Voice Quality and Laryngeal Complexity in Santiago Laxopa Zapotec

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Outline

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Research Overview

Overview:

This presentation explores what characterizes voice quality in a Santiago Laxopa Zapotec (SLZ), how is it is structured acoustically, and how this structure helps explain SLZ's laryngeal complexity.

Research Overview

Research Questions:

- How is phonation's acoustic space structured in a single language?
- Which measures are important for capturing phonation contrasts?
- How do these measures help explain SLZ's laryngeal complexity?

Research Overview

Answers to Research Questions:

- The acoustic space is three-dimensional and the dimensions are comparable to Keating et al.'s (2023) findings.
  - Dimensions are correlated with glottal-airflow (D1/D3) and nonmodal-to-modal (D2) continua.
- Only a handful of measures are important for capturing phonation contrasts.
- Measures show that SLZ's laryngeal complexity is weakly articulated and shows phasing.

What is Voice Quality?

- Broad sense = long-term characteristics of an individual's voice (Abercrombie 1967, Laver 1980).
- Narrow sense = how larynx affects phonetic characteristics of speech sounds (e.g., Esling et al. 2019).
- Sometimes used interchangeably with phonation
  - Barzilai & Riestenberg 2021 use *voice quality* for phonetic description and *phonation* for phonological contrasts.

How is voice quality used?

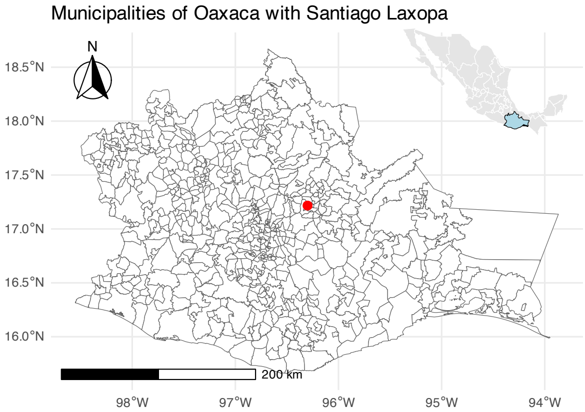
- Paralinguistic information by "indexing the biological, psychological, and social characteristics of the speaker" (e.g., Laver 1968, Podesva 2016)
- Phonological contrasts (e.g., Esposito & Khan 2020).

Why study voice quality?

- Voice quality plays a crucial role in speech communication.
- It is used in many languages to create phonological contrasts.
- It is a rich area of research that can help us understand speech production and perception.

What is Santiago Laxopa Zapotec

- Santiago Laxopa Zapotec (SLZ; *Dille'xhunh Laxup*) is a Sierra Norte variety of Zapotec (Oto-Manguean).
- Spoken by c. 1,000 speakers in Santiago Laxopa and in diaspora.



Why study SLZ?

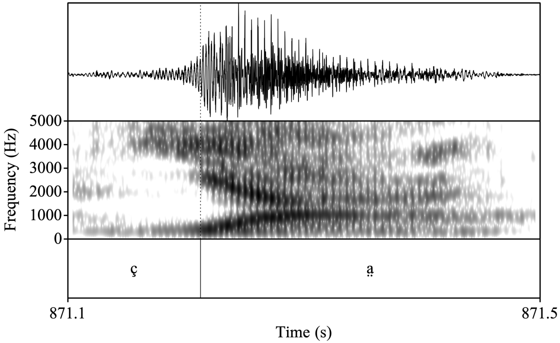
- SLZ is a relatively understudied language, so it provides an opportunity to contribute to our linguistic understaning.
- SLZ has a complex laryngeal system that is not well understood.
  - SLZ has a four-way phonation contrast.
  - SLZ has a five-way tonal contrast.
  - These contrasts are orthogonal, meaning that they can occur independently of each other.

Phonation in SLZ

- SLZ has a four-way phonation contrast:
  - Modal ([a])
  - Breathy ([a̤])
  - Checked ([a͡ʔ] or [a͡a̰])
  - Rearticulated ([a͡ʔa], [a͡a̰a], or [a̰])

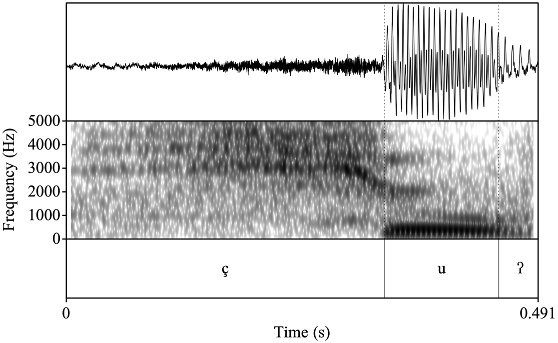
Breathy Phonation in SLZ

- Characterized by aperiodicity and noise in the harmonic structure.
- Longer duration than modal voice
- Lower fundamental frequency ($f0$)



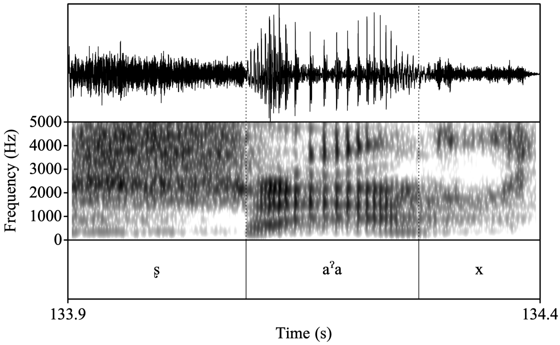
Checked Phonation in SLZ

- Glottal occlusion at the end of vowel or creaky voice in second half vowel.
- Decrease in voicing amplitude during second half.



Rearticulated Phonation in SLZ

- Glottal occlusion or creaky voice in the middle of the vowel.
- Longer duration than modal voice
- Decrease in voicing amplitude during first half.



Tone in SLZ

- SLZ shows a five-way tonal contrast on monosyllabic nouns (Brinkerhoff, Duff & Wax Cavallaro 2022).

High	*xha*	[z̧a˦]	‘clothing.poss’
Mid	*lhill*	[ɾiʒ˧]	‘house.poss’
Low	*yu’*	[ç̦uˀ˨]	‘earth’
Rising	*yu’u*	[ç̦uˀu˧˦]	‘lime (Sp. *cal*)’
Falling	*yu’u*	[ç̦uˀu˦˨]	‘house’

Interaction of Tone and Phonation in SLZ

- Tone and phonation are orthogonal in SLZ.

	Modal	**Breathy**	**Checked**	**Rearticulated**
High	✓	–	✓	✓
Mid	✓	✓	✓	✓
Low	✓	✓	✓	✓
Rising	✓	✓	–	✓
Falling	✓	✓	✓	✓

Measuring voice quality

- Long been established that phonation has correlates in the acoustic signal (e.g., Fischer-Jørgensen 1968, Klatt & Klatt 1990).
- Fischer-Jørgensen (1968) found that a strengthened fundamental (i.e., H1) correlated with breathy vowels in Gujarati.
  - Proposed H1—H2 amplitude as a measure to normalize for overall intensity differences
- Subsequent research has shown that H1—H2 is useful for classifying voice quality contrasts.
- However, it is not without its problems (see Chai & Garellek 2022 for an overview).

Measuring voice quality

- H2 and other normalizations (A1, A3) are really attempts to understand the relative strength of the fundamental (H1) to higher harmonic energy
- H1 and H2 are affected by subglottal pressure differently (Sundberg 2022)
  - This undermines the original reasoning behind H1—H2
- Researchers sometimes find that H1—H2 does not distinguish phonation types (e.g., Esposito 2010, 2012, Garellek & Esposito 2023).
- Error in measuring H1—H2 is uncomfortably high (e.g., Chai & Garellek 2022).

Measuring voice quality

- Many measures have been proposed to capture voice quality.
- Measures can be broadly categorized into several categories (Gordon & Ladefoged 2001):
  - Periodicity (e.g., HNR or CPP)
  - Energy
  - Spectral tilt (e.g., H1*−H2*, residual H1*)
  - Pitch (e.g., $f0$)
  - Duration
- Linguists have used combinations of these measures to model phonation (e.g., Blankenship 2002, Brunelle & Kirby 2016, Esposito 2012).

New measures of voice quality

- New measures are being developed all the time.
- Chai & Garellek's (2022) residual H1* is a new measure of spectral tilt that is more robust than traditional spectral tilt measures.
  - Does this by removing the the effects of Energy from the H1* measure.
  - This was the original goal of Fischer-Jørgensen (1968)
- Brinkerhoff & McGuire (2025) found that residual H1* is a better measure of spectral tilt than H1*−H2* for Santiago Laxopa Zapotec's four-way phonation contrast.

Too many measures

- There are many measures of voice quality, but it is not clear which ones are the most useful.
- It also makes it difficult to compare results across studies.
- VoiceSauce makes this a common issue (Shue et al. 2011).

Too many measures

- Kreiman et al. (2014, 2021) tackle this by proposing a psychoacoustic model of voice quality.
- Found certain measures are perceptually more important than others.

Model Component	**Parameters**
Harmonic source spectral shape	H1–H2 H2–H4 H4–2 kHz 2 kHz–5 kHz
Inharmonic source excitation	Spectrally-shaped noise-to-harmonics ratio
Time-varying source characteristics	$f0$ mean and standard deviation (or $f0$ track) Amplitude mean and standard deviation (or amplitude track)
Vocal tract transfer function	Formant frequencies/bandwidths Spectral zeroes/bandwidths

Modeling voice quality

- Early models proposed that voice quality is one dimensional and represents glottal airflow (Ladefoged 1971, Ladefoged & Maddieson 1996).

Open Glottis ⟷ Closed Glottis

[h] Breathy Modal Creaky [ʔ]

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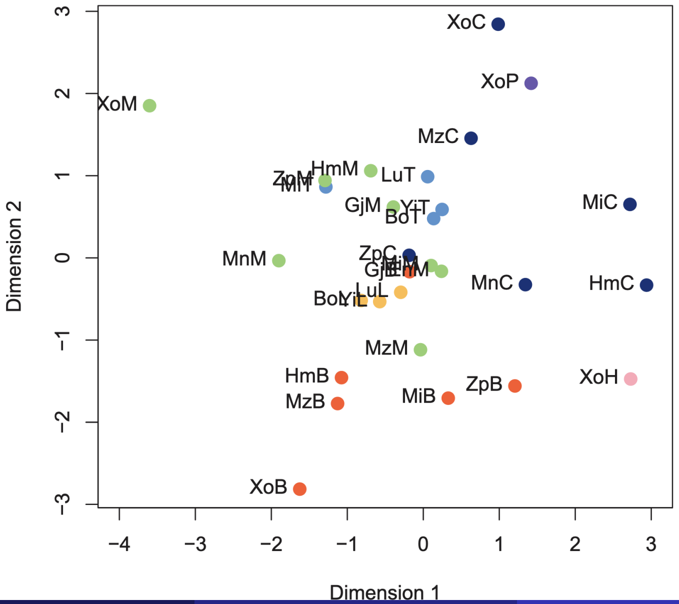
Voice quality's multidimensionality

- More recent work has shown that voice quality is not one-dimensional, but minimally five-dimensional (e.g., Garellek et al. 2016, Kreiman et al. 2021).
    - Especially in the case of individual speaker differences.
- Garellek et al. (2013) has argued that dimensionality might not be as complex for capturing phonation contrasts.

Keating et al. (2023)

- Explored phonation's cross-linguistic acoustic space.
- Found a two-dimensional space for phonation across 11 languages.
    1. First dimension = nonmodal-to-modal continuum.
    2. Second dimension = glottal-airflow continuum.
- Found languages with more contrasts used more of the acoustic space than languages with fewer contrasts.
- Found correlations between dimensions and acoustic measures.
    1. First dimension = periodicity and energy measures.
    2. Second dimension = spectral tilt and periodicity measures.

Keating et al. (2023)



What is Laryngeal Complexity

- *Laryngeal complexity* describes languages that use both contrastive tone and phonation (Silverman 1997a,b).
- Very common in the Oto-Manguean language family, but is also found in other languages.

Phonation's phasing

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Implicational hierarchy of patterns

- Silverman (1997a) proposed a hierarchy of laryngeal complexity phasing pattern.

Language	**Prevocalic**	**Postvocalic**	**Interrupted**
Jalapa Mazatec	hV˥, ʔV˥	—	—
Comaltepec Chinantec	hV˥, ʔV˥	Vh˥, Vʔ˥	—
Copala Trique	hV˥, ʔV˥	Vh˥, Vʔ˥	VhV˥, VʔV˥

Previous research on laryngeal complexity

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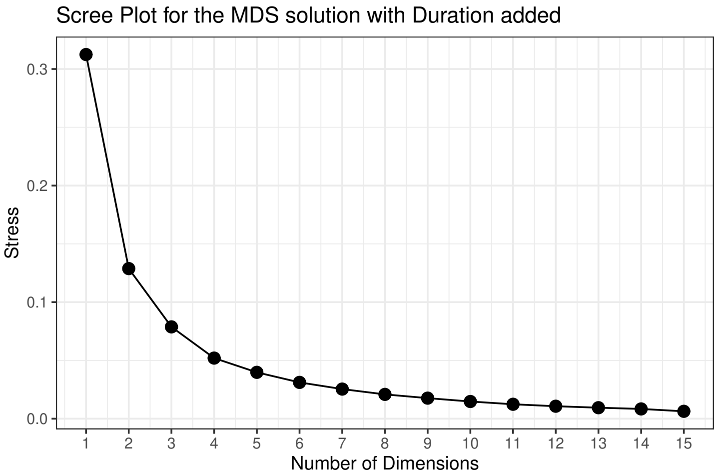
Data

- Data comes from fieldwork on Santiago Laxopa Zapotec (SLZ) from Summer 2023.
- Production data was collected from 10 speakers (5 male/5 female).

MDS analysis

- Multidimensional scaling (MDS; Kruskal & Wish 1978) was used to reduce the dimensionality of the data.

Number of Dimensions needed



Explanation of the plots

- Each point = unique speaker x phonation combination.
- Colors = phonation type.
  - Modal = black
  - Breathy = orange
  - Checked = blue
  - Rearticulated = green
- Axes = dimensions of the acoustic space.

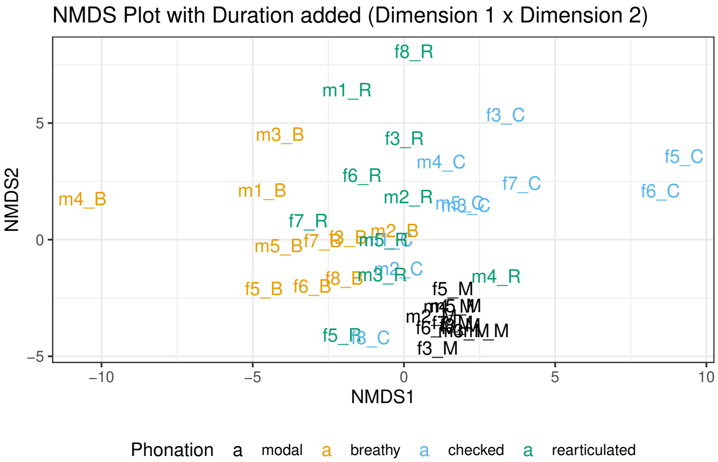
Dimensionality in SLZ

- Scan the QR code to see the three-dimensional space.

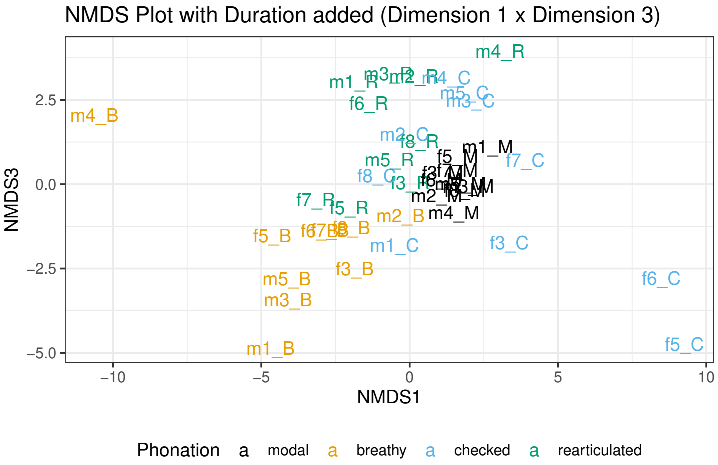
Takeaways from 3D plot

- Shows clear groupings of phonation types
-

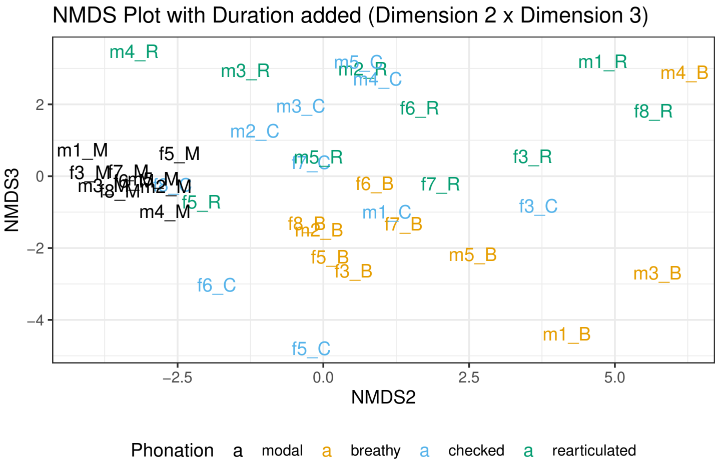
Dimensionality in SLZ



Dimensionality in SLZ



Dimensionality in SLZ



Summary of Dimensions

- Dimension 1 (D1) gives a rough continuum from breathy to creaky.
- Dimension 2 (D2) gives a rough continuum from modal to nonmodal.
- Dimension 3 (D3) gives a rough continuum from breathy to creaky.

Correlation to Acoustic Measures

- D1 correlated with spectral tilt measures:
  - H1*–A1* ($r^2 = -0.83$)
  - H1*–A2* ($r^2 = -0.86$)
  - H1*–A3* ($r^2 = -0.81$)
- D2 correlated with periodicity and energy:
  - HNR<500 Hz ($r^2 = -0.79$)
  - HNR<1500 Hz ($r^2 = -0.80$)
  - Energy ($r^2 = -0.79$)
- D3 correlated with spectral tilt:
  - residual H1* ($r^2 = -0.72$)
  - H2*–H4* ($r^2 = -0.69$)
  - H2* ($r^2 = -0.68$)

Summary of Acoustic Landscape

- SLZ's phonation occupies a three-dimensional space.
- Dimensions are correlated with glottal-airflow continuum (D1/D3) and nonmodal-to-modal continuum (D2).
- Dimensions are similar to those found in Keating et al. (2023).

What is a Random Forest?

- Random Forest is a subclass of decision trees that uses an ensemble of decision trees to make predictions (Breiman et al. 1986, Breiman 1996, 2001).
- More robust than

Interpreting Random Forests

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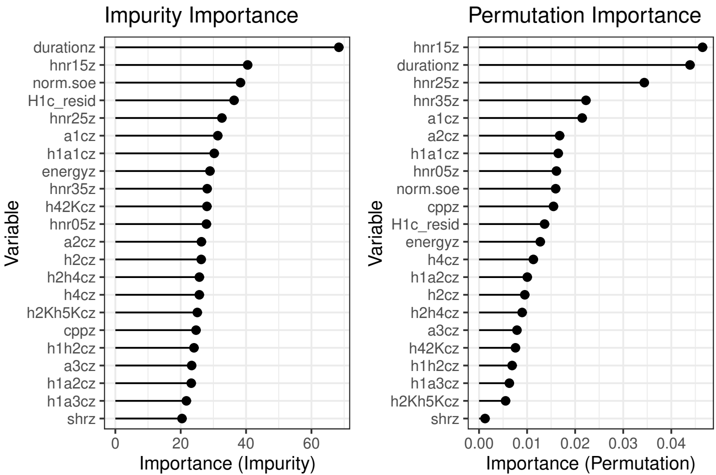
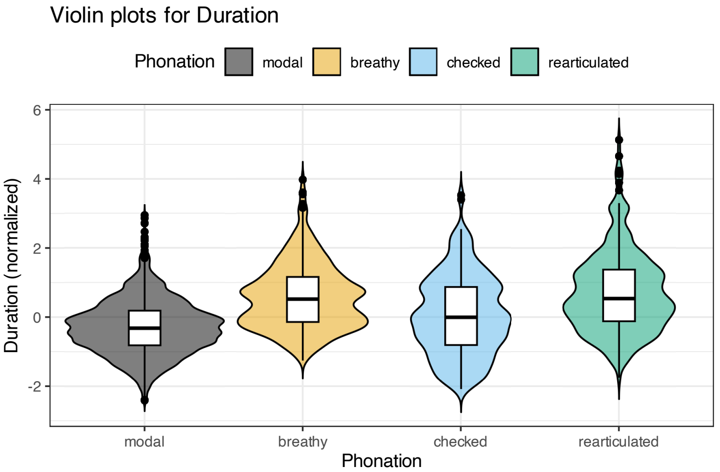
Variable Importance



Variable Importance

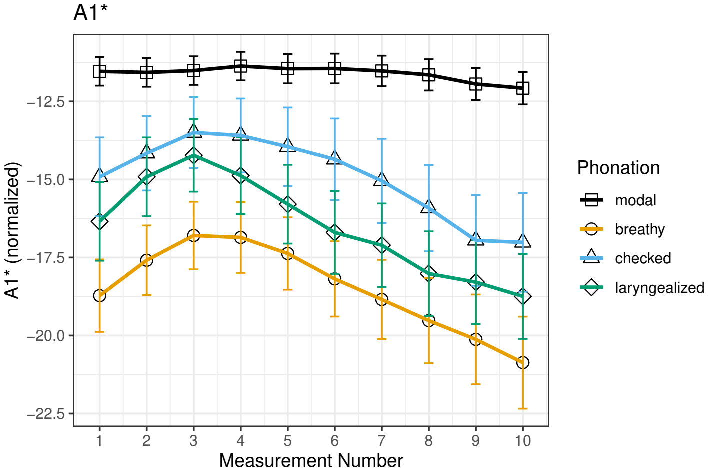
- Variable importance shows that only a handful of measures are important for capturing phonation contrasts.
    1. Duration
    2. A1*
    3. H1*−A1*
    4. Residual H1*
    5. HNR $<$ 1500 Hz
    6. Strength of Excitation (SoE)

Duration



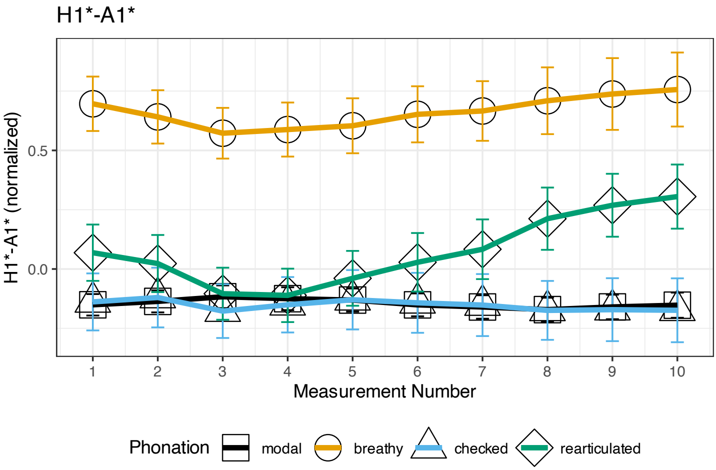
Violin plots for Duration
Phonation
modal
breathy
checked
rearticulated
Duration (normalized)
6
4
2
0
-2
modal
breathy
checked
rearticulated
Phonation

A1*



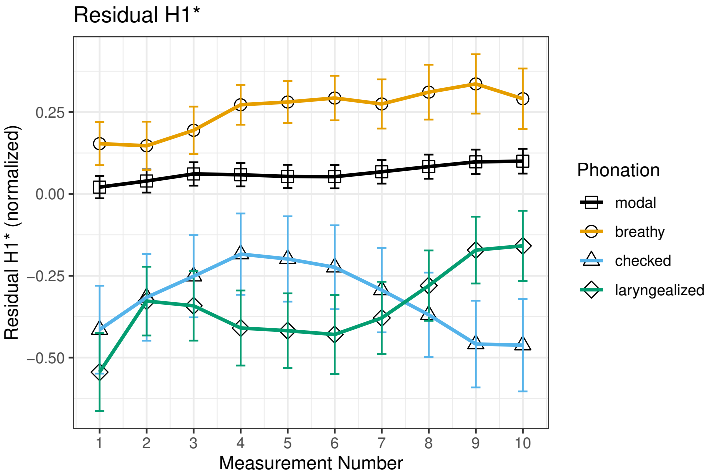
A1*
A1* (normalized)
−12.5
−15.0
−17.5
−20.0
−22.5
1
2
3
4
5
6
7
8
9
10
Measurement Number
Phonation
modal
breathy
checked
laryngealized

H1*—A1*



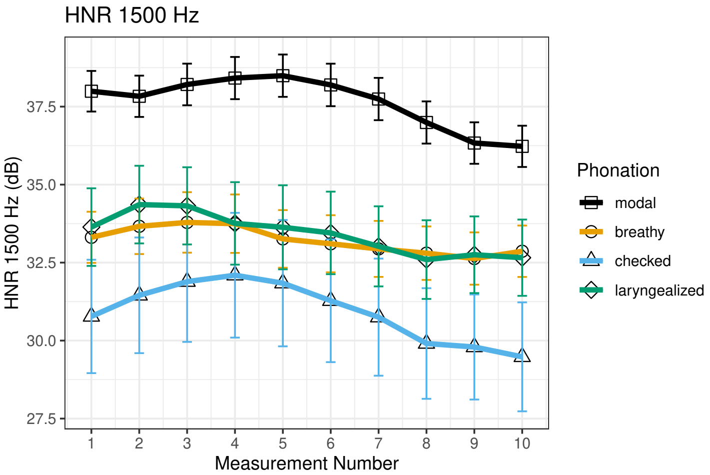
H1*-A1*
H1*-A1* (normalized)
0.5
0.0
1
2
3
4
5
6
7
8
9
10
Measurement Number
Phonation
modal
breathy
checked
rearticulated

Residual H1*

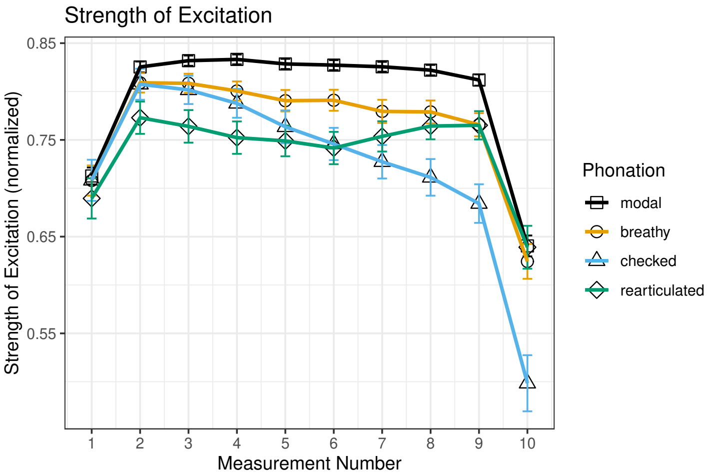


Residual H1*
Residual H1* (normalized)
0.25
0.00
−0.25
−0.50
1
2
3
4
5
6
7
8
9
10
Measurement Number
Phonation
modal
breathy
checked
laryngealized

HNR < 1500 Hz


HNR 1500 Hz
HNR 1500 Hz (dB)
37.5
35.0
32.5
30.0
27.5
1
2
3
4
5
6
7
8
9
10
Measurement Number
Phonation
modal
breathy
checked
laryngealized

Strength of Excitation (SoE)



Summary of Random Forest Results

- Only a handful of measures are important for capturing phonation contrasts.
- Duration, A1*, H1*−A1*, residual H1*, HNR $<$ 1500 Hz, and SoE are the most important measures.
- There is a lot of overlap between MDS' correlated measures and the important measures from the Random Forests.

Quanitfying Laryngeal Complexity

- Laryngeal complexity is the number of phonation contrasts in a language.
- More phonation contrasts means more complex laryngeal system.
- Laryngeal complexity can be measured by the number of phonation contrasts in a language.
- Laryngeal complexity can be measured by the dimensionality of the acoustic space.

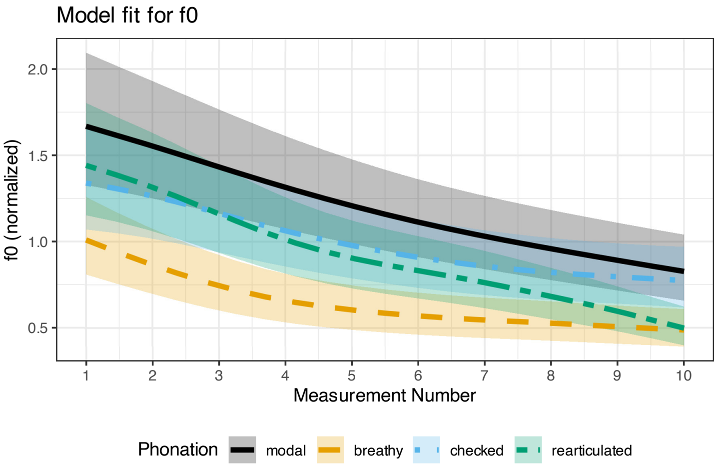
What are Generalized Additive Mixed Models (GAMMs)

- GAMMs are a type of statistical model that can be used to analyze non-linear relationships between variables.

Evaluating GAMMs

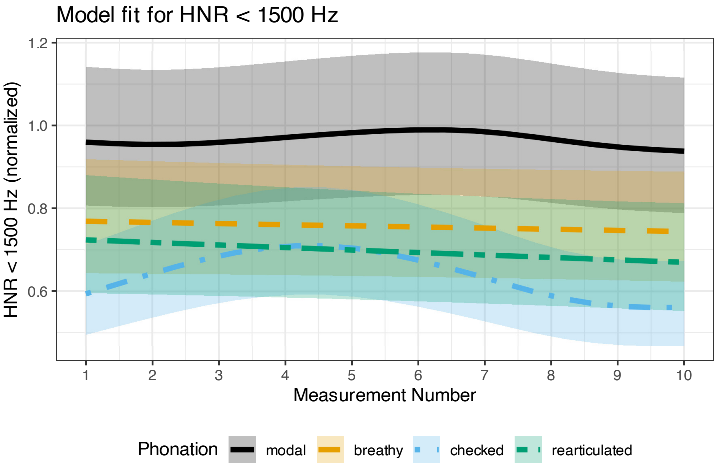
- Laryngeal complexity is measured by the number of phonation contrasts in a language.
- SLZ has four phonation contrasts.
- The more phonation contrasts a language has, the more complex its laryngeal system is.

Model fit for $f0$



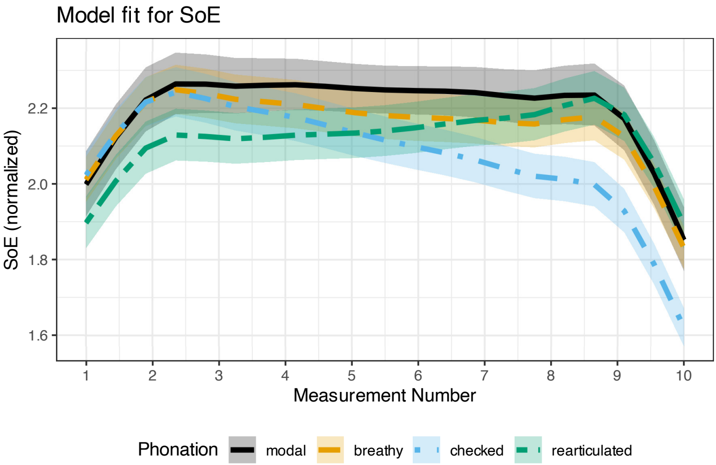
Model difference for $f0$

Model fit for HNR

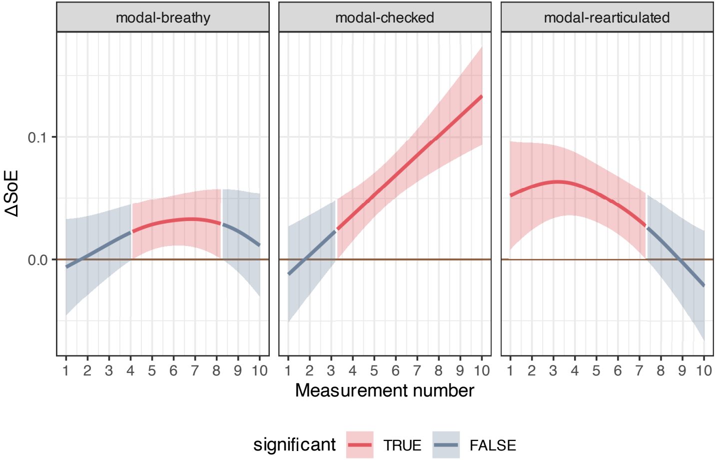


Model difference for HNR

Model fit for SoE



Model difference for SoE



Summary of Laryngeal Complexity

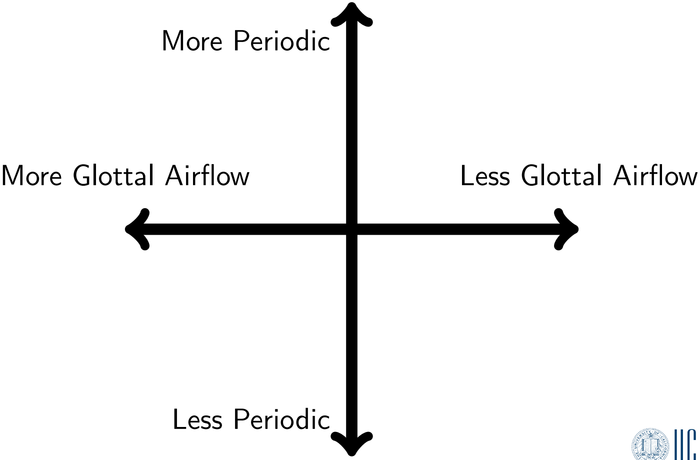
- SLZ has four phonation contrasts.
- SLZ's phonation occupies a three-dimensional space.
- Dimensions are correlated with glottal-airflow continuum (D1/D3) and nonmodal-to-modal continuum (D2).
- Dimensions are similar to those found in Keating et al. (2023).

Summary of Results

- SLZ's phonation occupies a three-dimensional space.
- Dimensions are correlated with glottal-airflow continuum (D1/D3) and nonmodal-to-modal continuum (D2).
    - Collaborated with acoustic measure correlations.
- Dimensions are similar to those found in Keating et al.

Summary

- Acoustic space can be reduced to two dimensions.
- More dimensions add more information about these two dimensions.



Summary

- Dimensionality reduction also occurs in a single language.
- Dimensions correspond to glottal-airflow and nonmodal-to-modal continua within a language and cross-linguistically.
- If additional dimensions are added, they only add additional information about these two dimension.

- Outlook
  - What are the perceptual cues that speakers use to distinguish between phonation types?
  - How do these dimensions relate to the phonology?

Duxhklhenhu' lhe' (Thank you)

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