Phonetic Structures in Jalapa Mazatec

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0. Introduction

Mazatecan belongs to the Popolocan branch of the Otomanguean language family (Gudschinsky 1958, Grimes 1988). It is composed of twenty three speech communities which are spoken in Mexico by approximately 125,000 people in the northeastern section of the state of Oaxaca, as well as in southern Puebla and western Veracruz.

This paper describes the phonetic inventory of the dialect spoken in San Felipe Jalapa de Díaz (henceforth Jalapa Mazatec). Jalapa Mazatec is spoken in the vicinity of San Felipe Jalapa de Díaz, district of Tuxtepec, by 6000-8000 people, many of whom are also fluent in Spanish. A practical orthography has been developed for Jalapa Mazatec, and some Christian texts and native folk tales have been published. Both Mazatec and Spanish reading are taught in local schools.

Data for this study were collected in March and April, 1993, in Jalapa de Díaz. Six male and six female native speaking adults were recorded. The primary corpus was a list of 335 words spoken in isolation. Two of the male speakers recorded the complete set on two occasions, giving us fourteen sets of recordings in all. Additionally, palatographic data were collected from one speaker. Airflow data for selected phonemes were also recorded.

This paper is organized as follows. Section 1 provides a brief overview of Jalapa Mazatec phonology and morphology. Section 2 presents the vowel system. Section 3 presents the consonant system.

1. Brief Overview of Phonology and Morphology

The Jalapa syllable is maximally CCGV. Consonant clusters consist of either fricative-stop sequences, or homorganic nasal-voiceless stop sequences. Despite the simplicity of the syllable structure, the availability of laryngeal augmentation greatly expands possible syllable types. Obstruents may be contrastively voiced, voiceless stops may be contrastively aspirated, and sonorants may be contrastively aspirated or glottalized. Additionally, vowels obligatorily possess tone, and may be augmented by breathiness or creakiness.

There are both diachronic and synchronic reasons to believe that breathiness and creakiness are affiliated with the vowel, and not with the onset consonant. Breathy vowels cannot be posited as a feature of proto Mazatec (Kirk 1966:38-44). Thus, Jalapa Mazatec is unique in that it is the only one of the twenty-three distinct Mazatec speech communities that developed breathy vowels. The breathy vowels in Jalapa Mazatec developed from Proto-Mazatec (PMaz) disyllabics of the form *-V.hV in which the laryngeal /h/ consonant margin of the second syllable was retracted through the vowel of the first syllable and the vowel of the second syllable coalesced with this first vowel. The development of these breathy vowels was conditioned by two further factors: (1) the syllable margin of the first syllable of these disyllabics had to be voiced, and (2) the vowels in both syllables contiguous to the /h/ had to be identical. If the tones in these PMaz disyllabics were the same in both syllables, they were reduced in length to those of a single tone; if the tones in these PMaz disyllabics were different, then they were coalesced into a tone glide. In present day Jalapa Mazatec whistle speech, these PMaz disyllabics are whistled with a single whistle pulse. Examples of the development of Jalapa Mazatec breathy vowels can be seen from the following PMaz cognate sets (cognate set numbers are from Kirk 1966 with tones indicated by the format of this paper) PMaz 406 *ntja^{1}hu^{1} ‘stone’ > early Jalapa Mazatec *ndjo^{1}ho^{1} > present day Jalapa Mazatec [ndjo̤^{1}]; PMaz 301 *ntʃe*^{2}he^{4} ‘thief’ > early Jalapa Mazatec *ndʒæ^{1}hæ^{2}> present day Jalapa Mazatec [ndʒæ̤^{12}]; PMaz 400 *ntu^{1}hwi^{13} ‘your soap’ > early Jalapa Mazatec *ndu^{1}hwi^{12} > present day Jalapa Mazatec [ndi̤i̤^{12}]; PMaz 329 *nĩ^{1}hĩ^{1} ‘dry ear of corn’ > present day Jalapa Mazatec [nĩ̤^{1}]. For a number of other cognate sets exhibiting the development of Jalapa Mazatec breathy vowels see Kirk 1966:45-46.

In a similar way present day Jalapa Mazatec contrasts disyllabics VʔV with monosyllabic creaky vowels. Compare [tʃu^{1}ʔu^{2}] 'bedbug' with [tsṵ^{3}] 'blouse'. However, a large number of PMaz disyllabics of the form *-VʔV have been reduced to monosyllabics with creaky vowel in Jalapa Mazatec. The [ʔ] retracted through the first vowel of the proto disyllabic, producing a creaky vowel with coalescence of the vowel in the second syllable. The development of these creaky vowels is thus parallel to the manner in which breathy vowels developed in Jalapa Mazatec with the retraction of [h]. The development of present day Jalapa Mazatec creaky monosyllabic vowels from PMaz disyllabics is evidenced by the following cognate sets: PMaz 45 *tsu^{4}ʔu^{4} 'blouse' > [tsṵ^{3}], PMaz 40 *tsĩ^{4}ʔã^{3} 'penis' > [tsḭ̃ã̰^{2}], PMaz 65 *tʃa^{2}ʔu^{2} 'bad' > [tʃo̰^{2}], PMaz 174 *kã^{4}ʔã^{3} 'alone' > [kã̰^{2}]. For further cognate sets exhibiting this development pattern see Kirk 1966:51.

Jalapa Mazatec roots are predominantly monosyllabic, while the rich inflectional system is by and large subsyllabic. Given this dichotomy between segmental poverty and morphological richness, each segment of the Mazatec word potentially accommodates a great number of linguistically significant components.

Further information about Mazatec phonology (historical and synchronic) and morphology can be found in Pike and Pike 1947, Gudschinsky 1958, Kirk 1966, Kirk 1970, Schram and Pike 1978, Schane 1985, Steriade 1993, and Silverman *in prep.*

2.0 Vowels

Jalapa Mazatec contains a basic five vowel system, as shown in (1).

(1)

i	**u**
	o
æ	**a**

Minimal pairs exemplifying these contrasts are presented in (2).

(2)

si^{2}	'dirty'
sæ^{2}	'he sings'
sa^{3}	'moon'
so^{2}	'you (pl) sing'
su^{2}	'lukewarm'

Tonal, phonatory, nasal, and length contrasts greatly expand the vowel inventory. Tone obligatorily accompanies every vowel. There are three tones, low (1), mid (2), and high (3). Some tonal contours (12, 32 23, 21, 31, 131) have also been recorded. These are found primarily in morphologically complex environments. In (3) are examples of each level lexical tone pattern.

(3)

ʃa^{3}	'work'
ʃa^{2}	'mountain lion'
ʃa^{1}	'mould'

Breathiness or creakiness may accompany Mazatec vowels. In either case, non-modal phonation is most prominent in the first portion of the vowel. Examples of breathy and creaky vowels follow.

(4)

BREATHY VOWELS		CREAKY VOWELS	
ŋgi̤^{2}	'he went'	**sḭ**^{3}	'holiday'
j̊æ̤^{1}	'boil' (noun)	**tʰæ̰**^{2}	'sorcery'
ki^{2}**ŋga̤**^{23}	'he fastened'	**tʃa̰**^{3}	'load, burden'
ki^{2}**ŋgo̤**^{2}	'you (pl) will fasten'	**tʃṵ**^{3}	'blouse'

Breathy vowels do not co-occur with voiceless stop onsets. In such environments however, a contrastive glottal abduction may occur at stop release, resulting in an aspirated stop followed by a modally phonated vowel.

All five vowels may be lexically oral or nasal. Vowels following nasal consonants are obligatorily nasal. Examples of both contrastively and redundantly nasalized vowels are shown in (5).

(5)

CONTRASTIVELY NASALIZED VOWELS		REDUNDANTLY NASALIZED VOWELS	
sĩ^{2}	'tasty'		
sæ̃^{1}	'ghost'	**nĩ**^{1}**m̥æ̃**^{3}	'corn'
sã^{2}	'acid, sour'	**mã**^{2}	'is able'
sõ^{21}	'song'		
sũ^{2}	'level, on'		

Phonatory and nasal contrasts cross-classify. That is, a given vowel may be both breathy and nasal, or both creaky and nasal. Some examples are given in (6).

(6)

BREATHY NASALIZED VOWELS	
nĩ̤^{1}	'ear of corn'
^{n}**dʒæ̤̃**^{2}	'visibility'
nã̤^{23}	'my tongue'
nõ̤^{2}	'your (pl) tongue'
^{n}**dʒṳ̃**^{2}**nĩ**^{1}	'tomorrow'

CREAKY NASALIZED VOWELS

ʃḭ̃^{1}	'man'
k^{w}a^{2}sæ̰̃^{2}	'he entered'
kã̰^{2}	'single, widowed'
tʃõ̰^{1}	'lightning'
nṵ̃^{3}	'vine'

Finally there is the possibility that there is a ballistic/controlled contrast in Jalapa Mazatec syllables. Previously thought limited to related Chinantec and Amuzgo, ballistic syllables have been variously described as possessing a fortis release of syllable-initial consonants, with a surge of energy, culminating in a weakened, breathy release (see Merrifield 1963, Bauernschmidt 1965, Mugele 1982, Silverman, 1994, *in preparation*). Controlled, or plain syllables do not possess these characteristics. Schram and Schram (personal communication) have pointed out to us a number of contrasts in Jalapa that might be worth investigating to see whether they manifested the ballistic/controlled contrast.

(7)

BALLISTIC SYLLABLES		CONTROLLED SYLLABLES	
***su^{2}**	'warm'	**su^{2}**	'blue'
nĩ^{2}*ntu^{2}	'slippery'	**nĩ^{2}ntu^{2}**	'needle'
***tsæ^{2}**	'guava'	**tsæ^{2}**	'full'
***hũ^{2}**	'you (pl)'	**hũ^{2}**	'six'

2.1 Modal Vowels

Two tokens of each vowel were recorded for each male speaker and each female speaker. Words from which formant structures were culled are listed in (8).

(8)

si^{2}	'dirty'	**hi^{2}**	'you (sg)'
sæ^{2}	'he sings'	**hæ^{2}**	'finished'
sa^{3}	'moon'	**ha^{3}**	'men'
so^{2}	'you (pl) sing'	**ho^{2}**	'two'
su^{2}	'lukewarm'	**tʃu^{1}tu^{2}hu^{2}**	'dove'

Figures 1 and 2 show vowel formant plots for two tokens each by three male and five female speakers, respectively. Note the wide distribution of F2 values for *u* in female speakers. This suggests that either lip rounding, tongue backness, or both, are varying in the production of this vowel.

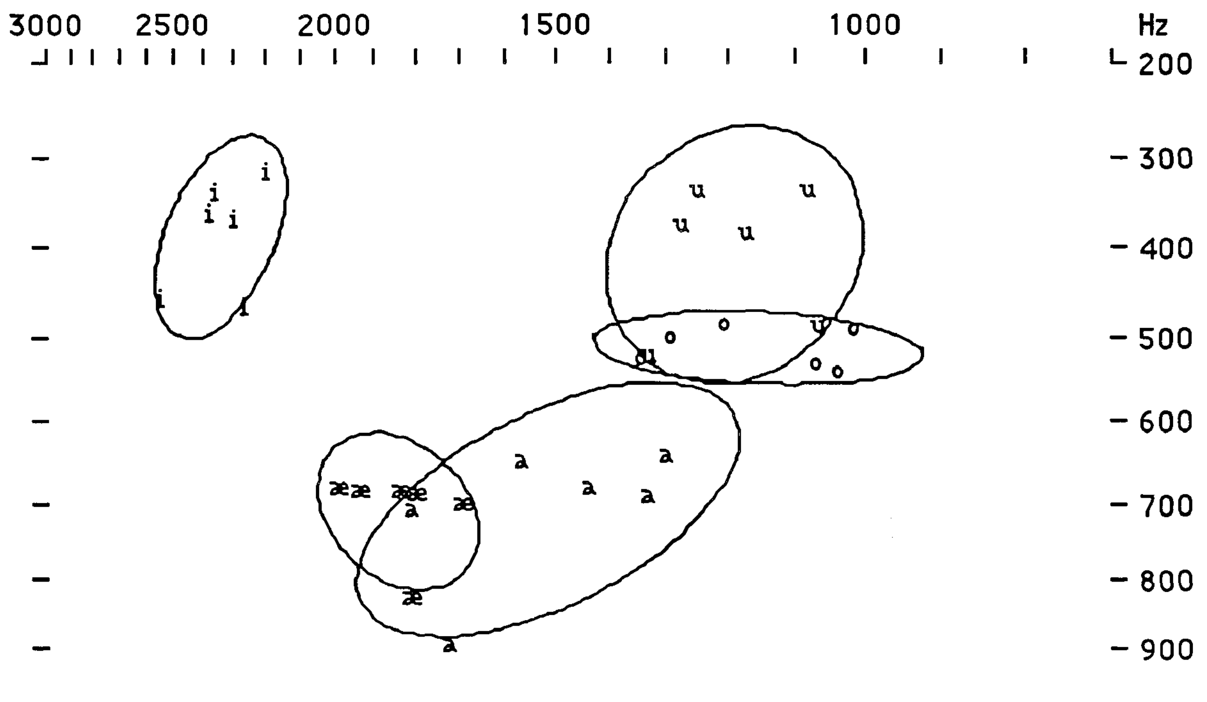

Figure 1. F1 versus F2 for two tokens each by three male speakers.

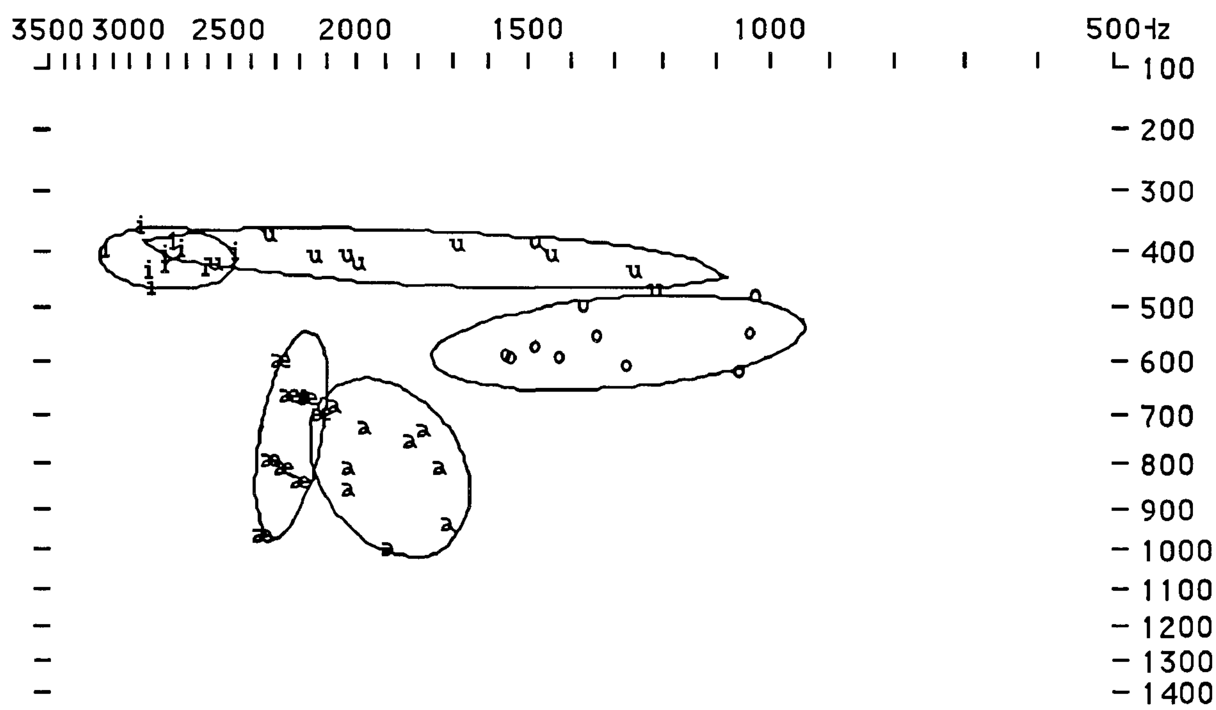

Figure 2. F1 versus F2 for two tokens each by five female speakers.

2.2 Nasalized Vowels

Vowel nasalization has proven difficult to characterize acoustically. In addition to a general weakening of F1, nasalized vowels have been reported to possess both a resonance (or nasal pole) and an anti-resonance (or nasal zero). However, the frequency of nasal poles and zeros seemingly display cross-linguistic, cross-speaker, and cross-vowel quality variation (see Smith 1951, House and Stevens 1956, Hattori, Yamamoto, and Fujimura 1956, Fant 1960, and Fujimura 1962). As we have noted, all five plain and breathy vowels have nasal counterparts, but we will leave the determination of how these contrasts are made to a later analysis.

2.3 Breathy Vowels

Jalapa Mazatec breathy vowels manifest their breathiness primarily during the first portion of the vowel. Following this period, breathiness is substantially reduced. This description holds true for the majority of recorded tokens, although there are exceptions. In some instances strong breathiness continues for the duration of the vowel. In others, voiceless aspiration is followed by modal phonation.

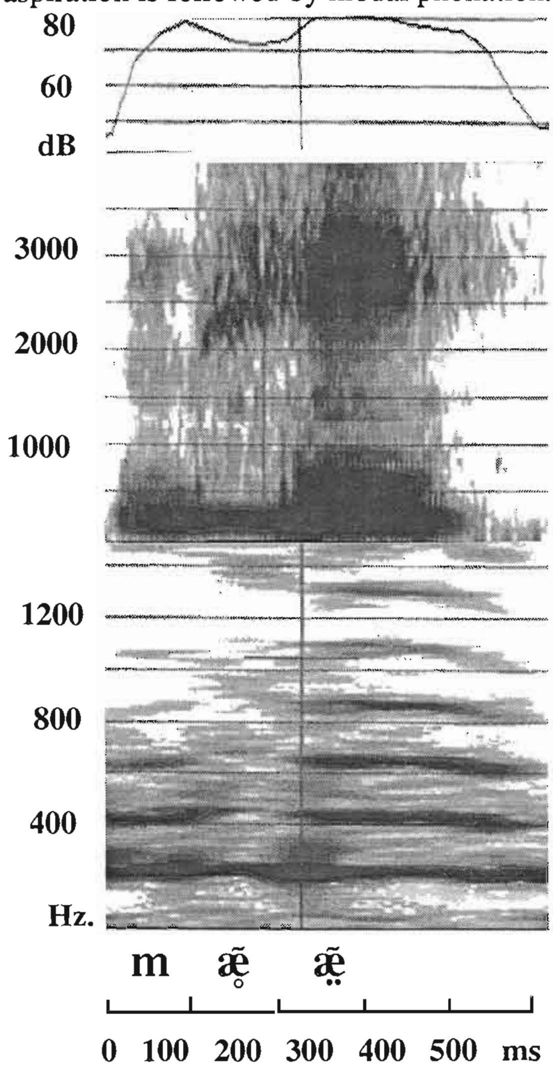

Figure 3. Energy contour, wideband, and narrowband spectrograms for mæ̤̃^{21},'he wants'

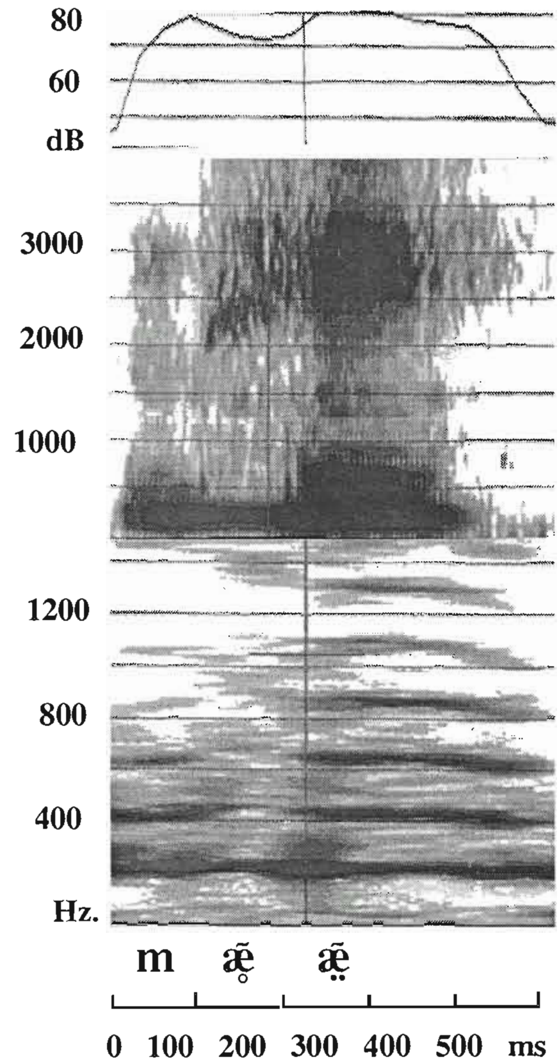

Figure 4. Energy contour, wideband, and narrowband spectrograms for nda̤^{23}, 'hard'

Figures 3 and 4 provide examples of both wideband and narrowband spectrograms of canonical breathy vowels, along with energy contours. The narrowband spectrogram shows that strong breathy phonation often weakens the harmonic structure, making the harmonics less prominent than in the latter portion of the vowel. The point of transition from strong breathy phonation to weak breathy phonation was determined by analyzing narrowband spectrograms in conjunction with energy contours, under the assumption that overall energy is greater during weak breathy phonation than during strong breathy phonation. This assumption is confirmed by observing that the onset of a salient harmonic structure coincides with an overall energy increase. Note finally that weak breathy phonation is often accompanied by a moderate increase in fundamental frequency. The subglottal pressure falls during the glottal abduction that results in breathiness. This reduction in subglottal pressure may account for both the decreased intensity and the moderate decrease in pitch which accompany breathy phonation, as subglottal pressure correlates positively with both intensity and pitch.

Table 1 presents data from eleven speakers (six male, five female) producing eight forms with breathy vowels, resulting in 88 tokens. The first column lists the mean duration (in ms.) of the strong breathy portion of these vowels for each of the eight forms. The second column lists the mean duration of the weak breathy portion for each of the eight forms. Finally, the third column shows the percentage of vowel duration which possesses strong breathy phonation. The bottom row lists means across both speakers and forms. These figures show that strong breathiness typically persists for a little less than half the duration of the vowel as a whole.

Table 1. The extent of breathy phonation in phonologically breathy vowels.

WORD	BREATHY DURATION (ms)	TOTAL DURATION (ms)	% BREATHY
ᵑgi̤^{2}	136.4	306.2	37.6
ki^{2}ŋga̤^{23}	096.2	225.3	42.7
ki^{2}ŋgo̤^{2}	096.3	247.2	39.0
ⁿdja̤^{1}	111.7	262.4	42.6
ⁿda̤^{2}a^{3}	108.4	290.0	37.3
no̤^{2}	107.7	263.4	40.8
βo̤^{2}	119.5	228.8	52.2
ⁿdṳ^{2}	099.3	223.5	44.3
MEAN	1094	255.6	42.8

2.4 Creaky Vowels

Creaky vowels, like breathy vowels, manifest their non-modal phonation primarily during the first portion of the vowel. Often, auditory impression suggests a full glottal closure marking the end of this creaky period, followed by modal phonation. However, wideband and narrow band spectrograms do not always reveal these characteristics.

Ladefoged, Maddieson, and Jackson (1988) showed that creaky vowels have a characteristic spectral tilt: compared to modally phonated vowels, the amplitude of H1 in creaky vowels is reduced relative to that of H2. The amplitude of H1 and H2 were measured, both during the initial strong creaky portion of the vowel, as well as during its latter portion. Data were collected from ten speakers (four male and six female), each uttering six distinct tokens, for a total of 60 forms measured. The difference H2 - H1 was subsequently calculated for each token, both during the initial portion and the latter portion. Table 10 presents these differences for each form, averaged across speakers. The bottom row lists averages across both speakers and forms.

Table 2. The relative intensities (in dB) of the first and second harmonics in creaky vowels.

word	H2 - H1 INITIALLY	H2 - H1 FINALLY	DIFFERENCE
sḭ^{3}	10.3	.03	10.27
t^{h}**æ̰**^{2}	6.27	-1.25	7.52
tʃa̰^{3}	6.99	-3.66	10.65
tʃõ̰^{2}**kũ**^{2}	9.30	5.48	3.82
tsṵ^{3}	10.03	3.6	6.43
ndæ̰^{1}	4.58	-3.28	7.86
mean	7.86	.15	7.71

During the initial portion of the vowel, the difference in amplitude between H2 and H1 across forms varies between 4.58 and 10.3 dB. During modal phonation, this difference varies between 5.48 and -3.66 dB. But within forms, H2 - H1 initially is always greater than H2 - H1 finally; the difference between these differences varies between 3.82 and 10.27 dB, for an average of 7.71 dB. These results support the findings of Ladefoged, Maddieson, and Jackson (1988), in that creakiness possesses a characteristic spectral tilt involving a weakening of H1 relative to H2. Our impression is that the creaky portion of the vowel is, like the breathy portion, a little under half the total duration, but we do not have a reliable way to determine the duration of creakiness in comparison to the duration of the vowel as a whole.

2.5 Ballistic Syllables

As mentioned earlier, there is a possibility that the ballistic syllable phenomenon, which has been reported in the related Otomanguean languages of Chinantec and Amuzgo, might also occur in Jalapa Mazatec. Descriptively, ballisticity in these languages has been described as a prosodic phenomenon affecting the entire syllable. Its primary features include:

1) fortis release of syllable-initial consonants
2) a gradual surge and rapid decay in intensity
3) post-vocalic aspiration

Mugele (1982) proposes that ballisticity is phonologically characterized by an increase in subglottal pressure. In contrast, Silverman (1994, in prep.) offers phonetic and phonological evidence that a laryngeal abduction is the phonologically relevant articulatory gesture.

Previously, ballisticity has not been reported in Mazatec. However, Schram and Schram (p.c) suggested to us that the forms presented in (9) were worth investigating from this point of view. For ease of discussion we will refer to one set as having ballistic syllables and the other set as having controlled syllables. As there are no IPA symbols for this distinction, we will use an asterisk before a ballistic syllable. Note that this usage is unrelated to the convention of denoting a reconstructed form by an asterisk, as was done in section 1 above.

(9)

BALLISTIC SYLLABLES		CONTROLLED SYLLABLES	
***su**^{2}	'warm'	**su**^{2}	'blue'
ni^{2}***ntu**^{2}	'slippery'	**ni**^{2}**ntu**^{2}	'needle'
***tsæ**^{2}	'guava'	**tsæ**^{2}	'full'
***hũ**^{2}	'you (pl)'	**hũ**^{2}	'six'

We now consider in turn each of the three primary descriptive features of ballisticity with respect to the forms in (9).

1) Fortis release of syllable-initial onsets. While the supposed fortition which accompanies ballisticity remains an impressionistic description with no reliable articulatory or acoustic correlates, there are two likely interpretations: a) syllable onset duration b) VOT.

a) Onset consonant duration. Table 3 shows the onset consonant duration for both ballistic and controlled syllables, averaged across three speakers.

Table 3. Durations of syllable onsets (ms).

	BALLISTIC	CONTROLLED
su	207.2	152.3
nĩntu	25.6	45.9
tsæ	69.2	45.9
hũ	196.3	170.0

As can be seen, there is no systematic difference between onset duration in ballistic versus controlled syllables. However, ballistic syllable onsets are marginally longer in the three monosyllabic words.

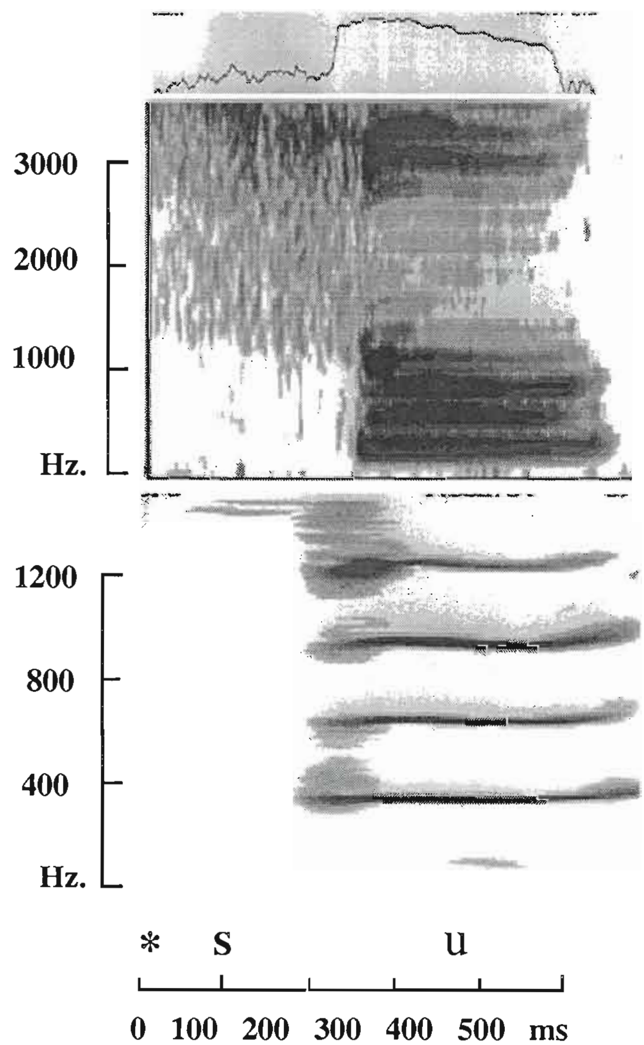

Figure 5. Energy contour, wideband and narrowband spectrograms for *su^2, 'blue'.

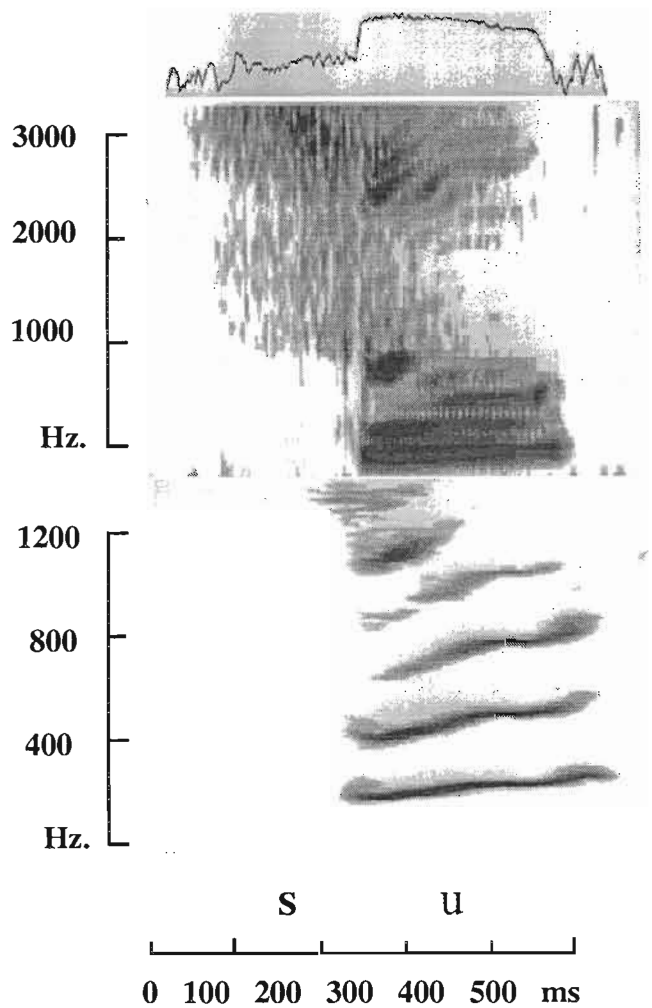

Figure 6. Energy contour, and wide and narrowband spectrograms for su[2], ‘warm’.

b) VOT. Wideband spectrograms in Figures 5, and 6, and Figures 7 and 8 — pairs which near-minimally contrast in so-called ballisticity — suggest no difference in VOT between ballistic and controlled syllables.

2) Intensity. A comparison of energy contours for both ballistic and controlled syllables yielded no systematic difference. Furthermore, energy levels measured at the vowel midpoint revealed no systematic difference between ballistic syllables and controlled syllables, although ballistic syllables often possess a marginally greater intensity. Table 4 reports these values for four ballistic/controlled pairs, averaged across three speakers.

Table 4. Intensity (dB) at the vowel midpoint in ballistic and controlled syllables.

	BALLISTIC	CONTROLLED
su	83.35 dB	79.07 dB
ńintu	82.97	82.21
tsæ	82.32	82.34
hũ	82.53	82.33

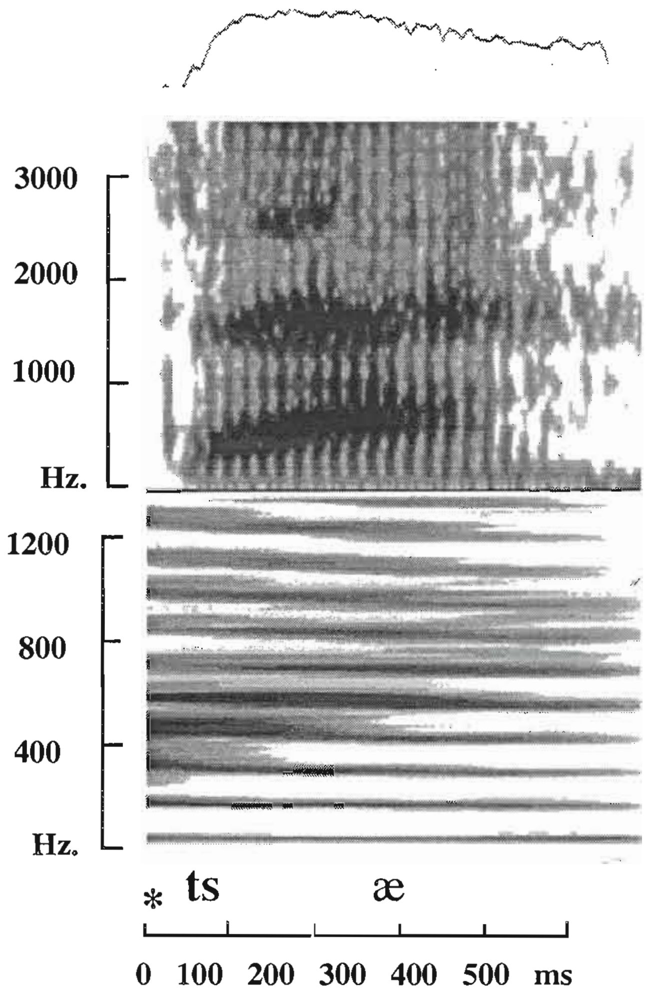

Figure 7. Energy contour, and wide and narrowband spectrograms for *tsæ², 'guayaba'

3) Post-vocalic aspiration. Cessation of voicing towards the end of isolated tokens is a common feature within the Jalapa Mazatec corpus. However, there is no tendency toward a greater degree of aspiration in ballistic syllables.

Thus, while native speakers distinguish the forms in (9), the distinction does not conform to the traditional ballistic/controlled contrast. Instead, these contrasts appear to involve a combination of tone and length differences. Table 5 shows the frequency in the middle of the vowel of and duration measures for the four contrastive pairs indicated, for two male speakers.

Table 5. Frequency (Hz) and duration (ms) of the vowel in four pairs of Mazatec syllables.

	BALLISTIC				CONTROLLED			
	***su**	**nĩ*ntu**	***tsæ**	***hũ**	**su**	**nĩntu**	**tsæ**	**hũ**
male 1								
F0	177	197	166	165	162	153	165	153
DURATION	16.1	10.6	14.1	17.3	23.9	17.8	21.8	24.4
male 2								
F0	183	186	179	188	167	159	165	164
DURATION	21.3	16.7	16.4	21.7	26.7	19.6	28.1	23.8

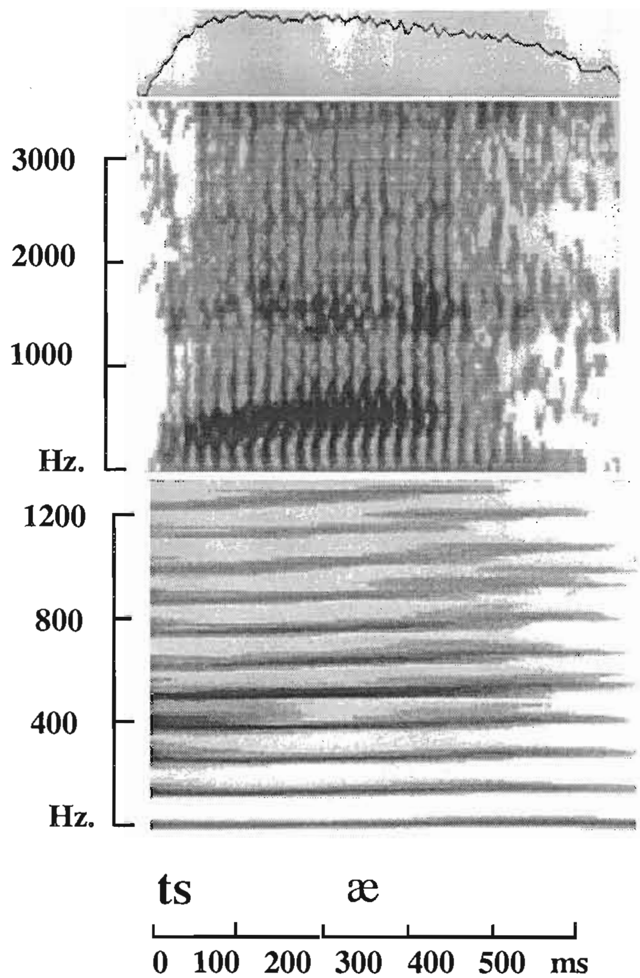

Figure 8. Energy contour, and wide and narrowband spectrograms for tsæ^2, 'full'

As can be seen, the so-called ballistic/controlled contrast apparently involves systematic differences in frequency and vowel duration. In each case the fundamental frequency is higher and the duration less in the ballistic syllable than in the corresponding controlled syllable. Schram and Pike (1978) in fact characterize the contrast in question as one involving length.

It is instructive to compare the F0 values in Table 5 to those in Table 6, which shows F0 averaged values for the three contrastive tonal patterns, High, Mid, and Low, for four female speakers and one male speaker.

Table 6. Mean F0 (Hz) for each of the three tones.

word		HIGH	MID	LOW
tjo	FEMALES	272	232	206
tjo	MALE	217	167	132
ha	FEMALES	255	232	199
ha	MALE	220	177	128

A comparison of Tables 5 and 6 shows that tonal contrasts involve a greater difference in pitch than is in evidence in so-called ballistic syllables. Thus ballisticity seemingly does not involve a lexical contrast in pitch.

Let us then consider in more detail the possibility that ballistic syllables involve a length contrast. While vowel length contrasts are clearly evident in morphologically complex environments, the data set provides no instances of morphologically simple length contrasts. This contrasts with many other Otomanguean languages, in which vowel length is phonemic (see, e.g., Rensch 1976). If so-called ballistic syllables exemplify a length contrast, this otherwise unexplained gap is accounted for: ballistic syllables may in fact be morphologically simplex short syllables. Given that the canonical Mazatec root is monosyllabic, we might expect a prevalence of bimoraic words, as increased duration is preferred within the open class of the lexicon, so that lexical contrasts may be rendered salient (see Silverman, *in preparation*n). Observed pitch increases in ballistic syllables may enhance the salience of short roots, as pitch increases render more prominent their acompanying segmental material.

For now, the data remain too limited to draw confident conclusions regarding the so-called ballistic/controlled contrast. However, length distinctions combined with enhancing pitch increases would seem a promising approach.

3. Consonants

The consonant phonemes are shown in Table 7. The plosives occur in five places of articulation: bilabial stop (limited to loanwords), dental stop, dental affricate, palatal affricate, and velar stop. There is also a glottal stop. Each of the plosives has a three-way contrast in voice onset time (VOT) with the voiced phoneme redundantly prenasalized. Moreover, the velar series may possess a contrastive labial offglide. Similarly, the dental series may possess a contrastive palatal offglide.

Table 7. Jalapa Mazatec consonants. Segments found only in loan-words are in parentheses.

	LABIAL	DENTAL	DENTAL AFFRICATE	POST-ALVEOLAR	VELAR	GLOTTAL
PLOSIVES	(p^h)	t^h	ts^h	tʃ^h	k^h	
	(p)	t	ts	tʃ	k	ʔ
NASALS	m̥	n̥	ɲ̊			
	m	n	ɲ			
	m̰	n̰	ɲ̰			
FRICATIVES		s		ʃ		h
APPROXIMANTS	w̥			j̊		
	w	(l)		j		
	w̰			j̰		

Nasal consonants occur in three places of articulation, bilabial, dental, and palatal. Each of these can be voiceless, voiced, or glottalized. Similarly, the approximants **w** and **j** exhibit a three-way contrast between voiceless, voiced and voiced glottalized articulation. Aspirated and glottalized sonorants may only co-occur with plain vowels.

Liquids are rare. [l] occurs primarily in loan words. A tap **ɾ** is present only in the clitic **ɾa** 'probably', and is thus marginal.

There is an alternation between ɸ before front vowels and w̥ beore back vowels, both in the full consonant (e.g., [ɸæ²] 'it is finished', [w̥a¹] 'Juan') and in the labial element of the aspirated labial velar (e.g., [$k^{ɸ}$æ¹] 'file', [$k^{w̥}$a¹] 'will happen'). The same alternation occurs between w/β and w̰/β̰ as full consonants.

A number of consonant clusters also occur. Both the aspirated and voiceless unaspirated plosives series can be preceded by homorganic nasals, giving **(mp^h), nt^h, nts^h, $ntʃ^h$, nk^h, $nk^{w̥h}$,** and **(mp), nt, nts, ntʃ, nk, nk^w,** There is no similar contrast between pre-nasalized and non-pre-nasalized voiced plosives. This series is voiced in initial position, and redundantly prenasalized when intervocalic. In addition to single segments, There are also voiceless consonant clusters with s followed by a dental, velar, or labial-velar, and ʃ followed by velar or labial-velar stops.

Surface clusters involving laryngeals are treated as single segments. Note that the aspirated plosives are the only laryngeally augmented onset consonants that may co-occur with creaky vowels: **tʃ**õ̰² (fifteen). Contrariwise, surface post-aspirated fricatives never co-occur with creaky vowels; they only co-occur with plain vowels. Given this distributional asymmetry, we regard all fricatives as plain.

3.1 Stops

The duration differences between the voiceless and the aspirated stops are summarized in Table 8. The measurements are means of 6 speakers, each saying a single word, except in the case of **k^h**, for which there were two words. Both the closure durations and the VOTs are comparable with those in other languages that have a three way voicing contrast. Also as is usual, the VOTs for the velar stops are longer than those for the alveolars.

Table 8. Durations of alveolar and velar medial stop elements (ms).

	CLOSURE	VOT	TOTAL
t^h	97	63	160
k^h	95	80	175
t	111	11	122
k	93	23	116

As we have noted, the voiced stops are prenasalized in initial position. The durations of the different portions are as shown in Table 9. Again, the measurements are means of 6 speakers, each saying a single word in the case of the bilabial stop, and two words in the case of the alveolar and the velar stops. The voiced stop portion was not always voiced throughout the oral closure; the voiced nasal portion was sometimes followed by a voiceless stop which was released with a very brief VOT (less than 10 ms).

Table 9. Durations of the oral and nasal closures of initial voiced stops (ms).

	NASAL	ORAL	TOTAL
^mb	66	42	108
nd	68	60	128
$ŋg^w$	50	21	61

3.2 Nasals

Spectrograms of the contrasting nasals are shown in Figure 9. The voiceless bilabial nasal at the top of the figure is similar to that found in Burmese and many languages of South East Asia (Bhaskararao and Ladefoged, 1993). The first part of the nasal is voiceless, but before the articulatory closure is released, voicing commences. The first upward pointing arrow in the illustration marks this point; the second arrow indicates the release of the articulation (the opening of the lips in this case) and the start of the vowel. In our sample the voiced portion exceeded half of the total closure duration in extreme cases, but averaged around one fourth of the total. The nasal with modal voicing in the middle of the figure is similar to that found in most languages of the world.

The glottalized nasal in the lower part of the figure has a number of creaky voice pulses preceding modal voicing for the portion immediatley before the vowel. Glottalized nasals (and, indeed, all the glottalized sonorants) were very variable in their articulation. Sometimes, as in the example illustrated here, there were creaky voice pulses before the nasal. Sometimes there was a single glottal pulse and then a long glottal closure before a modally voiced nasal. On some occasions there was almost no modal voicing, and much of the nasal was pronounced with creaky voice; on other occasions the glottalization spread even further so that the neighboring segments had creaky voice. It was usually impossible to measure the glottal portion of glottalized nasals in word-initial position, but in six tokens of initial glottalized nasals (two words spoken by each of three male speakers), there was some glottal activity noticeable from 241 to 359 (mean 296) ms before the short modally voiced nasal. This long interval with glottal activity may be due to these words' being produced as citation forms.

Table 10 summarizes duration measurements for the nasals. The figures for the glottalized nasals are unreliable, because (as noted above) they may be realized in several ways. The measurements are means for six speakers each saying a single word, except in the case of **m** for which two words were available.

Table 10. Durations of nasal elements (ms).

	VOICELESS NASAL	VOICED NASAL	TOTAL	POSITION IN WORD
m̥	101	37	138	medial
n̥	73	35	108	medial
ɲ̊	81	18	99	medial
m		75	**75**	initial
n		93	**93**	initial
ɲ		97	**97**	initial
	GLOTTAL CLOSURE			
m̰	70	43	113	medial
n̰	75	38	113	medial
ɲ̰	107	42	149	medial

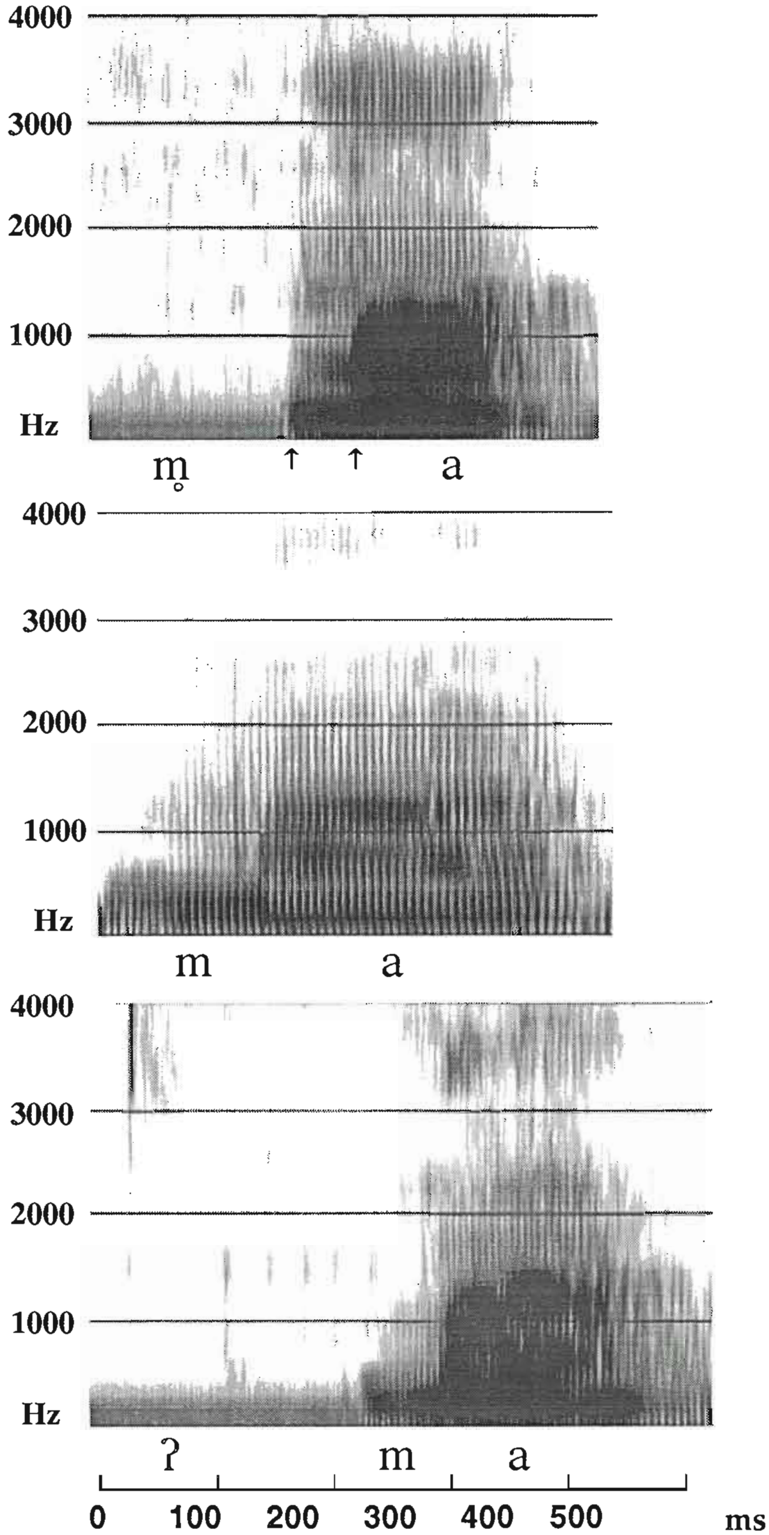

Figure 9. Spectrograms of **m̥a**^{2}, 'black, **ma**^{2}, 'is able, **m̰a**^{2}, 'hidden.

4. Conclusion

The sound system of Jalapa Mazatec is unusual in possessing a great number of linguistically significant laryngeal contrasts in both its consonant and vowel inventories. Moreover, the distribution of these laryngeal contrasts within the syllable abides by unusual co-occurrence restrictions.

The present approach to Jalapa Mazatec segmentation is surely not the only viable candidate (see, for example, Pike and Pike 1947, and Steriade 1993 for alternative accounts). We nonetheless hope that our instrumental analyses provide a foundation on which future investigations—both phonetic and phonological—may be based.

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