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Isthmus Zapotec Vowel Formants

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*This paper addresses several questions regarding the acoustic properties of Isthmus Zapotec vowels. Based on earlier recordings of a female, mother-tongue speaker of the language, average formant frequencies for each of the five phonemic vowels are determined for this speaker. I then look at differences in formant frequencies between stressed and unstressed modal vowels. Finally, I compare modal, laryngealized and checked productions of the vowels, to see if there are systematic differences between these three phonation types.**

1. Background

Isthmus Zapotec [zai] is a language of Mexico with approximately 85,000 speakers (Lewis 2009). Phonemically, Isthmus Zapotec has five vowels: /a/, /e/, /i/, /o/, and /u/. Also phonemically, these vowels are realized in three phonations: modal, laryngealized, and checked. Laryngealized vowels sound as though there is a glottal stop in the middle of the vowel, and checked vowels end in a glottal stop, sometimes audibly aspirated. In addition, Isthmus Zapotec is tonal, with five contrasting word melodies available to noun roots: High, Low, High-Low, Low-High, and Low-High-Low. Stress falls on the penultimate syllable of a word. If the following consonant is lenis, stress is realized as length in the vowel. If the consonant is fortis, stress is realized as length in the consonant (Pickett, Villalobos Villalobos and Marlett 2010).

In this paper, I am trying to answer several questions regarding the phonetic properties of these vowels: What are the average frequencies of their first and second formants? Is there a systematic difference in formant frequencies between stressed and unstressed modal vowels? If modal vowels exhibit a difference due to stress, does this difference carry over into the other two phonation types? Is there a systematic difference in formant frequencies between the three phonation types? Any conclusions I draw will necessarily be limited to the single speaker in the recordings.

2. Method

2.1 Materials

For the purpose of this study, I used an audio-recorded list of 106 words. Each word in the list was recorded in isolation. Most of the words in the list are nouns. A few of the nouns are modified with a demonstrative or a genitive to create another utterance, such as **mani'** 'animal' and **mani ca** 'that animal'. Some variant pronunciations are presented as well, such as **berendru'** and **berenB** for 'ant lion'. All words used in this study are presented in the appendix at the end of this paper.

* It is my privilege to acknowledge and thank Drs. Steve Marlett and John Clifton of SIL-UND. Dr. Marlett provided me with the recordings used in this paper. He was also constantly at my disposal as I came up with questions about Isthmus Zapotec. This paper began as an assignment for Dr. Clifton's Acoustic Phonetics class, and it was his excellent instruction that enabled me to write it. Both professors also suggested I submit this paper to the Work Papers, and I heartily thank them for their support and encouragement.

2.2 Subject

The speaker is María Villalobos Villalobos, a fluent female speaker. She was born in Juchitán de Zaragoza, the largest city in the language area, in 1941, and still lives there (Pickett, Villalobos Villalobos and Marlett 2010).

2.3 Procedures

The recordings were made by John Alsop, directly into his computer (Marlett, personal communication). They were provided to me by Stephen Marlett in the summer of 2009.

I used Praat (Boersma and Weenink 2010) to make measurements of the formants. The recordings were of excellent quality, and I was able to get clear formant measurements for all but one of the vowels of 104 out of the 106 utterances. For modal vowels, this was a relatively straightforward process. I looked for the point in the vowel that appeared to be the steadiest, and took my measurement there. Figure 1 gives an example. White dots mark the first two formants. The vertical line marks where I measured.

Figure 1. Spectrogram of the **a** portion of **mani** 'animal'

For laryngealized vowels, the process was a bit more complex. The section of the vowel that was causing the creaky sound was usually quite simple to identify: the voicing pulses were further apart and inconsistently spaced. The formants, however, continue unabated through the laryngealized portion and out through the other side into the rest of the vowel. I took my measurement within the laryngealized portion, at the place where the formants looked steadiest. Figure 2 shows how the formants continue through the laryngealized portion. My measurement point is once again marked with a vertical line.

Figure 2. Spectrogram of the laryngealized **a** portion of **ruzaa** ‘medium ripe’

Checked vowels did not require this kind of special consideration; they simply end in a glottal stop. Figure 3 shows a checked vowel. The vertical line once again marks where I measured, and the arrow marks the glottal stop.

Figure 3. Spectrogram of the checked **a** portion of **ba'du** ‘child’

The results of my measurements are presented in the appendix. After measuring the formants and plotting the vowels, I used Microsoft Excel 2007 to conduct paired, two-tailed t-tests, in order to see whether there was any significant difference between several pairs of formant values: stressed vs. unstressed modal vowels, stressed vs. unstressed checked vowels, stressed modal vs. laryngealized vowels, and stressed modal vs. checked vowels. There was only one instance of an unstressed laryngealized vowel, so I could not compare stressed vs. unstressed laryngealized vowels.

3. Results

Figure 4 shows the distribution of modal vowels. By and large, the realizations of each phonemic vowel are clustered together nicely in the vowel plot. However, some of the vowel realizations appear to stray rather far from the clusters formed by the majority of instances. In particular, /a/ covers quite a wide range. One instance of /u/ is almost exactly in the center of the vowel space, and one instance of /o/ is well into /u/'s territory.

Figure 4. Modal vowels

I compared stressed vs. unstressed modal vowels one by one. Figure 5 compares stressed and unstressed instances of /a/. It is apparent from the graph in Figure 5 that unstressed instances of /a/ tend toward a lower F₁ value than stressed instances. Articulatorily, they tend to be centralized in comparison to the stressed instances. Additionally, unstressed instances of /a/, although they have the same average position as stressed instances, are spread out further along the F₂ axis. This shows that unstressed instances of /a/ (and most likely all vowels) assimilate more easily toward the front and back of the vowel space than their stressed counterparts. A t-test returns a p-value of 0.0003 for a comparison of stressed and unstressed F₁ values. The difference between F₂ values is insignificant. Clearly, there is a significant centralization of this vowel in unstressed syllables.

Figure 5. Stressed and unstressed /a/

Figure 6 compares stressed and unstressed instances of /e/. Unstressed instances of /e/ appear to drift up and to the center. The t-test did not indicate a significant difference in F1 values, but returned a p-value of 0.04 for the difference in F2 values. Unstressed instances of /e/ are produced significantly further back than their stressed counterparts.

Figure 6. Stressed and unstressed /e/

Figure 7 compares stressed and unstressed instances of /i/. Instances of /i/ appear to be grouped more closely together. Indeed, a t-test shows no significant difference between stressed and unstressed instances of /i/ on either F_1 or F_2 .

Figure 7. Stressed and unstressed /i/

Figure 8 compares stressed and unstressed instances of /o/. Instances of modal /o/ are rare in the data available to me. Since there is only one instance of unstressed /o/, a t-test was not possible. The unstressed vowel is in fact the one noted above that occurs in the middle of /u/'s vowel space. Due to my inability to draw a statistically significant conclusion, I can only suggest that future research would do well to investigate a possible raising or centering effect on /o/ when it occurs in an unstressed syllable.

Figure 8. Stressed and unstressed /o/

Figure 9 compares stressed and unstressed instances of /u/. Unstressed instances of /u/ appear to occur more centrally than stressed instances. A t-test confirms this, returning a p-value of 0.003 for the difference between stressed and unstressed F_2 values. The F_1 difference is insignificant.

Three (possibly four) modal vowels exhibit articulatory alternations between stressed and unstressed positions. Does this difference carry over into vowels with other phonation types? There is only one instance of a stressed laryngealized vowel in the data, so I will compare checked vowels.

Figure 9. Stressed and unstressed /u/

Figure 10. Stressed and unstressed checked /a/

Figure 10 compares stressed and unstressed checked /a/. Once again, the unstressed instances of /a/ appear to drift up toward the center. A t-test confirms this: a p-value of 0.02 is found for the difference between stressed and unstressed F_1 . Just as with modal instances of /a/, the difference between F_2 values is insignificant.

Figure 11 compares stressed and unstressed checked /e/. Once again, it appears that unstressed instances of /e/ occur more toward the center. A t-test, however, denies that these results are significant, due to the fact that there are only five total instances of checked /e/. More research is required to draw a significant conclusion.

Figure 11. Stressed and unstressed checked /e/

Figure 12 compares stressed and unstressed checked /i/. As with the modal vowels, stressed and unstressed /i/ appear mostly to occupy the same area. A t-test confirms this; there is no significant difference in either F_1 or F_2 between stressed and unstressed checked instances of /i/.

Figure 12. Stressed and unstressed checked /i/

Figure 13. Stressed and unstressed checked /u/

There is no need to compare stressed and unstressed checked /o/. There is only one instance of each, and therefore there is no way to draw any significant conclusions. I will note, however, that in this pair the unstressed vowel is further back than the stressed vowel, which is the opposite of what I noted above in the modal vowel. More research is necessary.

Figure 13 compares stressed and unstressed checked /u/. Once again, it appears that unstressed vowels drift toward the center. A t-test, however, shows these differences to be insignificant. Since there are only two instances of stressed checked /u/, this is unsurprising.

I now move on to examine the difference, if any, between modal vs. laryngealized vowels and modal vs. checked vowels. For this portion of the research, I limited my data to stressed instances only, since that is where the vowels show the most distinction from one another. Figure 14 compares all modal, laryngealized, and checked stressed vowels. I have removed the gridlines for better visibility.

I conducted t-tests comparing modal to laryngealized and modal to checked for each vowel. None of the p-values were below 0.05, so I cannot draw any significant conclusions regarding oral articulatory differences between these phonation types. /a/ came quite close, showing a p-value of 0.055 when comparing F_2 between modal and laryngealized phonation. The F_2 is about 100 Hz higher on average.

4. Conclusions

The vowels of Isthmus Zapotec are correctly characterized as /a/, /e/, /i/, /o/, and /u/. They occupy spaces in the oral cavity traditionally associated with these IPA symbols.

All modal vowels except /i/ and possibly /o/ exhibit a phonetic difference between stressed and unstressed instances. They all move toward the center: /e/ moves back, /u/ moves forward, and /a/ moves up. Due to the low instance of checked vowels and the almost complete lack of unstressed laryngealized vowels in the available data, it is unclear whether this distinction holds for the other phonation types. The same difference is definitively exhibited for checked /a/, but for the other checked vowels the results were statistically insignificant albeit suggestive of the pattern's continuation.

Figure 14. Phonation types

There is no statistically significant difference in the oral articulation of the different phonation types. However, this may once again be due to the low instance of laryngealized and checked vowels in the available data.

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Appendix: Formant data

All numbers are in Hz, rounded to the nearest 5 Hz.

Notes on orthography:

Isthmus Zapotec has had a standard orthography since 1956. The orthography used in this table corresponds to that standard. An apostrophe after a vowel indicates that the vowel is checked. A double vowel indicates the vowel is laryngealized. Other orthographic correspondences are listed in the table below.

Orthography	IPA symbol	notes
B	ɓ	A bilabial trill.
dx	ɖ	
xh	ɬ	Before a consonant, the 'h' is not used.
x	ɬ	
jl	ɬl	
jn	ɲ	
c	k	
ch	tʃ	
y	j	

Modal /a/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
animal	mani'	1020	1645		
animal that	mani ca	870	1690	765	1695
arrow	baza	870	1115	645	1045
baby	badu huiini	665	1565		
body	ladi	885	1295		
child that	ba'du ca	800	1630		
disgusting	reduba'ya	690	1910		
dough	cuba	875	1620		
ear	diaga	880	1770	895	1740
ear of corn	niza	655	1765		
four	tapa	830	1260	790	990
girl	ba'du dxaapa huiini'	640	1385		
hill	dani	850	1235		
horn	cachu	870	1315		

huge	mboota	770	1665		
kind of basket	rubá	665	1375		
knot	porra	700	1675		
male	ngola	830	1720		
name	la	920	1665		
nothing	gasti'	865	1690		
plum	biadxi	880	1760		
rat	waga	915	1595	830	1660
road	neza	665	1675		
road of	jneza	660	1705		
saddle	xia	820	1895		
sediment	xia	755	1860		
that one	nga	895	1595		
they are carrying it	rine cabe ni	650	1740		
three	chonna	915	1595		
tobacco	gueza	625	1730		
tooth	laya	870	1735	845	1910
tree	yaga	865	1750	825	1670
two	chupa	755	1470		
water	nisa	740	1695		
wears long skirt	nahui	955	1560		
wooden doll	pancha yaga	785	1715	610	1940
wooden doll	pancha yaga	825	1790	740	1685
word that	diidxa ca	560	1895	805	1680
young corn plant	guela	800	1770		
Zapotec language	diidxaza'	585	1890		

Laryngealized /a/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
girl	ba'du dxaapa huiini'	625	1720		
medium ripe	ruzaa	915	1560		
palm mat	daa	965	1670		
planted field	ñaá	860	1685		
small amount	caadxi	955	1600		
young woman	dxaapa'	880	1645		

Checked /a/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
child	ba'du'	890	1600		
child that	ba'du ca	785	1560		
cot	luuna'	570	1680		

cot of	jluuna'	440	1620		
crown of flowers	la'pa'	905	1590	815	1580
disgusting	reduba'ya	805	1590		
fig	du'ga'	735	1605		
full	dxa'	910	1625		
girl	ba'du dxaapa huiini'	705	1170		
infected	da'	900	1645		
six	xhoopa'	775	1500		
tomb	ba'	885	1595		
word	diidxa'	735	1870		
young woman	dxaapa'	785	1485		
Zapotec language	diidxaza'	795	1665		

Modal /e/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
ant lion	berenB	440	2160	435	2125
ant lion	berendru'	470	1985	400	2090
chicken	bere	490	2435	395	2385
circles game	rieenque	510	2325		
deep	guete'	490	2290		
deep it is	guete ni	495	2250	555	2275
disgusting	reduba'ya	530	1995		
flame	belle	530	2270	385	2375
hammock	guixhe	470	2165		
head	ique	490	2370		
mold	be	495	2415		
old man	huelu	570	2250		
parent of child-in-law	xhuze	515	2170		
rabbit	lexu	550	2295		
road	neza	525	2475		
road of	jneza	465	2420		
scar	pesu	535	2175		
they are carrying it	rine cabe ni	535	2370	445	2235
tobacco	gueza	440	2405		
young corn plant	guela	430	2475		

Laryngealized /e/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
circles game	rieenque	550	2460		
fresh corn	zee	485	2390		
toasted corn meal	gueeze'	535	2405		

Checked /e/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
dead person	gue'tu'	520	2285		
deep	guete'	570	2185		
fence	le'	530	2400		
thigh	co're'	480	2255		
toasted corn meal	gueeze'	465	2165		

Modal /i/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
animal that	mani ca	420	2780		
baby	badu huiini	315	2670		
basket	dxumi	390	2590		
body	ladi	300	2665		
circles game	rieenque	385	2480		
cut	ruuchi	400	2335		
deep it is	guete ni	330	2820		
ear	diaga	360	2430		
ear of corn	niza	310	2925		
fire	gui	315	2670		
hammock	guixhe	295	2605		
head	ique	290	2650		
her long skirt	suudi	360	2625		
hill	dani	320	2870		
home of	lidxi	315	2650	315	2475
knee	xibi	355	2520	320	2505
leather g	guidi	310	2765	295	2745
leather y	guidi	305	2770	300	2690
one	tobi	300	2575		
plum	biadxi	365	2325	305	2475
saddle	xia	355	2360		
salt fricative	zidi	345	2700	305	2670

salt stop	zidi	275	2720	305	2625
sediment	xia	380	2370		
small amount	caadxi	390	2475		
squash	guitu	330	2650		
they are carrying it	rine cabe ni	355	2590	390	2730
thorn	guichi	345	2605	370	2500
water	nisa	365	2835		
wears long skirt	nahui	330	2730		
yours	xti-tu	325	2585		

Laryngealized /i/

gloss	word	v1 f 1	v1 f2	v2 f1	v2 f2
baby	badu huiini	310	895		
girl	ba'du dxaapa huiini'	305	2700		
little	huiini'	405	2735		
nose	xii	320	2685		
word	diidxa'	320	2765		
word that	diidxa ca	400	2755		
Zapotec language	diidxaza'	330	2615		

Checked /i/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
animal	mani'	365	2725		
dog	bi'cu'	320	2440		
dog of	xpi'ku'	340	2560		
excrement	gui'	315	2655		
girl	ba'du dxaapa huiini'	305	2685		
little	huiini'	350	2765		
mucous	guudxi'	325	2450		
nothing	gasti'	365	2520		
pimple	gui'dxu'	320	2680		

Modal /o/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
eats	ro	510	1130		
eight	xhono	525	1060	400	1145
knot	porra	515	1005		
male	ngola	470	895		
one	tobi	520	1010		
three	chonna	615	1105		

Laryngealized /o/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
huge	mboota	545	955		
rope	doo	545	1025		
rope of	xtoo	560	990		
six	xhoopa'	550	975		

Checked /o/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
smell	xho'	545	1110		
thigh	co're'	545	1005		

Modal /u/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
baby	badu huiini	320	1000		
basket	dxumi	355	945		
child that	ba'du ca	420	1400		
disgusting	reduba'ya	425	1080		
dough	cuba	345	880		
face	lu	365	910		
flower bud	mudu	345	885	445	1160
foam	bupu	395	895	N/A	N/A
girl	ba'du dxaapa huiini'	445	1690		
horn	cachu	435	1280		
kind of basket	ruba	385	1005		
medium ripe	ruzaa	480	1115		
old man	huelu	475	1085		
parent of child-in-	xhuze	405	1055		

law					
rabbit	lexu	310	1090		
scar	pesu	405	1200		
squash	guitu	390	1020		
two	chupa	395	1015		
wears long skirt	nahui	325	820		
youngest son	xhunku	415	1005	440	1045
yours	xiti-tu	440	1175		

Laryngealized /u/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
charcoal	buu	360	710		
cot	luuna'	360	700		
cot of	jluuna'	425	795		
cut	ruuchi	425	1130		
her long skirt	suudi	370	915		
mucous	guudxi'	425	845		

Checked /u/

gloss	word	v1 f1	v1 f2	v2 f1	v2 f2
ant lion	berendru'	355	990		
child	ba'du'	400	1215		
dead person	gue'tu'	390	1055		
dog	bi'cu'	380	985		
dog of	xpi'ku'	375	975		
fig	du'ga'	395	895		
non-Zapotec male soldier	dxu'	420	995		
pimple	gui'dxu'	365	1040		