined: each item belongs to one tone span, so item is a perfect predictor of tone span
- The model mainly used the by-item intercept to separate LH and HH
- Logistic regression on simulated data shows that when:
  1. there is a known underlying difference between span types in some predictor
  2. Item ID perfectly predicts span type
  - using by-item intercepts makes the effect of the predictor insignificant

By-Item Random Effects in Logistic Regression: Perfect Predictability





Logistic regression model without by-item intercept: significant difference in predictor between categories

Logistic regression model with by-item intercept: no significant difference in predictor between categories

Challenge: acoustic correlate methodology

Point measurements

- Vowel duration (ms) (Charles-Luce 1985; Port & Crawford 1989; Warner et al. 2004)
- Voice onset time (ms) (Roettger et al. 2014
- Closure duration (ms) (Charles-Luce 1985; Roettger et al. 2014)
- Formants at vowel center (Hz) (Fox & Jacewicz 2009)
- F0 minima and maxima (Hz) (Yuan & Chen 2014)

Trajectories

- Vowel formant contours (Stanley et al. 2021, Hualde et al. 2021)
- Liquid formant contours (Simonet et al. 2008)
- F0 contours (Chen et al. 2013, Gubian et al. 2015)