Phonetic Structures in Jalapa Mazatec

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Abstract. This paper describes the phonetic inventory of the San Felipe Jalapa de Díaz dialect of Mazatec (Jalapa Mazatec). 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. We focus on instrumental analyses of breathy vowels, creaky vowels, and so-called ballistic syllables, as well as glottalized and voiceless sonorant consonants.

1. Introduction. Mazatecan belongs to the Popolocan branch of the Otomanguean language family (Gudschinsky 1958; Grimes 1988). It is composed of twenty-three speech communities in Mexico and is spoken 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 the vicinity of San Felipe Jalapa de Díaz (henceforth Jalapa Mazatec), in the District of Tuxtepec, by 6,000–8,000 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. The speech of six male and six female native speaking adults was 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 2 gives a brief overview of Jalapa Mazatec phonology; section 3 presents the vowel system, while section 4 provides instrumental analyses of that system; and finally, in section 5, we consider the consonant system.

2. A brief overview of phonology. The Jalapa Mazatec syllable is maximally CCGV (consonant-consonant-glide-vowel). Consonant clusters comprise a sequence of either a fricative-stop or a homorganic nasal-voiceless stop. Despite the simplicity of the syllable structure, the availability of laryngeal contrasts 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 contrast for 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 of the second syllable onset metathesized with the vowel of the first syllable, and the vowel of the second syllable coalesced with this first vowel. Development of these breathy vowels was conditioned by two further factors: (1) the onset consonant of the first syllable of the 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 them were different, they then 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 are illustrated in 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 of the form 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 has been reduced to monosyllabics with a creaky vowel in Jalapa Mazatec. The *ʔ* metathesized with 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 metathesis of *h* and the vowel of the first syllable. 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).

Additional information about Mazatec phonology (historical and synchronic) can be found in Pike and Pike (1947), Gudschinsky (1958), Kirk (1966, 1970), Schram and Pike (1978), Schane (1985), Steriade (1993), and Silverman (1995).

3. Vowels. Jalapa Mazatec contains a basic five-vowel system, 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, laryngeal, 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. Examples of each level of lexical tone pattern are presented in (3).

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

Breathiness or creakiness may accompany Mazatec vowels. In either case, nonmodal phonation (i.e., either breathiness or creakiness) is most prominent in the first portion of the vowel. Examples of breathy and creaky vowels follow:

(4)

BREATHY VOWELS		CREAKY VOWELS	
$^{\text{ŋ}}$*gi̤*^{2}	'he went'	*sḭ*^{3}	'holiday'
jæ̤^{1}	'boil' (noun)	*t*^{h}*æ̰*^{2}	'sorcery'
ki$^{2\text{ŋ}}$*ga̤*^{23}	'he fastened'	*tʃa̰*^{3}	'load, burden'
ki$^{2\text{ŋ}}$*go̤*^{2}	'you (pl.) will fasten'	*tʃṵ*^{3}	'blouse'

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'		

Laryngeal 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 / CREAKY NASALIZED VOWELS

nĩ̤^{1}	'ear of corn'	*ʃḭ̃*^{1}	'man'
ⁿdʒæ̤̃^{2}	'visibility'	*k*^{w}*a*^{2}*sæ̰̃*^{2}	'he entered'
nã̤^{23}	'my tongue'	*kã̰*^{2}	'single, widowed'
nõ̤^{2}	'your (pl.) tongue'	*tʃõ̰*^{1}	'lightning'
ⁿdʒṳ̃^{2}*nĩ*^{1}	'tomorrow'	*nṵ̃*^{3}	'vine'

Finally, there is the possibility that a ballistic-controlled contrast exists in Jalapa Mazatec syllables. Previously thought to be limited to the related languages of 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, 1995). Controlled, or plain, syllables do not possess these characteristics. Judy Schram and Terry Schram (p.c. 1993) have pointed out to us a number of contrasts in Jalapa that might be worth investigating to determine whether they manifest the ballistic-controlled contrast. Ballistic syllables will be indicated with cross-hatching (#).

(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'

4. Instrumental analysis of vowels. In this section, we analyze, in turn, plain vowels, breathy vowels, creaky vowels, and the vowels of so-called ballistic syllables.

4.1. Plain vowels. Two tokens of each vowel were recorded for each male speaker and each female speaker. Words in which formant structures were examined 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'

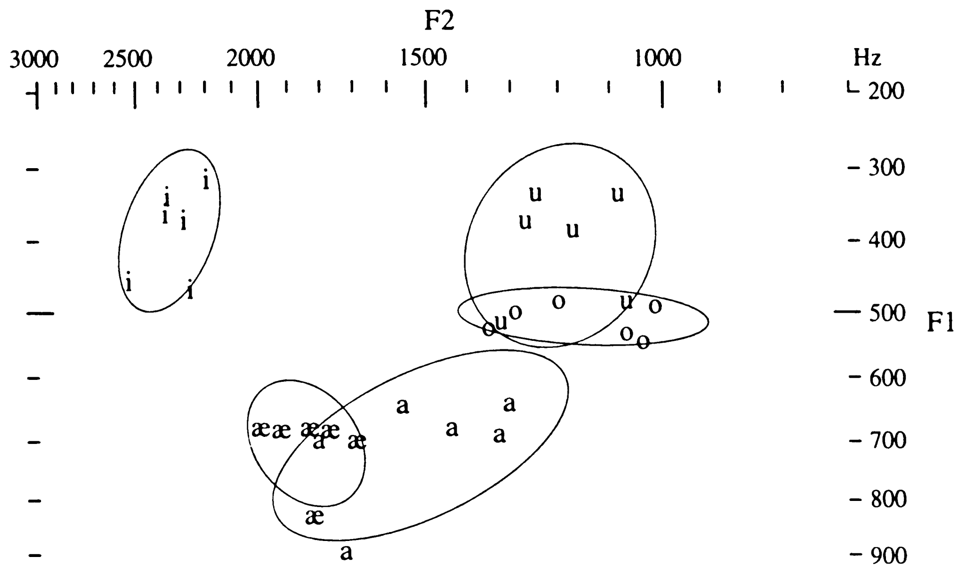

Figure 1. F1 vs. F2 for two tokens each by three male speakers.

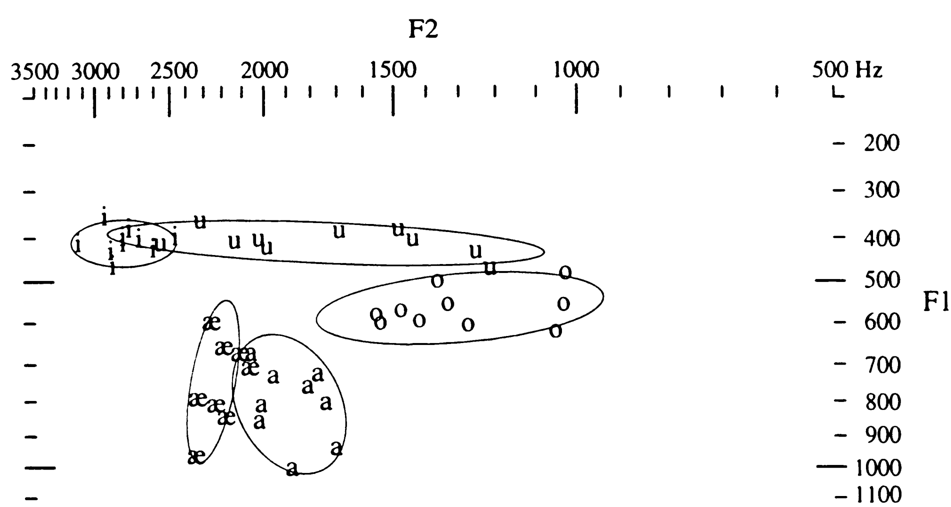

Figure 2. F1 vs. F2 for two tokens each by five female speakers.

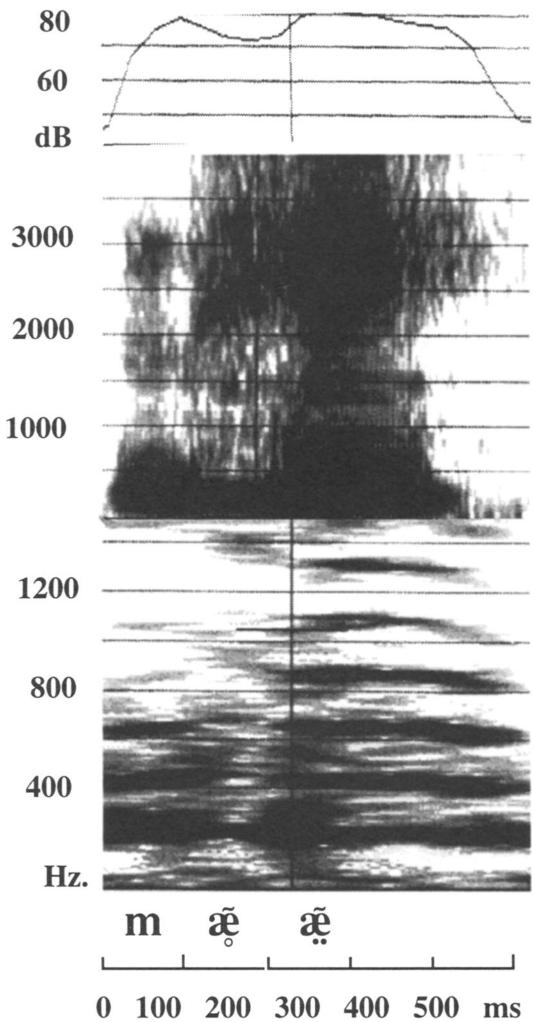

Figure 3. Energy contour, wideband, and narrowband spectrograms for *mæ̤̃*^{21} 'he wants'.

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.

4.2. 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.

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; 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 that accompany breathy phonation, as subglottal pressure correlates positively with both intensity and pitch (see, e.g., Ohala 1978).

Table 1 below presents data from eleven speakers (six male, five female) who produced eight forms with breathy vowels, resulting in 88 tokens. The second column lists the mean duration (in milliseconds [ms]) of the strong breathy portion of these vowels in each of the eight forms. The third column lists the total mean vowel duration in the same forms. Finally, the fourth column shows the percentage of vowel duration that possesses strong breathy phonation. The bottom row lists means across both speakers and forms. These values show that strong breathiness typically persists for slightly less than half the duration of the vowel as a whole.

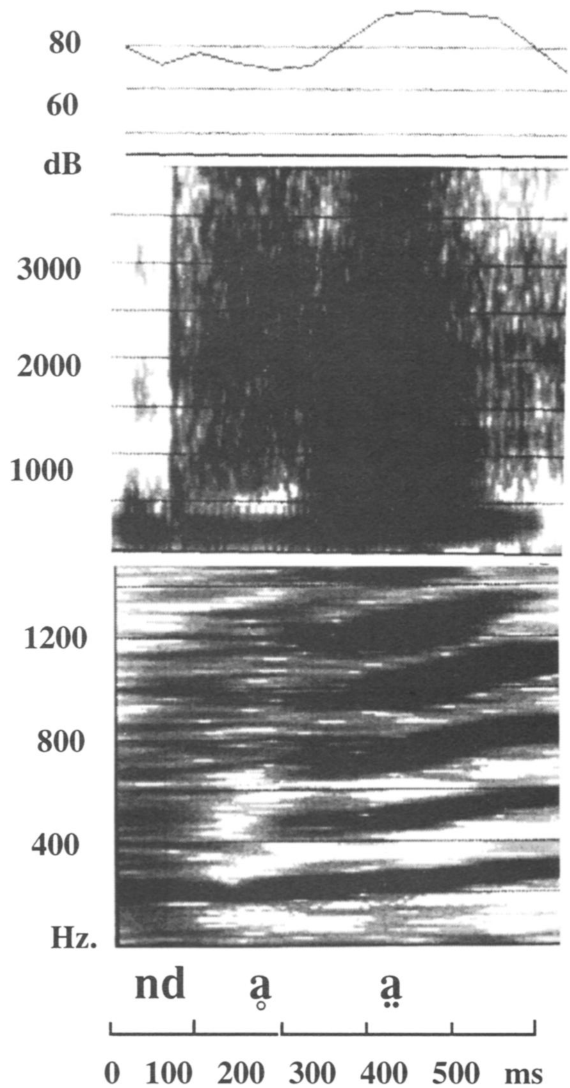

Figure 4. Energy contour, wideband, and narrowband spectrograms for ⁿ*da̤*[21] 'hard'.

4.3. Creaky vowels. Creaky vowels, like breathy vowels, manifest their nonmodal 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 narrowband spectrograms do not always reveal these characteristics.

Table 1. The Extent of Strong Breathy Phonation in Phonologically Breathy Vowels, across Speakers

WORD	STRONG BREATHY PORTION MEAN DURATION (ms)	TOTAL MEAN VOWEL DURATION (ms)	STRONG BREATHY PHONATION: PERCENTAGE OF VOWEL DURATION
^{n}*gi̤*^{2}	136.4	306.2	37.6
ki^{2n}*ga̤*^{23}	096.2	225.3	42.7
ki^{2n}*go̤*^{2}	096.3	247.2	39.0
^{n}*dja̤*^{1}	111.7	262.4	42.6
^{n}*da̤*^{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
^{n}*dṳ*^{2}	099.3	223.5	44.3
MEAN	109.4	255.6	42.8

Ladefoged, Maddieson, and Jackson (1988) showed that creaky vowels have a characteristic spectral tilt: compared to modally phonated vowels, the amplitudes 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 producing six distinct tokens, for a total of 60 forms measured. The difference between H2 and H1 was subsequently calculated for each token, both during the initial portion and the latter portion. Table 2 presents these differences for each form, averaged across speakers. The bottom row lists averages across both speakers and forms.

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 agree with the findings of Ladefoged, Maddieson, and Jackson (1988), in that creakiness is characterized by a spectral tilt measurable as a weakening of H1 relative to H2. Our impression is that the creaky portion of the vowel is, like the breathy portion, slightly 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.

Table 2. The Relative Intensities (in dB) of the First and Second Harmonics in Creaky Vowels, across Speakers

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
^{n}*dæ̰*^{1}	4.58	−3.28	7.86
mean	7.86	.15	7.71

4.4. 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:

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

Mugele (1982) proposes that ballisticity is phonologically characterized by an increase in subglottal pressure. In contrast, Silverman (1994, 1995) argues that a laryngeal abduction is the primary articulatory gesture.

Previously, ballisticity has not been reported in Mazatec. However, Judy Schram and Terry Schram (p.c. 1993) 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.

(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).

• **Fortis release of syllable-initial onsets.** While the supposed fortition accompanying ballisticity remains an impressionistic description that has not been previously analyzed by instruments, there are two likely interpretations: (a) onset consonant duration and (b) voice onset time (VOT).

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

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

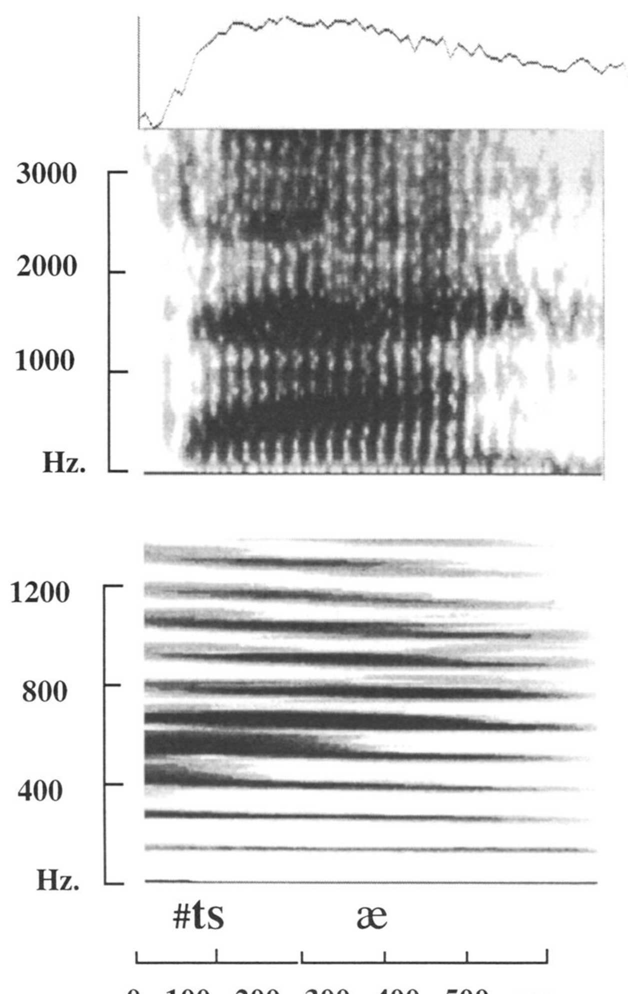

Figure 5. Energy contour, and wide and narrowband spectrograms for #*tsæ*² 'guayaba'.

Table 3. Mean Durations of Syllable Onsets (ms), across Speakers

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

(b) *VOT.* Pairs that near-minimally contrast in so-called ballisticity suggest no difference in VOT between ballistic and controlled syllables (see figures 5 and 6).

• **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. Mean Intensity (dB) at the Vowel Midpoint in Ballistic and Controlled Syllables, across Speakers

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

• **Post-vocalic aspiration.** Cessation of voicing toward the end of isolated tokens is a common feature in 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 so-called ballistic-controlled contrast. Instead, while the data remain too limited to draw confident conclusions, these contrasts appear to involve a combination of tone and length differences.

Table 5 below shows the fundamental frequency in the middle of the vowel for two male speakers, as well as the vowel duration measures of the four contrastive pairs indicated. As can be seen, the so-called ballistic-controlled contrast apparently involves systematic differences in fundamental 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. 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 does not solely involve a lexical contrast in pitch.

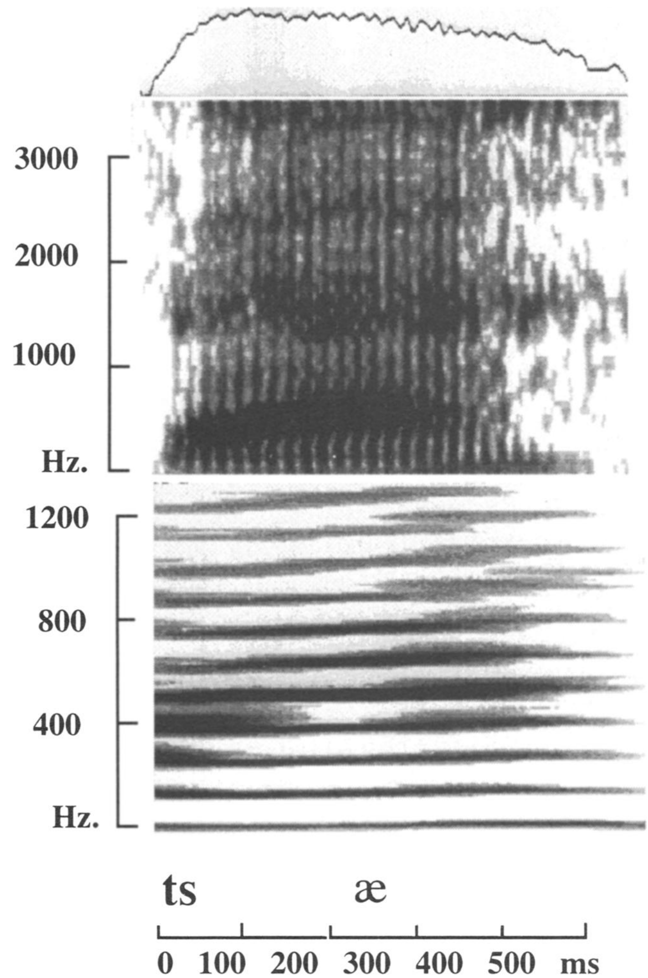

Figure 6. Energy contour, and wide and narrowband spectrograms for *tsæ*[2] 'full'.

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 situation 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 would be 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. Observed pitch increases in ballistic syllables may thus enhance the salience of short roots, as pitch increases render more prominent their accompanying segmental material. Finally, this approach also accounts for the slight increase in intensity found in ballistic syllables, as increases in intensity render contrasts more salient (see table 4).

Table 5. Mean Frequency (Hz) and Duration (ms) of the Vowel in Four Pairs of Mazatec Syllables, across Speakers

	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

Table 6. Mean F0 (Hz) for Each of the Three Tones, across Speakers

WORD	SEX	HIGH	MID	LOW
tjo	FEMALE	272	232	206
	MALE	217	167	132
ha	FEMALE	255	232	199
	MALE	220	177	128

5. Consonants. Consonant phonemes are shown in table 7. Plosives occur in five places of articulation: bilabial stop (limited to loanwords), dental stop, dental affricate, palato-alveolar affricate, and velar stop. There is also a glottal stop. Each of the plosives has a three-way contrast in VOT with the voiced plosive redundantly prenasalized. Moreover, the velar series may possess a contrastive labial offglide, while the dental series may have a contrastive palatal offglide.

Table 7. Jalapa Mazatec Consonants*

	LABIAL	DENTAL	DENTAL AFFRICATE	POST-ALVEOLAR	VELAR	GLOTTAL
PLOSIVES	*(pʰ)*	*tʰ*	*tsʰ*	*tʃʰ*	*kʰ*	
	(p)	*t*	*ts*	*tʃ*	*k*	*ʔ*
	ᵐb	*ⁿd*	*ⁿdz*	*ⁿdʒ*	*ᵑg*	
NASALS	*m̥*	*n̥*		*ɲ̊*		
	m	*n*		*ɲ*		
	m̰	*n̰*		*ɲ̰*		
FRICATIVES		*s*		*ʃ*		*h*
APPROXIMANTS	*w̥*			*j̊*		
	w	*(l)*		*j*		
	w̰			*j̰*		

*Segments found only in loanwords are in parentheses.

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 occur only with plain vowels.

Liquids are rare. *l* occurs primarily in loanwords. A tap *ɾ* is present only in the clitic *ɾa* 'probably' and thus is marginal.

There is an alternation between *Φ* before front vowels and *w̥* before back vowels, both in the full consonant (e.g., *Φæ*^{2} 'it is finished', *w̥a*^{1} 'Juan') and in the labial element of the aspirated labial velar (e.g., *k*^{Φ}*æ*^{1} 'file', *k*$^{w̥}$*a*^{1} '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 *(mpʰ), ntʰ, ntsʰ, ntʃʰ, nkʰ, nkʷ̥ʰ*, and *(mp), nt, nts, ntʃ, nk, nkʷ*. There is no similar contrast between prenasalized and nonprenasalized voiced plosives. This series is redundantly prenasalized. 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 contrastive onset consonants that may occur with creaky vowels: *tʲõ̰*^{2} 'fifteen'. Contrariwise, surface post-aspirated fricatives never cooccur with creaky vowels; they only occur with plain vowels. Given this distributional asymmetry, we regard all fricatives as plain.

5.1. Stops. The duration differences between the voiceless and the aspirated stops are summarized in table 8. The measurements are means of six 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. Mean Durations of Alveolar and Velar Medial Stop Elements (ms), across Speakers

	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. The durations of the different portions are as shown in table 9. Again, the measurements are means of six 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 that was released with a very brief VOT (less than 10 ms).

Table 9. Mean Durations of the Oral and Nasal Closures of Initial Voiced Stops (ms), across Speakers

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

5.2. Nasals. Spectrograms of the contrasting nasals are shown in figure 7. 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

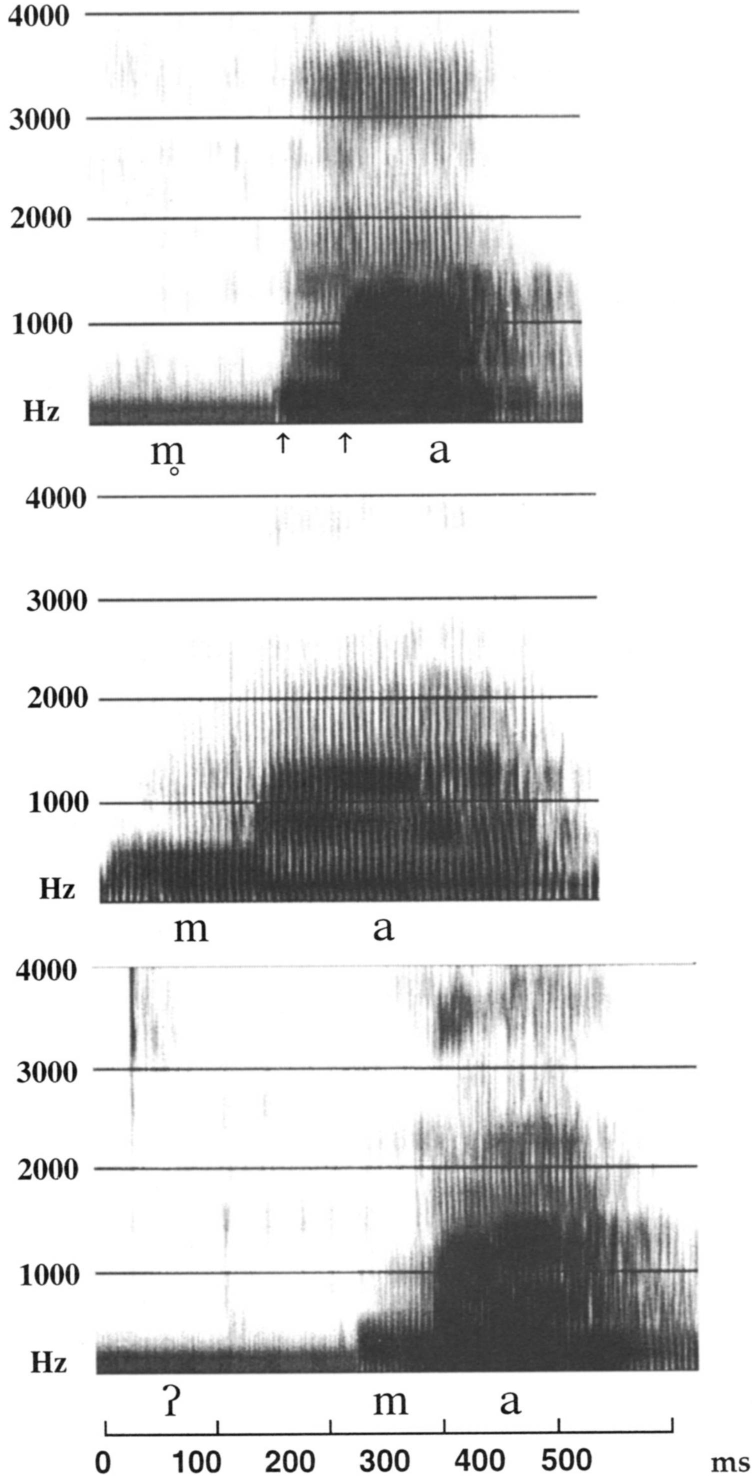

Figure 7. Spectrograms of *m̥a*^{2} 'black', *ma*^{2} 'is able', *m̰a*^{2} 'hidden'.

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 immediately 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 the fact that these words are citation forms.

Table 10. Mean Durations of Nasal Elements (ms), across Speakers

	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

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.

6. 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 cooccurrence restrictions.

We hope that our instrumental analyses provide a foundation on which future investigations—both phonetic and phonological—may be based.

Notes

Acknowledgments. This paper is for the people of San Felipe Jalapa de Díaz, especially our three principal consultants, Froylan Perez Moreño, Augustín Cruz Martinez, and Atanacio Zarate Asunción. Our research was supported by the National Science Foundation.

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