The acoustics of phonation in Santiago Laxopa Zapotec

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Contents

1 Introduction

- Phonation is a process where the larynx is used to alter the way different sounds are produced.
- This use of the larynx produces sounds which vary from being more breathy or creaky.
  - Although other types of phonation also exist (see Esling et al. 2019 for a detailed discussion on the different phonation types that exist and how the larynx produces them).
- In some languages these alterations are described as being pathological, with some speakers just being more breathy or creaky than others (e.g., Klatt & Klatt 1990).
- In other languages these phonation Sometimes these different phonation contrasts are used phonemically.

- This paper explores these

2 Background

- Since
- Ladefoged (1971) and Gordon & Ladefoged (2001)

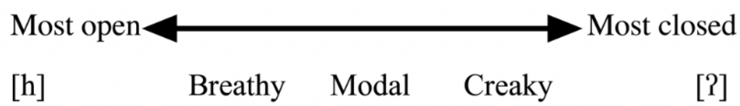

Figure 1: Simplified one-deminsional model for phonation. Based on Ladefoged (1971) and Gordon & Ladefoged (2001)

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3 Santiago Laxopa Zapotec

- Santiago Laxopa Zapotec (SLZ), endonym *Dille'xhunh Laxup*, is a a Northern Zapotec language spoken by approximately 1000 people in the municipality of Santiago Laxopa, Ixtlán, Oaxaca, Mexico and in diaspora communities in Mexico and the United States (Adler & Morimoto 2016, Adler et al. 2018, Foley, Kalivoda & Toosarvandani 2018, Foley & Toosarvandani 2020).
- Closely related to San Bartolomé Zoogocho Zapotec (Long & Cruz 2005, Sonnenschein 2005) and shares a high level of mutual intelligibility with it.
- SLZ is similar to other Zapotecan languages in distinguishing lenis and fortis consonants (e.g., Nellis & Hollenbach 1980, Jaeger 1983, Uchihara & Pérez Báez 2016).
- SLZ has a standard five vowel inventory.
- These five vowels, additionally, appear with one of four different phonation types which will be discussed in greater detail in Section 3.2.

3.1 Tone in Santiago Laxopa Zapotec

- Similar to other Otomanguean languages, SLZ is tonal(Suárez 1983, Campbell, Kaufman & Smith-Stark 1986, Silverman 1997, Campbell 2017a,b).
- SLZ has five distinct tonal patterns that appear on the syllables of nouns, see Table 3.

Table 1: Consonant inventory for Santiago Laxopa Zapotec

		bilabial	alveolar	post-alveolar	retroflex	palatal	velar	labio-velar	uvular
stop	lenis	b	d				g	gʷ	
	fortis	p	t				k	kʷ	
fricative	lenis		z	ʒ	ʐ				ʁ
	fortis		s	ʃ	ʂ	ç			
affricate	lenis		d͡z						
	fortis		t͡s		t͡ʃ				
nasal	lenis		n						
	fortis	mː	nː						
lateral	lenis		l						
	fortis		lː						
trill			r						
approximate								w	

Table 2: Vowel qualities in Santiago Laxopa Zapotec.

	front	central	back
high	i		u
mid	e		o
low		a	

Table 3: Examples of the five tonal patterns observed in the Santiago Laxopa Zapotec words.

High	a^{H}	*xha*	[$ʐa^{H}$]	'clothing.POSS'
Mid	a^{M}	*lhill*	[$liʒ^{M}$]	'house.POSS'
Low	a^{L}	*yu'*	[$çu^{ʔL}$]	'earth'
Rising	a^{MH}	*yu'u*	[$çuʔu^{MH}$]	'quicklime (Sp. cal)'
Falling	a^{HL}	*yu'u*	[$çuʔu^{HL}$]	'house'

- These five tonal patterns are illustrated in Figures 2 and 3 for two different SLZ speakers.
- Figures 2 and 3 shows the five tonal contrasts averaged for each tonal contrast from the onset to ending of the vowel.
- We can ignore the first 20-25% of the measure due to the influence of transitions out of the consonantal onsets.

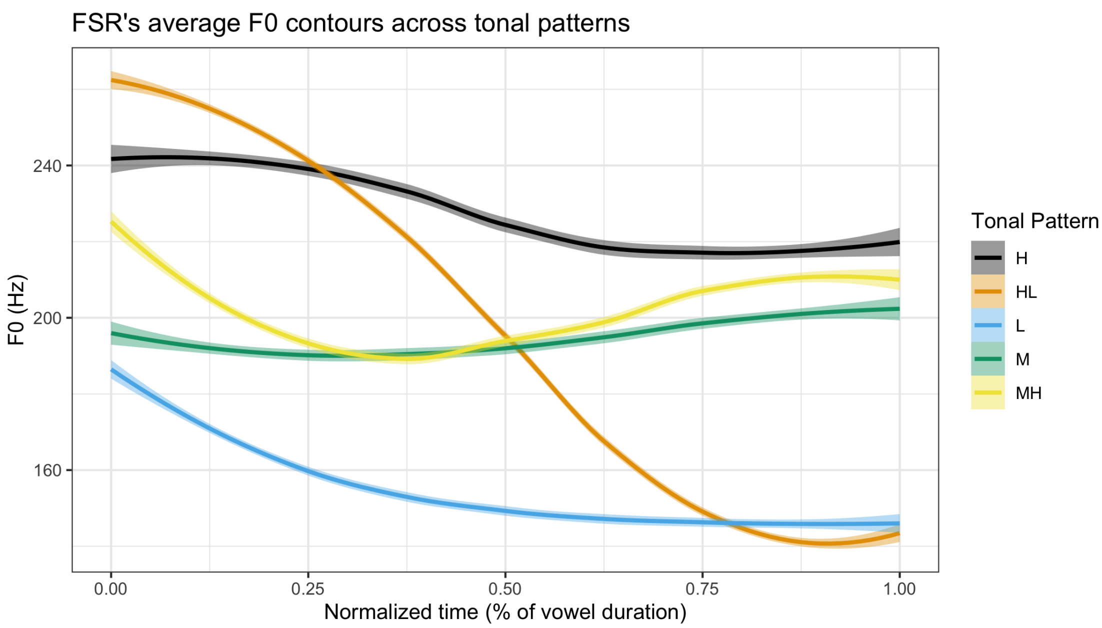


Figure 2: Tonal contrasts for FSR averaged and time normalized. Each line in this graph represents the average of approximately 10 syllables for each tonal pattern.

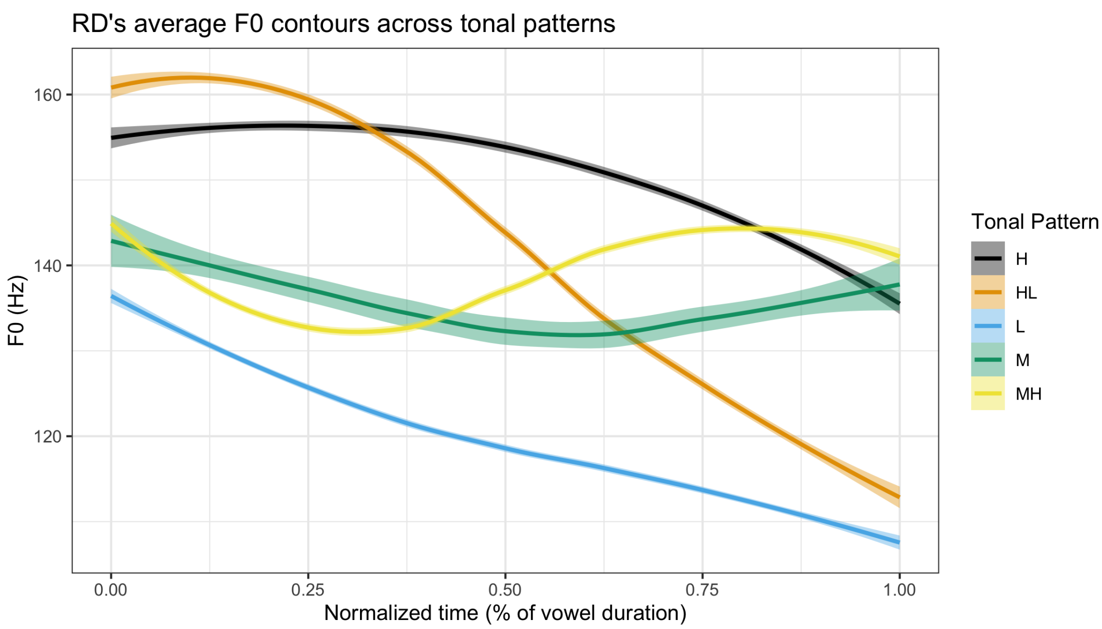


Figure 3: Tonal contrasts for RD averaged and time normalized. Each line in this graph represents the average of approximately 10 syllables for each tonal pattern.

3.2 Phonation in Santiago Laxopa Zapotec

- Zapotecan languages commonly make use of contrastive phonation on vowels (e.g., Avelino 2004, Long & Cruz 2005, Avelino 2010, López Nicolás 2016, Chávez-Peón 2010).

- SLZ is no different and has four contrastive phonation types: modal /a/, breathy /a̤/, checked /aˀ/, and laryngealized /aˀa/.
-

(1) Four-way near minimal phonation contrast
  a. *yag* [çag^{L}] ‘tree; wood; almúd (unit of measurement approximately 4kg)’
  b. *yah* [ça̤^{L}] ‘metal; rifle; bell’
  c. *yu’* [çu^{ˀL}] ‘earth’
  d. *ya’a* [çaˀa^{L}] ‘market’

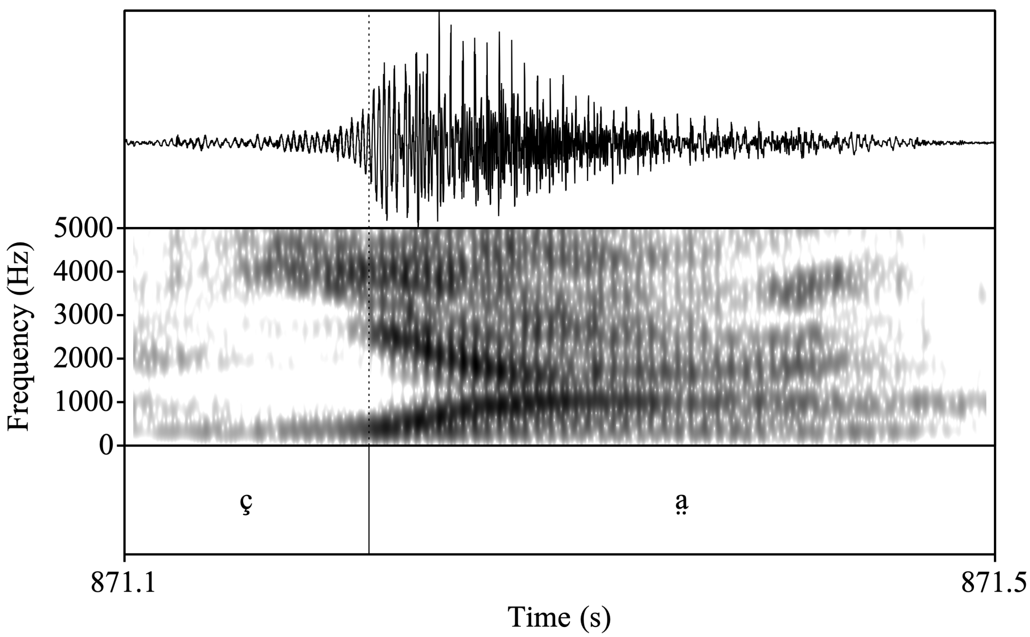


Figure 4: FSR’s breathy vowel in the word *yah* ‘metal; rifle’

Table 4: Layngealized Vowels in Yalálag Zapotec

/VˀV/	[VʔV]
	[VV̰V]
	[VV̰:V̆]
	[VV̰V̰]

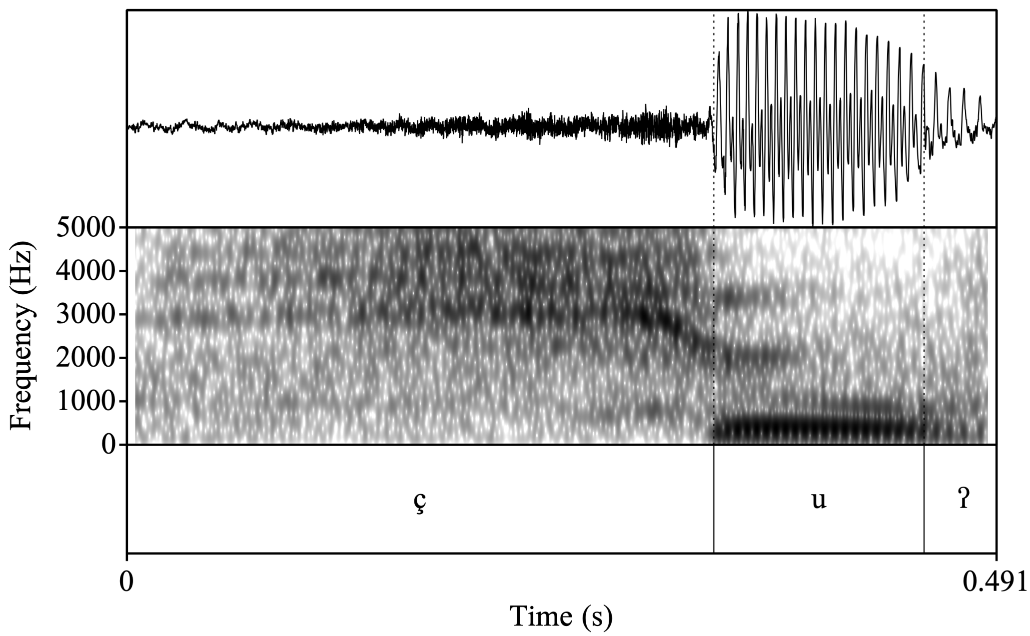
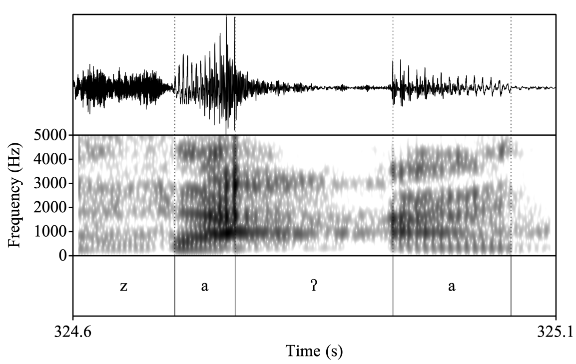
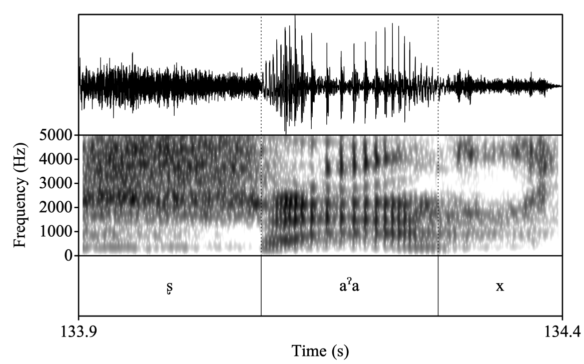


Figure 5: RD's checked vowel in the word *yu'* 'earth'



(a) *za'a* 'corncob'

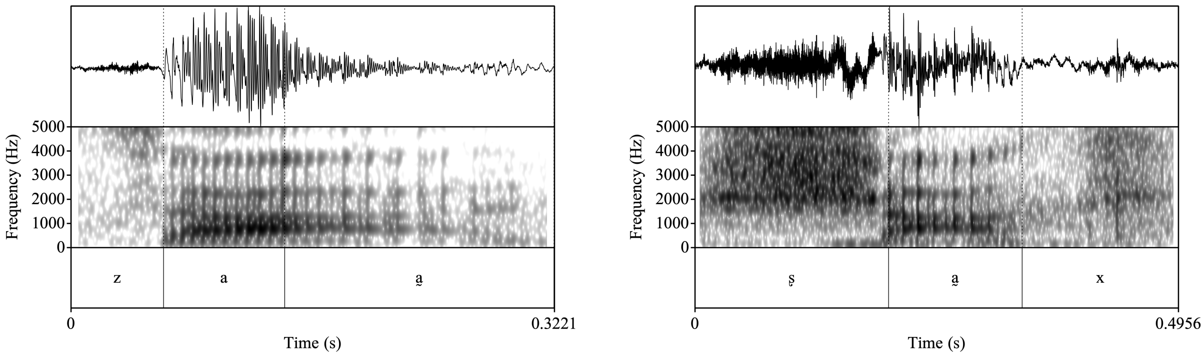


(b) *xa'ag* 'topil'

Figure 6: Comparison of FSR's laryngealized vowels in *za'a* 'corncob' and *xa'ag* 'topil'

Table 5: SLQZ tone and phonation interactions (Chávez-Peón 2010).

	Modal	**Breathy**	**Creaky**	**Interrupted**
High	✓	–	✓	✓
Low	✓	✓	✓	✓
Falling	✓	✓	✓	✓
Rising	✓	–	–	–



(a) *za'a* 'corncob' (b) *xa'ag* 'topil'

Figure 7: Comparison of RD's laryngealized vowels in *za'a* 'corncob' and *xa'ag* 'topil'

Table 6: Number of unique syllables for each interaction of tone and phonation in the data.

	Modal	**Breathy**	**Checked**	**Laryngealized**
High	12	–	5	3
Mid	7	1	2	1
Low	17	5	9	3
High-Low	9	1	2	1
Mid-High	1	1	–	1

3.3 Interaction of tone and phonation in Santiago Laxopa Zapotec

4 Methodology

5 Results

5.1 H1-H2 spectral-tilt

5.2 H1-A3 spectral-tilt

In the first third of the vowel, RD's mean value for H1-A3 is lower than the modal's H1-A3 value. However, there is a large degree of overlap between modals, checked, and laryngealized H1-A3 values, as evidenced by the boxes covering the same regions, see Figure 12.

In the second third of the vowel, Figure 13, the breathy vowel continues to be higher than the modal vowel. The checked and laryngealized vowels H1-A3 values for FSR are uninformative because of the large degree of overlap. For RD, these same measurements show a lower H1-A3 value than the modals which is consistent with creakier productions of vowels. This lower H1-A3 continues throughout the rest of the vowel for laryngealized vowels, see Figure 14b. This behavior is consistent with the observation that RD performs creaky voice throughout their production of laryngealized vowels. For the checked vowels, the measurements are very similar to those of the

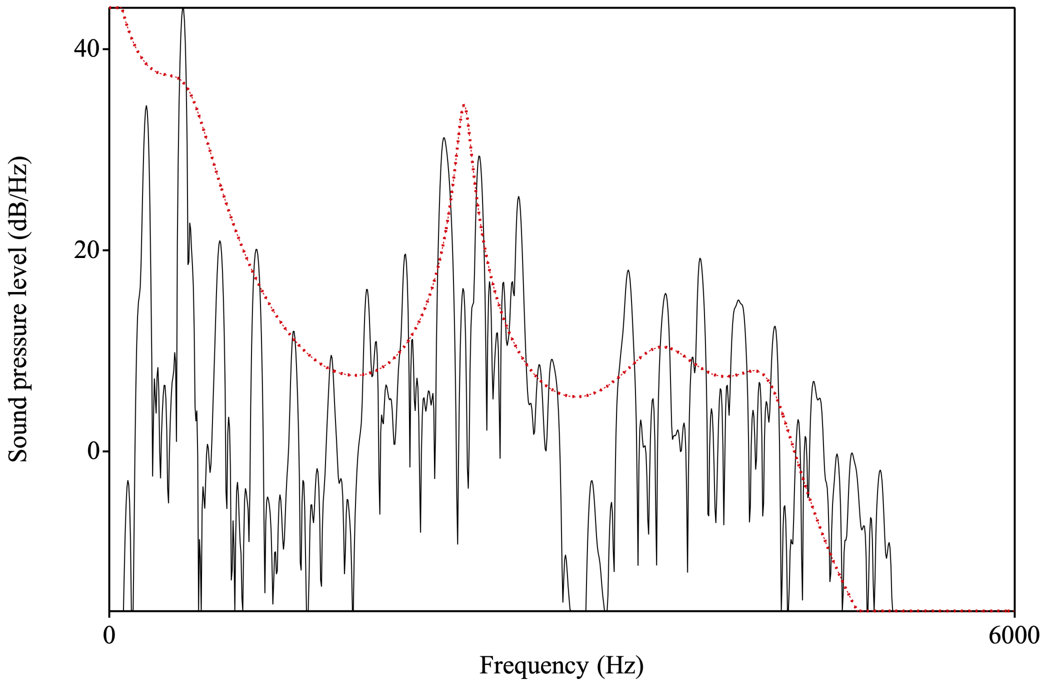
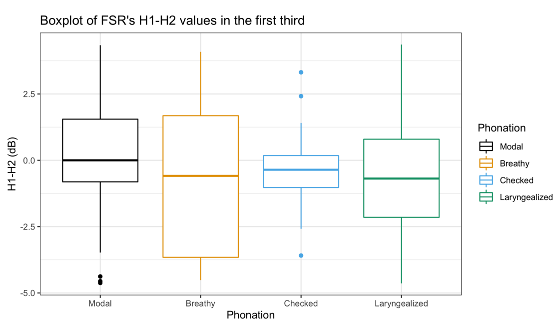
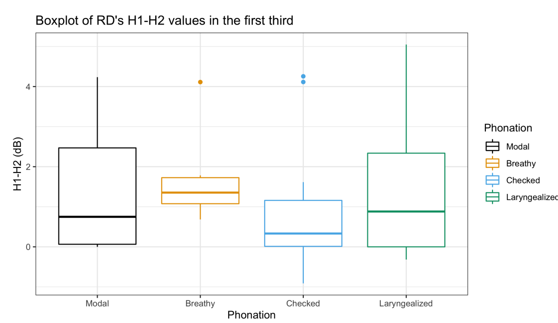


Figure 8: Spectral slice with LPC smoothed line overlaid for the vowel [e]. The harmonics in the spectral slice are represented by each of the dark peaks. The leftmost black solid line peak is the first harmonic (H1) and each subsequent peak represents the next highest harmonic (H2 through H*n*). The red dotted line represents an LPC smoothed line which identifies the formants by the peaks. Each of the harmonics that are closest to the formant peak is identified as A1 through A*n*.



(a) FSR's H1-H2 values.

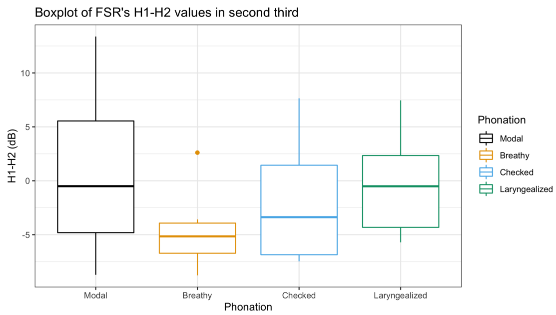


(b) RD's H1-H2 values.

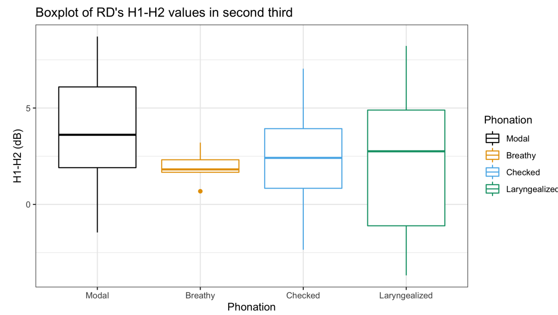
Figure 9: Mean H1-H2 values for the first third of the vowel according to each phonation type.

modal vowel.

In looking at the final portion of the vowels, Figure 14, the measurements continue to show similar behavior to the second portion for both FSR and RD. However, one exception is the lower H1-A3 value for FSR's checked vowels, suggesting that FSR produces a period of creakiness in the last portion of the vowel.

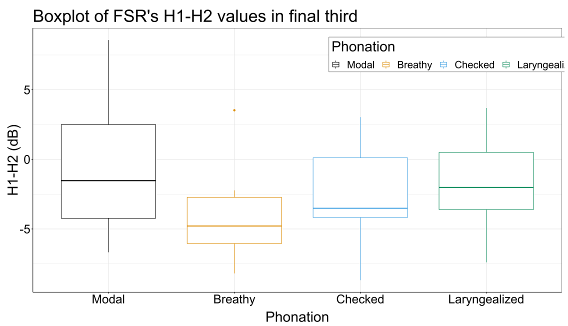


(a) FSR's H1-H2 values.

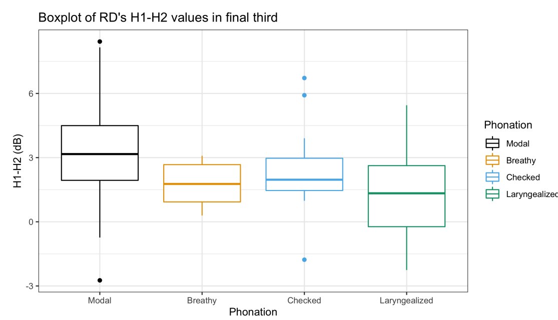


(b) RD's H1-H2 values.

Figure 10: Mean H1-H2 values for the second third of the vowel according to each phonation type.

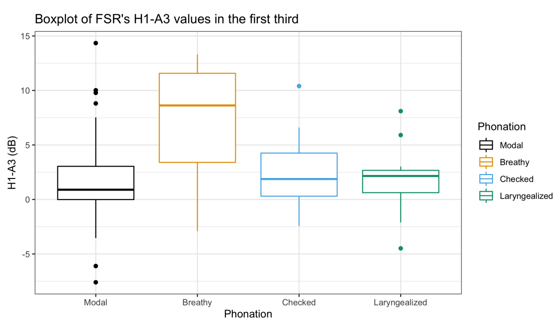


(a) FSR's H1-H2 values.

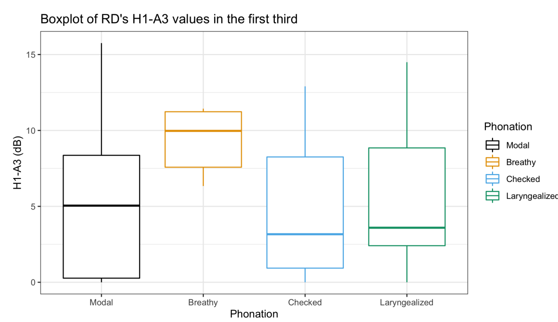


(b) RD's H1-H2 values.

Figure 11: Mean H1-H2 values for the final third of the vowel according to each phonation type.



(a) FSR's H1-A3 values.



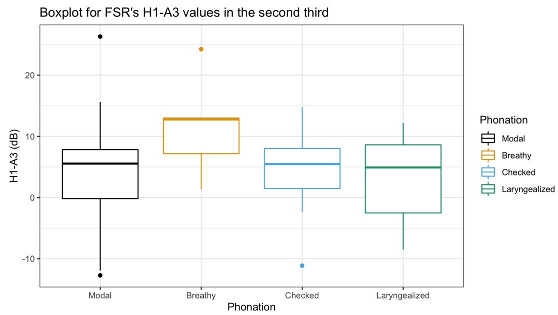
(b) RD's H1-A3 values.

Figure 12: H1-A3 values for FSR (a) and RD (b) for the first third of the vowel.

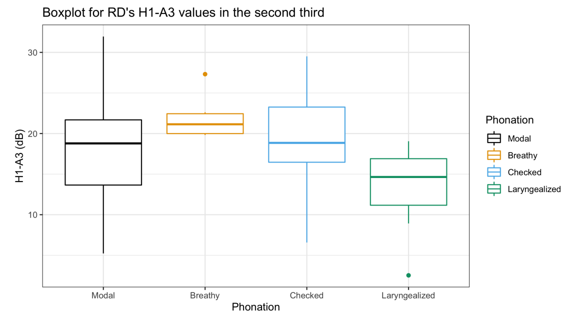
5.3 Cepstral Peak Prominence

5.4 Statistical results

As can be recalled from Section 5.1, both FSR and RD show a lower value for H1-H2 for breathy vowels in the last two-thirds of the vowels when compared to the model vowel's H1-H2 values. The results of the statistical analysis for the last two-thirds of the vowel, presented in Table 8 and

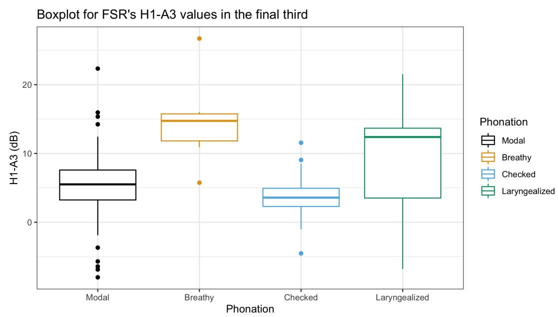


(a) FSR's H1-A3 values.

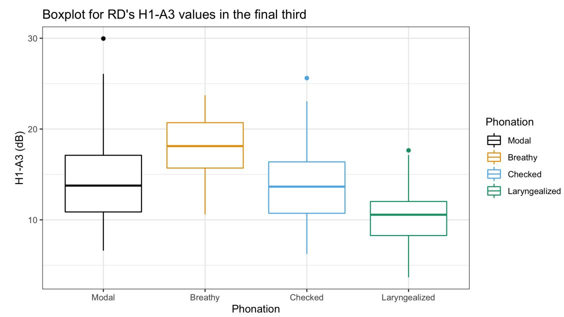


(b) RD's H1-A3' values.

Figure 13: H1-A3 values for FSR (a) and RD (b) for the second third of the vowel.

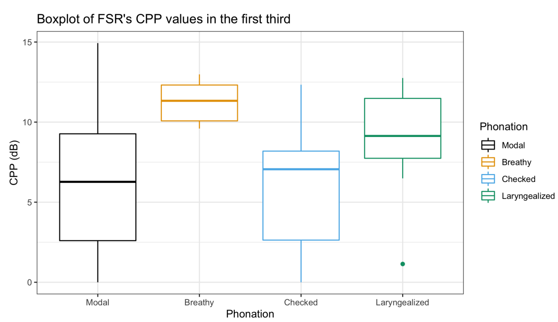


(a) FSR's H1-A3 values.

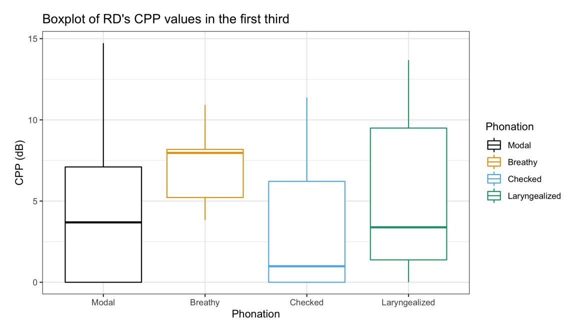


(b) RD's H1-A3 values.

Figure 14: H1-A3 values for FSR (a) and RD (b) for the final third of the vowel.



(a) FSR's CPP values.



(b) RD's CPP values.

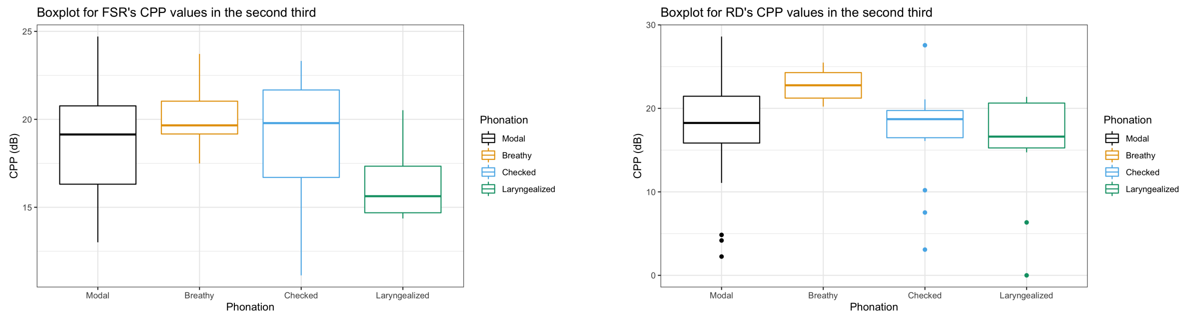
Figure 15: CPP values for FSR (a) and RD (b) for the first third of the vowel.

Table 9, show that this behavior is significant.

At no point do the other phonation types reach significance with respect to H1-H2.

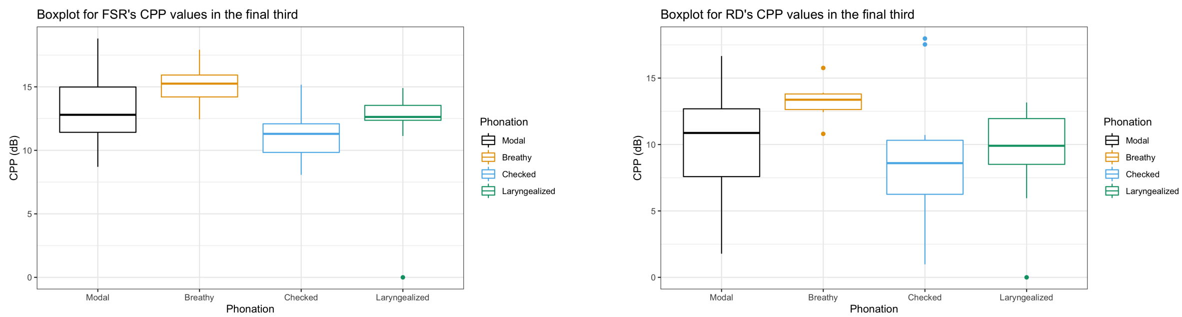
The second statistical analysis for the H1-A3 measurement shows some very clear behavior for breathy voice. As can be recalled from Section 5.2, we observe that breathy voice is clearly identified in all portions of the vowel with an elevated H1-A3 value when compared to the model vowels' values. We see that at all portions of the vowel, as seen in Tables 10, 11, 12 show significance.

However, the other phonations failed to reach significance when evaluated against H1-A3.



(a) FSR's CPP values. (b) RD's CPP values.

Figure 16: CPP values for FSR (a) and RD (b) for the second third of the vowel.



(a) FSR's CPP values. (b) RD's CPP values.

Figure 17: CPP values for FSR (a) and RD (b) for the final third of the vowel.

Table 7: Results of the mixed-effects linear regression analysis on the first third of the vowel for H1-H2.

	Estimate	Std. Error	df	t value	p-value
Breathy	-0.3049	0.5795	116.4255	-0.526	0.600
Checked	-0.4731	0.4029	145.6184	-1.174	0.242
Laryngealized	-0.2938	0.4675	101.9977	-0.629	0.531

Table 8: Results of the mixed-effects linear regression analysis on the second third of the vowel for H1-H2.

	Estimate	Std. Error	df	t value	p-value
Breathy	-3.4158	1.3400	126.9590	-2.549	0.0120
Checked	-1.7466	0.9197	146.9995	-1.899	0.0595
Laryngealized	-0.7405	1.0852	117.0669	-0.682	0.4963

It is important to realize that at this point that H1-H2 and H1-A3 both have failed to account for checked and laryngealized phonations. This is also born out by the observations in Sections 5.1

Table 9: Results of the mixed-effects linear regression analysis on the final third of the vowel for H1-H2.

	Estimate	Std. Error	df	t value	p-value
Breathy	-2.2131	1.0291	125.2092	-2.151	0.0334
Checked	-1.3487	0.6952	146.2461	-1.940	0.0543
Laryngealized	-0.8676	0.8202	116.8963	-1.058	0.2923

Table 10: Results of the mixed-effects linear regression analysis on the first third of the vowel for H1-A3.

	Estimate	Std. Error	df	t value	p-value
Breathy	4.29036	1.31288	137.12067	3.268	0.00137
Checked	0.15001	0.84476	134.62215	0.178	0.85932
Laryngealized	-0.05694	1.07130	137.16596	-0.053	0.95769

Table 11: Results of the mixed-effects linear regression analysis on the second third of the vowel for H1-A3.

	Estimate	Std. Error	df	t value	p-value
Breathy	4.398	2.027	147.003	2.169	0.0317
Checked	1.195	1.426	147.000	0.838	0.4033
Laryngealized	-2.694	1.627	147.001	-1.656	0.0998

Table 12: Results of the mixed-effects linear regression analysis on the final third of the vowel for H1-A3.

	Estimate	Std. Error	df	t value	p-value
Breathy	5.2928	1.7966	127.0400	2.946	0.00383
Checked	-0.7825	1.2487	147.1011	-0.627	0.53189
Laryngealized	0.2669	1.4224	117.4917	0.188	0.85151

and 5.2 which did not show any remarkable differences from the model. When we consider CPP we see both checked and laryngealized vowels clearly differentiated. This is born out in the statistical analysis. This analysis took CPP as fixed and speaker and word as random. This analysis showed that the first third of the vowel, Table 13 both breathy and checked voice were identifiable with CPP.

When considering the second-third of the vowel, Table 14, laryngealized vowels become clearly identifiable by CPP which is born out by the significance of laryngealized phonation and the lack of significance with breathy and checked. This is consistent with the observation that somewhere in the middle of the vowel there is either a full glottal stop or a period of creakiness in the two

Table 13: Results of the mixed-effects linear regression analysis on the first third of the vowel for CPP.

	Estimate	Std. Error	df	t value	p-value
Breathy	3.4470	1.1743	145.9760	2.935	0.00387
Checked	-1.4190	0.7088	120.5020	-2.002	0.04754
Laryngealized	0.8240	0.9530	147.0083	0.865	0.38868

speakers that were evaluated for this study. This observation also bears witness to observations made by Avelino (2010) about the how each of the different manners that laryngealized vowels are produced in Yalálag Zapotec each have a period of model phonation followed by a aperiodicity or a glottal constriction beginning in the middle of the vowel.

Table 14: Results of the mixed-effects linear regression analysis on the second third of the vowel for CPP.

	Estimate	Std. Error	df	t value	p-value
Breathy	1.5044	1.4073	128.0083	1.069	0.287094
Checked	-0.5804	0.9789	146.0792	-0.593	0.554154
Laryngealized	-2.2898	1.1354	117.6213	-2.017	0.046006

In considering the final portion of the vowel, Table 15, the statistical analysis shows that only checked vowels can be reliably determined using CPP. This observations is consistent with the facts that checked phonation consists of a period of creakiness or full glottal closure at the end of the vowel. The other phonation types fail to reach significance.

Table 15: Results of the mixed-effects linear regression analysis on the final third of the vowel for CPP.

	Estimate	Std. Error	df	t value	p-value
Breathy	1.6391	1.0173	139.8563	1.611	0.10939
Checked	-2.1386	0.6449	129.1392	-3.316	0.00119
Laryngealized	-1.1158	0.8142	140.5570	-1.370	0.17274

6 Discussion

6.1 Laryngeal Complexity Hypothesis

- Silverman (1997) and Blankenship (1997, 2002)

6.2 Laryngeal Articulator Model

Table 16: A list of the different nodes and their abbreviations in the Laryngeal Articulator Model.

States/Nodes	Physiological description
vfo	vocal folds open (abducted)
vfc	vocal folds closed (adducted/prephonation)
epc	epilaryngeal constriction
epv	epilaryngeal vibration
tfr	tongue fronting
tre	tongue retraction
tra	tongue raising
tdb	tongue double bunching
↑lx	raised larynx
↓lx	lowered larynx
Hf0	increased vocal fold tension, less vibrating mass (high f0)
Lf0	decreased vocal fold tension, more vibrating mass (lower f0)

These twelve nodes not only represent the interactions of the larynx but also represents actual physiological representations. This means that any given node represents what is occurring with a given part of the larynx. For example, the node ‘epc’ represents any epilaryngeal constriction when activated. Now these nodes are not just independent entities but interact in complex ways with other nodes. These interactions are best captured as a network or web of nodes as seen in Figure 18.

7 Conclusion

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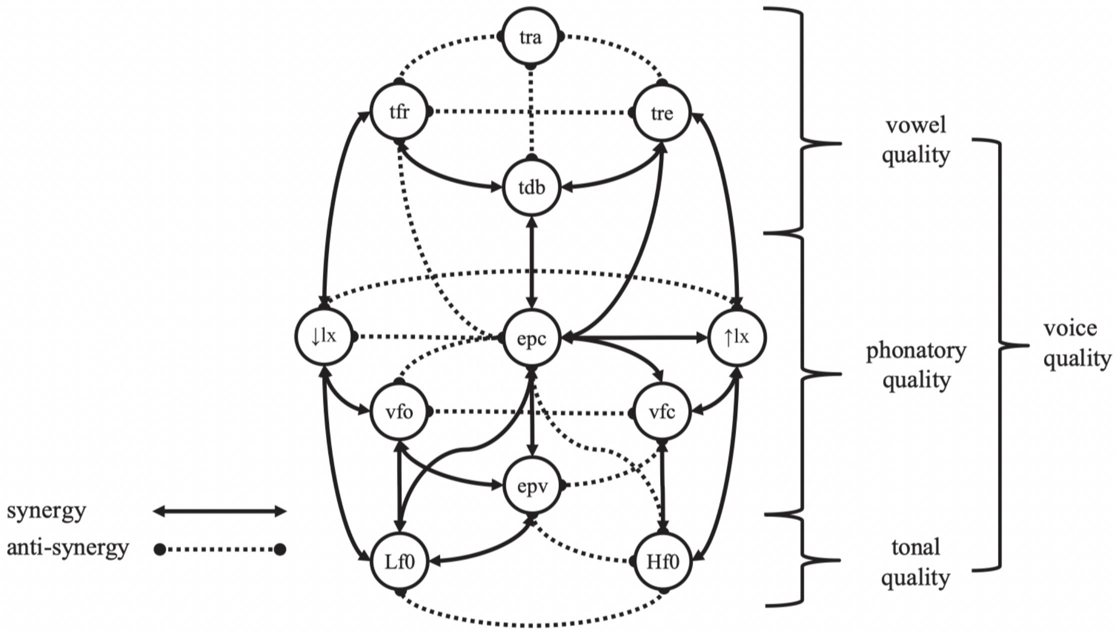

Figure 18: Network of synergistic and anti-synergistic nodes in the Laryngeal Articulator Model. Taken from Esling et al. (2019).

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