# Phonetic implementation of phonologically different high tone plateaus in Luganda

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

TAI 1, University of Southern Denmark

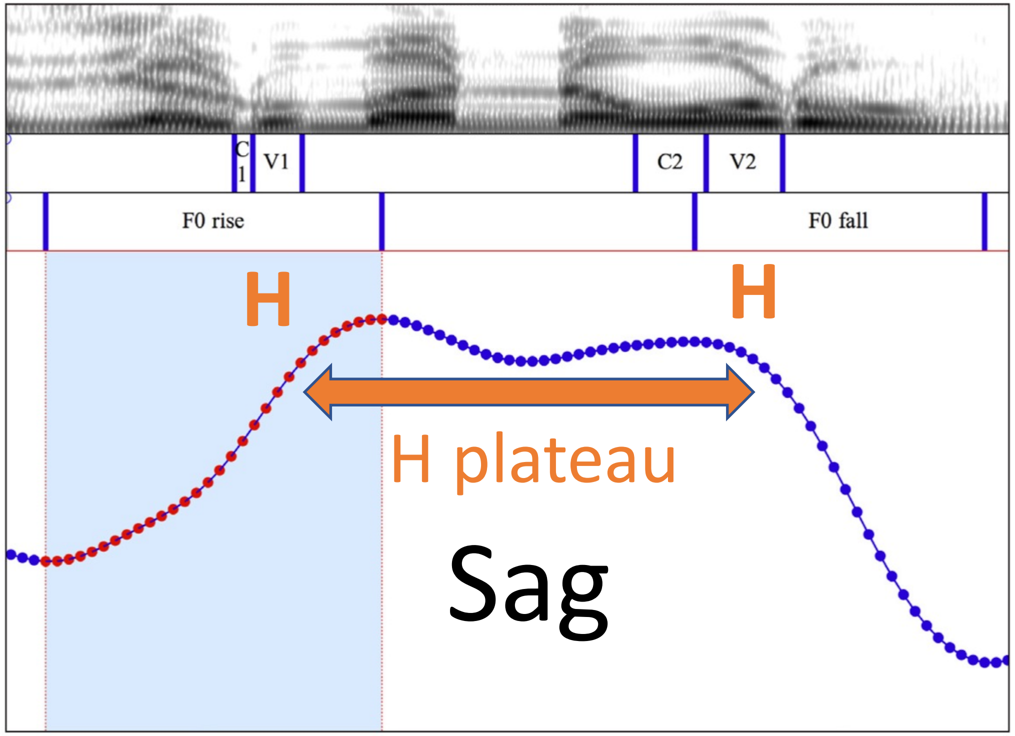
December 6, 2021

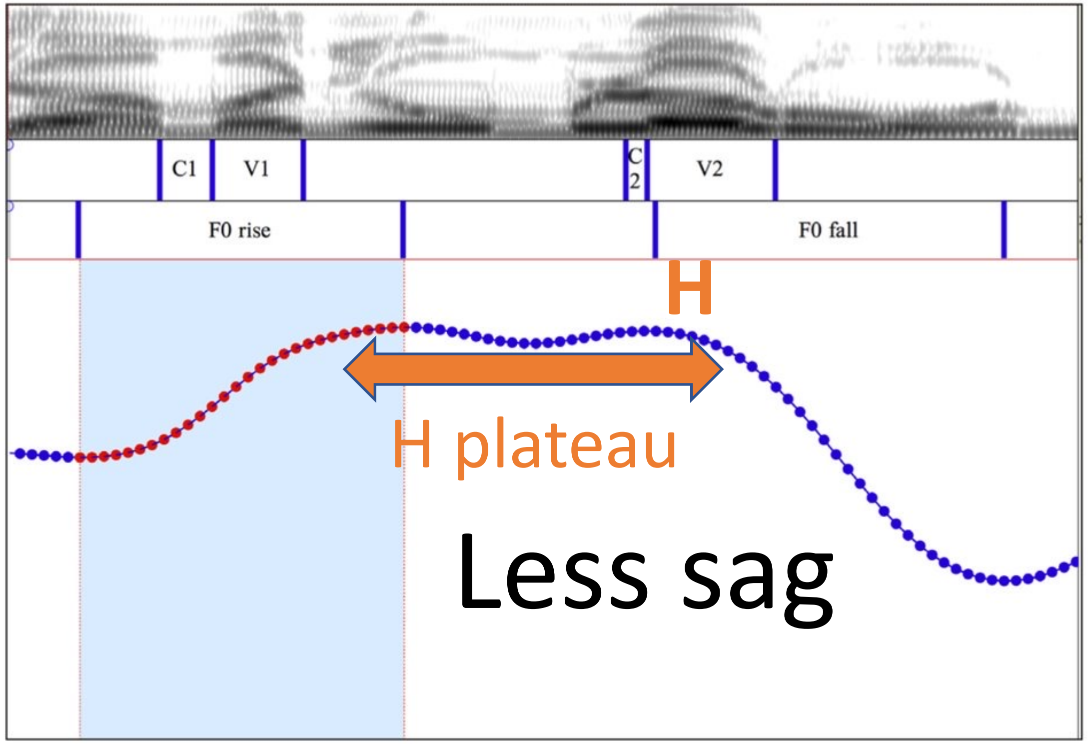
UMass Amherst

# Luganda high tone spans

Do we see a difference in the plateau shape?

Data from Myers et al. 2018




[òmùlèːnzìjà**lúmánːáwó**lòvù]
"The boy bit the chameleon."

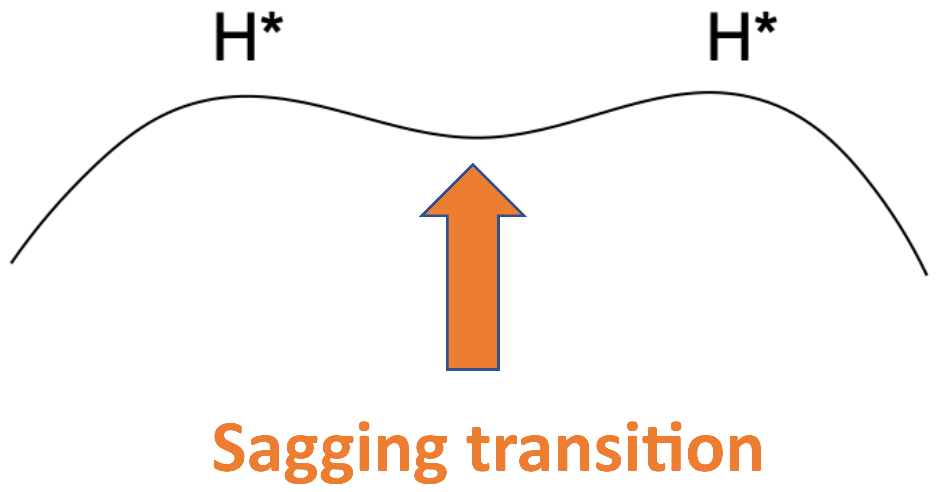
[òmùlàːŋgìràː**máɲóːmúlá**lwòːnò]
"The prince recognizes this mad person."

# Phonetic implementation of high tone spans

- How are high tone spans phonetically implemented in general?
- If we find a systematic difference in the phonetic implementation:
  - The neutralization is incomplete
- There has been a lot of work on incomplete neutralization with segments, but not so much on tone

# Autosegmental Metrical (AM) Theory

- Focus has been on tonal targets and turning points rather than transitions
- Possibility for interesting findings if we look at the characterization of the transitions between targets
- Linear interpolation between unlike targets (e.g. H & L)
- Pierrehumbert 1980- "sagging" transition as a function of distance between H* targets separated by tonally underspecified syllables
- Little work on transition between like targets in tone languages, relevant for cases of tone spreading



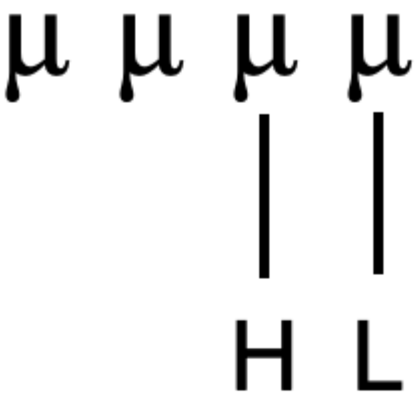
# Luganda tone spans

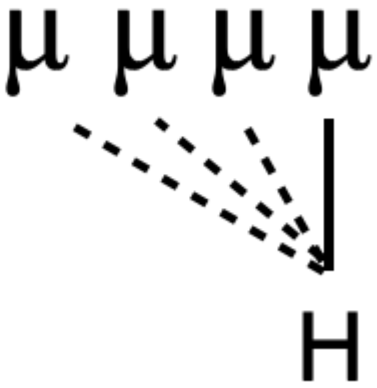
Short tone span | Long tone spans

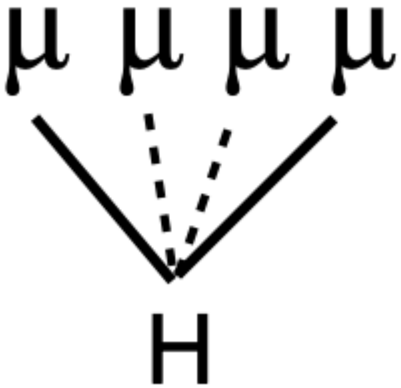
Lexical | Intonational

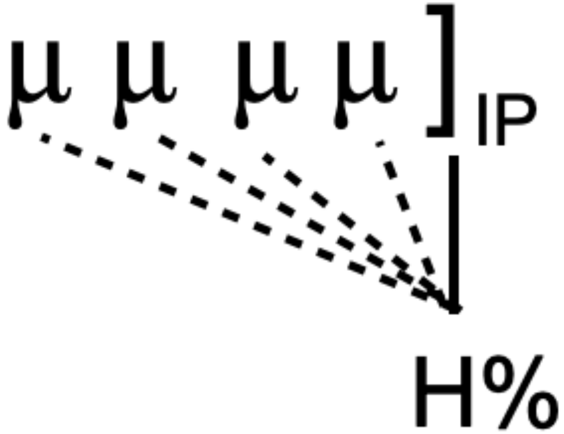
HL LH HH LL

[òmùlèːnzàː**nó**nèɲːàmà] [òmùlàːŋgìràː**máɲóːmúlá**lwòːnò] [òmùlèːnzìjà**lúmánːáwó**lòvù] [òmùlàːŋgìràː**lámúlóːmúlímí**]



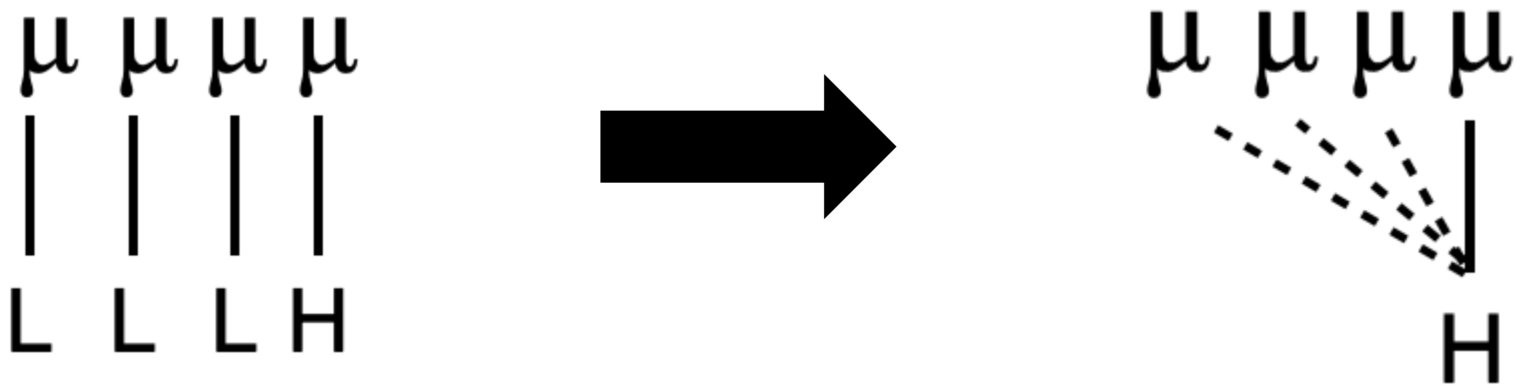



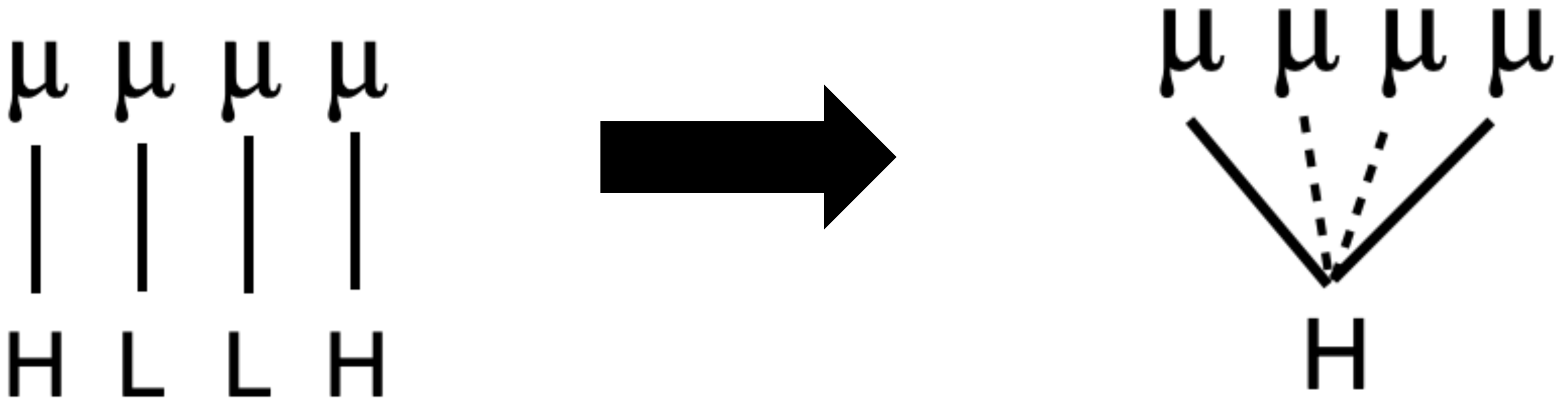
# H tone spread

Hyman & Katamba 2010

**LH:** High Tone Anticipation (HTA)



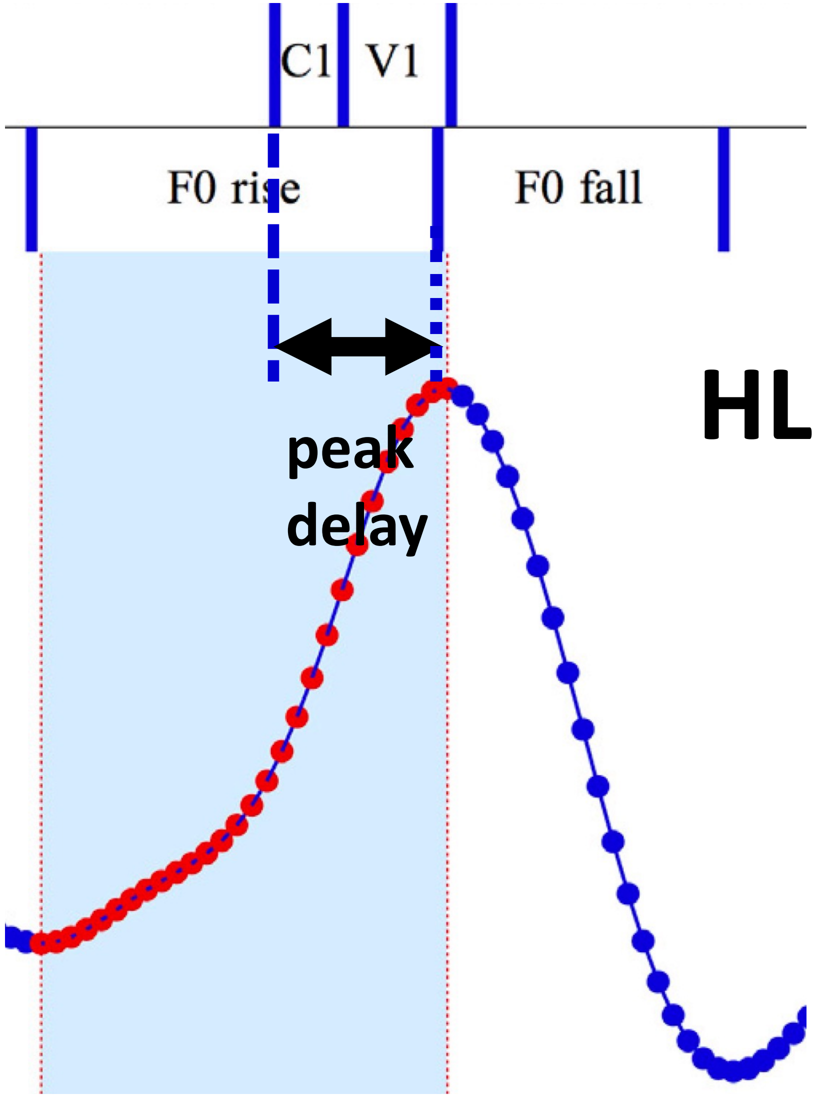

**HH:** High Tone Plateau (HTP)



# Data

- Data from Myers, Selkirk & Fainleib 2018 kindly shared by Scott Myers
- Production experiment with 10 native speakers of Luganda
- Examined f0 level and timing

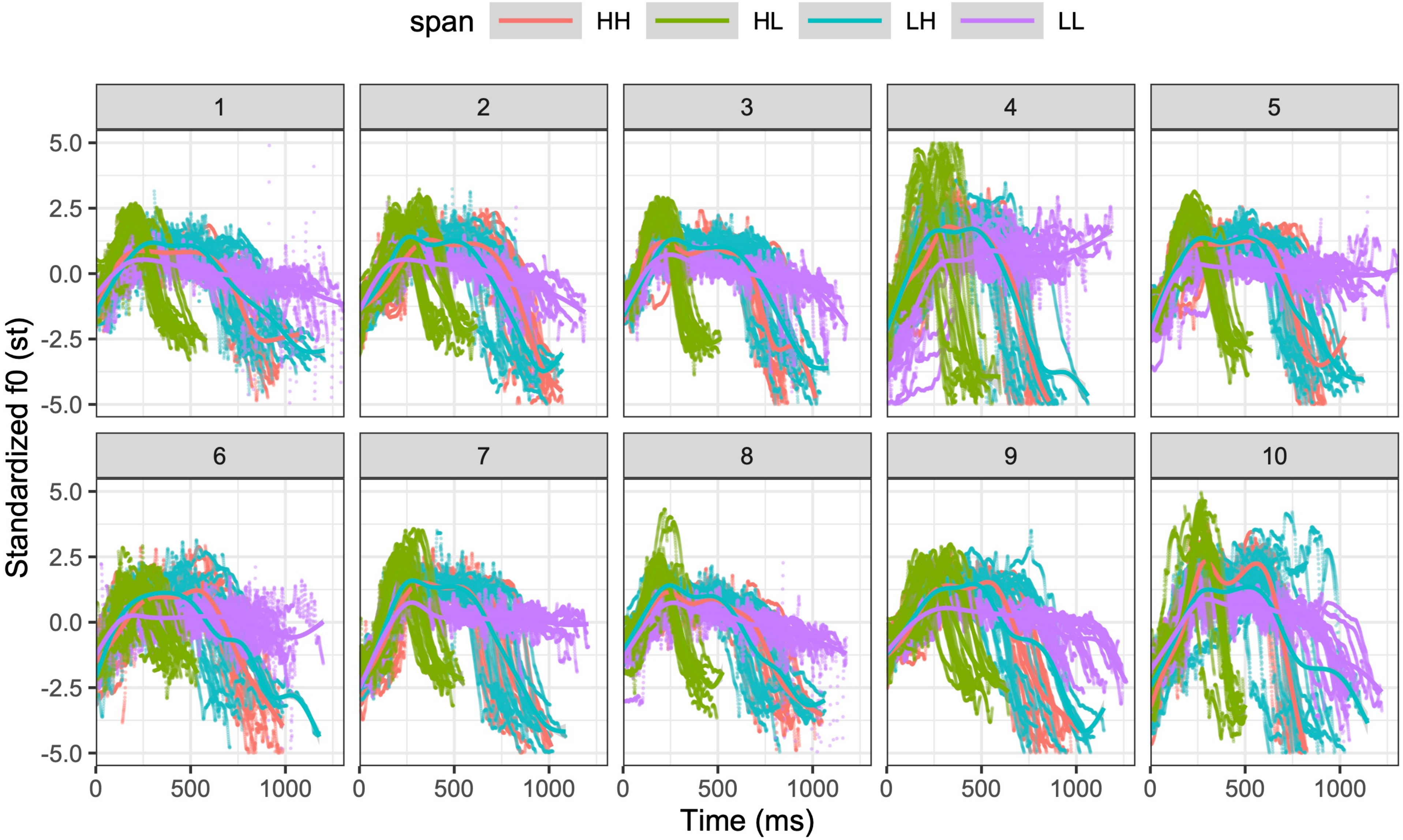
- Less peak delay for HL compared to long spans




- Lower f0 level for intonational H span compared to lexical H span


Myers et al. 2018

# F0 contour shapes by span and speaker




Our study: what do we find when we consider the **curve shape**, or *transitions* between f0 targets?

# Functional Principal Components Analysis (FPCA)

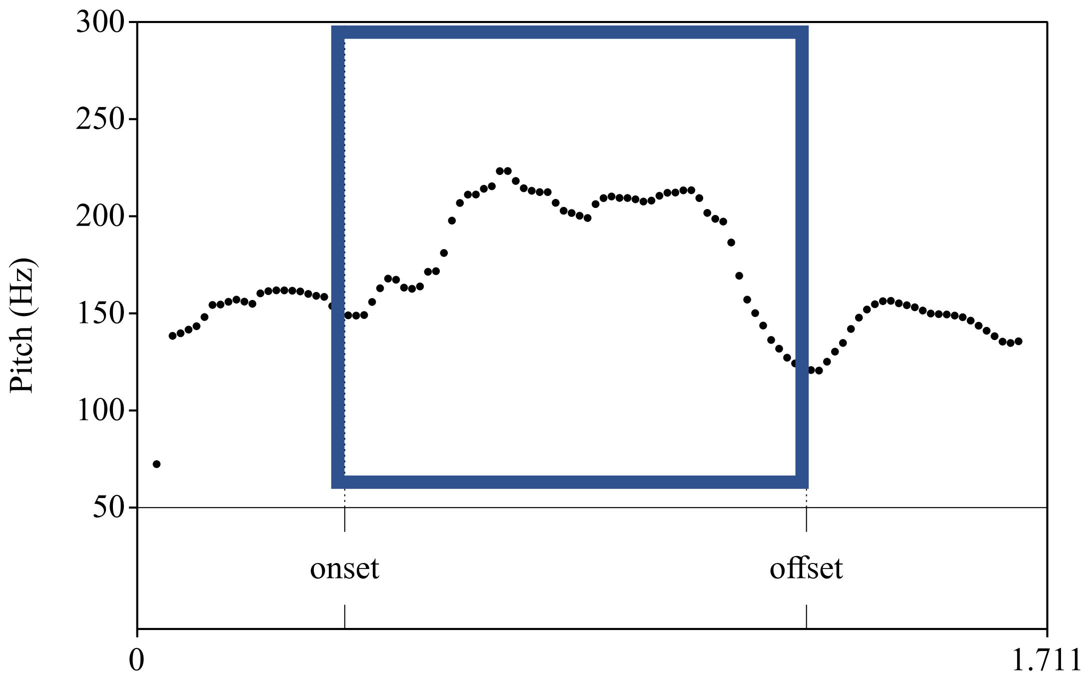
- Finds principal component functions (PCs) that characterize variation in the data (the f0 contours)
- Each f0 contour in the data can be approximated by a weighted sum of the component functions

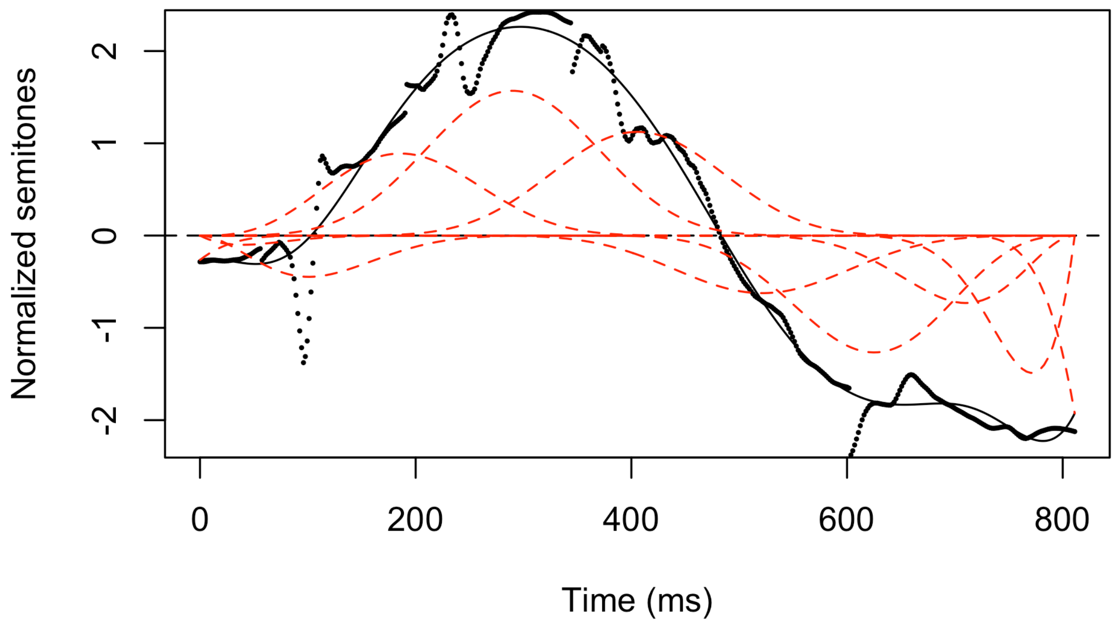
$$f(t) \approx \mu(t) + s_1 \cdot PC1(t) + s_2 \cdot PC2(t) + \ \dots$$

- Data-driven and limiting researcher degrees of freedom: span labels are not provided, and we use all f0 contours instead of choosing only the particular span types LH and HH
- Emergent from the data, not dependent on theoretical assumptions
- Allows us to test theoretical assumptions

# Methods

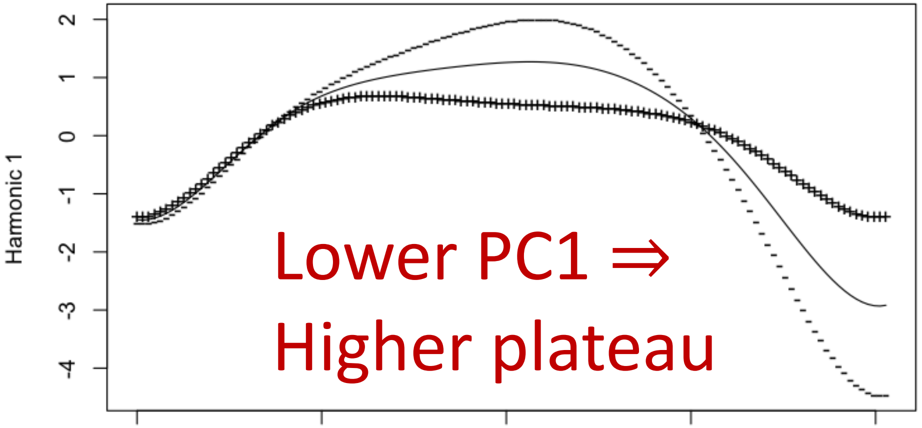
- F0 extracted using VoiceSauce (Shue et al. 2011) with STRAIGHT algorithm (Kawahara et al. 1998)
- Analyzed from rise onset to offset as marked in Myers et al. (2018)
- Functional data analysis in R using *fda* package (Ramsay et al .2021)
- b-spline basis functions for F0 contour smoothing and parameterization
- Mixed effects regressions with span type as dependent variable and principal components (PCs) as fixed effects (and vice versa)



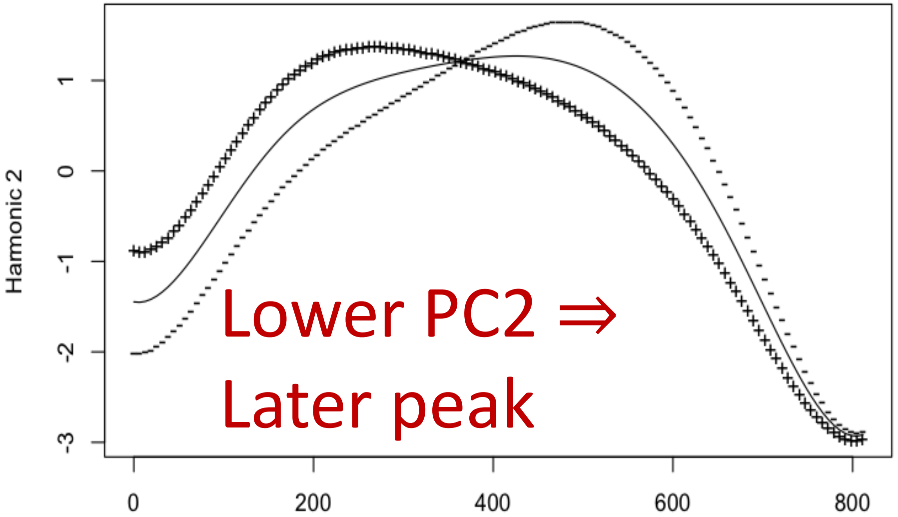



# Principal Components

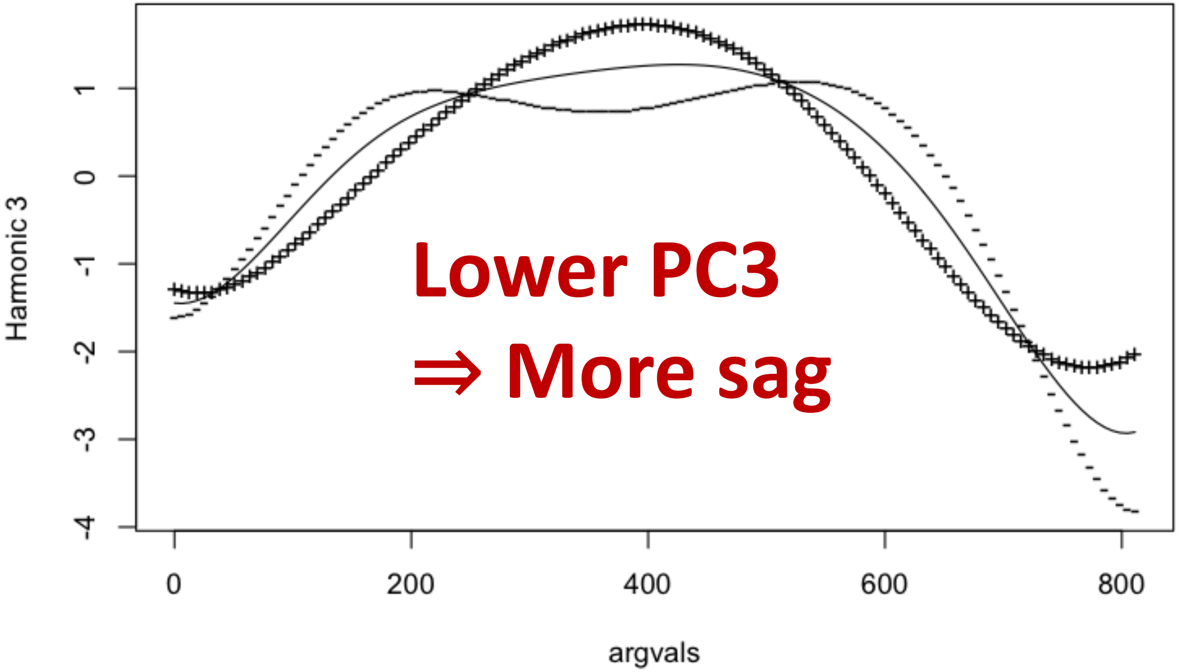
## PC1: 48.5% of variability



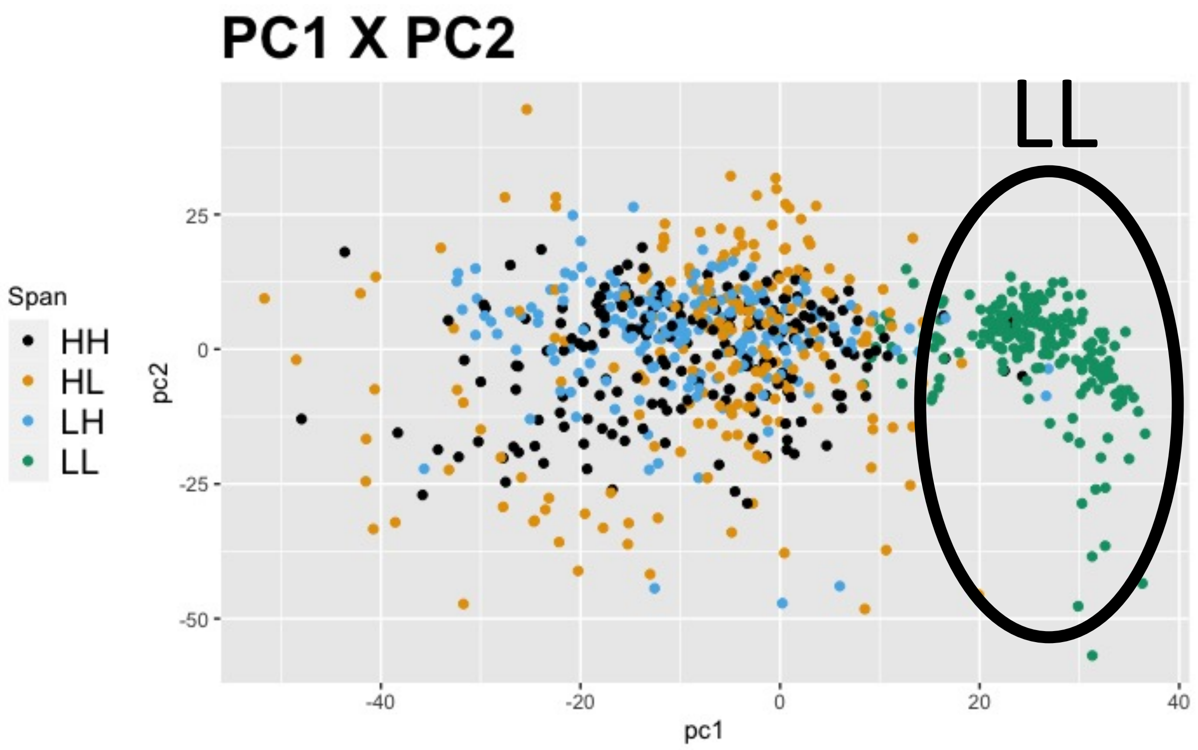

## PC2: 23.5% of variability

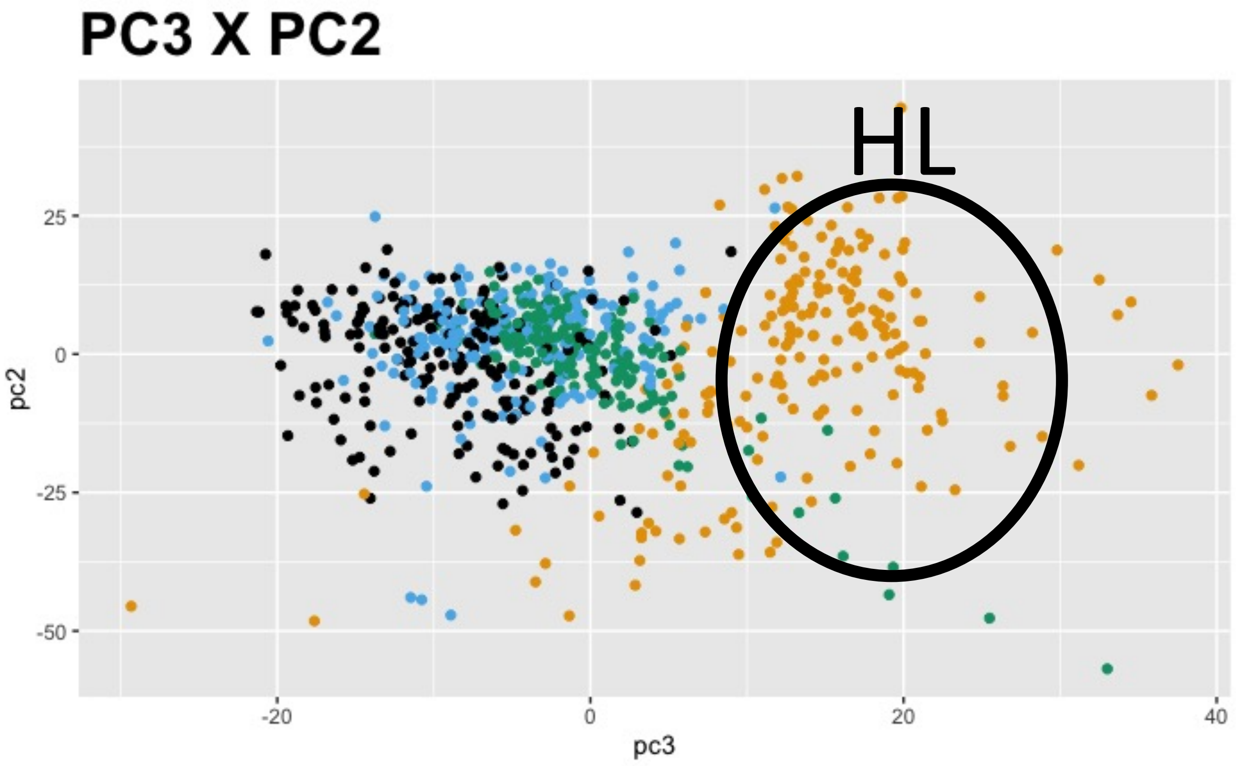



## PC 3: 16.6% of variability



# Replicating Myers et. al, 2018

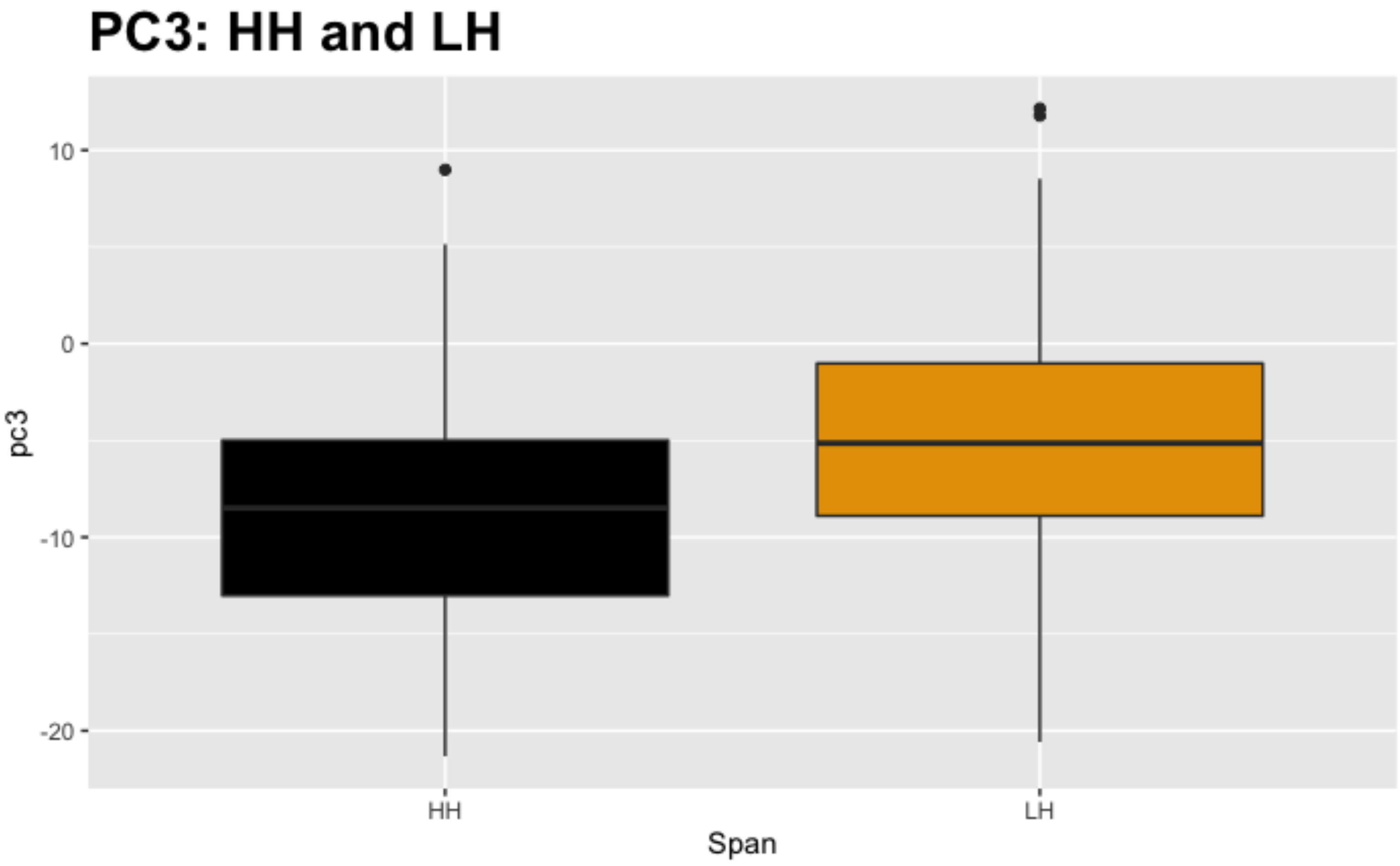



High PC1: LL has a lower peak
LL = intonational high tone span

High PC3: HL has no sag
HL= short span, no plateau

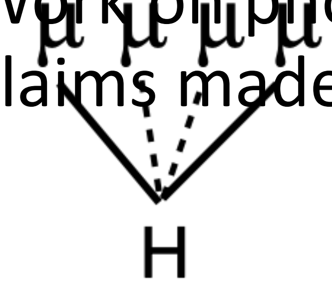
# Low PC3: HH has more sag than LH



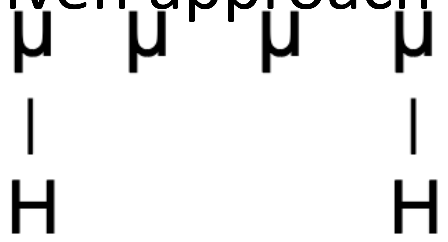

- Duration of each tone span was included as a factor in the regression model, but PC3 was not subsumed by duration
- It wasn't the case that longer span had more sag regardless of span type
- One of the PCs computed without HL still characterized the amount of sag
- There was a significant difference in that PC between HH and LH

# Discussion and Conclusion

- Our findings suggest that HH and LH, which both result in a high tone span, differ in their phonetic implementation
- A further step toward understanding phonetic implementation of H tone spans
- Potential evidence for incomplete neutralization of tone spans
- Phonetic implementation invites us to think about other phonological representations
- Work on phonetic data using a data-driven approach can evaluate theoretical claims made about phonology




Also compatible?:



# Selected References


Gubian, M., Torreira, F., & Boves, L. (2015). Using Functional Data Analysis forinvestigating multidimensional dynamic phonetic contrasts. Journal of Phonetics, 49, 16–40.

Hyman, L. M., & Katamba, F. X. (2010). Tone, syntax, and prosodic domains in Luganda. *ZAS Papers in Linguistics*, *53*, 69-98.

Kawahara, H., Cheveigne, A. D., & Patterson, R. D. (1998). An instantaneous-frequency based pitch extraction method for high-quality speech transformation: revised TEMPO in the STRAIGHT-suite. In *Fifth International Conference on Spoken Language Processing*.

Myers, S., Selkirk, E., & Fainleib, Y. (2018). Phonetic implementation of high-tone spans in Luganda. *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, *9*(1).

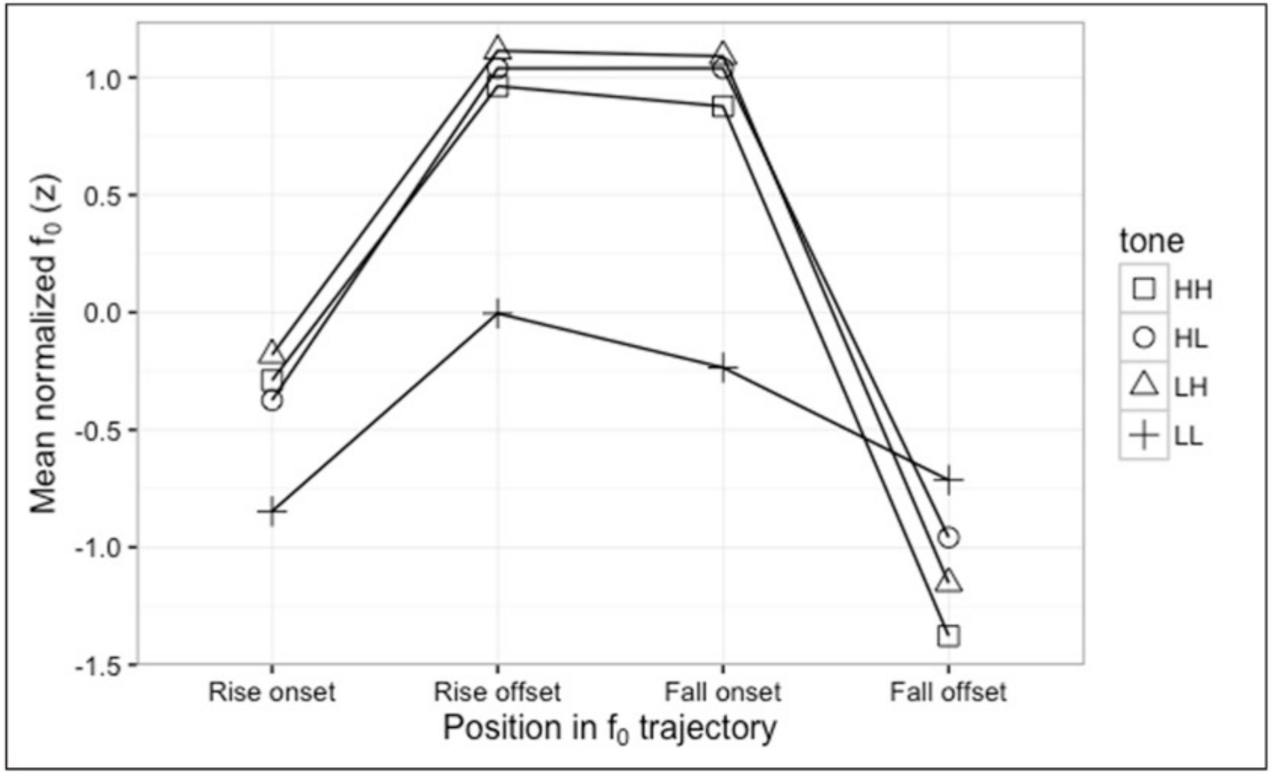
Pierrehumbert, J. 1980. The phonology and phonetics of English intonation. PhD Dissertation, MIT.

Ramsay, James O., Hooker, G., and Graves, *S.* (*2009*), *Functional Data Analysis in R and Matlab,* Springer, New York.

Shue, Y.-L., et al. 2011. Voicesauce: A program for voice analysis. Proceedings of ICPhS XVI.

# Methods in Myers et al. 2018

- Measured:
  - f0 at rise onset (1st pitch point followed by a point w/ higher f0)
  - rise excursion (f0 value at rise offset minus the value at rise onset)
  - plateau excursion (f0 value at rise offset minus the value at fall onset)
  - fall excursion (f0 value at fall onset minus the value at fall offset)

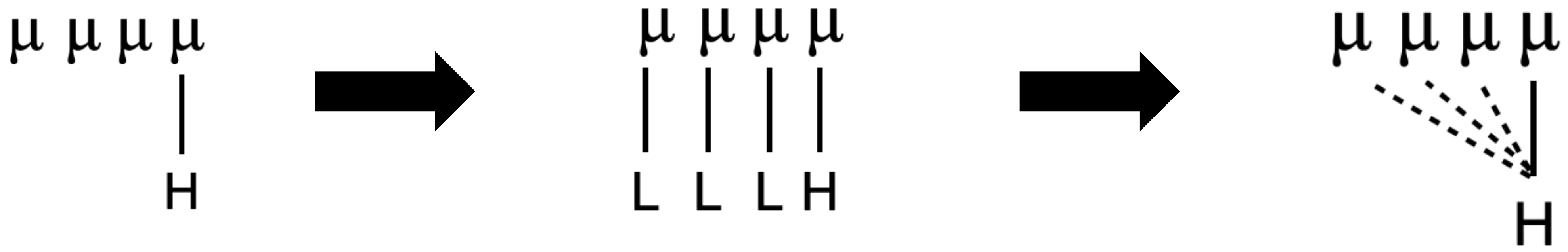


# H tone spread

Hyman & Katamba 2010

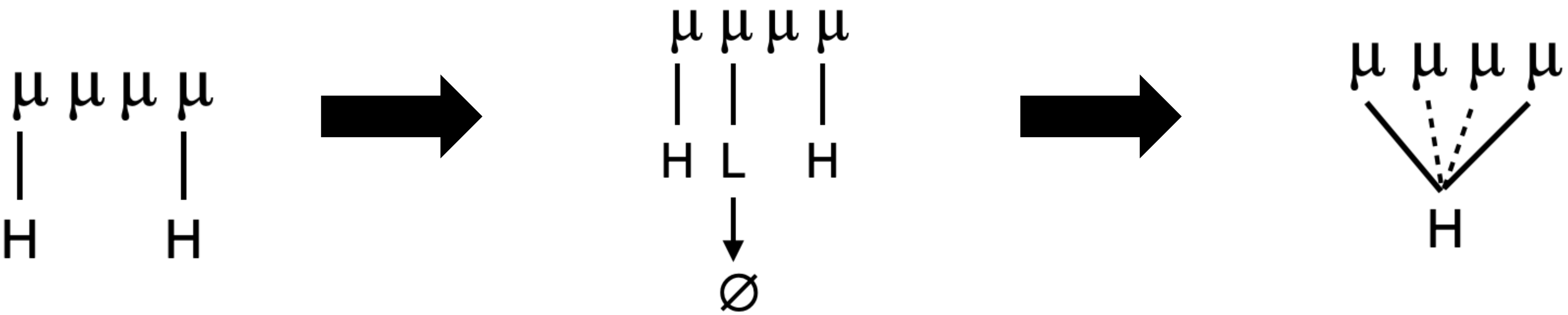
## High Tone Anticipation (HTA)

Underlying: Intermediate: Surface:




## High Tone Plateau (HTP)

Underlying: Intermediate: Surface:

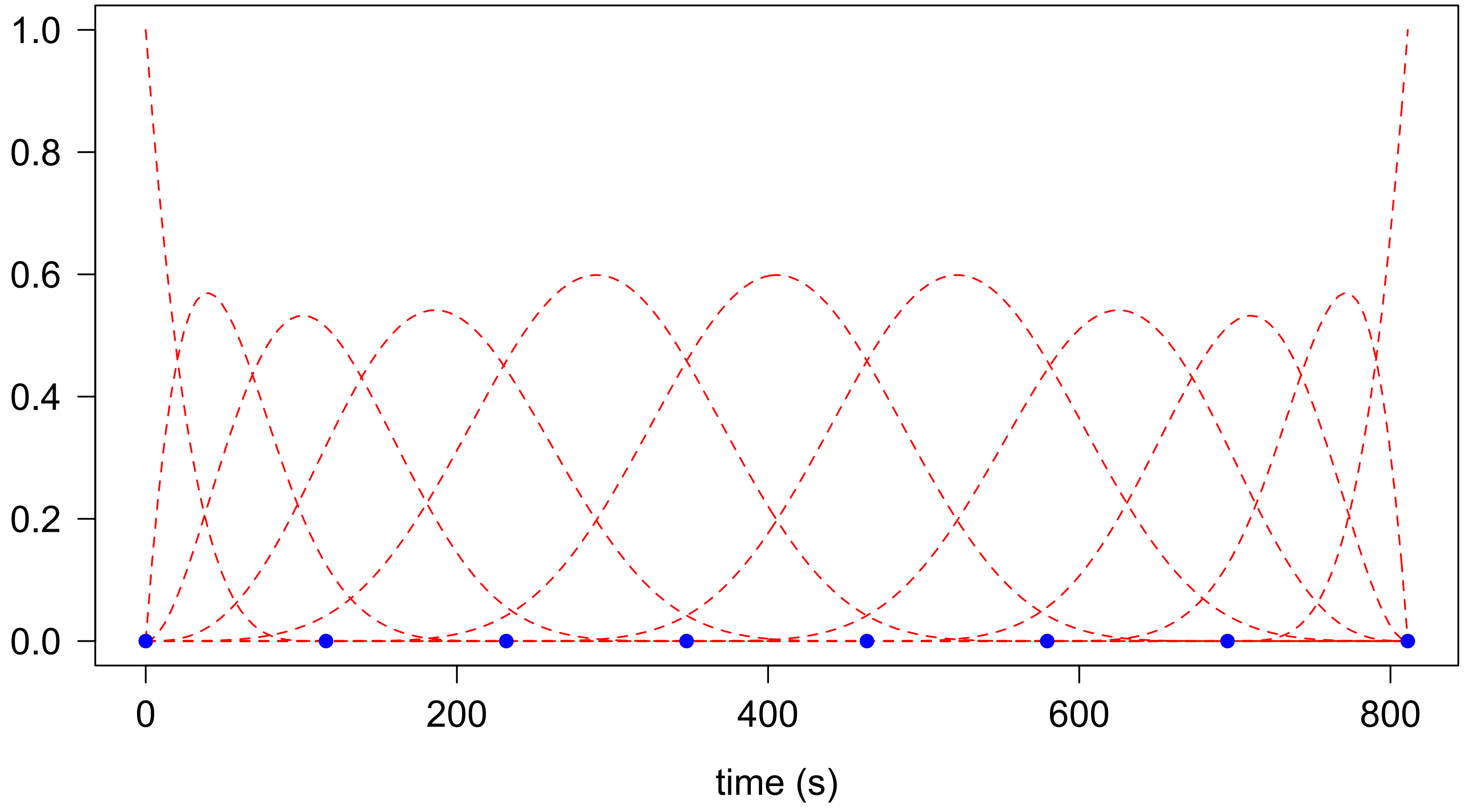


# Discussion: what level phonetics allowed to look at?

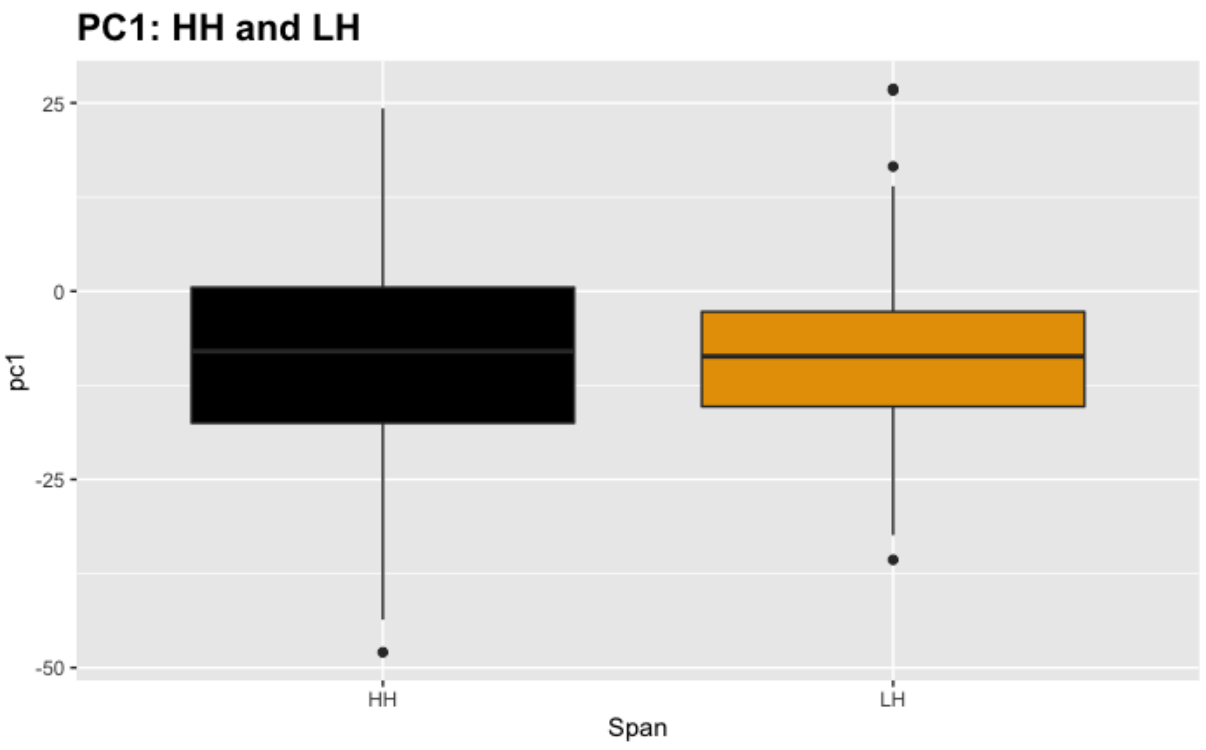
- Our results potentially raise questions about what level of representation is subject to phonetic implementation
- If it's the surface, post-lexical level, why do we see a difference between LH and HH spans?
- If underlying or intermediate level, it differs from the classical model where the phonetic module can only depend on the surface representation, not the underlying representation (see Aaron Braver 2014 for a review relevant to English /t/ and /d/ flapping)
  - Alternative approaches: allowing phonology more control over phonetic implementation, a 'projection' relation between phonological features and phonetic output, exemplar theory

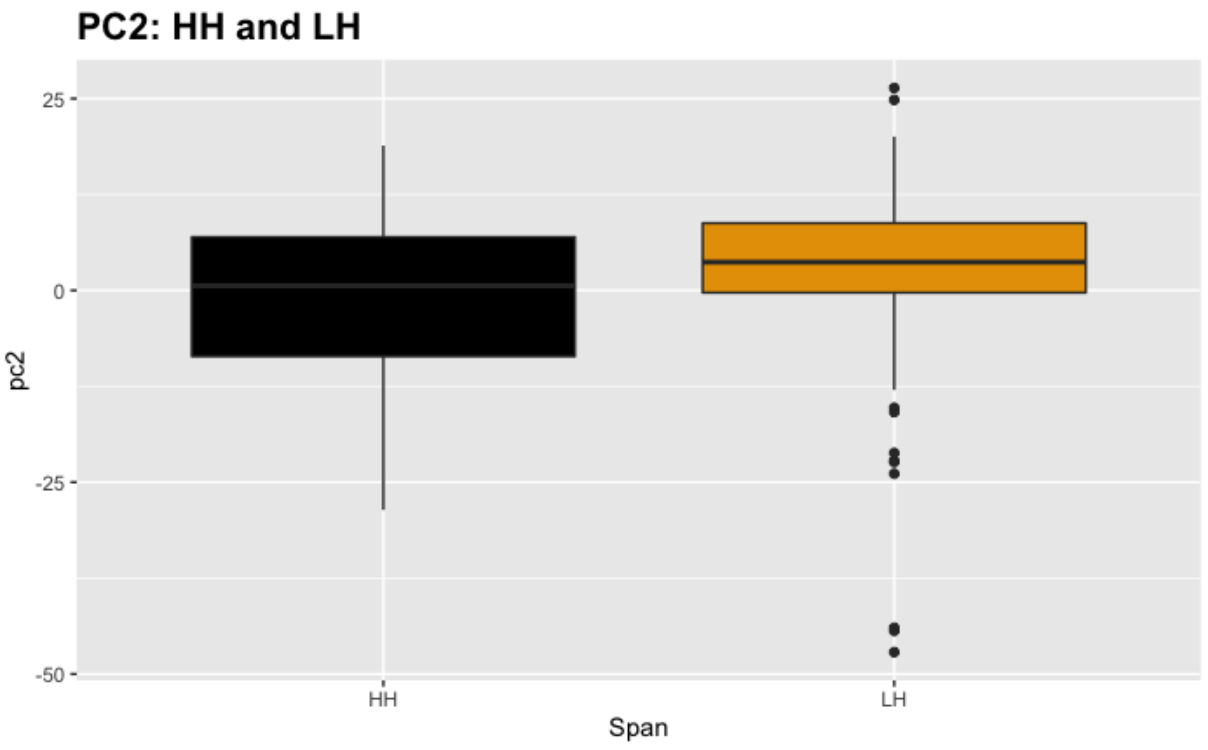
# FDA Settings

- Implemented using R package fda (Ramsay, Hooker & Graves 2009)
- 8 knots, order 5 B-splines
    - Rising/falling of sag on the order of 100ms, spans on average about 800ms
- Penalization for rate of curvature change (Lfdobj = 3), with a weight of lambda = 10^6
- Insensitivity of PCs to these parameters, e.g., same PC shapes for 5 nots, order 4 B-splinaes

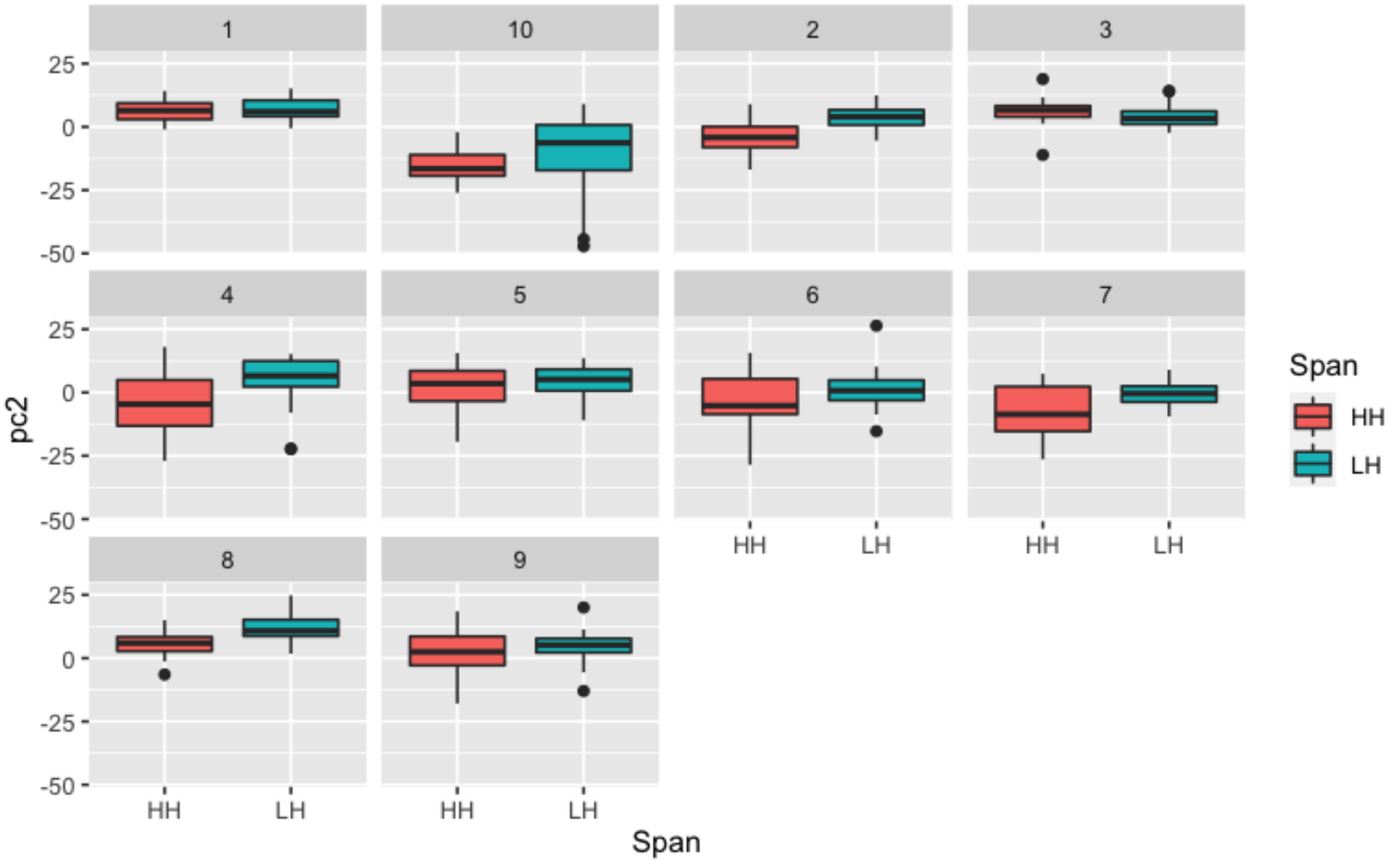


# PC1 & PC2: HH and LH

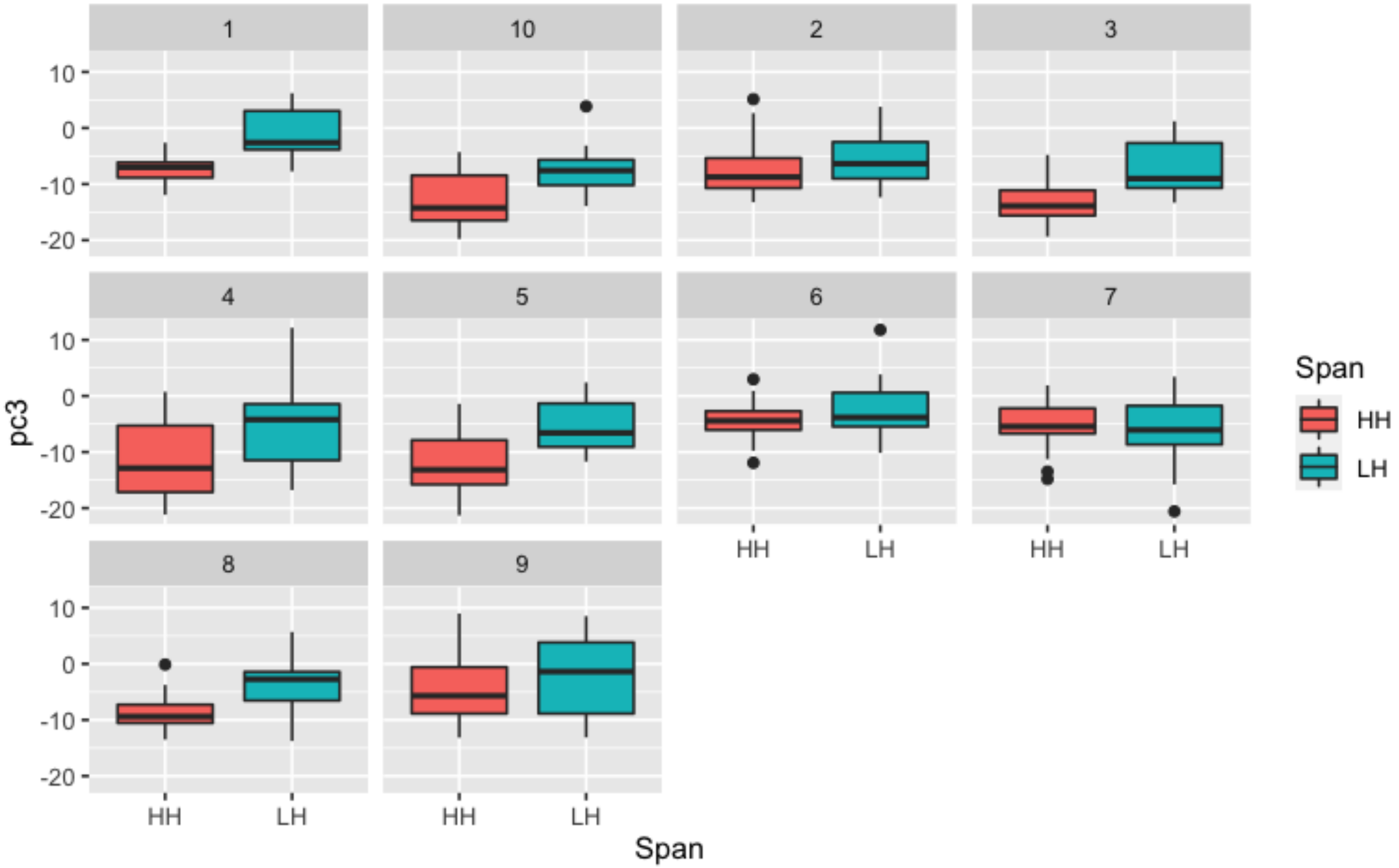


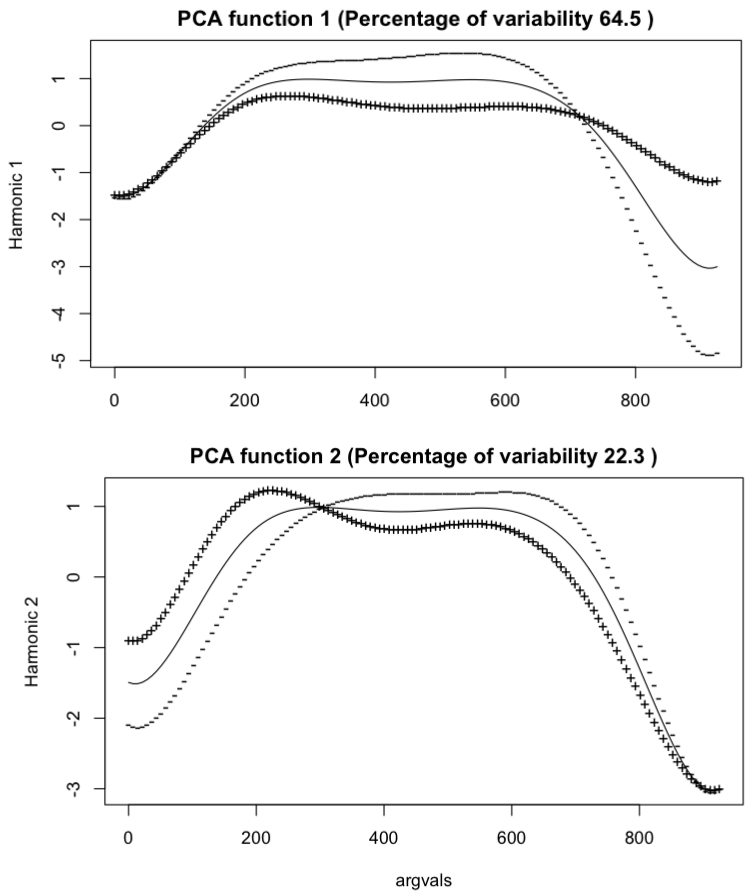
# PC2: Individual variation

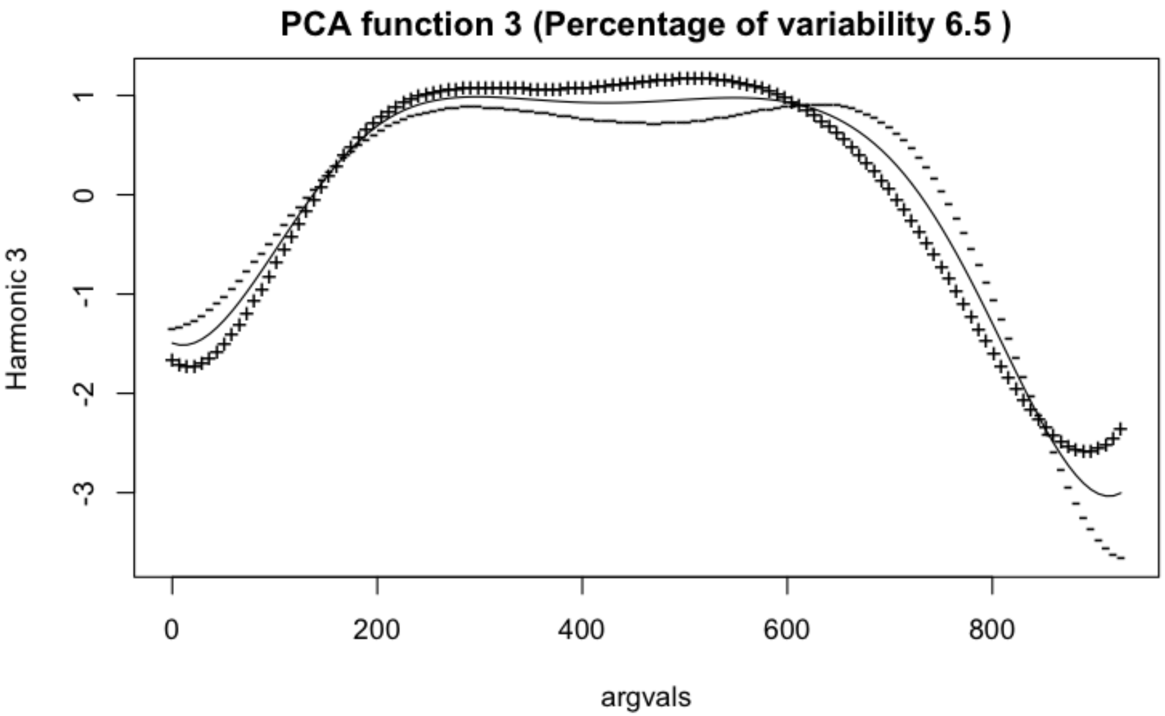


# PC3: Individual variation

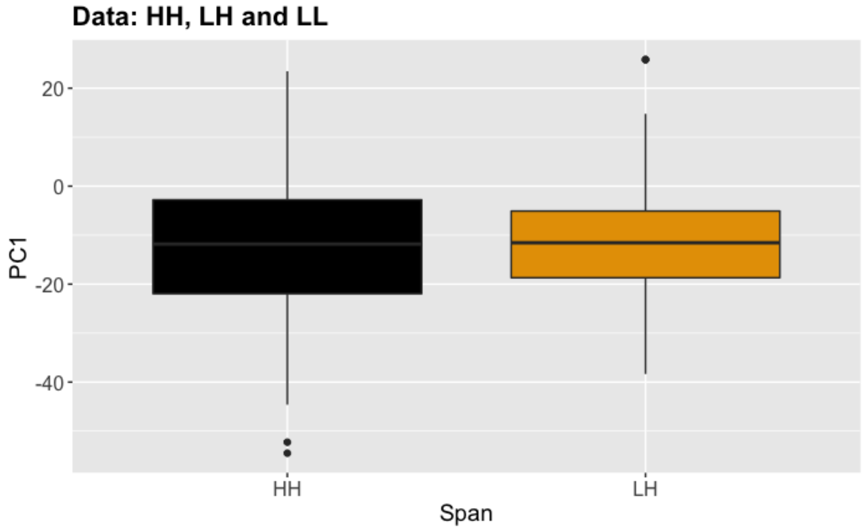


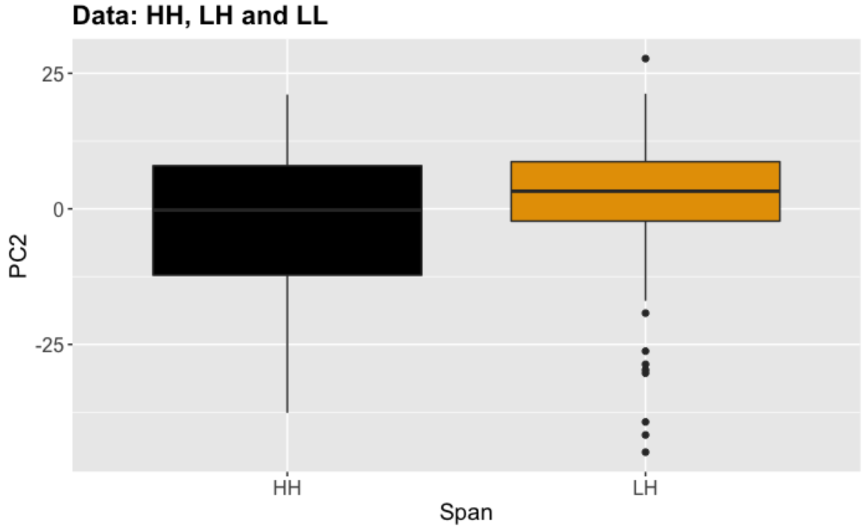
# PCs: Data without HL

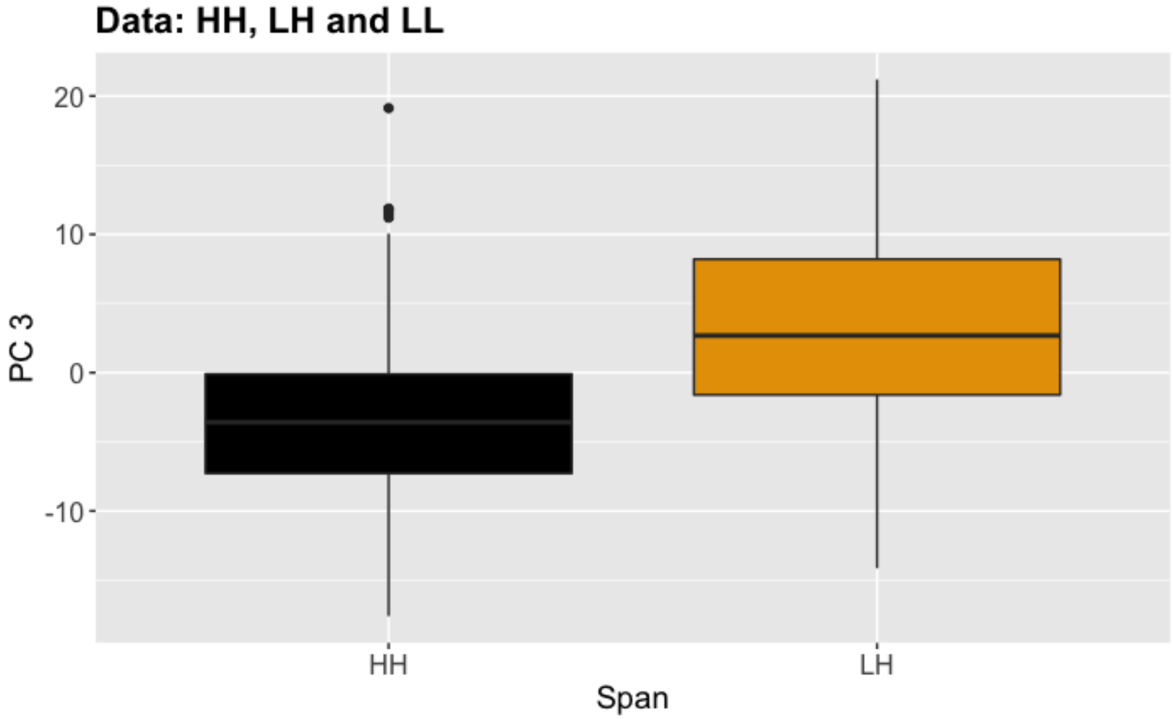


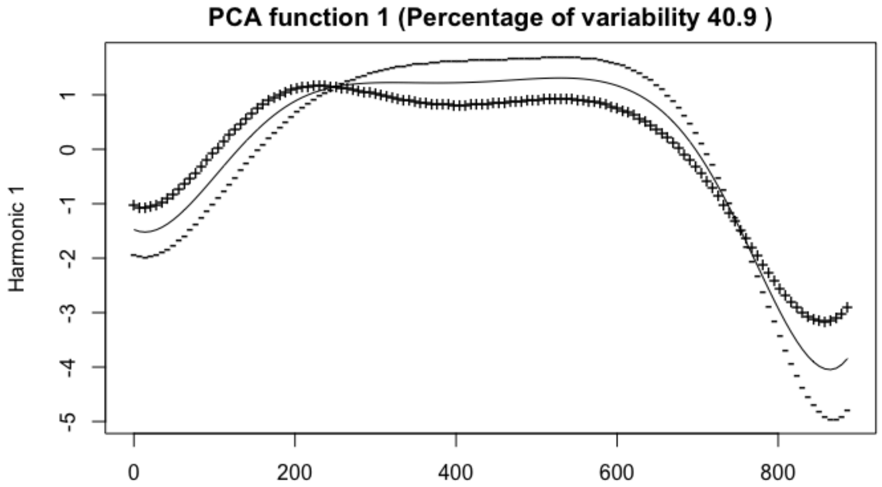
# Data without HL

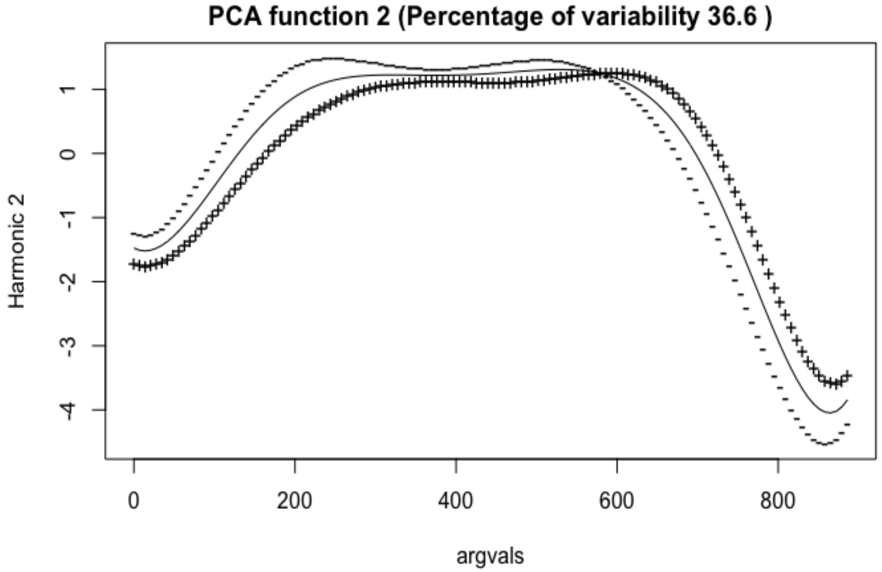


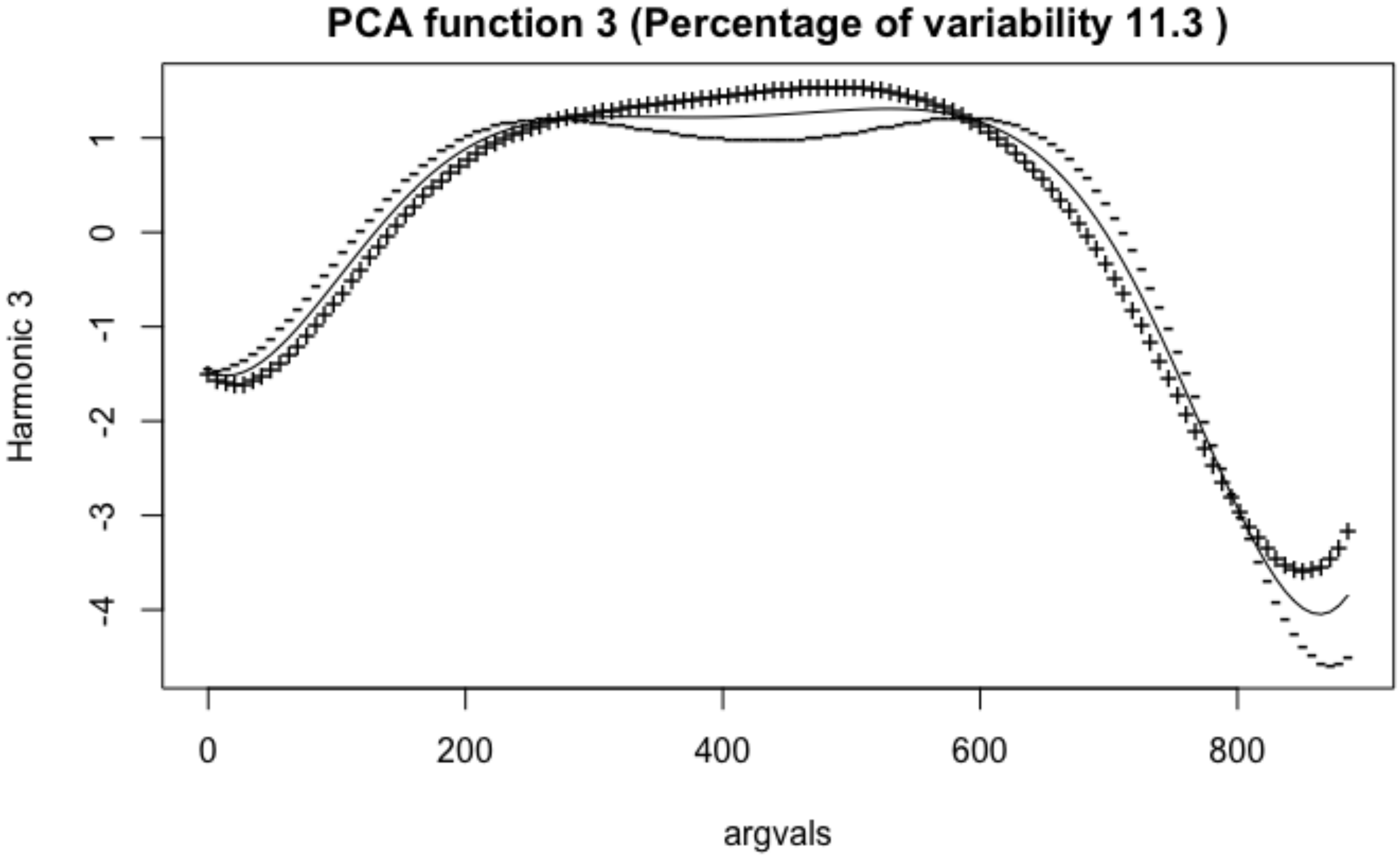



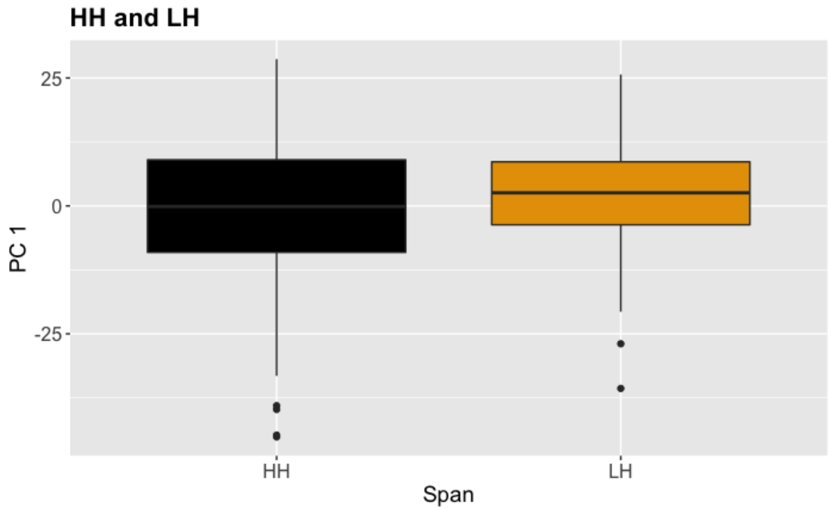
# PC: Data HH and LH only

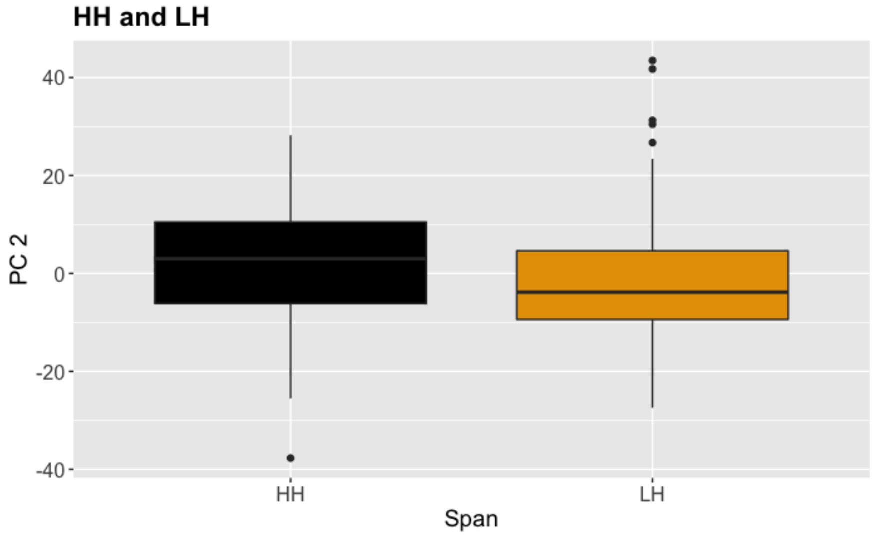


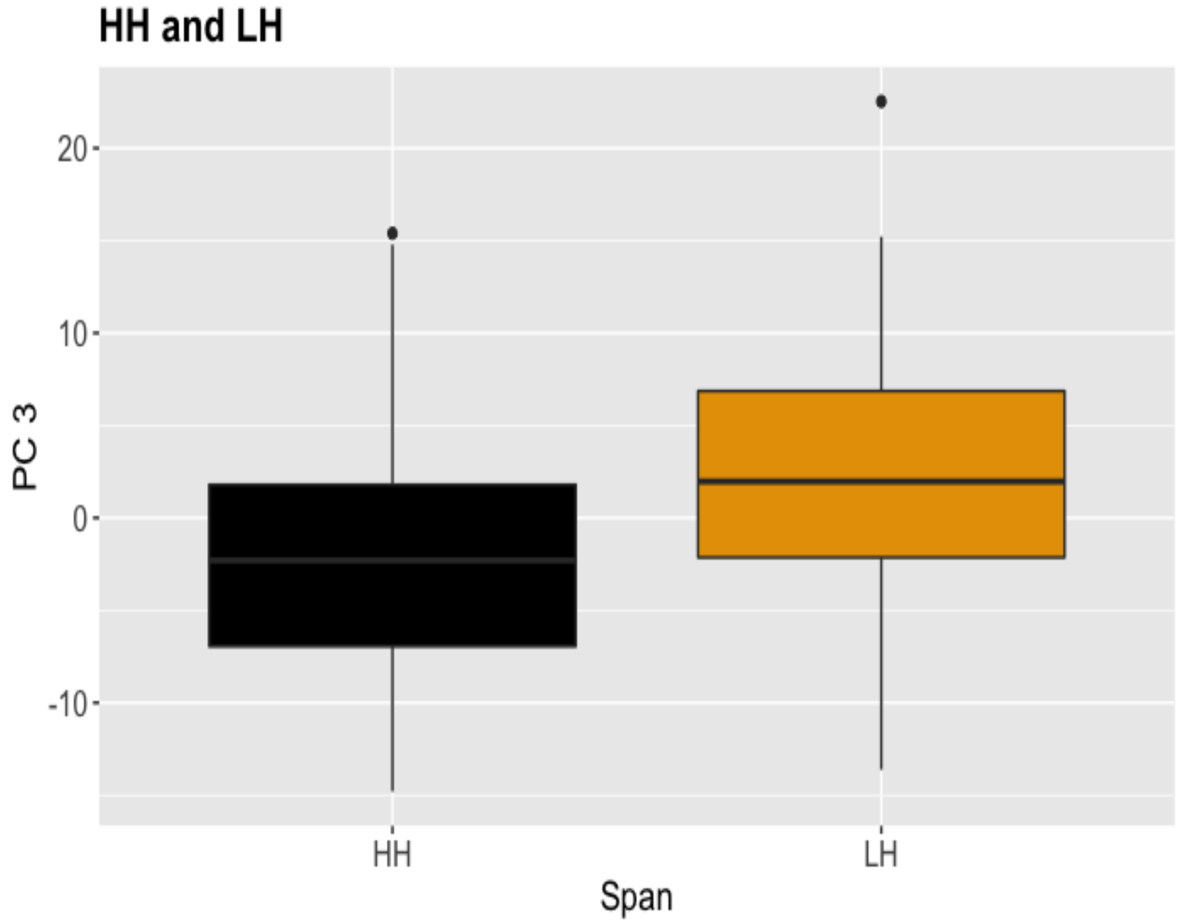



# Data HH and LH only



# Logistic regression: HH and LH

| Characteristic | log(OR)[1] | 95% CI[1] | p-value |
|---|---|---|---|
| pc1 | 0.01 | -0.02, 0.04 | 0.3 |
| pc2 | 0.08 | 0.05, 0.12 | <0.001 |
| pc3 | 0.17 | 0.12, 0.22 | <0.001 |
| duration | 2.1 | 0.41, 3.8 | 0.015 |

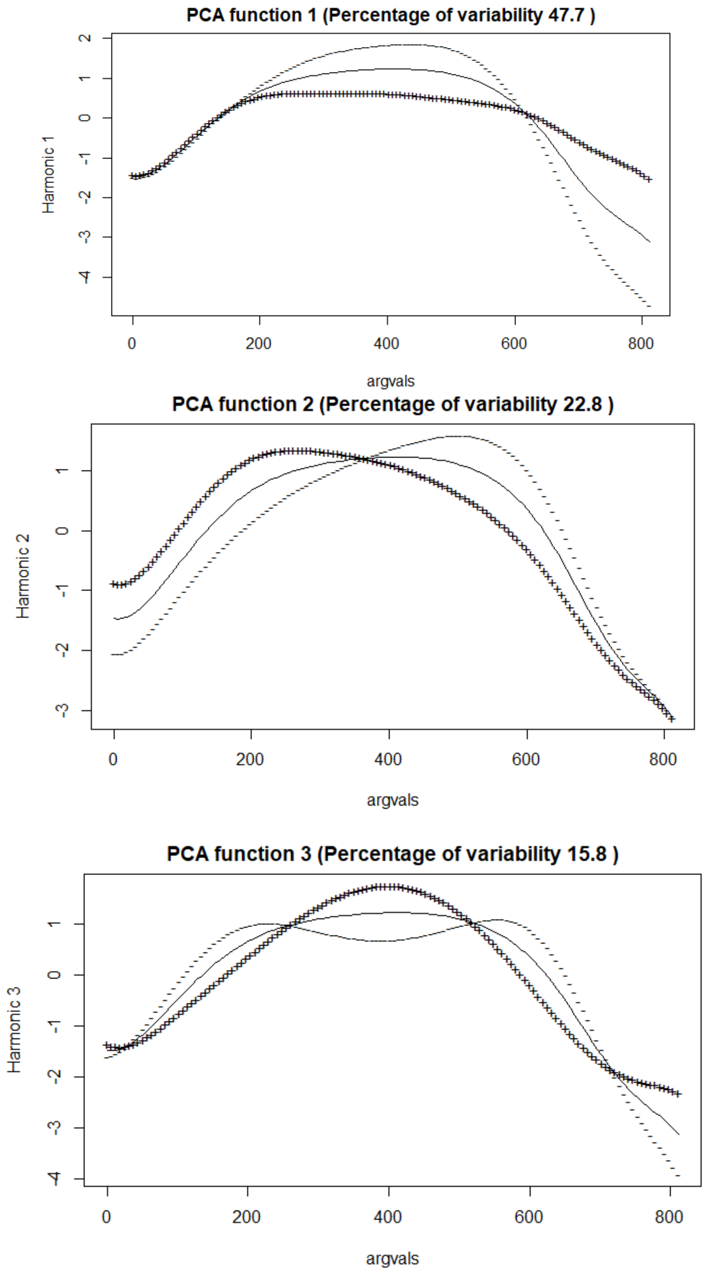
[1] OR = Odds Ratio, CI = Confidence Interval

| Characteristic | log(OR)[1] | 95% CI[1] | p-value |
|---|---|---|---|
| pc1 | 0.02 | -0.07, 0.12 | 0.6 |
| pc2 | 0.10 | -0.02, 0.21 | 0.10 |
| pc3 | 0.22 | 0.05, 0.39 | 0.012 |
| duration | 1.8 | -0.32, 3.9 | 0.10 |
| pc1 * duration | -0.01 | -0.10, 0.09 | 0.9 |
| pc2 * duration | -0.01 | -0.13, 0.10 | 0.8 |
| pc3 * duration | -0.05 | -0.22, 0.11 | 0.5 |

[1] OR = Odds Ratio, CI = Confidence Interval

# Cross Validation of PCA

- The f0 contours were randomly assigned to 1 of 5 folds
- FPCA was repeated 5 times, each time leaving out a different fold
- Each time, the first three PCs appear to have roughly the same shape as when FPCA is conducted on the whole dataset




Shown: PC curves for one of the 5 repetitions

# Multinomial logistic regression: HH as ref.

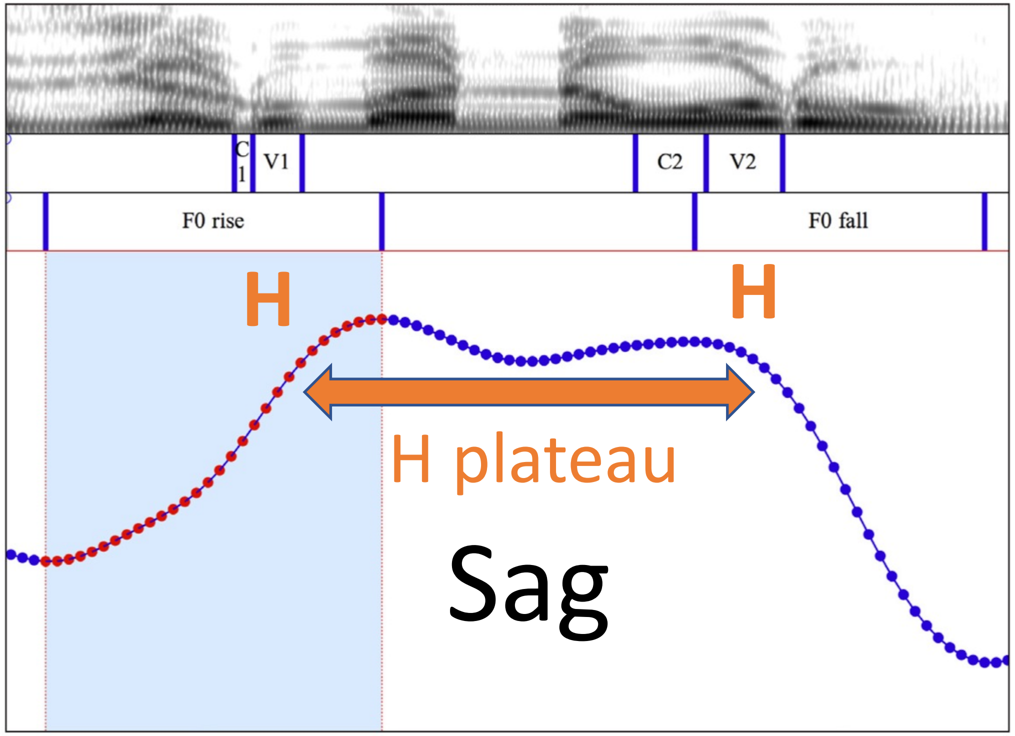
```
Call:
multinom(formula = Span ~ (pc1 + pc2 + pc3) * duration, data = dat.pc.scores)

Coefficients:
   (Intercept)          pc1         pc2       pc3   duration pc1:duration pc2:duration pc3:duration
HL -0.08468288  0.029001552 -0.04836188 0.5936409 -0.6770708   0.04628559  -0.03632203  -0.02588859
LH  0.50787176 -0.004071648  0.05757479 0.1573436  0.1130129  -0.01094180  -0.02427356  -0.04660831
LL -6.07485855  0.623546230 -0.07304272 0.5807668  2.7901803  -0.23224053   0.08107037  -0.34876188

Std. Errors:
   (Intercept)        pc1        pc2        pc3  duration pc1:duration pc2:duration pc3:duration
HL   1.4884729 0.07457400 0.07406409 0.18244517 1.3963280   0.07303242   0.07274608   0.17456017
LH   0.7979404 0.03481658 0.04482121 0.07180288 0.7422944   0.03520044   0.04419008   0.06953447
LL   3.6217529 0.20244910 0.14632393 0.23207176 3.1387931   0.17578893   0.13638968   0.21099222
```

P-values

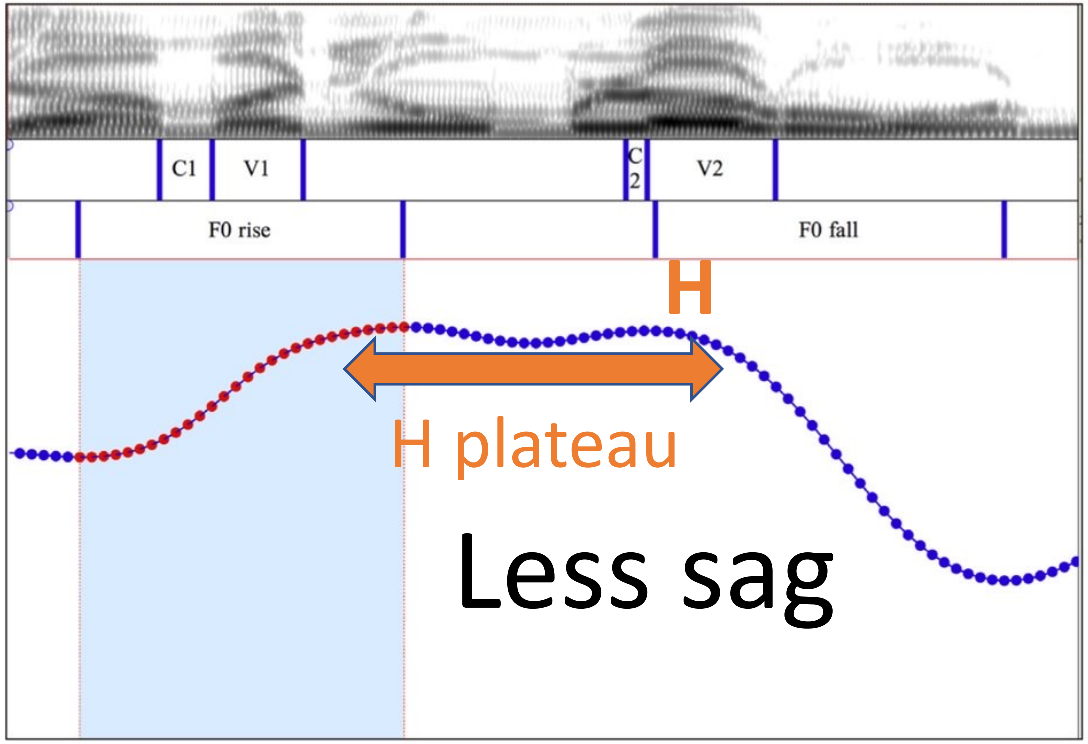
```
Residual Deviance: 752.9595
AIC: 800.9595
   (Intercept)         pc1       pc2         pc3  duration pc1:duration pc2:duration pc3:duration
HL  0.95463086 0.697352852 0.5137735 0.001138707 0.6277517    0.5262325    0.6175689   0.88210005
LH  0.52446471 0.906903112 0.1989519 0.028428176 0.8789913    0.7559202    0.5828004   0.50267250
LL  0.09347885 0.002069903 0.6176490 0.012330880 0.3740385    0.1864571    0.5522429   0.09833883
```

# Perceptibility of sag

Data from Myers et al. 2018




[òmùlèːnzìjà**lúmánːáwó**lòvù]
“The boy bit the chameleon.”




[òmùlàːŋgìràː**máɲóːmúlá**lwòːnò]
“The prince recognizes this mad person.”

# Incomplete Neutralization: Perception and Meta-Analysis

- For other examples of incomplete neutralization, do listeners perceive the difference between incompletely neutralized segments/tone spans?
- Bruno Nicenboim meta-analysis for production of vowel length differences with German stop voicing neutralization
  - Supporting evidence for a production difference
- Warner 2004 finds listeners can use small durational differences as cues to different underlying forms of voicing-neutralized stops in Dutch
- Aaron Braver production and discrimination experiment for English /d/-/t/ flapping
  - Speakers produce slightly longer vowels before /d/ flaps than /t/ flaps
  - Speakers could not distinguish between underlyingly different flaps