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The phonetics of tone in Chalcatongo Mixtec couplets[1]

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I. Introduction

The Mixtec subgroup of the Otomanguean language family of Mexico comprises approximately 30 mutually unintelligible languages. These have traditionally been termed "dialects" in linguistic literature and are named for the communities where they are spoken (Josserand 1983). The variety under discussion is that spoken in Chalcatongo in the mountainous Mixteca Alta of the Mexican state of Oaxaca.

The goal of this study is to present a detailed phonetic description of tone in isolated Chalcatongo Mixtec (ChM) couplets. To this end, fundamental frequency (F0) was examined in various ways, since it is generally the primary cue for perception of a tone (Gandour 1978, Hombert 1978). Pertinent areas of description were a given tone's range in F0 and its average value, and average values of F0 at given intervals in tonal contours.

Mixtec languages are almost invariably analyzed in terms of the couplet (Pike 1948:79, Mak and Longacre 1960:27, Josserand pp.180ff.), a bimoraic morphological unit having the structure (C)V(C)V. Indeed, the couplet is the premiere morpheme shape in modern Mixtec. Morphemes with this structure far outnumber polysyllabic single morphemes and monomoraic clitics.

ChM is a three-tone system, as, it seems, are most Mixtec languages, with H(igh), M(id), and L(ow) tones. Every vocalic mora carries a tone. Since the canonical word shape is bimoraic, and since each tone can occur in either mora, nine theoretical combinations are possible, but only eight are realized. (LM does not occur in ChM; LL tone, however, corresponds nearly always to LM in neighboring San Miguel el Grande Mixtec, which has no LL couplet.) Each combination will be referred to as a "tonemic couplet" when confusion with morphemic couplets is likely; it can be seen that the two are closely connected.

II. Methodology

To meet the goal of this study, all eight tonemic couplets (HH, HM, HL, MH, MM, ML, LH, LL) associated with both morphemic couplets ((C)VV, (C)VCV) were examined.[2] The first and second vowels were the same in all but three tokens; for these the first syllable of one word and the second syllable of another word were used to come up with an artificial sample where V1=V2. Tokens containing each of the six ChM vowels /a, e, i, ɨ, o, u/ were sought. Glottalized ([Vʔ]) and nasalized vowels, while the subjects of smaller ancillary investigations, were avoided.

Voiceless obstruents were the most highly desired consonants since their occurrence is obvious from the near absence of amplitude, F0, etc., although other or less desirable sorts /b, ⁿd, kʷ, n, r/ were employed occasionally when consonants of the former type were not available. Hombert (pp.79-81) demonstrates that voiceless obstruents cause F0 of the following vowel to be higher than that of a vowel following a voiced obstruent in English (although he does not include vowel-initial controls). While this may be the case in ChM, it was assumed that it would not affect results significantly since most tokens began with voiceless obstruents. And Hombert suggests that "there may be a tendency in tone languages (which does not exist in nontonal languages) to minimize the intrinsic effect of prevocalic consonants actively--probably in order to render the different tones maximally perceptually distinct."(p.83) Another small side study was intended to investigate the effect of initial consonants on tone.

A MM CVV was chosen as a reference point for all elicitations, so that the format of each token was "čāā [pause] [token]". (A macron indicates M tone; *čāā* means 'write'.)

Elicitations were made under mostly controlled conditions, i.e. in a very quiet, though not sound-treated room, with a unidirectional microphone, and a good quality cassette recorder. The recordings were sampled at 10,000 Hz, digitized, and pitch-tracked at 200 Hz with appropriate software[3] on an IBM AT, then printed.

As a general principle, measurements of F0 were made from the printout at positions where a vowel's amplitude was respectable[4] and where the pitch-tracking program had evaluated its own measurement as being highly accurate.[5] Descriptions of each tone contour were obtained by assessing F0 every 50 msec for vowels with shorter durations (as in CVCV) or with rapid pitch change, and every 100 msec for vowels with longer durations (as in CVV). These readings were then averaged. Transitions between consonant (or silence) and vowel were excluded from the measurements because the pitch extractor performed poorly here. Final transitions were included only for durational information and for approximate pitch information. The values of F0 in end transitions are less reliable than those in vowels' cores. Vowel durations which differed greatly from the average duration of their couplet group were adjusted to the average by taking measurements at shorter or longer intervals, as necessary.

To figure the average F0 of each tone, readings were taken from gliding contours at their endpoints or where the direction of the tone changes, as recommended by Pike (p.6). For level tones, readings were taken at 100 and 400 msec for CVVs and, for CVCVs, at 50 msec of V1 and 100 msec of V2.

Values for the range in F0 of tones were chosen from the same places that averages were taken, as well as from the first H or L reading in the first syllable of CVCVs, which points are not included in averaging. Included also was the last reading for V1 of a MM CVCV.

III. Results and Discussion

Ranges and Averages

The three tones' ranges and averages of F0 are listed below:

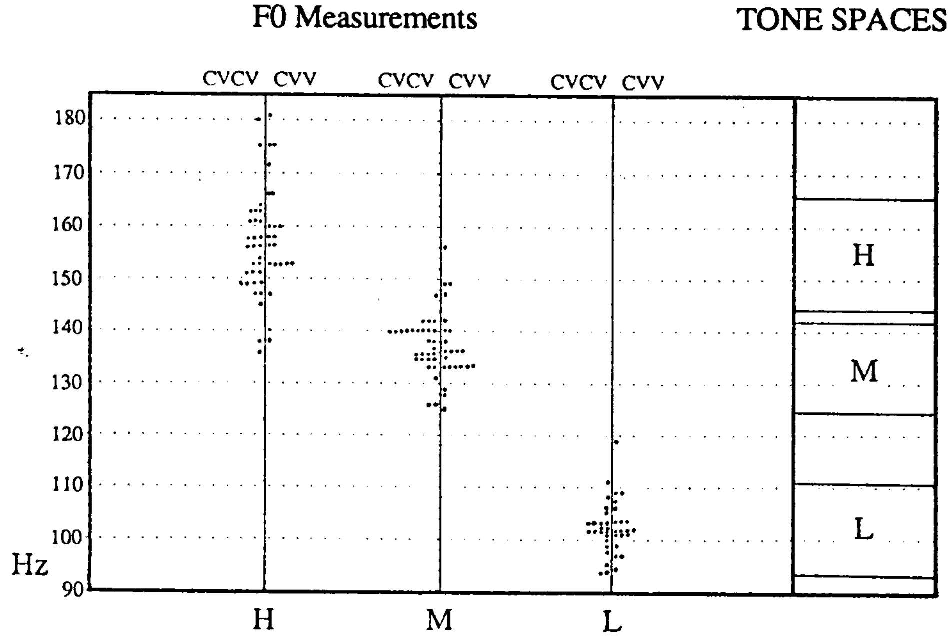
	Ranges (in Hz)		Averages (in Hz, with number of samples)					
	Low	High	μ1	#	μ2	#	Overall	#
H:	136	181	155.0	25	158.3	26	156.6	51
M:	121	147	137.0	28	137.5	23	137.2	51
L:	93	131	103.0	18	102.0	22	102.5	40

H tone's lowest reading was at the peak of a LH CVCV, and its highest, at the beginning of a HL CVV contour. M tone's low was found at the end of V1 in a MM CVCV, while its high was at the beginning of a ML CVCV. L tone had its lowest reading at the end of V1 in a LH CVCV and its highest at the beginning of V1 in a LH CVCV.

The average values for H, M, and L are similar in their relationship to those Faraclas (1983) obtained from the same consultant in his study of ChM tonal phonetics, although they are at a lower absolute register than Faraclas'. Compare the ratios of average F0 of ChM tones to each other:

	Present study	Faraclas 1983:323 (Sample 2)
H/M:	1.14	~1.18
H/L:	1.53	~1.62
M/L:	1.34	~1.35

Plotting the measurements used to calculate each tone's average F0, one finds that each tone has a cluster of values (or "tone space") of approximately 19 Hz, about 20% of the total range of 88 Hz (93-181 Hz). H tone's space was from 145-166 Hz. M's tone space was from 125-142 Hz. Tone space for L was 93-111 Hz. Of course, occasional excursions outside a tone's boundaries occur, usually upward. H and M's spaces are virtually adjacent, but there is a gap equaling almost a full tone space which separates M from L. Interestingly, this gap is where a fourth tone is observed in nearby Atatlahuca Mixtec (Dürr 1987:31).



Average couplet durations ranged from 456 to 619 msec. Average length of a CVV contour was 546 msec (31 tokens) and of a CVCV contour 489 msec (40 tokens), with an overall average duration of 514 msec.

Descriptions of contours and their Average F0

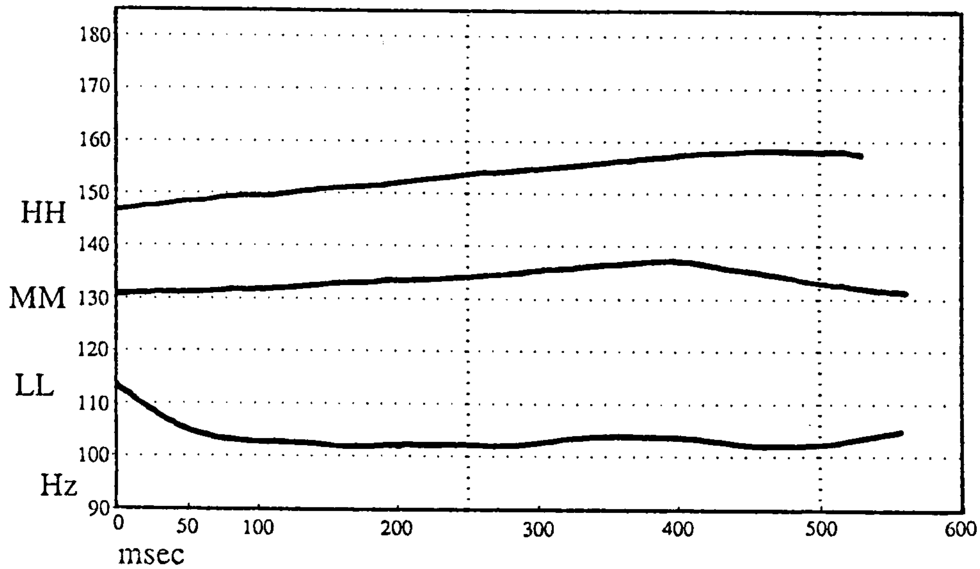
While F0 in couplets is more often changing than remaining level, these changes are not distinctive. F0 crosses tonemic boundaries within a mora only in cases of transition between endpoints of a contour, so each mora carries only one tone. All tonemic couplets can therefore be analyzed as sequences of level tones.

HLs in this sample deserve special mention. They are all CVV, and their average duration of 352 msec is over 100 msec shorter than the next shortest contour (456 msec for MH CVCV). This shorter duration is perceptually quite salient and might foreshadow development of a contour tone. However, it does not indicate a contour tone at present, for one tone is associated with each mora, as demonstrated by HL CVVs with two vowels, e.g. *síà* 'release'. Examination of HL CVʔV samples reveals that liaison between vowels is not a determining factor in length, because durations in two of three samples were as short as in CVVs, averaging 366 msec.

This brief duration can be a determining factor in perceiving phonemic H or M. One token of HL CVʔV rose to its highest F0 at 140 Hz, which is analyzed strictly phonetically as a M. One must assume that the brief duration of this contour allows what would otherwise be M tone to be interpreted unambiguously as H. Compare this duration, 364 msec, to the average ML's, 483 msec, which is a full 119 msec longer. Another instance of phonemic H equaling phonetic M is with LH CVCVs. In two (one-third) of these tokens, F0 rose to a M tone, 137 Hz. But since phonemic LMs are lowered to LL phonetically, LH remains the only contour rising from L, and it may not matter that the tone is phonetically M at its highest point. It seems that phonetic M may function as phonemic H if the contour has some unique characteristic, e.g. the brief duration of HL, the mere rise from the L tone space of LH. One may conclude that factors other than F0 at the endpoints of of gliding contours can influence, or even determine, the perception of tone.

A close description follows of each tonemic couplet, including F0 and duration. Measurements here describe the entire couplet group and are averages of the samples of that group. Graphs depict average tonal contours of vowels' cores.

LEVEL CVV



HH CVV: This tone contour rises for most of its duration, 10.4 Hz from vowel onset of 147.2 Hz, reaching its highest point late, and falls back down to the end transition. (Measurements were taken as though this were a gliding, rather than a level, contour.)

Low point at 0 msec: 147.2 Hz	High point at 500 msec: 157.6 Hz
(Vowel) Duration: 529 msec	with end transition: 574 msec

MM CVV: This pattern is practically level but does have a steady and very slight rise of 4 Hz (range 0-7 Hz) from 100 to 400 msec, from which it glides to the end transition.

At 100 msec: 132.3 Hz	At 400 msec: 136.3 Hz
Duration: 561 msec	with end transition: 595 msec

LL CVV: This tone contour is virtually flat for it entire duration, except for a rapid fall at vowel onset and a blip in the end transition. The initial descent averages 9.8 Hz over 100 msec (7.7 Hz by 50 msec). This contour had the longest average duration in the sample.

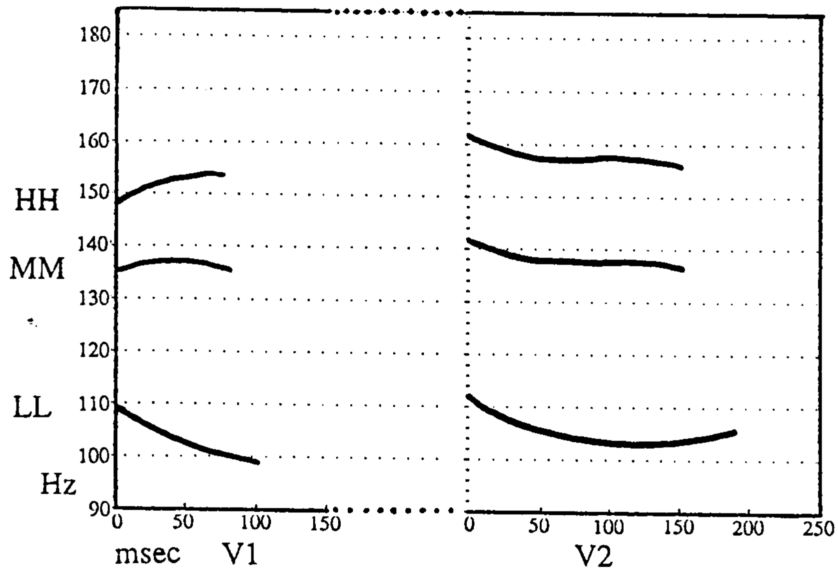
At 100 msec: 101.8 Hz	At 400 msec: 103 Hz
Duration: 558 msec	with end transition: 619 msec

LEVEL CVCV

HH CVCV: Tones in HH couplets rise 4.9 Hz on V1 by 50 msec and remain at this level for the very short remainder of V1's duration. V2 falls slightly (4 Hz by 50 msec) and then remains essentially at this level until end transition. $\mu 2$ is 4.3 Hz higher than $\mu 1$ (V1 at 50 msec measured against V2 at 100 msec). While this is the same pattern we see in HH CVV, it is not as dramatic a rise over the course of the word here as there (10.4 Hz).

V1 at 50 msec: 153.2 Hz
V1 duration: 76 msec
V1 to end: 472 msec

V2 at 100 msec: 157.5 Hz
V2 duration: 151 msec, with end transition: 208 msec



MM CVCV: Tone on the vowels in MM CVCV remains essentially level. V2's F0 falls nearly 4 Hz by 50 msec and stays around this level until end transition.

V1 at 50 msec: 136.8 Hz
V1 duration: 82 msec
V1 to end: 512 msec

V2 at 100 msec: 137 Hz
V2 duration: 165 msec, with end transition: 226 msec

LL CVCV: As with LL CVV, here we see a fall from onset, in both syllables, of 6.6 Hz by 50 msec. µ1 is actually a falling contour throughout its duration (10.2 Hz over 102 msec), while µ2 evens out after the initial drop by 50 msec, and may rise slightly at the end (3 out of 5 samples). There is a 5.2 Hz difference between µ1 and µ2's lowest points, µ2 being higher, so the pitch, i.e. perception of F0, of the contour may rise very slightly over the course of the word. As with level CVVs, H CVCVs are shortest, L CVCVs longest.

(V1 at 0 msec: 108.8)
V1 at 100 msec: 98.6 Hz
V1 duration: 102 msec
V1 to end: 573 msec

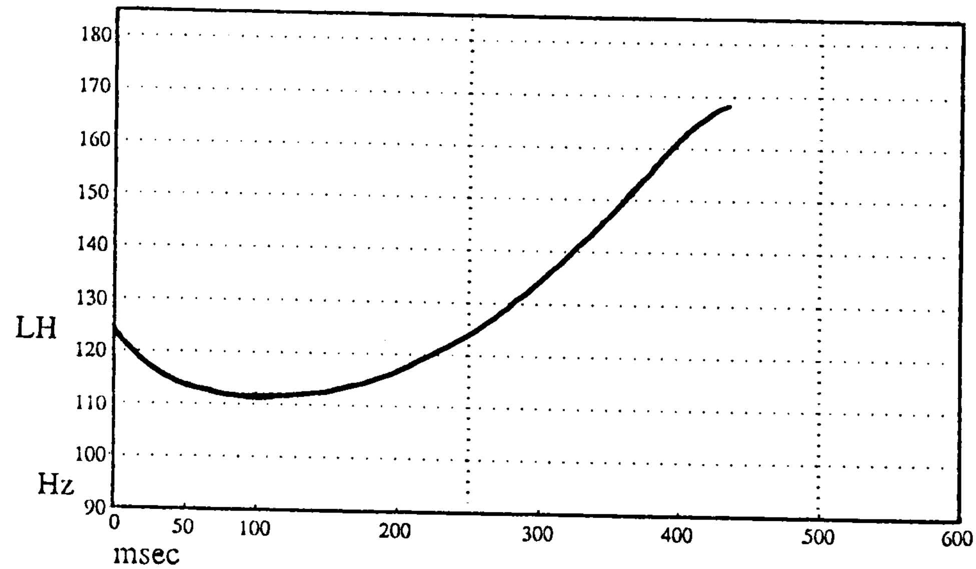
V2 at 100 msec: 103.8 Hz
V2 duration: 192 msec, with end transition: 229 msec

RISING CVV

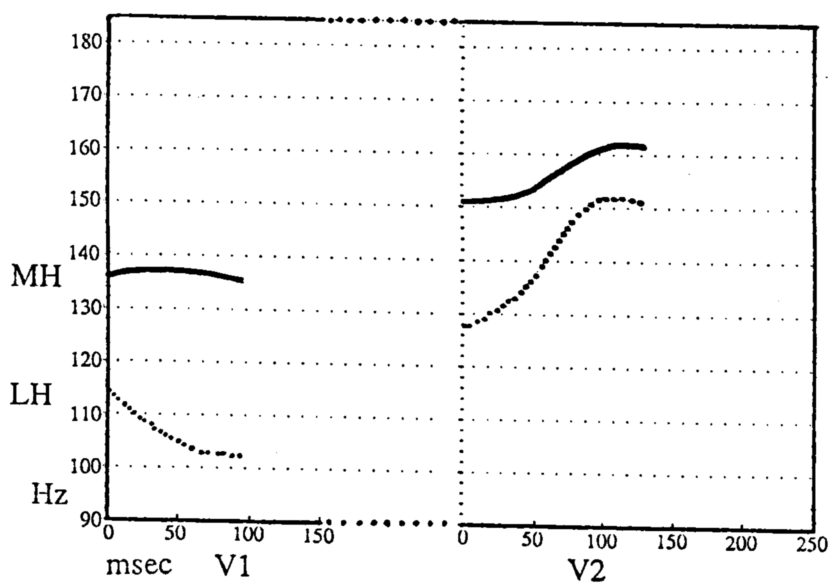
LH CṼṼ: Since it was found that contrastive vowel nasalization has no significant effect on F0, three LH CṼṼ tokens were added to the core sample. This contour is the only rising CVV contour but resembles other *Lx* contours in that it falls 10.6 Hz from vowel onset to 100 msec. From this point it rises gradually to 200 msec (4 Hz) and then rapidly to the end of the core vowel (51.7 Hz over 238 msec), the fastest rate being between 300 and 400 msec (27.3 Hz over 100 msec).

Low point at 100 msec: 112.3 Hz
Duration: 438 msec

High point at 438 msec: 168 Hz
with end transition: 494 msec



RISING CVCV



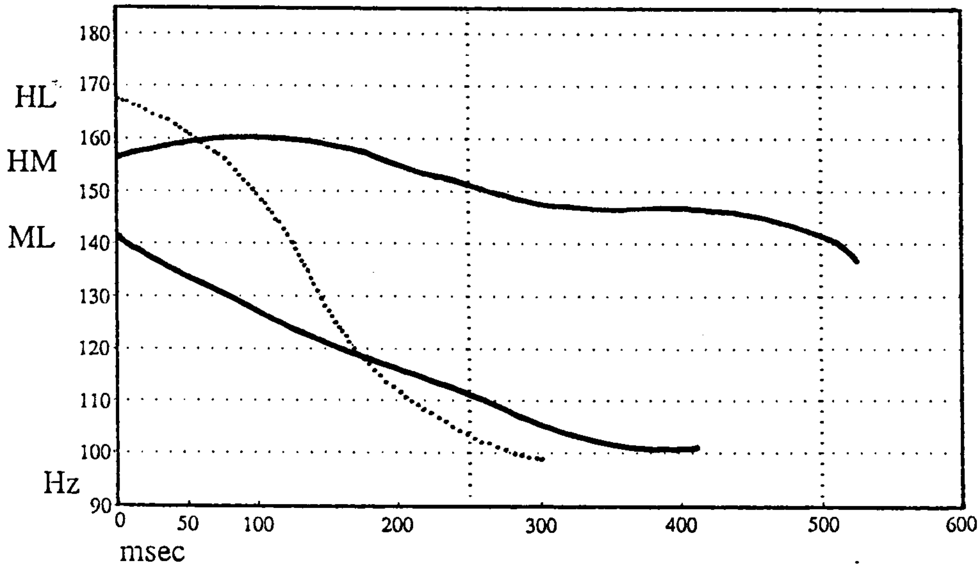
MH CVCV: This couplet, one of three rising contours, has a stable M on µ1 which can be compared to µ1 of MM CVCV. F0 in V2 climbs most rapidly between 50 and 100 msec (7.8 Hz).

V1 at 50 msec: 136.8 Hz	V2 high point at 131 msec: 161.6 Hz
V1 duration: 92 msec	V2 duration: 131 msec, with end transition: 190 msec
V1 to end: 456 msec	

LH CVCV: Both morae in this couplet have dynamic tone. µ1 has low tone falling 11.9 Hz, most rapidly in the first 50 msec, 7.9 Hz. This is comparable to µ1 of a LL CVCV. µ2 has a rising tone which climbs rapidly, 9.4 Hz, from onset to 50 msec, and even more quickly from 50-100 msec, 14.1 Hz. MH contours also have their most rapid rise in this phase. Interestingly, in µ2 one third of the sample (2 tokens) rose to a M tone (137 Hz at 100 msec), as discussed above. Another third rose to a low H (148 Hz at 100 msec). The remaining third rose to a healthy H (169 Hz at 100 msec).

(V1 high point at 0 msec: 114.2 Hz V2 low point at 0 msec: 127.8 Hz)
V1 low point at 95 msec: 102.3 Hz V2 high point at 100 msec: 151.3 Hz
V1 duration: 95 msec V2 duration: 129 msec, with end transition: 166 msec
V1 to end: 466 msec

FALLING CVV



HM CVV: This contour starts at its peak or reaches it by 100 msec, from which point it descends gradually through M level and the end transition.

High point at 100 msec: 160.6 Hz Low point at 500 msec: 141 Hz
Duration: 523 msec with end transition: 591 msec

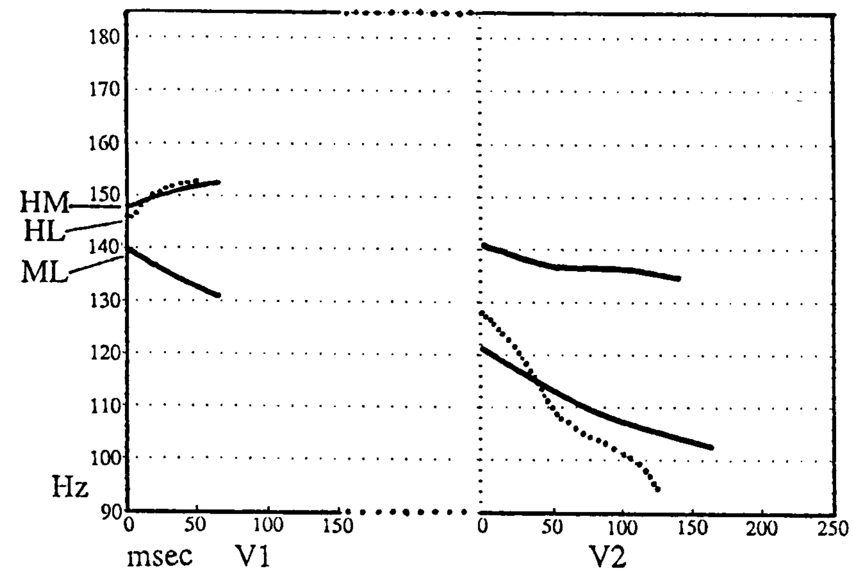
HL CVV: There is a fairly rapid descent of 7.4 Hz during the first 50 msec which accelerates greatly to fall 48.7 Hz over the next 150 msec, where the rate of fall again becomes more gentle. This contour is much shorter than others, as discussed above.

High point at 0 msec: 167.7 Hz Low point at 300 msec: 98.7 Hz
Duration: 301 msec with end transition: 352 msec

ML CVV: This falling contour descends gradually through the first 3/5 of the word, then levels off through the end transition.

High point at 0 msec: 140.6 Hz Low point at 400 msec: 101 Hz
Duration: 411 msec with end transition: 504 msec

FALLING CVCV



(The HL curve is actually the average CV?V contour. CV?V was not part of the core sample and is included here only to approximate a HL CVCV for purposes of comparison.)

HM CVCV: This tone contour resembles the first H in a HH plus the second M in a MM contour. µ1 has a slight rise of 4 Hz, and µ2 has a small fall of 3.9 Hz in the first 50 msec but is then mostly stable through until end transition.

(V1 at 0 msec: 148.2 Hz)
V1 high point at 63 msec: 152.2 Hz
V1 duration: 63 msec
V1 to end: 471 msec

V2 at 100 msec: 136.3 Hz
V2 duration: 142 msec, with end transition: 211 msec

ML CVCV: F0 in this couplet falls 9.2 Hz over average 66 msec. (Since measurements of V1 varied so widely (32 - 100 msec), I just took readings at 0 msec and endpoint.) µ2 sees the F0 falling rapidly in the first 50 msec, after which it descends more gradually, leveling off at 150 msec. µ2 resembles µ2 of LL CVCVs.

V1 high point at 0 msec: 139.4 Hz
(V2 at 0 msec: 121.6 Hz)
V1 duration: 66 msec
V1 to end: 483 msec

(V1 at 66 msec: 130.2 Hz)
V2 low point at 150 msec: 103.8 Hz
V2 duration: 166 msec, with end transition: 200 msec

Other phenomena of interest

H tones rise an average 3.9 Hz at the beginning of a word in four of the five couplets where it occurs, HH and HM CVV and CVCV. The short duration of HL CVV may prevent it from participating in this ascent.

L tones fall in the first 100 msec of a vowel by an average 10.3 Hz.

Level contours (all HH, MM, and LL couplets) rise an average 4.4 Hz over the course of the couplet. LL CVV and MM CVCV do so minimally (1.2 Hz and 0.2 Hz, respectively), while HH rises significantly (10.4 Hz).

V1 in CVCVs is generally about 1/2 the length of V2. But in rising contours of the shape CVCV (LH and MH), V1 is longer proportionally, averaging about 3/4 (71.8%) of V2's length.

Except for HM couplets, falling contours begin at their highest point and fall immediately. As noted above, HMs rise slightly, perhaps so that they can be maximally clear perceptually. They do not have far to fall, 14 Hz from onset and 18 Hz from peak, as compared to 40-59 Hz for ML and HL contours. This may be a way of asserting their highness.

Examination of F0's rate of change between points where F0 was assessed in gliding tonemic couplets revealed that the fastest rate occurred at about the same point in couplets with the same morphological shape and direction of change. Each result here is the point at which the fastest rate of change was observed, expressed as a percentage of the length from V1 onset through V2 core:

	Rising CVCV		Falling CVCV/CV?V			Falling CVV	
	LH	MH	HM	ML	HL	HL	HM
% of duration:	87%	85%	71%	69%	69%	42%	48%

(ML CVV was radically different, falling most rapidly at 6.1% of duration.) Additionally, the fastest rate of change was very similar in couplets of the same contour, despite difference in morphological structure:

	LH		HL		HM		ML	
	CVV	CVCV	CVV	CV?V	CVV	CVCV	CVV	CVCV
Hz/msec:	.27	.28	.41	.39	.07	.08	.16	.20

Investigation into tone on glottalized vowels, most often realized as a sequence of vowel and glottal stop, yielded mixed results. F0 was not obviously affected in the MM CV?V or CV?NV samples examined. However, the glottal feature did seem to raise F0 in five of the seven couplets with falling contours. F0 on two ML (1 CV?V and 1 CV?NV) contours rose 2 and 3 Hz, respectively, over the course of V1, whereas ML CVCVs fall about 9 Hz here. F0 of V1 from one HL CV?V rose 7 Hz, from another 19 Hz, and from a HL CV?NV, F0 of V1 rose 2 Hz. HL CVVs, instead, fall about 7 Hz in their first 50 msec, which is approximately the length of these V1s. The glottal feature may be affecting the F0 of the MM contours examined, but it would be difficult to determine, since MM CVCVs rise only slightly or remain level during V1.

F0 of V2 of the ML CV?V tokens was also affected, falling 22 Hz from 0 to 50 msec, whereas the main corpus samples' F0 fell only about 10 Hz. Again, MM CV?Vs seemed unaffected. Such a great drop in F0 may be attributable to the effects of the glottal stop on the following vowel. This higher-pitched glottal-vowel transition would not be inconsistent with the hypothesis, suggested by Pankratz and Pike (1967:287-288) and expanded by Dürr (1987), that Proto-Mixtec had final glottalized vowels which over time became regular vowels with some phonological effect, now usually a floating H that is inserted on the following couplet.

Duration was also affected in couplets with glottalized vowels. V1s were shorter in CV?Vs than in CVCVs, but V1 end transitions were longer. CV?V V2s were longer, but overall lengths were comparable to CVCVs:

	MM		ML		
	CVCV	CV?V	CVCV	CV?V	
V1	82	55	66	54	msec
V1 end transition	41	59	42	70	msec
V2	165	181	166	214	msec
V1 to end	512	504 (2 of 3)	483	498	msec

Nasalization of vowels was examined in various contexts. Contrastive nasalization (/V/ vs. /Ṽ/) was found not to affect F0, although it lowered the amplitude slightly in two samples, significantly in one. Based on these findings, three tokens of LH CṼṼ were added to the core sample.

Contextual nasalization had various slight effects. An initial nasal stop may lower F0 of V1. In falling contours (HL and ML were examined), this caused the contour either to start lower and fall less from onset to 50 msec (0-2 Hz) or to rise slightly before falling (2-3 Hz). This contrasts with the normal behavior of these contours, where the highest point is at onset, and F0 falls ca. 8 Hz from 0 to 50 msec. Nasals seem to have no other effect on F0, except that medial nasals allow an uninterrupted contour in CVNVs since they can bear tone phonetically. As in English, vowels before medial nasals in ChM are non-contrastively longer. In the core sample, V1s lasted an average 15.1% of the duration from their onset to word's end, with a comparable 16.7% average for the CVCVs in the nasal investigation. Vowels before nasals, however, had an average duration of 26.6%, nearly twice that of vowels before obstruents.

Examination of effects of various initial consonants on following vowels in ML CVVs was hampered by the poor performance of the pitch tracker at C-V transitions. If Hombert's vowel normalization hypothesis is correct, then this is where any effect would be most clearly manifested. Some results did emerge, however. Compare the results of initial nasals above. A palatal glide [y] lowers F0 of a following vowel in a similar manner. Vowel-initial (zero consonant) couplets rise very briefly: an average 4 Hz by 9 msec for 24 msec. By 50 msec, F0 has fallen back to or below the level at 0 msec. Effects of initial obstruents were mostly lost, but in one rare reading, in the transition from C to V, F0 at -21 msec was 6 Hz higher than at 0 msec. This reading would be consistent with findings in other experiments where F0 on vowels after voiceless stops falls from the beginning of the vowel to the center. (Hombert, pp.78-83)

V2 in HH, MM, and LL CVCVs begins with a slight fall. It is difficult to determine with certainty any effects of C2 on V2, as all but three of the concerned couplets have a medial obstruent whose influence the pitch tracker cannot measure. These three tokens were CṼnṼ, and two of the three F0 readings were more level over V2 than for their CVCV counterparts, which presumably shows less disruptive influence of a nasal (than of an obstruent) on the F0 of V2.

It was hypothesized that the M of ML contours was lower than the M of MH contours. But findings in the core sample do not bear this out. ML CVCVs begin slightly higher than MH CVCVs (139.4 vs. 136 Hz), but their curves quickly cross (at ca. 14 msec). MH then has an F0 of 136.8 Hz at 50 msec, as compared to ML's F0 of 130.2 Hz at 66 msec. It may be that the preceding *čāā* in the elicitations influenced the starting point for these couplets. A small investigation of MLs and MHs elicited without such potential influence ended with similar results, however. (ML and MH tokens, *kākà* 'ask' and *bāká* 'cow', were elicited alone, after a couplet of the same type as the token, and before each other.) Alone, the M in ML is higher than the M in MH (140 vs. 135 Hz). This might be due either to the difference in voicing of the initial obstruents, or to attempts by the language to make the tonal contours contrast maximally. Or it may be that the acoustic impressions, which led us to formulate the hypothesis in the first place, are borne out after all. M in ML may be perceived as lower because, for most of its duration (52 of 66 msec in the core sample), it falls and is lower, just as M in MH is higher for 78 msec (of 92 msec). This would be further support for the claim that tone perception depends on more than just the F0 at the endpoints of gliding contours. Other results were that F0 of both V1s was lowest after a MH and highest in the first of two couplets. MLs were significantly lower after a couplet, no matter whether it ends in H or L.

IV. Conclusion

Examined were 71 ChM couplets of both morphological shapes, with all tonemic couplets and vowels possible, to determine average F0 values for H, M, and L tones and their associated tone spaces. A detailed description of each tonal contour was provided for a system analyzed as having three level tones. Phonetic phenomena of interest were noted and discussed. Some evidence was presented that factors other than traditional F0 readings influence tone perception. It is hoped that this study will prove useful in future studies of ChM tone, such as phonetic investigations into polymoraic utterances and rapid speech phenomena, and examinations into the possible influence of phonetics on ChM phonology.

Notes

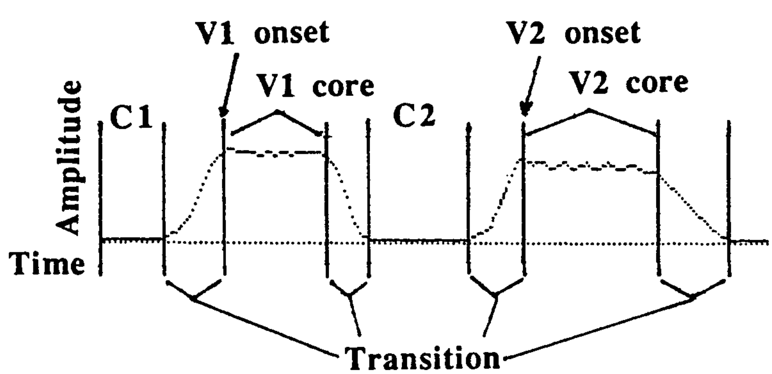
[1]The data for this paper were collected during sessions over AY90-91 with language consultant Luciano Cortés Nicolás, to whom I am very grateful for his knowledge and patience. Many thanks also to Leanne Hinton, Anita Liang, and Laurel Sutton for their helpful comments and suggestions. The usual disclaimers apply.

[2]Some interesting gaps in distribution were made clear from my attempts to locate appropriate tokens. While CVCVs are well represented in most tone patterns, they are virtually absent from HLs, which are either CVV or CVʔV. (The one CVCV token elicited was a word our consultant was not comfortable with.) In the rising contours, CVVs are absent from MH and are restricted in LH, where vowels are either nasal or glottalized. There are very few CVV HLs where one vowel is associated with both morae.

[3]*PLIB* (Phonology Lab In a Box), copyright 1988 by Dr. LST: Software.

[4]Values for amplitude were very inconvenient to access, but I believe such impressionistic descriptions as "respectable" would be borne out if amplitudes were quantified.

[5]The following figure of the amplitude printout for *tātá* 'older man' show the points and stretches of speech signal which terminology in this paper is meant to describe:



"Vowel onset" should be taken to mean the onset of the vowel after transition.

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