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## **Santa Ana del Valle Zapotec Phonation \***

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### **1 Introduction**

The Zapotec language family provides an interesting case for the study of contrastive phonation. Accounts of Zapotec languages describe more interesting phonations than are typically expected, such as the possibility of a four-way phonation contrast, and the possibility of complex phonation contours within a single syllable. In addition, many accounts report phonations that are coupled with a wide array of tones. However, little is known about the phonetic properties of these phonations and tones. This study investigates the phonetic properties of the phonation and tone in one Zapotec language, Santa Ana del Valle Zapotec.

### **2 Santa Ana del Valle Zapotec**

Santa Ana del Valle Zapotec (hereafter SADVZ) is an OtoManguean language spoken in Santa Ana del Valle, Oaxaca, Mexico. The Ethnologue (Grimes 1990) classifies SADVZ into the San Juan Guelavía Zapotec subgroup. (The Ethnologue classifies the numerous Zapotec languages into 58 different sub-groupings based on a variety of complex criteria.) The San Juan Guelavía subgroup contains the numerous and diverse languages spoken in the Valley of Oaxaca, such as San Juan Guelavía (for which the subgroup is named), San Lucas Quiavini, Tlacolula, Jalieza, Mitla, and Teotitlán del Valle Zapotec, to name a few. There are approximately 28,000 speakers (1990 census) for the entire San Juan Guelavía Zapotec subgroup (Grimes 1990); it is not known what portion of this is composed of SADVZ speakers.

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Abbreviations: hab. = habitual, irr. = irrealis.

The Ethnologue considers San Juan Guelavía Zapotec to be the ‘lingua franca’ of the group, even though it is quite different from the other Zapotec languages spoken in the Valley of Oaxaca. (The languages within the San Juan Guelavía subgroup have various levels of mutual intelligibility (59-100%) (Grimes 1990).) For example, San Juan Guelavía Zapotec does not contain breathy vowels (Jones and Knudson 1977), while many of the other languages in the subgroup do (e.g. Mitla Zapotec (Stubblefield and Stubblefield 1991); San Lucas Quiavini Zapotec (Munro and Lopez et al. 1999)).

Perhaps the best-studied languages in this subgroup are San Juan Guelavía Zapotec (Jones and Knudson 1977) and San Lucas Quiavini Zapotec (Munro and Lopez et al. 1999). While both of these languages have a practical orthography, this orthography is not used for SADVZ, which remains unwritten.

## **2.1 Brief Overview of Phonemic Inventory**

### **2.1.1 Consonants**

The consonant inventory of SADVZ is shown in Table 1. The Zapotec languages have been described as having a fortis/lenis contrast for the obstruents and the sonorants, rather than a difference in voicing (Jaeger 1983; Avelino 2001). The fortis/lenis distinction is characterized by greater duration and increased energy for the fortis consonants compared to the lenis ones. In the table below, the symbol to the left of each pair is fortis and the right, lenis. (I have represented the fortis/lenis obstruents with the symbols for voiceless and voiced consonants, respectively, since this is their typical orthographic representation in Zapotec languages. Likewise, the fortis sonorants are represented by a double consonant, and the lenis ones by a single consonant.) Consonants in parenthesis only appear in loan words, which are generally from Spanish.

	Labial	Dental	palatal-alv.	retroflex	palatal	velar	glottal
Stop	(p) b	t d				k g	ʔ
fricative	(f)	s z	ʃ ʒ	ʂ ʐ			
affricate			tʃ dʒ				
nasals	mm m	nn n				ŋŋ ŋ	
laterals		ll l					
approximants					j j	(w)	
Trill		rr r					
Tap		r r r					

**Table 1: Consonants of SADVZ**

I have included the glottal stop as a consonant, even though its distribution is somewhat defective in that it only occurs after vowels. Analyses of other Zapotec languages include the glottal stop as a vocalic feature, and vowels that bear this feature are referred to as “checked vowels” (e.g. Jones and Knudson 1977; Nellis and Hollenbach 1980; Munro and Lopez et al. 1999, to name a few). The possibility of a checked phonation will be considered in this study.

### 2.1.2 Vowels

SADVZ has six vowel qualities /i, e, ɨ, u, o, a/ (the /ɨ/ does not occur as often as the other five vowels) which are presented in Table 2.

	Front	Mid	Back
high	i	ɨ	u
mid	e		o
low			a

**Table 2: Vowels of SADVZ**

## 2.2 Structure of SADVZ Words

The vast majority of native Zapotec words are monosyllabic, while Spanish loan words are typically polysyllabic. Native polysyllabic words can be formed by the addition of

morphemes; these can create changes in phonation. For example, the irrealis aspect can trigger a change from breathy to modal phonation. In the examples below, the verb “to wash” [riɡɨbi] has a breathy vowel in the habitual form (1), but a modal verb in the irrealis<sup>1</sup> form (2):

1. ri-ɡɨbi  
hab.-wash
2. k-ibi  
irr.-wash

To avoid any changes in phonation, the majority of words examined in this study were monosyllabic. Section 7 of this study concentrates on polysyllabic words. These words were carefully chosen to avoid morphemes that would trigger changes in phonation.

### **2.3 Phonation and Tone**

No research has been done on the phonation or tones of SADVZ. However, it is expected that this language shares some of the features of phonation and tone found in other Zapotec languages. Before discussing the results obtained for SADVZ, I will review the descriptions of phonation and tone in other Zapotec languages, and then present the phonetic literature on phonation, in general.

### **2.4 Overview of Phonation and Tone in Zapotec Languages**

There are numerous and diverse accounts of the phonations types and tones in Zapotec languages. Here, I briefly summarize some of these accounts.

Cajonos Zapotec (Nellis and Hollenbach 1980) includes four vowels /i,o,e,a/, which can occur with one of three phonations: modal, checked, and laryngealized. Checked vowels, which only occur in open syllables, are articulated as a vowel followed by a glottal stop. Laryngealized vowels are defined as “a rapid sequence of two vowels with an intervening glottal stop” (Nellis

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<sup>1</sup> The underlying form of the irrealis of ‘wash’ is /g-ɡɨbi/. The /g-g/ sequence is realized phonetically as [k].

and Hollenbach 1980: 99) that is analyzed as a single-vowel segment. There is also a four-way tonal distinction between high, low, mid, and a “downglide from high to low” tones (Nellis and Hollenbach 1980: 99). The tonal distribution is quite complex and determined by a number of factors such as the number of syllables in a word, if the vowel is followed by a lenis or fortis consonant, and the phonation of the vowel. For example, in “... monosyllabic roots with open syllables, simple vowels closed by either a fortis or lenis consonant, or checked vowels, there is a contrast only among the high...low...and glide” (Nellis and Hollenbach 1980: 101). In monosyllabic roots “with laryngealized vowels, there is a four way contrast: both morae may have high tone, both low tone, the first high tone and the second mid, or the first high and the second low” (Nellis and Hollenbach 1980: 101). In native disyllabic roots, the tonal pattern is “high-high, low-high, and low-low” (Nellis and Hollenbach 1980: 101).

Choapan Zapotec (Lyman and Lyman 1977) includes six vowels /i,e,ɛ,u,o,a/, and three phonations: laryngealized, checked, and modal (“unchecked”). A laryngealized vowel is a sequence of two vowels, which do not have to be of the same quality, with an intervening glottal stop. A checked vowel is a vowel followed by a glottal stop. A typical Choapan syllable can have up to three phonation types over one vowel segment. The tones of Choapan Zapotec include: a high tone (which is slightly rising), a low tone (which is perceptually longer in duration than the other tones), and a mid tone. It is not clear if there is any relationship between tone and phonation in this language.

San Juan Guelavía (Jones and Knudsen 1977) includes six vowels /i,e,ɨ,a,u,o/ each of which can occur with one of three phonations: modal, laryngealized, and checked. Modal and checked vowels contrast phonemically. Laryngealized and checked vowels occur in complementary distribution. Laryngealized vowels occur preceding lenis consonants or glides

and checked vowels occur elsewhere. In addition, there are three level phonemic tones: low, mid, and high, which can occur with any of the three phonations.

San Lucas Quiaviní Zapotec (SLQZ) (Munro and Lopez et al. 1999) includes six vowels /a,e,i,o,u, ɨ/ which can occur with four phonations: modal, breathy, checked, and creaky. A checked vowel is defined as a vowel followed by a glottal stop; creaky vowels co-occur in syllables with checked vowels. An SLQZ syllable can have up to three different phonations. “The fullest SLQZ syllable template is CCGVVVCG, where C represents a true consonant, G a glide and V is a vowel” (Munro and Lopez et al. 1999:3). Most often, “only the final syllable of a non-compound uninflected native word ... is as elaborated as this template” (Munro and Lopez et al. 1999:3). Within the syllable the VVV sequence, referred to as the vowel complex, “may contain up to three individual vowels, each with its own phonation” (Munro and Lopez et al. 1999:3). SLQZ is also a tonal language, but the tones are dependent on the number and type of phonations found in a word. A characterization of the tonal system of SLQZ is as follows: “plain vowels (especially two plain vowels together) have high tone, creaky vowels have low tone ... and final phrasal breathy vowels have an extra-low tone. The tone of checked and other breathy vowels is derived from the vowel complex environment in which they occur” (Munro and Lopez et al. 1999:3).

In sum, the phonations of Zapotec languages are complex, and vary across languages. Some studies describe either a four-way contrast between modal, creaky, breathy, and glottalized (“checked”) vowels (e.g. San Lucas Quiaviní Zapotec) or a three-way contrast between modal, laryngealized, and checked vowels (e.g. Cajonos Zapotec; Choapan Zapotec; San Juan Guelavía). For many analyses, it is not clear to what extent the checked vowel is thought to be a distinct phonation. It is possible that the checked vowel is a combination of a modal vowel

followed by a glottal stop, but this is not explicit. On the same note, some analyses use the term laryngealized, but it is not clear if the term laryngealized is used to refer to creaky phonation or the presence of a glottal stop.

Tonal analyses also vary from language to language. Languages such as San Lucas Quiavini Zapotec (Munro and Lopez et al. 1999) describe a strong correlation between tone and phonation, while in languages such as San Juan Guelavía (Jones and Knudsen 1977) there is no link between tone and phonation.

In addition, some accounts describe the possibility of having up to three phonation types in one syllable (Choapan Zapotec (Lyman and Lyman 1977) and San Lucas Quiavini Zapotec (Munro and Lopez et al. 1999)).

Based on the accounts of other Zapotec languages, it is possible that SADVZ could have up to four phonations, which may or may not be correlated with tone, and could have changes in phonation within a single syllable.

### **3 Cross-linguistic Overview of Phonation**

In this section, I will present a cross-linguistic overview of phonation, to see how Zapotec phonations compare. I will begin by discussing how the different phonations are characterized in the phonetic literature, limiting the discussion to languages that use phonation types contrastively, and then discuss properties commonly associated with non-modal phonation, such as an increased duration and localization.

There are three main types of phonations that occur cross-linguistically: modal, breathy, and creaky voice. Modal voice is the neutral phonation to which other phonations are compared. It is characterized by vocal folds with normal adductive and longitudinal tension. During modal



phonation, the vocal folds are open during approximately half of the glottal cycle, and closed for the other half, which results in regularly spaced glottal pulses.

Breathy voice is characterized by vocal folds that vibrate, but without much contact. For breathy voice, there is minimal adductive tension and little longitudinal tension in the vocal folds. Breathy voice is contrasted with modal voice on vowels in languages such as Gujarati and Tamang (as reviewed by Gordon and Ladefoged 2002).

Creaky voice is distinguished from breathy and modal voice by high adductive tension and little longitudinal tension in the vocal folds. During creaky voice, the vocal folds are opened just enough to allow for voicing, which often results in irregularly spaced glottal pulses. Creaky voice is contrasted with modal voice on vowels in Sedang and Southern Nambiquara (as reviewed by Gordon and Ladefoged 2002). In addition, certain languages use a voice quality that is similar to creaky voice, but does not fall precisely under the category of creaky. Examples of this are Bruu, which has a contrast involving stiff and slack vocal folds, and !Xóǀ, which uses a strident voice quality to distinguish vowels (as reviewed by Gordon and Ladefoged 2002).

Some languages, such as Jalapa Mazatec and Chong, have a three-way contrast in phonation between modal, breathy, and creaky vowels (Blankenship 1997). In the phonetic literature, no languages have been described as contrasting four phonation types, or as having a sequence of contrastive non-modal phonations within a syllable. (Laver (1980) presents a more elaborate set of phonetic phonations, but only breathy, modal, and creaky phonations are known to contrast.)

### **3.1 Other Features of Non-modal Phonation**

#### **3.1.1 Localization of Non-Modal Phonation**

Non-modal phonation on vowels is often confined to a portion of the vowel, especially in languages with contrastive phonation and contrastive tone. This is the case for Jalapa Mazatec, a language that contrasts both tone and phonation. In this language, creaky and breathy voice are localized to the first portion of the vowel (Blankenship 1997; Silverman 1997). “The second portion of the vowel usually possesses severely weakened breathiness or creakiness, verging on modal phonation” (Silverman 1997: 238). Silverman (1997) suggests that the localization of non-modal phonation is linked to the use of tone. Since non-modal phonation influences the saliency of the fundamental frequency, it would be difficult for creaky or breathy vowels to carry a full range of tonal contrasts. But, by limiting creaky or breathy voice to the beginning of the vowel, a portion of the vowel remains modal, and thus is able to support a full range of tonal contrasts (Silverman 1997).

#### **3.1.2 Duration of Vowels with Non-Modal Phonation**

In some languages, non-modal phonation is associated with an increase in duration. This is true of Jalapa Mazatec, where creaky and breathy vowels are longer than modal ones (Silverman et al. 1995). However, this is not true of all languages that have contrastive phonation. In San Lucas Quiaviní Zapotec, a language that also contrasts creaky and breathy vowels, there is not a significant difference in duration between modal and non-modal phonation (as reviewed by Gordon and Ladefoged 2002).

In summary, the Zapotec languages presented in section 2.3 are typologically unusual when compared cross-linguistically. For example, the four-way contrast in phonation (e.g. San Lucas Quiaviní Zapotec (Munro and Lopez et al.1999) is unusual since most languages have a maximum of three phonations. Another unusual feature is the sequence of phonations within a

syllable that is described for some Zapotec languages (e.g. Choapan Zapotec (Lyman and Lyman 1977) and San Lucas Quiavini Zapotec (Munro and Lopez et al. 1999)).

In the next section, I will discuss one of the most common ways to measure non-modal phonation, spectral tilt.

### **3.2 Spectral Tilt**

There are a number of ways to measure non-modal phonation from an audio signal such as periodicity, acoustic intensity, spectral noise, and spectral tilt (for a review of these see Gordon and Ladefoged 2002). Spectral tilt, one of the most common ways to measure phonation, is the extent to which intensity drops off as frequency increases. Subtracting the amplitude of a higher frequency harmonic from the amplitude of the fundamental frequency (also called the first harmonic) yields a largely positive value for breathy vowels, a smaller positive value for modal vowels, and a negative value for creaky vowels. Spectral tilt has been a reliable measure of phonation in numerous languages such as Jalapa Mazatec, Gujarati, Kedang, and Hmong (as reviewed by Gordon and Ladefoged, 2002).

There are different ways to characterize spectral tilt. Primarily, the difference between the amplitude of the first (H1) and second harmonics (H2), which correlates with the portion of the glottal cycles in which the glottis is open (the open quotient), has been used to distinguish between modal and non-modal phonation. However, other studies have made use of the relationship between H1 and harmonics exciting higher formants, which correlates with the abruptness of the closure of the vocal folds. These include: H1-F3 (Stevens and Hanson 1995; Blankenship 1997), H1-F1 or H1-F2 (Ladefoged 1983) and the average of H1-H2 compared to F1 (Stevens 1988). Other studies have used the relationship of higher formants to lower ones such as F2-F3 (Klatt and Klatt 1990).

Because they reflect different aspects of phonation, the different measures of spectral tilt do not always distinguish phonation types, even within a single language. For example, Blankenship (1997) found that in Mpi, H1 – H2 was a more reliable measure of phonation on vowels with high tone than with mid or low tone. This suggests that in Mpi, the phonations of high tone vowels differ in their open quotient, while the phonations of low tone vowels do not.

#### **4 Experimental Comparison of Phonation in SADVZ**

As we saw in section 2.3, the numerous and diverse accounts of phonation in Zapotec languages cast doubt on a simple three-way contrast as an accurate description for the phonation of SADVZ.

As a starting point, however, I propose a three-way contrast in phonation for SADVZ, because a near-minimal triplet [lat] ‘tin can’, [l̥at] ‘place’, and [l̥ats] ‘field’ (distinguished by the phonation of the vowel) can be found. Once a measure of phonation has been selected to distinguish the near-minimal triplet, it will be possible to see if the proposed three-way contrast in phonation should be expanded to include a possible fourth “checked” phonation or any other additional phonation types, and to determine if phonation ever changes over the course of a syllable.

##### **4.1 Selecting a Measurement of Phonation**

Spectral measures were used to measure phonation in SADVZ. Spectral noise, periodicity, and acoustic intensity were not measured.

###### **4.1.1 Spectral Measures**

Since different spectral measures yield different results depending on the nature of the phonation, it was first necessary to determine which measures would best distinguish phonations for this study. Six measures (H1-H2, H1+H2/2-F1, H1-F1, H1-F2, H1-F3, and F2-F3) were

tested on the near-minimal triplet [lat] ‘tin can’, [laṭ] ‘place’, and [laṭs] ‘field’. The near-minimal triplet was selected based on cognates in a variety of Zapotec languages in the San Juan Guelavía Zapotec sub-group. Perception confirmed that these words were cognates in SADVZ.

Each word was uttered in sentence-medial position, and repeated ten times by three native speakers ranging from 40-50 years of age (two male, Speaker 1 and Speaker 2, and one female, Speaker 3). Tokens were digitized and analyzed in PCQuirer at a sampling rate of 22050 Hz. Figures 1-3 and Figures 4-6 are spectrograms, waveforms and Fast Fourier Transforms (FFT) of the sample data as produced by Speaker 1 (male speaker) and Speaker 3 (female speaker), respectively. Each measurement was made over a 30 ms window, 50 ms before the end of the vowel. Spectrograms were used to position the 30 ms window. In the case of creaky tokens, this window would naturally include the silent intervals between pitch pulses. In addition, for the female speaker’s breathy tokens, the window is partially during the noise interval.

Measurements were taken manually from the FFT. H1 is equal to the height of f0 in the FFT; H2 equals the height of the second harmonic. F1 is the amplitude of the highest harmonic near the first formant. F2 is the amplitude of the highest harmonic near the second formant. F3 is the amplitude of the highest harmonic near the third formant. The measure of phonation is the difference between the two measures (H1-H2,  $H1+H2/2-F1$ , H1-F1, H1-F2, H1-F3, and F2-F3) in dB.

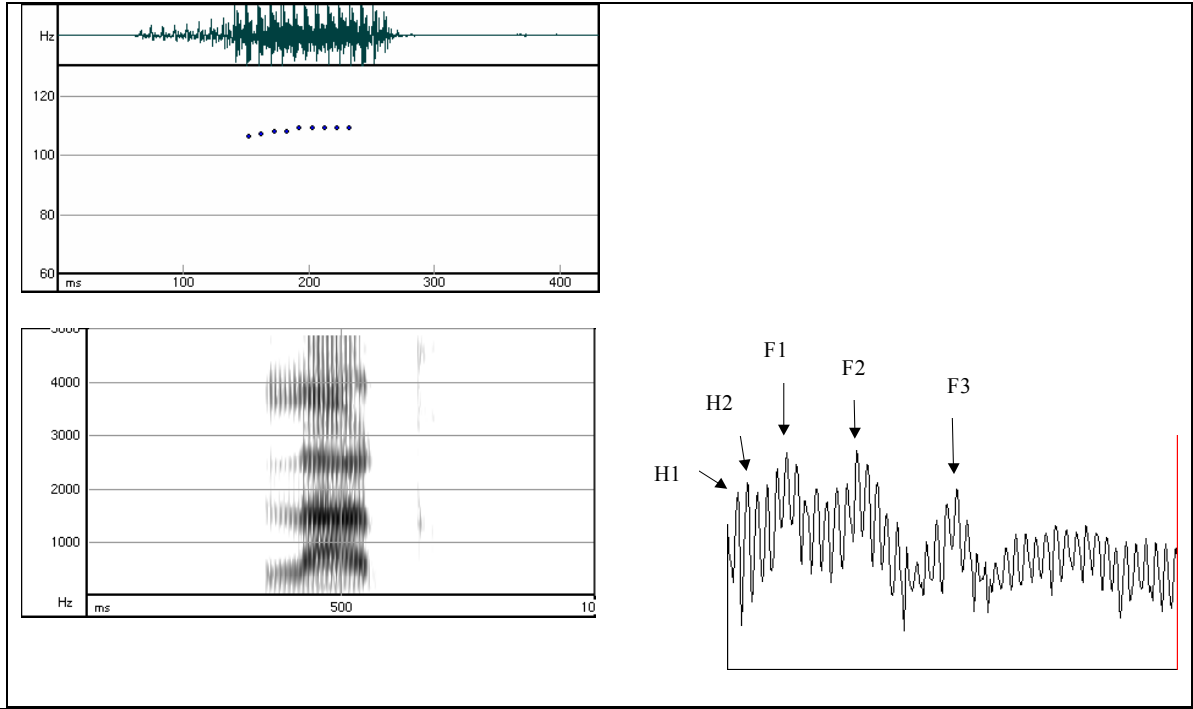


Figure 1: Waveform, spectrogram and FFT of ‘can’ [lat] produced by Speaker 1. Pitch track fails at end.

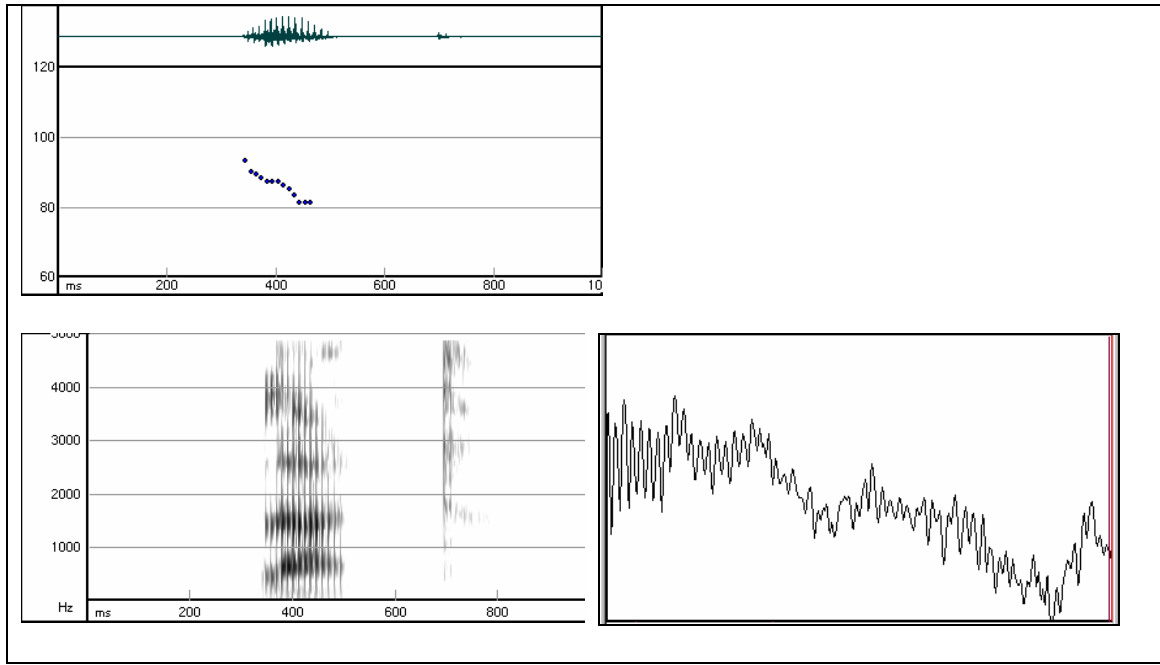
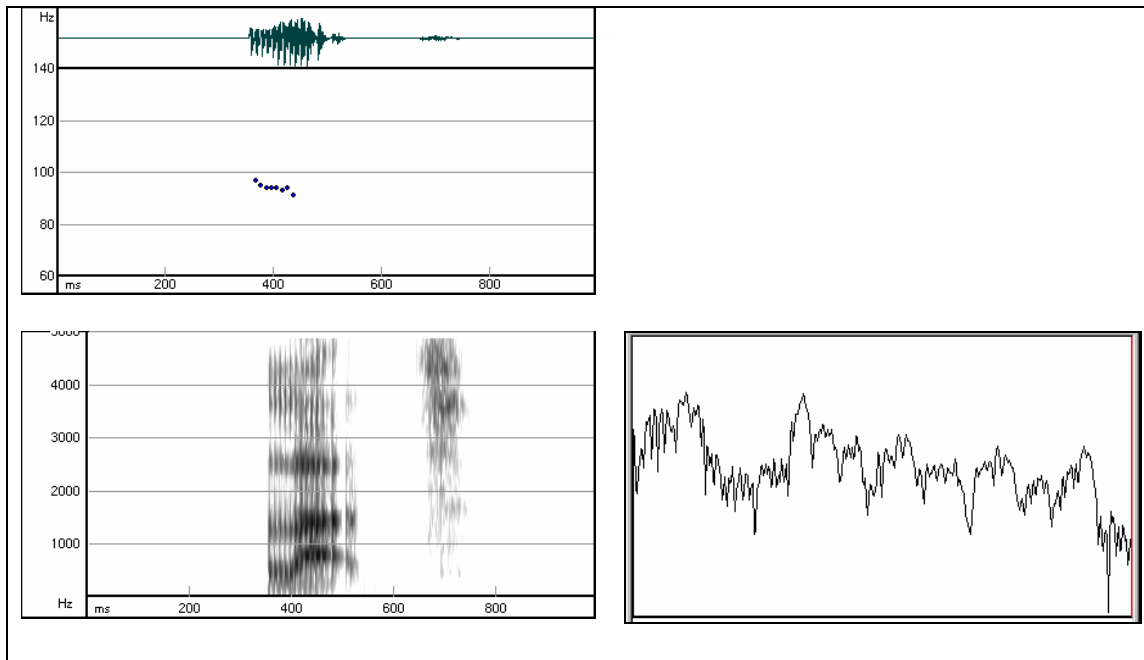
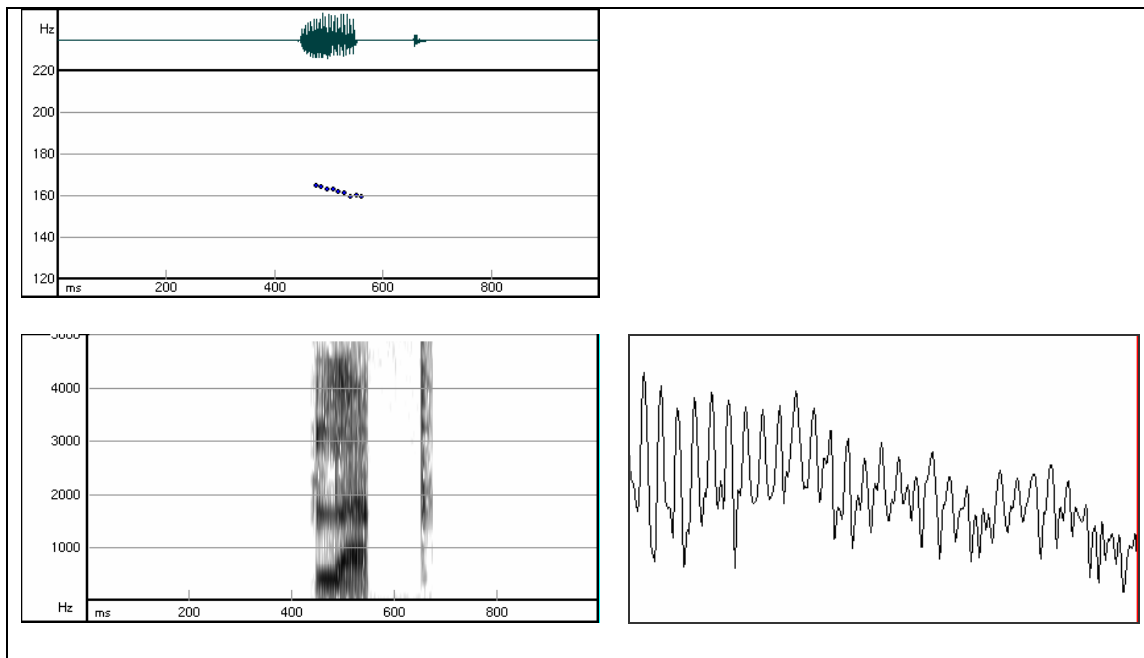


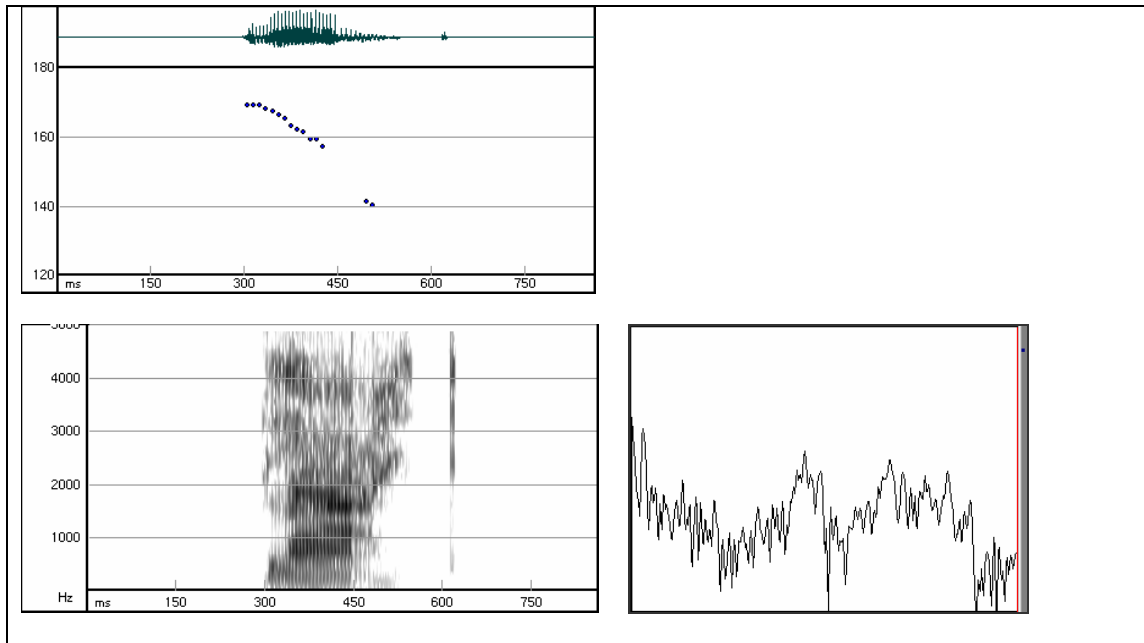
Figure 2: Waveform, spectrogram and FFT of ‘place’ [lat] produced by Speaker 1.



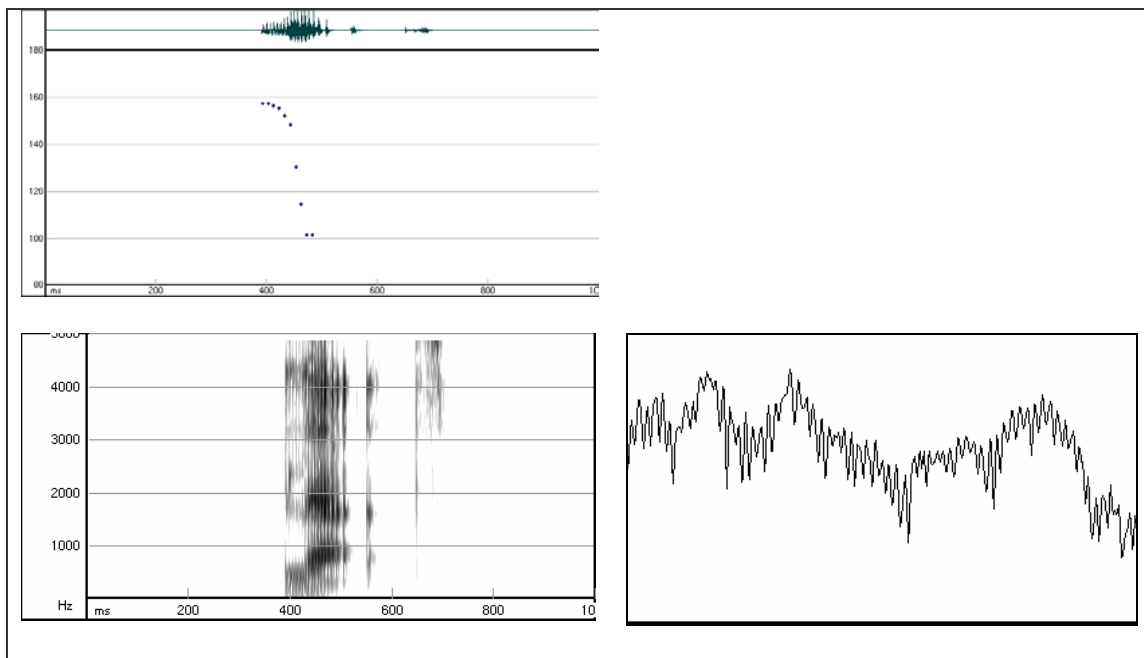
**Figure 3: Waveform, spectrogram and FFT of ‘field’ [lat] produced by Speaker 1. Pitch track fails at end.**



**Figure 4: Waveform, spectrogram and FFT of ‘can’ [lat] produced by Speaker 3.**



**Figure 5: Waveform, spectrogram and FFT of ‘place’ [lɑt] produced by Speaker 3. Pitch track fails at end.**



**Figure 6: Waveform, spectrogram and FFT of ‘field’ [lɑt] produced by Speaker 3. Pitch track fails at end.**

Table 3 shows the number of times the measures of phonation were successful on the near-minimal triplet (the maximum is ten). The expected direction of difference is given at the



top of the chart. The shaded boxes represent the most successful measures for a given speaker. A measure was considered successful if it had any amount of difference in the expected direction.

A statistical comparison of the measures was not performed.

Measures	Creaky (expected: creaky < modal)			Breathy (expected: breathy > modal)		
	Speaker 1	Speaker 2	Speaker 3	Speaker 1	Speaker 2	Speaker 3
<b>H1-H2</b>	4	4	10	0	0	10
<b>H1+H2/2-F1</b>	3	2	4	0	0	4
<b>H1-F1</b>	5	3	0	4	5	2
<b>H1-F2</b>	4	5	0	2	5	1
<b>H1-F3</b>	10	10	0	10	10	0
<b>F2-F3</b>	2	0	2	4	4	2

**Table 3: Number of times the measures succeeded**

H1-F3 was the most successful measure both breathy and creaky phonations for the male speakers, while H1-H2 was the most successful measure for the female speaker. The different measures indicate a difference in the production of phonation by the speakers. For the female speaker, H1-H2 was the most successful measure of phonation. H1-H2 correlates with the open quotient, the portion of time the vocal folds are open during each glottal cycle. When the vibration of the vocal folds has a large open quotient, the fundamental frequency dominates the spectrum. This is the case for breathy phonation, which has a large open quotient and a spectrum dominated by H1. Thus, the value of H1-H2 is largely positive for breathy phonation.

The most successful measure of phonation for the male speakers was H1-F3. H1-F3 reflects the manner and speed at which the vocal folds close. When the vocal folds come together abruptly, it excites the higher frequencies of the vowel. For this reason, creaky phonation, which is characterized by vocal folds that close abruptly, has a higher value for F3 than H1. Thus, the phonation differences of the male speakers are apparently produced by the speed of closure of the vocal folds (which correlates with H1-F3), and not the proportion of time the vocal folds are open or closed. The opposite is true of the female speaker. Her phonations are apparently

produced by changes in the portion of time the vocal folds are open or closed (H1-H2), and not the rate of closure.

## **4.2 Phonation in SADVZ**

Now that a measure of phonation has been determined for each speaker, it is possible to apply this measure to a wider range of words in SADVZ to determine whether a simple three-way phonation contrast, with no phonation contours within a syllable, suffices to describe its phonations.

### **4.2.1 Methods**

#### **4.2.1.1 Speakers**

The same three speakers were used again for this part of the study.

#### **4.2.1.2 Speech Materials**

A wordlist was selected based on cognates in related languages. The wordlist included tokens that could potentially exhibit a more complex phonation contrast than simply breathy, modal, and creaky, and could potentially exhibit a change in phonation throughout a syllable. The wordlist was composed of monosyllabic words all with the target vowel [a] (the first formant of low vowels does not influence the amplitude of the first or second harmonics as much as in higher vowels) and a range of consonants.

#### **4.2.1.3 Procedure**

The three speakers were recorded over multiple sessions in a sound-proof booth. All words were uttered in the frame sentence [*guni* \_\_\_ *primer*] “Say \_\_\_ first.” The sentence was selected since it was determined (through H1-F3 and H1-H2) that these two words only included modal phonation. The sentence was produced as a single intonational phrase. Each token was repeated 5 times.

As before, tokens were digitized and analyzed in PCQuirer at a sampling rate of 22050 Hz. An FFT was calculated over a 30 ms window starting 50 ms before the end of the vowel. To calculate the phonation for the male speakers, the amplitude of H1 and the amplitude of the highest harmonic near F3 was taken from the FFT; for the female speaker, the amplitude of H1 and H2 was taken. The measure of phonation is the difference between these two measurements (H1-F3, H1-H2) in dB. Thus, a value of zero means that the two measured harmonics had the same value.

#### **4.2.2 Changes in Phonation within a Syllable (Contour Phonations)**

H1-F3 (for the males) and H1-H2 (for the female) was measured at three timepoints within a vowel: initial, medial, and final. Figures 7-9 show the frequency of occurrence of the values of H1-F3 (in dB) for Speaker 1. (Since all three speakers displayed the same results, I will only present the histogram for Speaker 1.) The x-axis represents the measure of phonation (H1-F3) in dB. The y-axis represents the number of tokens with each value.

Figure 7 represent H1-F3 (in dB) for the initial portion of the vowel. Here, the data fall into two distinct groups, corresponding to two phonations. In the initial portion of the vowel, there is a distinction between modal (2-6 dB) and breathy phonation (14-20 dB).

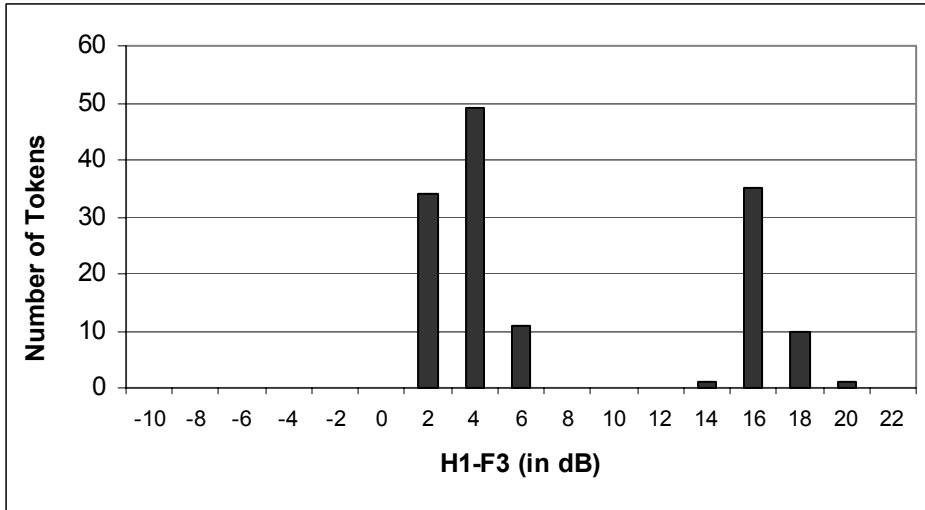


Figure 7: Frequency of H1-F3 values for Speaker 1 (initial portion of vowel).

Figure 8 represents the measure H1-F3 in the middle of the vowel. Again, there are two distinct groups, representing two phonations: modal (0-6 dB) and breathy (10-16 dB).

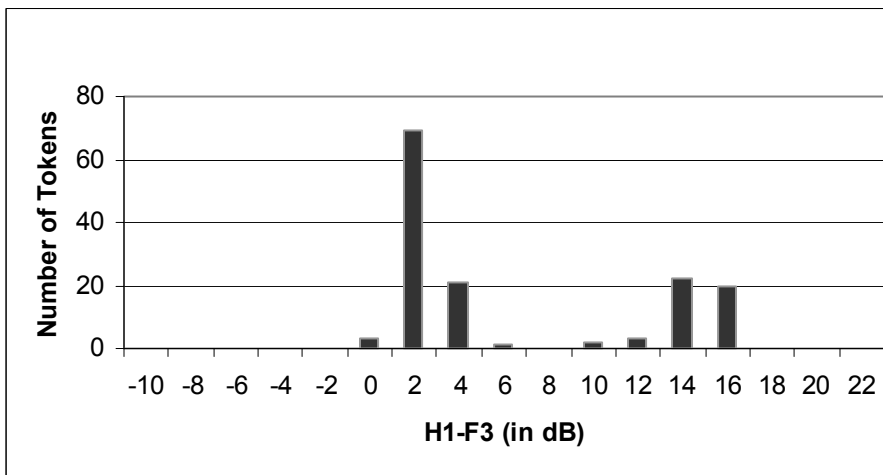
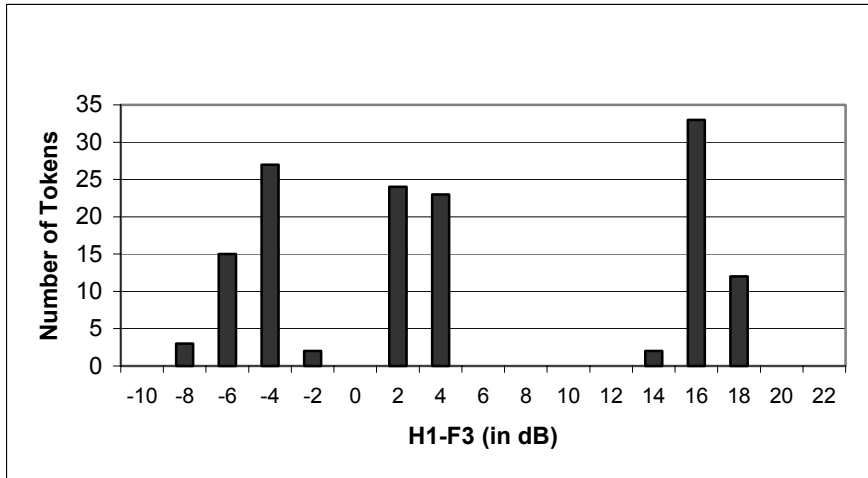


Figure 8: Frequency of H1-F3 values for Speaker 1 (medial portion of vowel).

Figure 9 represents H1-F3 (in dB) for the final portion of the vowel. In this graph, three distinct groups emerge. Thus, in the last portion of the vowel, it is possible to have creaky (-8 to -2 dB), breathy (14-18 dB), or modal (2-4 dB) phonation.

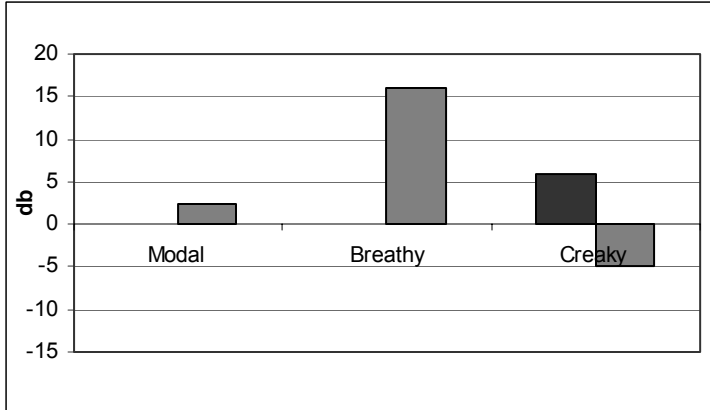


**Figure 9: Frequency of H1-F3 values for Speaker 1 (final portion of vowel).**

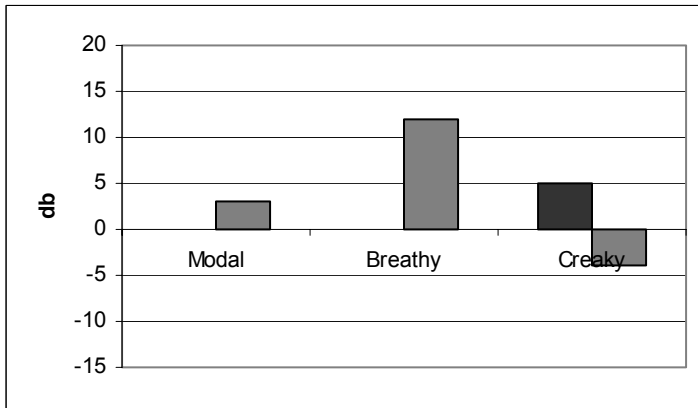
Figures 7-9 show that there is not a change in phonation over the course of a vowel, except in the case of creaky phonation. Creaky vowels begin with modal phonation, but end with creak. The creaky phonation is localized to the end of the vowel. (In addition, right before the creaky voicing begins, there is a brief portion of the vowel that looks breathy, though the spectral measure over the 30 ms window was creaky. For the female speaker, breathy vowels have a voiceless segment at the end, but this does not show up in the measurements, since it is not voiced.)

### **4.3 Three phonations (Modal, Breathly, Creaky)**

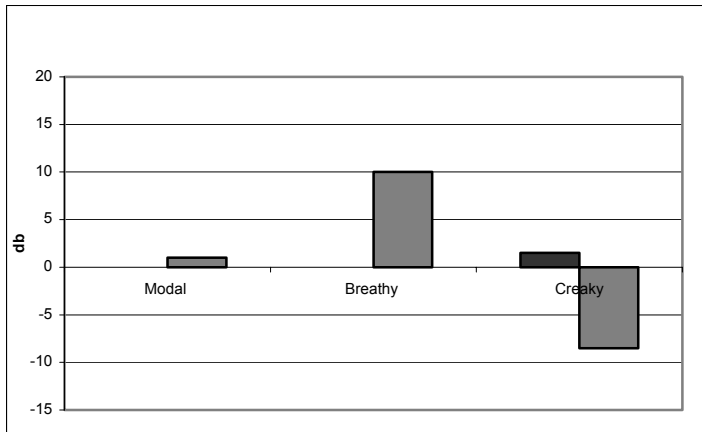
In this section, detailed results for the three phonations that have been found are presented. The results of the measures of phonation for all three Speakers can be found in Figures 10-12. For creaky vowels, the measurement is shown at both the beginning and the last 50 ms of the vowel. For modal and breathly tokens, only one point is shown, at the last 50 ms of the vowel. The difference between the amplitudes of H1 and F3/H2 is given on the y-axis. Results for the three speakers are similar.



**Figure 10: H1-F3 for Speaker 1 (sentence-medial position)**



**Figure 11: H1-F3 for Speaker 2 (sentence-medial position)**



**Figure 12: H1-H2 for Speaker 3 (sentence-medial position)**

Thus, the measures of phonation (H1-H2 and H1-F3) distinguish three phonations in SADVZ: modal, breathy, and creaky. There was no evidence for a fourth “checked” phonation.

Vowels that were followed by a glottal stop had the same phonation as creaky vowels that were not followed by glottal stops.

### 4.3.1 Other Differences Among and Within Phonations

#### 4.3.1.1 F0

From the FFT, f0 was measured at three time-points (initial, medial, and final) for each vowel. F0 corresponds to the frequency of H1. Figures 13-15 are graphs of the f0 value at the beginning, middle, and end of the vowel. Timepoints are represented on the x-axis and f0 in HZ is represented on the y-axis.

For all three speakers, there was a strong relationship between phonation and f0 (which will be described here as tone). Creaky vowels always have a large falling tone, which will be represented by a falling accent. Breathy vowels have a smaller falling tone (though this is less apparent for Speaker 1), which will be represented by a grave accent. Modal vowels have either a high level, or a high-rising tone, which will be represented by an acute and rising accent, respectively.

While the relationship between high and high-rising is not consistent across speakers, for all three speakers there are two distinct modal tonal categories – high level and high-rising.

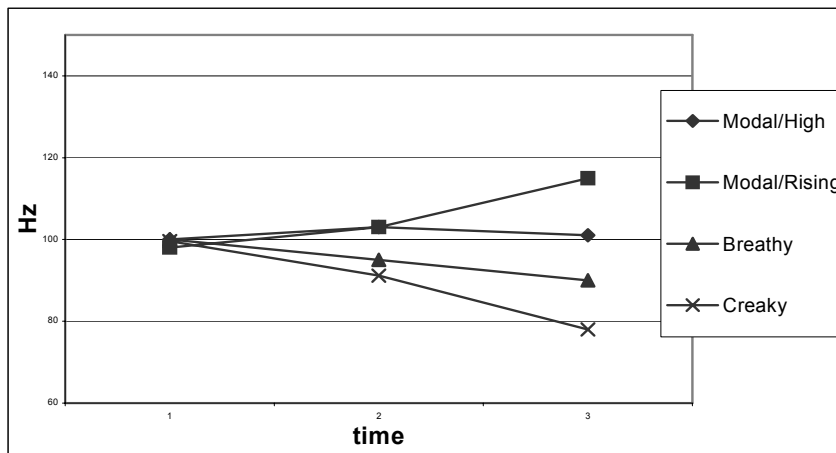
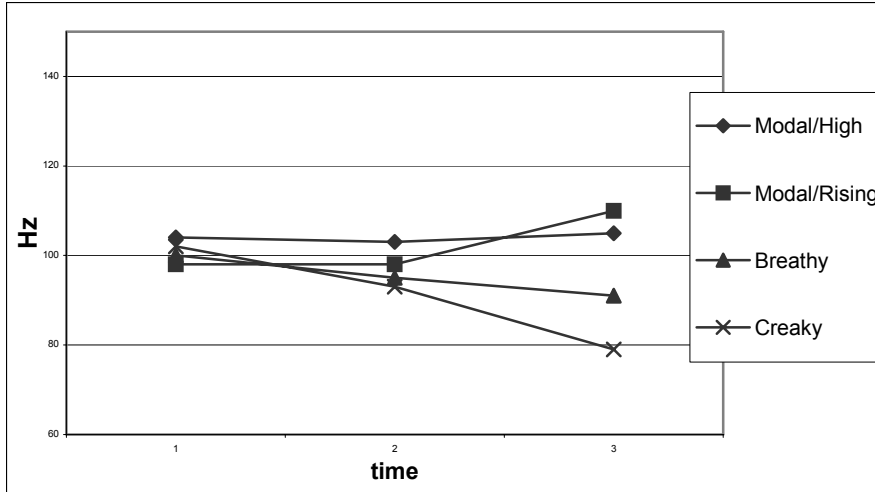
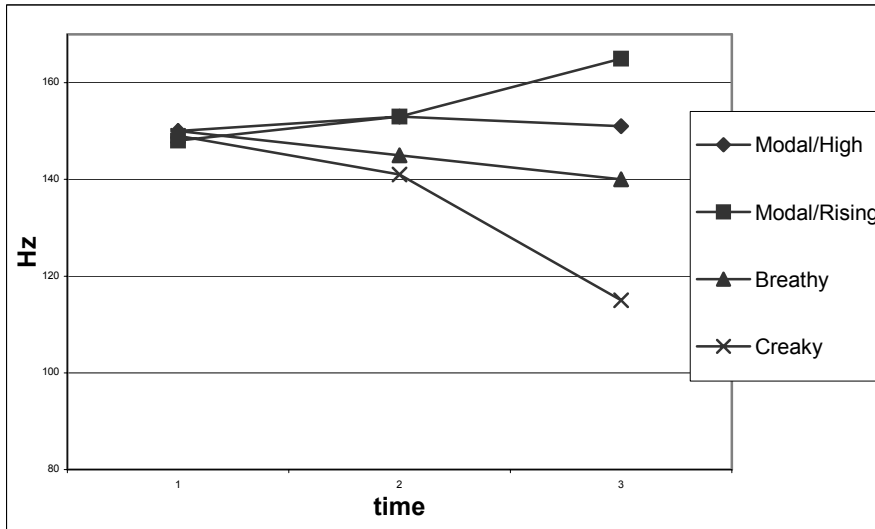


Figure 13: F0 for Speaker 1 (sentence-medial position)



**Figure 14: F0 for Speaker 2 (sentence-medial position)**



**Figure 15: F0 for Speaker 3 (sentence-medial position)**

Given the two tonal categories (high and high-rising) for modal phonation, the question arises as to whether there is a difference in phonation too. The phonation of modal vowels with high versus high-rising tone is presented in Figures 16-18. (The graphs represent the average of H1-H2/F3 for 10 tokens per phonation.) The difference between the amplitudes of H1 and F3/H2 (in dB) is given on the y-axis.



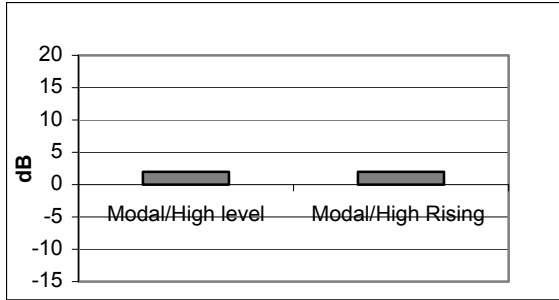


Figure 16: H1-F3 of Modal Phonation with High Level and High-Rising Tone (medial position, Speaker 1)

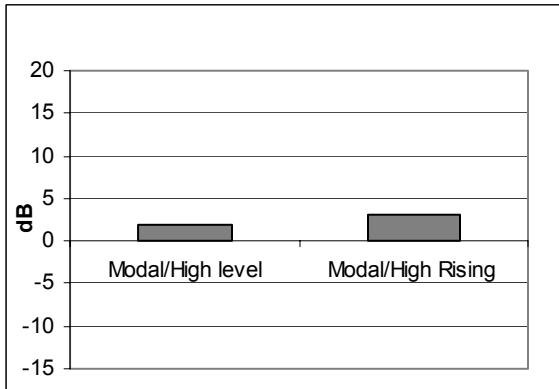


Figure 17: H1-F3 of Modal Phonation with High Level and High Rising Tone (medial position, Speaker 2)

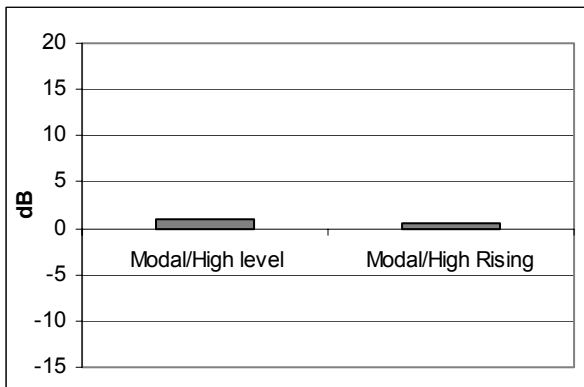


Figure 18: H1-H2 of Modal Phonation with High Level and High Rising Tone (medial position, Speaker 3)

The graphs in Figures 16-18 indicate that there is not a difference in phonation between the high and high-rising vowels.

### 4.3.1.2 Duration

Duration (in ms) was measured for the three phonations. No difference was found in the duration of vowels with modal versus non-modal phonation. I have presented the results for Speaker 1 below. Duration is plotted on the y-axis in ms.

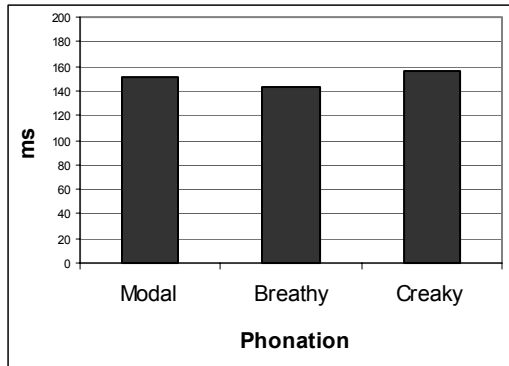


Figure 19: Duration of Modal and Non-Modal Phonation (Speaker 1)

## 4.4 Summary of Results

The study presented in this section has measured the phonation,  $f_0$ , and duration of [a] in a variety of monosyllabic words in sentence-medial position. Results for all three speakers showed that SADVZ's three-way contrast in modal, breathy, and creaky phonation is distinguished acoustically in the directions expected. No evidence was found for a fourth "checked" phonation in that vowels followed by a glottal stop had the same phonation as creaky vowels that were not followed by glottal stops. In addition, no change in phonation within a syllable was found, except for creaky phonation. Creaky vowels are characterized by creakiness that is limited to the end of the vowel; creaky vowels are not distinct from modal vowels until the last portion of the vowel.

In addition, each of the phonations is associated with one or two tonal patterns: modal vowels can have a high or high-rising tone, and breathy and creaky vowels have a falling tone.

Given these results, I will now transcribe words systematically with phonation and tone diacritics.

Finally, there is no difference in duration between modal and non-modal phonation.

## **5 Testing other Vowels**

Since the measure H1-F3 is not affected by the formants of higher vowels, it was possible to expand the comparison to the other SADVZ vowels ([i,e,o,u]), and not limit the study to [a]. The vowel [i] was omitted from this subset since it was difficult to find enough tokens that included this vowel. (It was not possible to examine the phonation of the other vowels for the female speaker since her measure of phonation was H1-H2. The measure H1-H2 is only successful as a measure of phonation on low vowels since the first formant of low vowels does not influence the amplitude of the first or second harmonics.)

### **5.1 Method**

#### **5.1.1 Speech Materials**

Speaker 1 was asked to produce a list of words composed of five monosyllabic tokens per phonation/ tone group, per vowel [i,e,o,u] and a range of consonants. The wordlist was selected based on cognates in related languages.

#### **5.1.2 Procedure**

The same procedure for measuring phonation and f0 that was used in the first experiment was repeated here. Again, H1-F3 was used as the measure of phonation.

### **5.2 Results**

The results of H1-F3 are presented in Figures 20, 23, 25, and 27. Just as with [a], there is a tonal distinction within modal phonation, but it is not accompanied by any difference in phonation (thus, the tone groups are not distinguished in the figures below). The difference between the amplitudes of H1 and F3 is given on the y-axis. Figures 22, 24, 26, 28 are of the f0

at three time-points (initial, medial, and final). Time-points are represented on the x-axis, and  $f_0$  is represented in Hz on the y-axis.

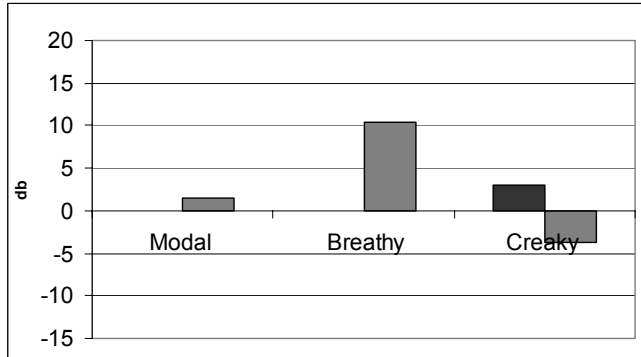


Figure 20: H1-F3 for [e] (Speaker 1, medial position)

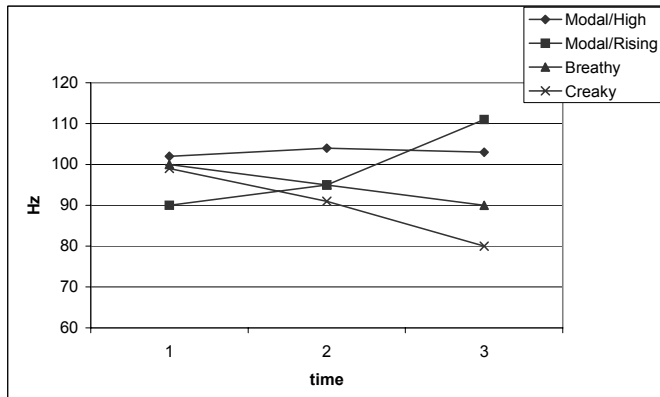


Figure 21: F0 for [e] (Speaker 1, medial position)

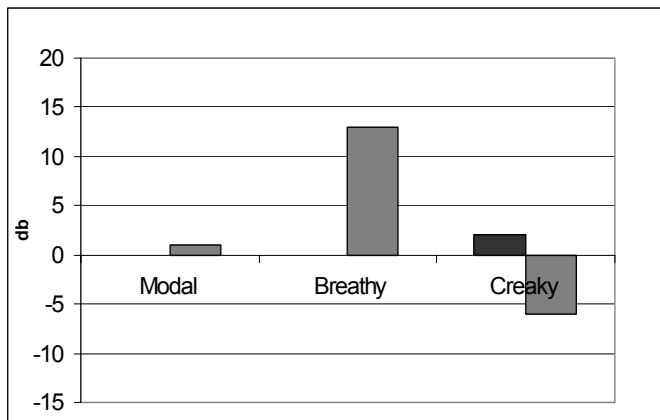


Figure 22: H1-F3 for [u] (Speaker 1, medial position)

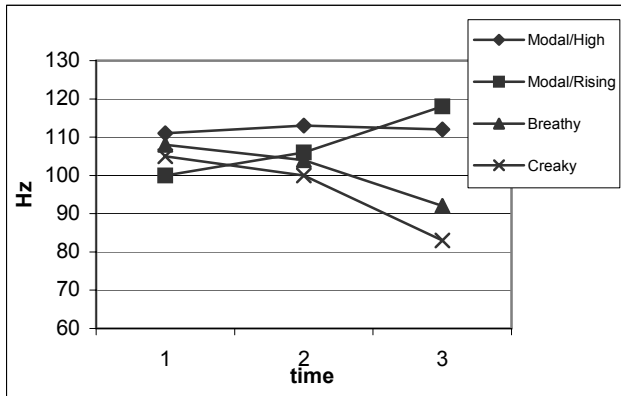


Figure 23: F0 for [u] (Speaker 1, medial position)

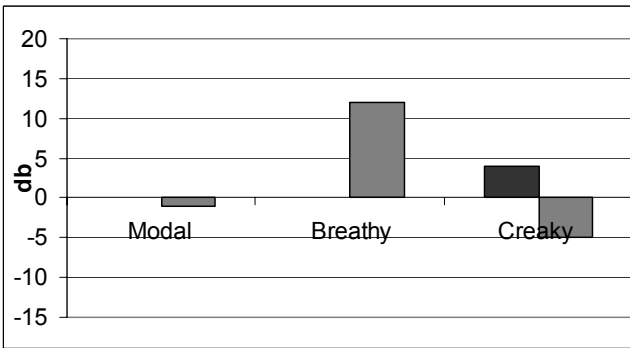


Figure 24: H1-F3 for [i] (Speaker 1, medial position)

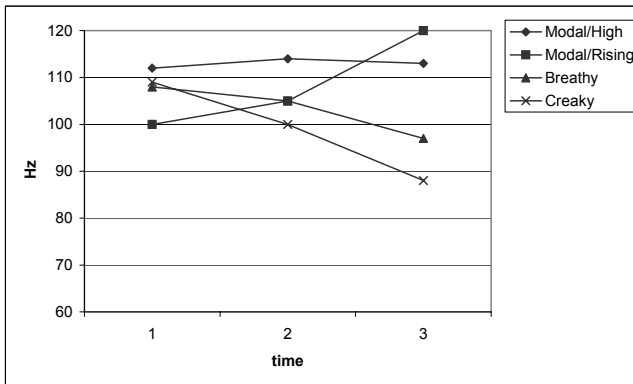


Figure 25: F0 for [i] (Speaker 1, medial position)

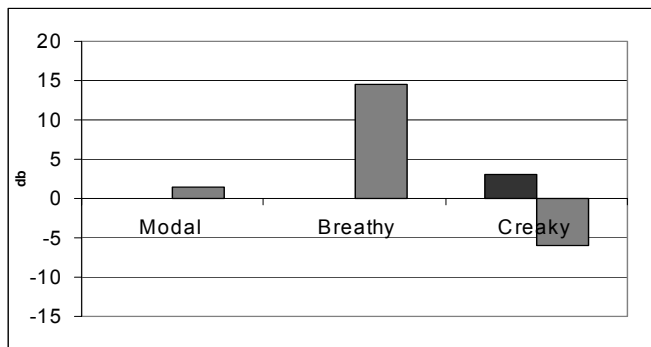


Figure 26: H1-F3 for [o] (Speaker 1, medial position)

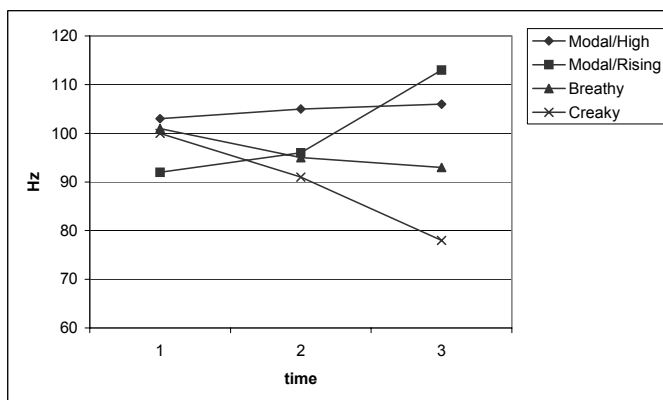


Figure 27: F0 for [o] (Speaker 1, medial position)

## 6 Summary of Results

As with [a], the other vowels of SADVZ that were examined [i,e,o,u] showed three phonations (modal, breathy, and creaky) and three tones (high, high-rising, falling).

## 7 Polymorphic, Disyllabic Words

Thus far, this study has concentrated on phonation in monosyllabic words. In this section, the experiment will be expanded to polysyllabic words to see how phonation is expressed in longer tokens and to determine if there is an effect of position-in-word on phonation.

## 7.1 Methods

### 7.1.1 Speech Materials

Speaker 1 was asked to produce a wordlist composed of 20 polymorphemic, disyllabic words (5 words per phonation/tone group), all with the target vowel [a] in both syllables and a range of consonants. The wordlist was selected based on cognates in related languages.

### 7.1.2 Procedure

Again, the tokens were read in the frame [*guni* \_\_\_ *primer*] “Say \_\_\_ first.” For both the first syllable and the second syllable, H1-F3 was measured following the same procedure established in section 4. In addition, f0 and duration were also measured following the procedure established in section 4.

## 7.2 Results

The results for H1-F3 are presented in Figure 28. The difference between the amplitudes of H1 and F3 (in dB) is given on the y-axis. The first syllable of the disyllabic words always has modal phonation; the second syllable has one of the three phonation contrasts. (The phonation category labeled on the x-axis represents the phonation in the second syllable of the word.)

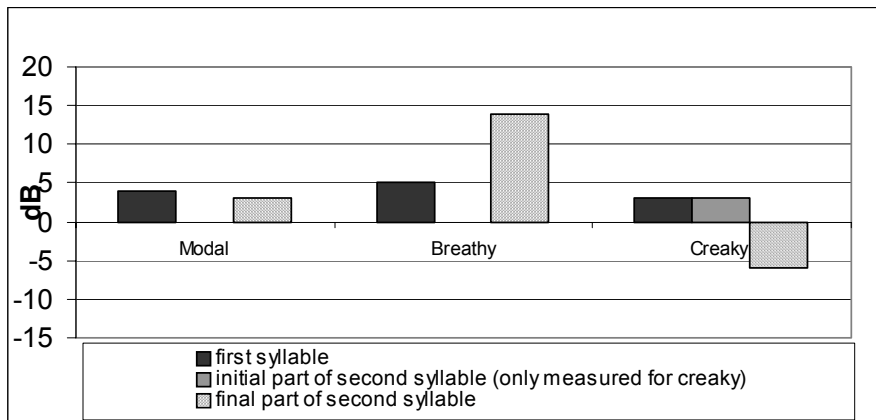


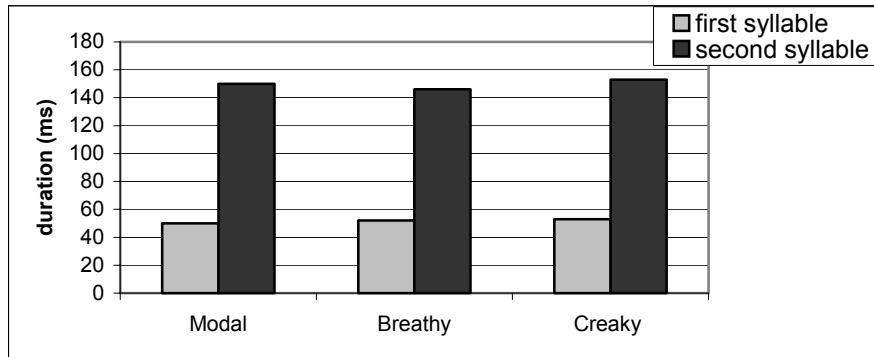
Figure 28: Graph of H1-H3 for the First and Second Syllables (Speaker 1, medial position)

## 7.2.1 Other Differences

### 7.2.1.1 Duration

Duration was also measured (in ms) for the first and second syllable. The first syllable of the disyllabic words is always shorter than the second syllable. This is presented in Figure 29.

Duration (in ms) is represented on the y-axis.



**Figure 29: Duration for the First and Second Syllable (in ms) (Speaker 1, medial position)**

### 7.2.1.2 F0

F0 for each syllable was measured from the FFT at three time-points (beginning, middle, and end) and is graphed in Figures 30- 31. Figure 30 shows the f0 of the first syllable; Figure 31 shows the f0 of the second syllable. The time-points are represented on the x-axis and f0 is represented in Hz on the y-axis. The first syllable of the disyllabic words has a fairly mid-level F0 (approximately 100 Hz). The second syllable has one of the three tonal contrasts (high, high-rising, or falling).



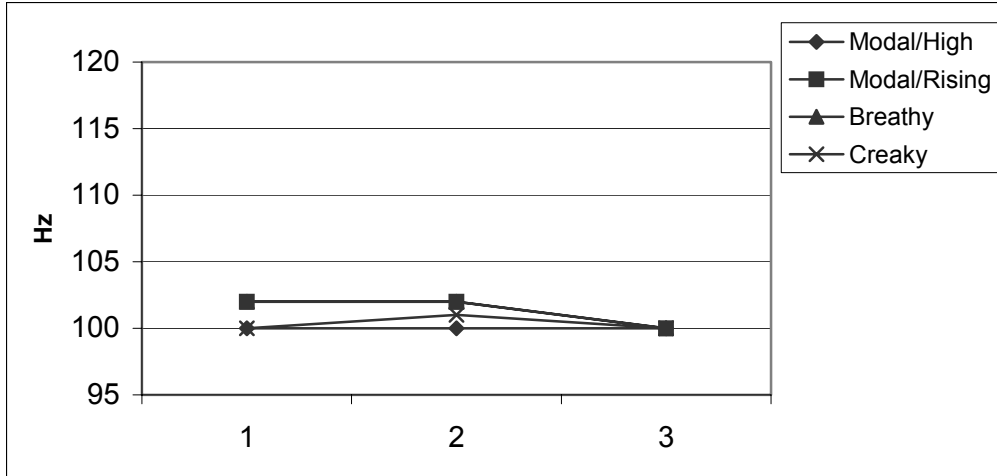


Figure 30: F0 for the First Syllable in Disyllabic Words. The phonation given in the legend corresponds to the phonation of the second syllable. (Speaker 1, medial position)

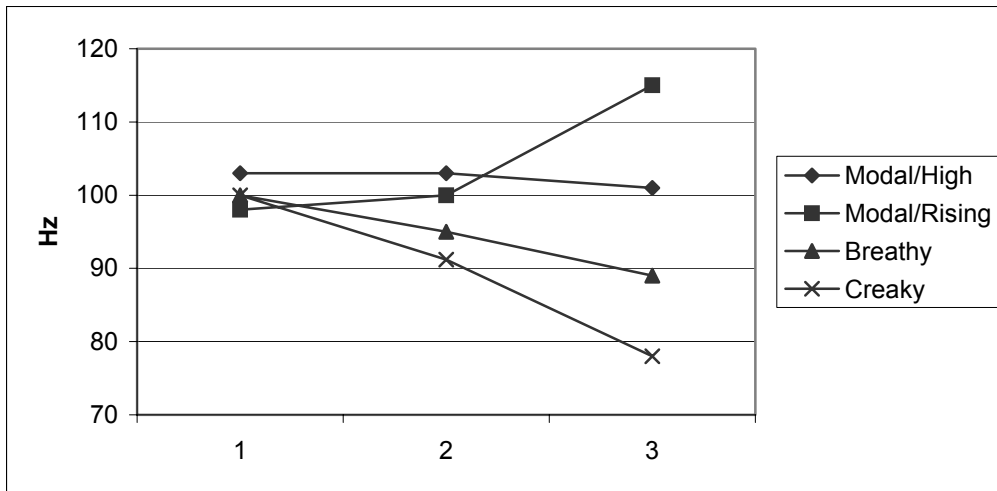


Figure 31: F0 for the Second Syllable in Disyllabic Words (Speaker 1, medial position)

## 8 Summary of Results

The same pattern emerges for all the disyllabic words. The first syllable of the disyllabic words always has a fairly mid-level tone (around 100 Hz), and is always shorter in duration than the second syllable. In addition, the first syllable always has modal phonation. The second syllable carries the phonation and tone contrast.

## 9 Summary

This paper has investigated the issue of phonation in Santa Ana del Valle Zapotec, a member of a language family where phonation contrasts are unusual and complex. Below, I will summarize the major findings of this study.

The measures used in this experiment have shown that SADVZ has a three-way contrast in phonation between breathy, modal, and creaky for all the vowels examined. In some ways, this analysis diverges from the different analyses of the Zapotec languages presented in section 2.4. No evidence was found to support a possible fourth “checked” phonation type in that vowels that were followed by a glottal stop had the same phonation as creaky vowels that were not followed by glottal stops. For both monosyllabic and disyllabic words, only one phonation was found per syllable, except in the case of creaky phonation, where the vowel begins with modal phonation and concludes with creak.

In addition, a strong relationship between  $f_0$  and phonation was found, unlike in some of the other Zapotec languages, which can have several independent tones and phonations. In SADVZ, modal phonation can be either high or high-rising. Breathly phonation has a small falling tone, and creaky phonation, a large falling tone.

Position-within-word did have an effect on phonation since the initial syllable of the disyllabic words did not have a phonation contrast. The first syllable of the disyllabic words always has a fairly mid-level tone (around 100 Hz, for the male speaker), and a shorter duration than the second syllable. The first syllable always has modal phonation. The second syllable carries one of the phonation types and tones. It remains to be seen how this applies in words longer than two syllables.

The results obtained in this study show that there is a simple three-way contrast in phonation in SADVZ. This study was unsuccessful in its goal of describing and understanding the more complex phonations typically associated with Zapotec languages. On closer examination, SADVZ did not prove to be a good example of the unusual and fascinating phonations that are reported for other Zapotec languages. It remains to be seen how SADVZ compares with other Zapotec languages describe in the literature, especially a language with complex phonation contours.

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