Word-level Prosody in Balsas Nahuatl: The Origin, Development, and Acoustic Correlates of Tone in a Stress Accent Language

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Abstract

In this paper we investigate the historical origins and acoustic correlates of tone as it has developed in subdialects of the Guerrero dialect of Nahuatl spoken in the Balsas River valley of central Guerrero state in Mexico. Some subdialects have developed high tone on a syllable preceding a syllable with a breathy-voiced coda [ɦ] (< **h*). In subdialects retaining [ɦ], vowels in syllables with coda [ɦ] have slightly lowered F0. Given this, we hypothesize that, in the tonogenetic Nahuatl variants, the relatively higher F0 on the preceding syllable was phonologized as a high-low F0 contour beginning on the preceding syllable and ending on the syllable containing the coda [ɦ]. Through this tonal development, hybrid stress and tone systems have arisen, as the historical penultimate stress accent found in Nahuatl generally has been retained. Though such systems are rare, a comparison of the development of other such hybrid systems indicates that they follow a similar historical path. That is, a stress languages develops tone through the reinterpretation of a coarticulatory F0 effect as a tonal specification. We suggest that hybrid stress and tone systems may be unstable and found that, in subdialects with innovated tone, stress may be transitioning to tone.

[200 words]

Keywords: Nahuatl, stress, tone, pitch accent, word prosody, tonogenesis, breathy voice

1. Introduction

The word-level prosody in some subdialects of the Guerrero dialect of Nahuatl spoken along the Balsas River has recently undergone a change. In what is a historically fixed stress accent language, tone has developed from the loss of a breathy coda segment. While hybrid tone and stress accent systems are not unattested, they are rare. The rarity of such systems may reflect a phonologically unstable situation or it may simply be that such systems rarely develop in languages. In either case, the Nahuatl varieties investigated here provide us with an opportunity to study the origin and development of a hybrid prosodic system. Acoustic investigation revealed that the innovated tones are encoded solely by F0. The penultimate stress accent, on the other hand, is encoded primarily by spectral amplitude (H1-H2 and H1-A2) and secondarily by duration. However, in subdialects that have developed tone, the penultimate stress accent may be transitioning to tone, as it exhibits less stress-like acoustic qualities (i.e., reduced H1-H2, H1-A2, and/or duration effects). Additionally, the historical stress accents have begun to interact phonologically with the innovated tone in certain environments, indicating that they may form part of the same level of the prosodic system.

1.1. Typological Background on Stress, Tone and Hybrid Systems

Before detailing the current study, we locate our work within the typology of word-prosodic systems and change within those systems. This is no easy task, as various typologies have been proposed for word-level prosody. While not providing an exhaustive treatment, here we consider some of the main types of word-prosodic systems that have been proposed. One primary dividing line among typologies is how the category "accent" is defined and delineated from other prosodic types. One view, proposed by Beckman (1986), is that accentual systems mark syntagmatic contrasts within a word. In other words, accented syllables stand out relative to unaccented syllables. Tonal systems, on the other hand, mark paradigmatic contrasts in which one tone can contrast with another tone in the same domain (e.g. word or morpheme). In Beckman's view, accent may be realized phonetically as either *stress accent* or *non-stress accent*. Stress accent is hypothesized to differ phonetically from non-stress accent by using acoustic correlates other than F0 to a greater extent than non-stress accent. Stress accent may employ duration, amplitude, and vowel quality. Hyman (2006) has recently proposed a different approach to word-level prosodic typology. *Stress accent* is the only accentual type admitted and it is defined by features of metrical prominence. A language with stress accent must meet the word-level metrical criteria of *obligatoriness*, every word must have at least one syllable marked with the highest degree of metrical prominence (primary stress), and *culminativity*, every word must have at most one syllable marked with primary stress (Hyman, 2006:231). The only other category admitted is *tone*, which is defined as an indication of pitch on the lexical realization of at least some morphemes.

Languages like English and Dutch are categorized as stress accent by both of these typologies. Likewise, languages with multiple, lexically contrastive tones, such as Mandarin, are categorized as tone by both typologies. Where they differ is in the categorization of languages that have tonal specifications for only some words or morphemes, especially in the case of a privative (i.e., present or absent) specification on a limited number of syllables in the word. Tokyo Japanese is a classic example of such a language (e.g., Pierrehumbert & Beckman, 1988). Beckman's (1986) typology would classify these cases as accent, due to the syntagmatic nature of the contrast. Hyman's (2006) typology would classify these cases as tone because they violate the criterion of obligatoriness needed for stress accent but conform to the definition of tone by specifying an indication of pitch on the lexical realization of at least some morphemes. These sorts of cases have been the subject of much debate among typologists. Another approach has been to classify such cases as *pitch accent* (e.g., Van der Hulst & Smith, 1988).

As will be illustrated below, some of the varieties of Nahuatl studied here have developed privative specifications for pitch on some words and morphemes. In other words, they have developed the difficult-to-categorize patterns that have variously been termed non-stress accent, tone, or pitch accent. Here, we will refer to these innovations as *tones*, following Hyman (2006), as well as other recent treatments of typologically similar prosodic phenomena (e.g., Gussenhoven, 2004). These varieties of Nahuatl also exhibit the word prosody found in all other extant varieties, which may be uncontroversially termed *stress accent* in either of the typologies reviewed here. As will be presented below, this accentual prominence is obligatorily located on the penultimate syllable of the word and encoded by phonetic properties typical of stress languages (although this accent may be displaced by the innovated tone, as discussed below).

Thus, some of the Nahuatl varieties treated here are analyzed as hybrid systems with both tone (in Hyman's sense) and stress accent. Few such systems have been found. Indeed, as Remijsen and van Heuven (2005) have noted, some earlier views of word prosody disallowed hybrid systems (cf. Clements & Ford, 1979; Haraguchi, 1988). However, languages with independent tone and stress systems have been attested. For example, Pike (1986) described the Athapaskan language, Central Carrier, as having word final stress with three different, word-level, tonal patterns and Clark (1988) analyzed the Bantu language, Zulu, as having four tonal patterns which are independent of stress placement.

More recent studies have offered thorough phonetic investigations of hybrid systems. Everett (1998) described the Amazonian Mura language, Pirahã, as a tone language in which every vowel is specified for one of two tones. In addition, Pirahã has an independent stress accent that is assigned by syllable weight. An acoustic investigation of the stress accent revealed that stressed syllables have greater peak amplitude, as well as a greater duration of the onset consonant. On the other hand, vowel quality and fundamental frequency (F0) were not correlated with stress accent. Remijsen (2002) described the Austronesian language, Ma'ya, as having contrastive stress accent, as well as an independent three-way tonal contrast on final syllables. Stressed vowels were found to have longer duration, less centralization, and relatively more energy in the 1000-1750 Hz range than unstressed syllables, while F0 was a relatively weak correlate to stress. On the other hand, the tonal contrasts were primarily correlated with F0. Remijsen and van Heuven (2005) described Curaçao Papiamentu, a Caribbean Creole, as having contrastive stress that is independent of the tonal specification found on the penultimate syllable in some words. In an innovative design, Remijsen and van Heuven elicited words varying in stress and tone in multiple prosodic contexts; specifically, they controlled position in the utterance (medial and final), and focus condition (narrow focus, default focus, and out of focus). Though not a full factorial design, the manipulation of prosodic condition revealed an F0 specification for tone, regardless of discourse context. On the other hand, F0 was not correlated with stress. F0 specifications on stressed syllables could be attributed to intonational effects such as focus-induced prominence or an utterance-final fall. Stressed syllables were instead correlated with greater duration—the primary cue—greater intensity, and vowels produced in more peripheral locations in the vowel space, regardless of discourse context.

1.2. Development of Tone in Stress Accent Systems

In the current paper, we present an investigation of the origin, as well as a synchronic realization, of a hybrid stress and tone system in two subdialects of Balsas Nahuatl. It is thus of interest to consider the historical development of similar prosodic systems to determine if there is a typical pathway of development. The studies on hybrid systems reviewed in the last section only describe synchronic systems[1]. There are, however, a few studies that provide some discussion of the mechanics of development of tone in stress languages. Graden (1966) describes the Mon-Khmer language Jeh as having stress on the 'main' syllable, which is the final of two syllables or the only syllable in the case of monosyllabic words. At the same time, some words have developed a rising tonal specification on final syllables that have lost a coda /h/. In one dialect, Dak Trap, the tone has a wider distribution and is also found on final syllables in which coda voiceless stops have become nasals. Wayland and Guion (2005) report that the Phnom Penh dialect of Khmer, also a Mon-Khmer language, has developed tonal specifications on some words conditioned by the loss of an onset /r/. Like Jeh, Khmer has one stress per word in monosyllables or disyllables, with the exception of some compounds. The Uto-Aztecan language, Hopi, has also been described as a stress language that has developed tones. Manaster-Ramer (1986) compares modern Hopi to work done in the 1930's and finds that where modern Hopi has a long vowel with high-to-low falling tone, earlier Hopi had a short vowel followed by a either segmental coda /h/ or the pre-aspiration of a stop consonant in the following syllable onset.[2] This development introduced independent tonal specifications on some words, although the historical stress falling on one of the first two syllables is apparently kept.

Given this rather limited set of data, a tentative developmental course can be proposed for stress systems developing into hybrid stress and tone systems. In such cases, tone is acquired through the loss of some segmental phonological contrast that is maintained in the form of an F0 specification on a lexical item. This would seem to require the loss of a phonological entity that has F0 as an acoustic correlate. In other words, a phonological specification that has F0 as a secondary perceptual cue is reinterpreted as a phonological specification for which F0 is the primary cue. Such a proposal is also made here for the Nahuatl subdialects under consideration. Specifically, the loss of coda [ɦ] conditioned the development of a specification for pitch on some lexical items. The effect of breathy voicing on fundamental frequency and its role in the conditioning of tonal innovation will be discussed in the next section.

1.3. Background on Balsas Nahuatl

Nahuatl is the southernmost language of the Uto-Aztecan family, with variants spoken from the northern Mexican state of Durango (where it is known as Mexicanero) to the Cozcatlán province of El Salvador (where it is known as Pipil). To date, the variants of Nahuatl investigated in this paper are the only ones described as having developed tone.

Since classical times, linguistic accounts of Nahuatl have described an "accent" or "stress" on the penultimate syllable in a word as the predominant prosodic pattern (Beller & Beller, 1979; Brewer & Brewer, 1971; Brockway, 1979; Lastra, 1981; Ramírez & Dakin, 1979; Sischo, 1979; Tuggy, 1979).[3] The domain of stress assignment, which can be termed a phonological word, may consist of many morphemes in this agglutinative language. For example, a noun or verb may have several prefixes and suffixes with just one penultimate stress (see (1) and (2) for examples from a non-tonogenetic variety of Nahuatl spoken in Ameyaltepec).

(1) nipi͡tsokoneːˈkoːwkeː͡tɬ

ni-	pi͡tso-	koneː-	koːw	-keː	-͡tɬ
1SG.S	pig	child	buy	AGENT	ABS[4]

'I am a buyer of piglets'

(2) timit͡swaːlpaleːwiːsneˈkiskeh

ti-	mit͡s-	waːl-	paleːwiː	-s	-neki	-skeh
1PL.S	2SG.O	INTRA.DIR	help	FUT.SG	want	FUT.PL

‘We wanted to come help you’

We expect that the stress accent in Nahuatl will be realized by acoustic correlates typically found in stress languages such as duration and amplitude characteristics that are thought to be related to vocal effort (Sluijter & van Heuven, 1996a, 1996b). It is also possible that the stressed syllable will serve as a location for the alignment of intonational pitch accents (see, e.g., Ladd, 1996; Pierrehumbert, 1980). If this is the case, F0 effects may be associated with stressed syllables for some pragmatic functions, such as focus, or some positions within the utterance, such as initial or final position.

Some varieties of Nahuatl along the Balsas River in Guerrero, Mexico, have developed new, lexical tonal specifications conditioned by coda [ɦ], while maintaining the penultimate stress accent. Amith (unpublished ms.) described the phonological patterning of the new tones in the Nahuatl spoken in the village of San Agustín Oapan. He postulated high tones on some, but not all, words and noted that it was possible to have multiple high tones in one word. If these novel high tones are not present in a word, then only a penultimate accent is present. Nahuatl speakers in the village of Ahuelicán, also located along the Balsas River, have developed new tonal specifications as well, though the patterning of the novel tones is somewhat different from that in Oapan. It will be our goal in the current paper to investigate the phonetic properties of the novel tones in these two villages, along with the phonetic properties of the penultimate accents found in these and in neighboring villages (Ameyaltepec and San Miguel Tecuiciapan, see Table 1).

Table 1 approx. here.

Amith (unpublished ms.) has proposed that the novel high tones in Oapan are related to the position of a historical non-word-final coda **h* (which developed into [ɦ] and was then lost in some subdialects). The high tone appears either on the syllable preceding the one with *h or on the same syllable, depending on the location of the *h . In both cases, the historical *h has been lost in Oapan. The Oapan words in (3) and (4) illustrate the development of a high tone on a syllable preceding that with coda *h. The historical forms, marked with '*', are shallow reconstructions of Balsas area Nahuatl based on correspondences with neighboring varieties and informed by evidence from classical Nahuatl. The Oapan words in (5) and (6) illustrate the development of a high tone on a vowel tautosyllabic to coda *h. Amith proposed that the original development was in the syllable preceding coda *h (as in (3) and (4)) and that high tones on syllables with *h (as in (5) and (6)) came about through later developments in Oapan that did not occur in Ahuelicán.

(3) mit͡st͡ɬásoˈt͡ɬaskeh < *mit͡st͡ɬaso**h**ˈt͡ɬaskeh

Ø-	mit͡s-	t͡ɬasoht͡ɬa	-skeh
3PL.S	2SG.O	cherish	FUT.PL

'they will cherish you'

(4) kipóloˈtokeh < *kipolo**h**ˈtokeh

Ø-	ki-	poloh	-tokeh
3PL.S	3SG.O	lose	DUR.PRES.PL

'they are losing it'

(5) mát͡ɬaˈpaɬli <*ma**h**t͡ɬaˈpalli

maht͡ɬapal	-li
(unbent or unjointed) wing	ABS

'wing'

(6) mápilˈt͡siːnt͡ɬi   <*ma**h**pilˈt͡siːnt͡ɬi

mah   -pil   -t͡siːn   -t͡ɬi

hand/arm   child   DIMIN   ABS

‘finger (diminutive)’

The words presented in (3)-(6) have penultimate accents that correspond to those of other varieties of Nahuatl. However, many other words in Oapan no longer have penultimate accents. Amith has proposed that the development of a high tone conditioned by **h* can cause the penultimate accent to shift to the final syllable. The words in (7) and (8) illustrate the change from a penultimate accent to a final accent (compare, especially (4) and (8)). While we write the stress accent with the IPA stress mark and the tone with a high tone symbol, their interaction suggests that they may share some phonological specification. It may be either a metrical process, in which case the interaction may be a type of clash avoidance process (see, e.g., Hayes, 1995) or it may be on a tonal tier, in which case the interaction may be a type of dissimilation process. We will return to this point later on.

(7) t͡ʃíːtaˈt͡ɬi   <*t͡ʃiːˈta**h**t͡ɬi

t͡ʃiːtah   -t͡ɬi

cradle   ABS

‘cradle’

(8) oːtihpóloˈkeh   <*oːtikpoˈlo**h**keh

oː-   ti-   k-   poloh   -keh

COMPL   1PL.S   3SG.O   lose   PERFV.PL

‘we lost it’

A preliminary analysis of the patterning of the novel tones in Ahuelicán, a different subdialect, reveals a more conservative pattern. First, historical **h* has not been lost and a high tone is apparently manifested only on the syllable preceding the one with coda **h*. If there is no preceding syllable, then no tone was conditioned.

Moving back to a consideration of the origin of tone in Oapan and Ahuelicán, let us consider the effects of coda /h/ generally. We propose that the origin of the innovated tones may be in a lowering of F0 in the tautosyllabic vowel. Coda /h/ has been proposed as a conditioning environment for low or falling tone in many languages (Abramson, 2004; Matisoff, Manaster-Ramer, 1986; 1973; Ohala, 1973; Svantesson, 2001). Synthesizing work from several studies, Hombert, Ohala, and Ewan (1979) reported that coda /h/ lowers F0 across the preceding vowel by 25 to 50 Hz and that F0 drops as small as 10 Hz are perceptible to listeners. Recently, Thurgood (2002) has further refined our understanding of the effect of coda /h/ as a trigger for tonogenesis by proposing that coda /h/ can condition a low or falling tone when produced with breathy voicing. That is, a breathy-voiced [ɦ], as opposed to a voiceless [h], lowers F0 and conditions tonal developments. This proposal is supported by the correlation between low F0 and breathy voicing in so-called 'register' distinctions in Southeast Asian languages (see, e.g., Thongkum, 1988). Breathy voicing is also known to be associated with lower F0 than modal voice cross-linguistically (Gordon & Ladefoged, 2001).

In the case of the Nahuatl varieties in question here, we have the opportunity to investigate the conditioning effects of non-word final coda **h* on the development of tone[5]. In Ahuelicán, the coda **h* is preserved and produced with breathy voicing (i.e., as [ɦ]). There is also another village in the vicinity, San Miguel Tecuiciapan, which preserves the coda **h* but has not innovated tone. If, indeed, breathy-voicing has a lowering effect on F0, we should find relatively lower F0 for vowels in syllables with coda [ɦ] in Ahuelicán and San Miguel. We also investigate the Nahuatl of another village in the Balsas River area called Ameyaltepec. This variety has lost coda **h* without innovating tone. Here we do not expect F0 variations to be affected by coda **h*, as no [ɦ] is present to potentially affect F0. Appendix A provides spectrograms and waveforms illustrating the synchronic production of segmentally-matched syllables with and without historical coda **h* for the four villages.[6] These graphs clearly show that the **h* is produced with breathy voicing in the villages where it is preserved. Note that **h* is only found in coda, and not onset position. Table 1 provides a summary of the four varieties of Balsas Nahuatl investigated in the study.

1.4. Overview of Acoustic Studies

In the following sections, two studies are presented that investigate origins and acoustic correlates of tone and stress in Balsas Nahuatl. In the first study, we investigate the proposal that coda [ɦ] conditioned tonogenesis by determining the effect of [ɦ] on F0. We also investigate the F0 patterning of tone and stress. Also, in order to gain a preliminary understanding of intonational uses of F0, words were produced in two phrasal positions. The F0 patterns of stress accents will be compared to the F0 patterns of tones in both phrasal positions. Though there may be some small variations, consistency in overall F0 patterns across phrasal position is expected for tonal specifications. On the other hand, F0 patterns may vary greatly by phrasal position for stress accents.

After gaining an understanding of the F0 patterns in the first study, in the second study, we sought to determine whether there were other acoustic correlates to either stress accent or tone. Previous acoustic studies of hybrid stress and tone systems reported that tone was coded by F0 and stress by other acoustic correlates such as amplitude, duration, or vowel quality, with F0 related to alignment of intonational pitch accents on stressed syllables (Everett, 1998; Remijsen, 2002; Remijsen & van Heuven, 2005). We expect similar findings here, but also predict that the stress accents in Oapan and Ahuelicán may be becoming more tonal, as evidenced by phonological interaction between the innovated tones and the historical stress accents.

2. Study 1—F0 Patterns of Words in Balsas Nahuatl

Here we investigated the production of F0 patterns in words with and without **h* spoken by inhabitants of the four villages presented in Table 1. We hypothesized that the realization of **h* as a breathy [ɦ] in coda position conditioned tonogenesis in Oapan and Ahuelicán through a lowering of the fundamental frequency of the tautosyllabic vowel. The F0 patterns on innovated tones, as well as stress accents, were analyzed. Words were elicited in phrase-medial and phrase-final position in a preliminary attempt at dissociating intonational effects from word-level cues to stress.

2.1. Method

2.1.1. Participants

Twenty-four native speakers of Nahuatl were paid to participate in the study. The speakers had all lived in the Balsas River communities in central Guerrero, Mexico, since birth. All participants were second-language speakers of Spanish and reported normal hearing and no history of language or speech disorders. Six speakers were recorded from each of four villages: San Miguel, Ameyaltepec, Ahuelicán, and Oapan. The participants were 4 women and 2 men with an age range of 45-60 years old in San Miguel, 3 women and 3 men with an age range of 38-66 years old in Ameyaltepec, 4 women and 2 men with an age range of 43-65 years old in Ahuelicán, and 3 women and 3 men with an age range of 28-51 in Oapan.

2.1.2. Materials and Procedure

Table 2 lists the phonetic transcription of the words recorded for this study. The first column presents a shallow reconstruction of the historical forms for Balsas River area Nahuatl. The first section of the table has words with coda **h* in the first of three syllables, the second section of the table has words with **h* in the second of three syllables, and the third section of the table has words with no coda **h*. The tones and stresses are transcribed as heard by the researchers. Note that there are some syllables that have a coda /h/ in dialects that have lost **h* (see fn. 6). However, such a coda /h/ is a secondary development. Take for example, the /h/ in the second syllable of [kókohˈkeːt͡ɬ] ‘wood chopper’ in Oapan which is from **w* in **kʷahˈkʷawkeːt͡l.* In four cases the cognate to an elicitation word was not part of the lexicon of a particular subdialect. In two of these cases, a word with similar segmental content was substituted. In the two other cases a word with similar segmental content was not available and the data are missing.

Table 2 approx. here

All words were recorded in both phrase-medial and phrase-final positions. It was reasoned that if F0 patterns differed by phrasal position, the F0 effects could be attributed to intonational pitch accents related to phrasal position. On the other hand, if the F0 patterns did not differ by position, they could either be attributed to word-level tone or stress, or to an intonational pitch accent present in both phrasal positions. Such a pitch accent may occur with words in pragmatic focus, as is likely to be the case for target words in elicited speech. In preliminary work with the participants, an attempt was made to shift the focus to and from the target word, as has been done in previous studies (e.g., Bruce, 1977; Remijsen & van Heuven, 2005; Sluijter & van Heuven, 1996a, 1996b). However, based on an auditory assessment, there were no apparent intonational cues to focus. Rather, it seems that in Balsas Nahuatl focus is indicated by word order and morphosyntactic marking (e.g., an emphatic pronoun). Further work will be needed to test this observation. In the current study, however, we will be able to compare the patterning of the innovated tones and stress accents by phrasal position. We predict that the tones will show little variation in F0 by phrasal position, but that the stress accents may exhibit such variation.

Phrase-medially, the target words were embedded in the phrase [aːˈmantsiːn ______ nikteːˈneːwas[7]] 'Now ____ I will say'. Phrase-finally, the target words were added to the end of the phrase [aːˈmantsiːn nikteːˈneːwas ______] 'Now I will say ____'. Given the relatively flexible word order of Nahuatl, both of these phrases were judged to be natural by the participants. Note that the words in the carrier phrases contained no coda **h*.

The words under investigation here were recorded as part of a larger list of words, some of which will be investigated in the second study reported in this paper. When recording the large list of words, a group of roughly 20 words was recorded in medial position and then the same group of words was recorded in final position. For this study, 936 productions were analyzed (20 words x 2 phrasal positions x 4 dialects x 6 speakers – 24 missing). The speakers were recorded in a quiet room in a home using a digital recorder (44,100 Hz sampling rate) with a head-mounted microphone (Shure-SM10A). Two or three speakers, all from the same village, were recorded in a single session in the field in the respective villages. Thus, inhabitants of the same village as the speaker were present during the recordings, along with the authors JDA and SGG.

Author JDA, a fluent non-native speaker of Balsas Nahuatl, produced the target word in isolation as a prompt. He attempted to produce the words in the subdialect of the village, when possible. However, he was more familiar with some subdialects than others. The participant then produced the target word in the appropriate carrier phrase. An aural prompt, rather than a written one, was used because most of the participants did not typically write or read in Nahuatl. It seems unlikely that the participants simply mimicked the aural presentation by the researcher for two main reasons. First, participants often produced the words in a different manner than the prompt, including both prosodic and segmental differences. Second, the participants discussed specific features of the experimenter's pronunciation and commented on how they said certain words differently in their village. They then proceeded to produce the words in the manner typical of their village and not simply repeat the model presented by the experimenter. A similar recording technique has been used successfully by other researchers investigating the acoustic correlates to prosody in other less-studied languages (e.g., Martin & Johnson, 2002).

2.1.3. Analysis and Predictions

The F0 of each syllable in the target words was measured. The measurements were made at the temporal midpoint of the vowel in each syllable with the software Praat (Boersma & Weenink, 2005), using the autocorrelation method with recommended settings. It is possible that the long and short vowels could have had different types of F0 patterns, namely long vowels may be able to have more tonal targets than short vowels. An inspection of the F0 tracks, however, indicated that F0 patterns were similar for long and short vowels and that there was no indication of multiple tonal targets on the long or short vowels. See Appendix B for example F0 tracks. The target words were investigated for an effect of coda **h*. Vowels in syllables with [ɦ] were predicted to have a slightly lower F0 than vowels in syllables without [ɦ] in the coda. Additionally, subdialects with innovated tones were expected to show a difference in F0 by word type depending on the placement of coda **h*. Words with tones were expected to show the same overall pattern for both phrasal positions, but words with only stress accents were thought likely to show different patterns by phrasal position.

2.2. Results

The patterns found for the target words by word type (coda **h* in the first syllable, coda **h* in the second syllable, and no **h*) are presented by subdialect. The data from individual speakers were first inspected and compared to other speakers of the same subdialect. Speakers of a given dialect showed consistency in F0 patterning for each word type in each phrasal position. Accordingly, the data has been pooled across the speakers in the analyses reported below.

2.2.1. San Miguel (**h* retained, penultimate stress only)

Figure 1 presents the mean F0 at vowel midpoint for each syllable in the words produced by the San Miguel participants. As this subdialect has not innovated tones and preserves the penultimate stress accent, we only expected to find large F0 excursions on the penultimate syllable, possibly affected by phrasal position. Additionally, the vowels preceding coda [ɦ] (< **h*) were expected to have a slightly lower F0 than vowels in comparable position with no coda [ɦ]. The exact magnitude of the effect cannot be predicted from previous work by other researchers, but given the report of a relative 25-50 Hz drop across vowels followed by /h/ (Hombert, Ohala & Ewan, 1979), we expected that our midpoint measures would result in 5 to 25 Hz lowering effects, as midpoint effects would be smaller than F0 drops across the entire vowel.

In Figure 1(a), the target word was produced phrase-medially and in Figure 1(b), the target word was produced phrase-finally. Note that, overall, the three word types, those with **h* in the first syllable, those with **h* in the second syllable, and those with no **h*, exhibited the same general F0 patterns. In phrase-medial position, the F0 rose across the word and in phrase-final position, the F0 rose to the penultimate syllable and then fell on the final syllable. These results indicate that a high-low pattern beginning on the penultimate syllable is a phrase-final intonational pattern.

Moving on to the effects of [ɦ], as can be seen in Figure 1, vowels with a breathy coda have a relatively lower F0. Consider the words with [ɦ] in the first syllable (filled circles). In these words, the first syllable had a relatively lower F0, regardless of the target word's position as phrase-medial or phrase-final. Likewise, words with [ɦ] in the second syllable (empty circles) had a relatively lower F0 in the second syllable than words with no [ɦ] (filled triangles) but not lower than those with [ɦ] in the first syllable (filled circles). The effect of [ɦ] on F0 in the second syllable was less pronounced than the first syllable, possibly due to an overall F0 depression beginning in the first syllable for words with [ɦ] in the first syllable.

Figure 1 approx. here

The individual vowel midpoint F0 measurements for the San Miguel speakers were submitted to a multivariate analysis of variance (MANOVA) with two factors. The dependent variables were F0 at midpoint for the first, second, and third syllable in the target words and the independent variables were Word Type (**h* in the first syllable, **h* in the second syllable, no **h*) as a between subjects factor and Phrasal Position (medial, final) as a within subjects factor. This design compared the same speakers' productions to each other for each level. Thus, even though male and female speakers were entered together, each level of comparison had similar variance due to the fact that the same speakers were represented in the same proportion in each statistical cell. An alpha level of .05 was used for all statistical tests. Also, here and in all subsequent tests, main effects will not be interpreted directly in the case of significant interactions. In these cases, the interpretation will focus on the interaction. The main effects of Word Type [$F(6,246)=2.78$, $p=.01$, $\eta_p^2=.06$][8] and Phrasal Position [$F(3,122)=103.16$, $p<.001$, $\eta_p^2=.72$] were significant, but the interaction [$F(6,246)=0.30$, $p=.94$] was not significant. The Phrasal Position effect was due to the different F0 patterns in the two phrase types: gradual rising in phrase-medial position and rising-falling in phrase-final position.

The small Word Type effect ($\eta_p^2=.06$) was further investigated with Tukey's pair-wise comparisons ($p<.05$) for each of the syllables (first, second, third) for each of the phrasal positions. In the case of the first syllable of the target words, the syllable with coda [ɦ] had a significantly lower F0 than the other two types in phrase-medial position (198 Hz vs. 204 Hz and 205 Hz, i.e., 3% lower) and lower than the words with no [ɦ] in phrase-final position (172 Hz vs.

180 Hz, i.e., 4% lower). In the case of the second syllable of the target words, the syllable with coda [ɦ] had a significantly lower F0 than words with no [ɦ] in both phrase-medial (205 Hz vs. 217, i.e., 6% lower) Hz and phrase-final position (211 Hz vs. 222 Hz, i.e, 5% lower). There were no significant effects for the final syllable in the target words for either phrase-medial or phrase-final position. These differences, in which the syllable with [ɦ] was approximately 6 to 12 Hz lower (i.e., 3-6%), seem to reflect a local F0 perturbation conditioned by a coda breathy [ɦ].

2.2.2. Ameyaltepec (**h* lost, penultimate stress only)

Figure 2 presents the mean F0 at vowel midpoint for each syllable in the words produced by the Ameyaltepec participants. As this subdialect has not innovated tones and preserves the penultimate stress accent, we only expected to find large F0 excursions on the penultimate syllable, possibly affected by phrasal position. Additionally, as **h* has been lost (i.e., there is no coda [ɦ]), no local lowering effects related to **h* were predicted. Note that the three word types exhibit the same general F0 patterns. In both phrase-medial and phrase-final position, F0 was highest on the penultimate syllable. The fall from the penultimate was greater in the phrase-final position.

As mentioned previously, the Ameyaltepec variety has lost non-word-final coda **h* but does not exhibit innovated tone. The F0 data presented in Figure 2 indicate no residual effect of coda **h* on the F0 patterns. Unlike the data from San Miguel, syllables with a historical **h* did not show a lowering of F0 vis-à-vis other word types.

Figure 2 approx. here

The individual vowel midpoint F0 measurements for the target words for Ameyaltepec speakers were submitted to a MANOVA with the same design as that employed for the San Miguel data. The main effect of Phrasal Position [$F(3,122)=32.67$, $p<.001$, $\eta_p^2=.45$] was significant, but neither Word Type [$F(6,246)=0.99$, $p=.44$] nor the interaction [$F(6,246)=0.60$, $p=.73$] was significant. The Phrasal Position effect was due to the greater fall from the penultimate syllable found in the word final position, as well as the overall lower F0 in phrase-final position.

2.2.3. Ahuelicán (**h* retained, innovated tone)

Figure 3 presents the mean F0 at vowel midpoint for each syllable in the words produced by the Ahuelicán participants. We expected to find large F0 excursions on syllables preceding those with coda [ɦ] (< **h*) due to the tonal innovation in this subdialect. With regard to stress, large F0 excursions were expected on the penultimate syllable in cases with no tonal innovation and on the final syllable in cases where a high tone had been conditioned on the antepenultimate syllable, in which case the stress shifted to the final syllable. These F0 excursions may be affected by phrasal position. Additionally, the vowels preceding coda [ɦ] were expected to have a slightly lower F0 than vowels in comparable position with no coda [ɦ]. Notice that, overall, the word type with **h* in the second syllable displayed a different pattern than the other word types. The first syllable was high, the second low and the final high again. This was the case for both phrase-medial and phrase-final positions. In contrast, the F0 patterns for the other two types (**h* in the first syllable and no **h*) varied by phrasal position. As in the case of San Miguel, the F0 gradually rose across the word phrase-medially and exhibited a high F0 on the penultimate syllable phrase-finally, indicating an intonational phrase-final effect.

Figure 3 approx. here

The individual F0 measurements at the midpoint of the vowel for Ahuelicán speakers were submitted to a MANOVA with the same design as employed previously. The main effects of Word Type [$F(6,214)=25.41$, $p<.001$, $\eta_p^2=.42$] and Phrasal Position [$F(3,106)=91.54$, $p<.001$, $\eta_p^2=.72$] were significant, as was the interaction [$F(6,214)=13.04$, $p<.001$, $\eta_p^2=.27$]. The interaction was due to the differential effect of Phrasal Position on the different levels of Word Type.

The interaction of the Word Type effect with the Phrasal Position effect was further investigated with Tukey's pair-wise comparisons ($p<.05$). The effect of Word Type for each of the syllables (first, second, third) for each of the phrasal positions was tested. First let us consider differences between words with coda [ɦ] in the second syllable (i.e., those with the novel F0 patterns) and the other two word types. In phrase-medial position, the first syllable of words with [ɦ] in the second syllable was also significantly higher than the first syllable of the words of the other two types (205 Hz vs. 167 Hz and 179 Hz, i.e., 15% and 23% higher). Comparing the F0 of the second syllable, words with [ɦ] in the second syllable were significantly lower than the other two word types (153 Hz vs. 202 Hz and 207 Hz, i.e., 24% and 26% lower). In the final syllable, there were no differences between the word types. In the phrase-final position, the first syllable of words with [ɦ] in the second syllable was significantly higher than the other two types (207 Hz vs. 167 Hz and 177 Hz, i.e., 24% and 17% higher). In the second syllable, words with [ɦ] in the second syllable were significantly lower than the other two types (147 Hz vs. 242 Hz and 242 Hz, i.e., 39% lower). In the final syllable, words with [ɦ] in the second syllable were again significantly higher than the other two types (226 Hz vs. 144 Hz and 145 Hz, i.e., 57% and 56% higher). These differences of 38 to 95 Hz (i.e., 15-57%) are much larger than those expected due to a local F0 perturbation conditioned by [ɦ] (i.e., 5-25 Hz). Thus, we suggest that the differences reported here reflect different F0 targets due to different tonal specifications across the words. Words with coda [ɦ] in the second syllable have a high-low-high pattern in both phrase-medial and phrase-final position, whereas words with coda [ɦ] in the first syllable or no [ɦ] have similar global F0 patterns that seem to be determined by phrasal position (but note local effects to be discussed below).

Second, let us consider differences between words with coda [ɦ] in the first syllable vs. words with no [ɦ]. In phrase-medial position, words with [ɦ] in the first syllable had a significantly lower first syllable F0 than words with no [ɦ] (168 Hz vs. 179 Hz, i.e., 6%). There were no differences between the two for the second and third syllables. In the phrase-final position, again, words with [ɦ] in the first syllable had a significantly lower first syllable F0 than words with no [ɦ] (167 Hz vs. 177 Hz, i.e., 6%). There were no differences between the two for the second and third syllables. As in the case of San Miguel, these differences, in which the syllable with [ɦ] is slightly lower (6-12 Hz in San Miguel and 10-11 Hz in Ahuelicán), seem to reflect a local F0 perturbation conditioned by a coda breathy [ɦ]. Thus, it seems that although **h* in the first syllable has slightly lowered the F0 of the tautosyllablic vowel; it has not conditioned a phonological specification for tone. The presence of **h* in the second syllable, however, apparently has conditioned tonal changes.

2.2.4. Oapan (**h* lost, innovated tone)

Inspection of the F0 patterns for the speakers from Oapan consistently revealed two distinct F0 patterns for words with **h* in the first syllable, depending on whether the second syllable had a long or short vowel (compare, e.g., [kíˈkiːsket͡ɬ] and [kókohˈkeːt͡ɬ] in Table 2). Thus, Figure 4 displays four different word types: **h* in first syllable and a long vowel in the second, **h* in the first syllable and a short vowel in the second, **h* in the second syllable, and no **h*. We expected to find large F0 excursions on syllables preceding those with **h*, and on initial syllables with **h* due to the tonal innovation in this subdialect. With regard to stress, large F0 excursions were expected on the penultimate syllable in cases with no tonal innovation or in cases with an innovated high tone on an initial syllable followed by a long vowel in the second syllable. Large F0 excursions were also predicted on the final syllable in cases where a high tone had been conditioned on an initial syllable followed by a short vowel in the second syllable. These F0 excursions may be affected by phrasal position. Additionally, as **h* has been lost (i.e., there is no coda [ɦ] < **h*) no local lowering effects related to **h* were predicted.

There was a complex patterning by word type. First let us consider the words with no historical coda **h* (Figure 4, filled triangles). These words displayed an F0 pattern similar to all the words in Ameyaltepec. There was a high F0 on the penultimate syllable in both phrasal positions, with a greater fall on the final syllable when the target word was in phrase-final position. Second, let us consider the words with coda **h* in the second syllable (open circles) and words with coda **h* in the first syllable and a short vowel in the second syllable (filled circles). Similar to the Ahuelicán words with **h* in the second syllable, these words exhibited a high-low-high pattern. However, in Oapan, the final syllable's F0 rose relatively more when the target word was in the final rather than the medial position. Finally, consider words with coda **h* in the first syllable and a long vowel in the second syllable (open triangles). A pattern unlike those found in any of the other dialects was seen. The first two syllables were relatively high and the third syllable lower. As with the other word types in Oapan, the final syllable has a relatively greater F0 movement away from the penultimate syllable when the target words was in phrase final position.

Figure 4 approx. here

The individual vowel midpoint F0 measurements for the target words for Oapan speakers were submitted to a MANOVA. The dependent variables were F0 at midpoint for the first, second, and third syllable in the target words and the independent variables were Word Type (**h* in the first syllable with a long vowel in the second, **h* in the first syllable with a short vowel in the second, **h* in the second syllable, no **h*) as a between subjects factor and Phrasal Position (medial, final) as a within subjects factor.

The main effects of Word Type [$F(9,351)=15.13$, $p<.001$, $\eta_p^2=.28$] and Phrasal Position [$F(3,115)=5.68$, $p<.001$, $\eta_p^2=.13$] were significant, as was the interaction [$F(9,351)=6.97$, $p<.001$, $\eta_p^2=.15$]. The interaction was apparently due to the greater relative change in F0 from the penultimate syllable to the final syllable in phrase-final position than in phrase-medial position. Even though the overall patterns were similar in both phrasal positions, a more extreme F0 movement was found for the final syllable (either higher or lower F0) in the phrase-final position.

The interaction of the Word Type effect with the Phrasal Position effect was further investigated with Tukey's pair-wise comparisons ($p<.05$) for each of the syllables (first, second, third) for each of the phrasal positions. In the case of the first syllable in the target words, word types with **h* in the first or second syllable had higher F0 values than the words with no coda **h* (approx. 12% higher on average). As for the second syllable in the target words, the words with **h* in the coda of the second syllable, as well as words with **h* in the first syllable followed by a short vowel in the second syllable, had a lower F0 than the other two types for both phrasal positions (approx. 11% lower on average). Finally, for the third syllable, the effects varied by phrasal position. There were no significant differences between the groups for phrase-medial position. In phrase-final position, however, the words with **h* in the coda of the second syllable as well as words with **h* in the first syllable followed by a short vowel in the second syllable had a higher F0 than the other two types. Thus, all word types showed similar patterning in phrase-medial and -final position, with the final syllable showing more extreme movement from the penultimate in phrase-final position.

Words with *h in the second syllable are similar to the cognate words in Ahuelicán in that they have a high-low-high pattern. The patterning of these words in both these Nahuatl subdialects suggests that coda *h has conditioned a tonal pattern in which the preceding syllable has a high F0 and the tautosyllabic syllable has a low F0. The two dialects differ, however, in the production of words with *h in the first syllable. In Ahuelicán words with *h in the first syllable and words with no *h displayed similar F0 patterns (although the slight pitch depressing effect of *h in the first syllable is clearly manifested): F0 rose across the word in phrase-medial position and had a low-high-low pattern when the word was in phrase-final position. In Oapan, however, words with *h in the first syllable were different from words with no *h. In other words, the loss of *h in the first syllable has had an effect on F0 production in these words. In cases where the second syllable had a short vowel, the pattern was the same as that found in words with coda *h in the second syllable: specifically a high-low-high pattern across the three syllables of the word. In cases where the following second syllable had a long vowel, a high-high-low pattern was found. In neither of these cases can we attribute the high F0 of the first syllable to an effect of [ɦ] (<*h). In the following discussion section, an explanation for the high F0 on these syllables will be proposed.

2.3. Discussion

The investigation of the F0 patterns revealed different behaviors for innovated tonal patterns related to coda *h from those related to the historical penultimate stress accent: F0 patterns varied by phrasal position for stress accent but not for tone. High F0 was found on the preceding or same syllable as the *h in both phrase-medial and -final positions. Consistent with our proposal, this finding indicates that a high tone is part of the lexical specification of these words: it is consistently found, regardless of prosodic environment. The penultimate accent, on the other hand, varied in F0 pattern by phrasal location in some subdialects. In San Miguel and Ahuelicán, high F0 for the penultimate syllable was found only in phrase-final position. We suggest this is due to an intonational pitch accent associated with the final stressed syllable of the phrase, in this case the penultimate syllable. In Oapan and Ameyaltepec, the high F0 on the penultimate syllable of the target words was found in both phrasal positions. This may reflect an intonational pitch accent aligned with the stressed syllable on a focused word in both phrasal positions, as the target words represented new information in the same, repeated carrier phrase. Alternatively, it may be that F0 is part of the implementation of stress in these subdialects, irrespective of discourse prominence.

Further work using a methodology similar to Remijsen and van Heuven (2005), in which phrasal position and focus are orthogonally varied, would be needed to more thoroughly investigate the relationship of F0 to penultimate stress accent. For the time being, however, we may note differences in F0 related to phrasal position for stress accent but not for tone. In the next section, the acoustic correlates to the penultimate stress and the innovated tones will be further examined.

Now let us turn to a discussion of tonogenesis and the effect of **h*. Ameyaltepec has lost coda **h*, seemingly without any effect on the prosodic system. In the village of San Miguel, which has not innovated tones, non-word-final coda **h* is preserved as [ɦ]. Here, vowels in syllables with coda [ɦ] had a 6-12 Hz lower F0 value (i.e., 3-5%) than matched syllables with no coda [ɦ]. This suggests that the slight lowering effect of coda [ɦ] on F0 may be the origin of the tonal developments in Oapan and Ahuelicán. We propose that this effect of coda [ɦ] on F0 was reinterpreted as lexically-specified tone and enhanced into a high tonal specification on the preceding syllable in Oapan and Ahuelicán.

Coda /h/ has been documented as conditioning a low or falling tone in a variety of languages (Matisoff 1973; Ohala 1973; Svantesson 2001) and Thurgood (2002) has proposed that, specifically, a breathy laryngeal is indicated in these sorts of sound changes. The results reported here lend support to the proposal that a coda [ɦ] can condition a slightly lowered F0 on the tautosyllabic vowel that may be the origin of falling F0 contours. Note, however, that in San Miguel, there were no major effects of **h* on the prosodic system. Thus, it seems that this subdialect offers insight into the original conditioning environment of the tonal developments attested in other varieties of Balsas Nahuatl.

Providing more evidence for our proposed course of development, the village of Ahuelicán still has [ɦ] as a reflex of **h*, along with innovated tones. When there was a syllable preceding a syllable with a coda [ɦ], a high-low patterning was found across the two syllables. In this case, the syllable with coda [ɦ] was roughly 25-50% lower, and the preceding syllable roughly 15-24% higher than comparable syllables with no coda [ɦ]. However, when there was no preceding syllable, the syllable with coda [ɦ] had only a slight reduction in F0 (roughly 10Hz or 6%). Thus, in Ahuelicán, there is evidence for both the original locus of the innovated tones, as well as the segmental preconditioning of the tonogenesis.

In the village of Oapan, **h* has been lost and the tonal system has undergone developments beyond those found in Ahuelicán. First, as in Ahuelicán, when a syllable with a historical **h* was preceded within a root or stem by another syllable, a high-low patterning was evidenced across these two syllables. We suggest that Oapan went through a stage when **h* was pronounced as breathy voiced [ɦ], which conditioned a slight lowering of the F0 of the tautosyllabic vowel due to the effects of breathy phonation. The preceding syllable, which would most likely not have been affected by the breathy voicing, would have had a relatively higher F0. This relatively higher F0 was then reinterpreted as a high F0 target yielding the high-low pattern that we have documented (see e.g., the first two syllables of the word in (9) and note that the penultimate stress accent has shifted to the final syllable)[9].

(9) t͡ɬáso'ti < *t͡ɬa'so**h**ti (cf. Ahuelicán t͡ɬásoɦ'ti)

Ø-	t͡ɬasohti	-Ø
3SG.S	be.dear	PRES.SG

‘it is dear (or scarce)’

This high-low pattern is also found in both Ahuelicán and Oapan when a root- or stem-initial syllable has **h* in the coda and there is a prefix. Consider the word in (10) with the initial prefix *no-* ‘my’.

(10) nókʷeˈton < *noˈkʷe**h**ton (cf. Ahuelicán nókweɦˈton)

no-	kʷehton	-Ø
1SG.POSSR	pillow	ALIEN.POSSD.SG

‘my pillow’

However, these two subdialects diverge in cases where the root- or stem-initial syllable has coda **h* but no preceding syllable. In these cases Oapan Nahuatl manifests a further, and what we consider subsequent, development that is absent in Ahuelicán. Specifically, there is a high tone on these initial syllables (11). Note that this prosodic pattern cannot be directly explained by the F0-lowering hypothesis of breathy-voiced [ɦ].

(11) kʷétoˈmat͡ɬ < *kʷe**h**ˈtomat͡ɬ (cf. Ahuelicán kweɦˈtomat͡ɬ)

kʷehtoma	-t͡ɬ
pillow	ABS

‘pillow’

This suggests a stage beyond that found synchronically in Ahuelicán in which tone is tied to the location of coda [ɦ]. In Oapan, when coda [ɦ] was lost, the high-low tonal pattern may have come to be associated with the root itself. By this analysis, the high-low pattern would be produced on the root when the first syllable of an unprefixed root ended with a coda **h* (as seen with [kʷétoˈmat͡ɬ] in (11)). Consider also the forms in (12) and (13). The verbal root *t͡ɬa**h**palowa ‘to greet’ has Oapan forms in which a high tone is found on the first syllable of the root, *even when* there is a prefix, as in (12). With prefixes having a long vowel, however, the high tone is found on the preceding syllable, as in (13).

12) kit͡ɬápaˈlowa < *kit͡ɬa**h**paˈlowa

Ø-	ki-	t͡ɬahpalowa	-Ø
3SG.S	3SG.O	greet	PRES.SG

‘s/he greets him/her’

13) né:ʃt͡ɬapaˈlowa < *ne:t͡ʃt͡ɬahpaˈlowa

Ø-	ne:t͡ʃ-	t͡ɬahpalowa	-Ø
3SG.S	1SG.O	greet	PRES.SG

's/he greets me'

Thus, we hypothesize a second stage unique to Oapan. Once the coda *h* was lost, the innovated high tone was no longer tied to the syllable preceding the syllable with coda *h*; it may also be located on the syllable with coda *h*. This proposed set of events may be an example of the development of autosegmental, tonal patterning in a language, as tones come to be associated with roots rather than the conditioning environment. Oapan has further developed in this regard and now has some morphological uses of tone (e.g., speakers in Oapan use a high tone for some meanings encoded by a reduplicant in other Balsas subdialects).

Now let us consider the second high in the high-low-high patterning found in Ahuelicán and Oapan for words with *h* in the second syllable. Two likely possibilities present themselves as to the origin of this second high. First is the proposal that the following high is a dissimilatory high, similar to the high preceding the syllable with *h*, in that it arose in contrast to the low F0 of the syllable with coda *h*. Another possibility, the one we support here, is that the following high is a reflex of the penultimate accent that has been displaced to the final syllable. Words with more than three syllables are needed to disambiguate these two possibilities. Amith (unpublished ms.) proposes the second analysis and provides some example data to support this view.

Consider for example, the word in (14). The first two syllables have a high-low pattern. However, there is no other high on the syllable immediately following the low on the second syllable. The next prominence is found on the penultimate syllable and does not seem to be related to the *h*. Instead, this would seem to be the penultimate stress accent found throughout Nahuatl dialects. Contrast this to the accentual pattern in (15). Here there are two high-low tonal patterns related to the placement of *h*. We suggest stress accent in (15) is from the historical penultimate accent that has been moved to the final syllable in a shift process so that a stress accent does not immediately follow a high tone.

14) né:ʃtete:ˈmowa < *ne:t͡ʃte**h**te:ˈmowa

Ø-	ne:t͡ʃ	teh-	te:mowa	-Ø
3SG.S	1SG.O	RDP.S/h	look.for	PRES.SG

‘s/he looks for me’

15) o:né:ʃteté:moˈkeh < *o:ne:t͡ʃte**h**te:ˈmo**h**keh

o:-	Ø-	ne:t͡ʃ-	teh-	te:moh	-keh
COMPL	3PL.S	1SG.O	RDP.S/h	look.for	-PERFV.PL

‘they looked for me’

The tonal patterning of words with **h* in the first syllable in Oapan may also be related to this analysis. Recall that words of this type with a short vowel in the second syllable had a high-low-high pattern but that words of this type with a long vowel in the second syllable had a high-high-low pattern (see Figure 4). The historical penultimate accent may be retained on the long penultimate syllable even though, in so doing, the low of the high-low pattern is not produced (see Appendix B). However, in the words with a short vowel, the historical penultimate accent is shifted to the following syllable. This suggests a weight or moraic factor is involved with the stress shift phenomenon.

In investigating the prosodic patterns of Balsas Nahuatl so far, we have focused on F0. However, we have hypothesized that the stress accents will be correlated with other types of acoustic cues, such as duration and spectral amplitude characteristics. We also hypothesized that the innovated tones will be exclusively correlated with F0. Yet given the phonological interaction between the innovated tones and the penultimate accents in Oapan, we also want to investigate the possibility that the historical stress accents are becoming tonal, in a shift to a tone language from a stress accent language, through a hybrid system.

3. Study 2—Acoustic Correlates to Tone and Stress in Balsas Nahuatl

In this section, we present an investigation of the acoustic correlates to stress and tone in four subdialects of Balsas Nahuatl. The focus here is on the production of the vowel in (1) the penultimate syllable preserving the historical penultimate stress accent in all subdialects and (2) the syllable preceding a syllable with **h* in the subdialects with innovated tones (Oapan and Ahuelicán). These syllable types were selected because stress accents can be found on penultimate syllables in all subdialects and on syllables preceding **h* in all the tonal subdialects, allowing for the examination of common syllable types across the subdialects. The vowels in these syllable types were compared to vowels in matched, unstressed syllables in order to compare vowels with high tone or stress to vowels unaffected by **h* and stress.

Three potential correlates to stress and tone were investigated here: fundamental frequency, vowel duration, and spectral amplitude measures. Stress accent in well-studied languages such as English and Dutch has been related to perceived loudness for quite some time (e.g., Fry 1955). More recently, Sluijter and van Heuven (1996a, 1996b, 1997) have argued that perceived loudness is related to the distribution of intensity across the spectrum, such that relatively greater energy in the higher frequencies is subjectively perceived as louder than relatively weaker energy in the higher frequencies. This relatively flatter spectrum is therefore a correlate of stress in English and Dutch and is thought to be related to greater vocal effort or more tense voice quality in stressed syllables (Sluijter and van Heuven, 1996a, 1996b; but see Campbell & Beckman 1997, who suggest variation by level in the stress hierarchy). In contrast, the primary acoustic correlate to tone (in Hyman’s sense) is F0 (Beckman, 1986; Gussenhoven, 2004; Hyman, 2006), although, to our knowledge, spectral balance correlates have not been investigated in tonal languages.

3.1. Method

3.1.1. Participants

The same 24 native speakers of Nahuatl, 6 each from four villages, who participated in Study 1 also participated in this study.

3.1.2. Materials and Procedure

Tables 3 and 4 provide a phonetic transcription of the words recorded for this study. The vowel that was measured for the analysis is underlined in these tables. Table 3 lists the words recorded to investigate the production of penultimate stress. Words for which the stressed penultimate vowel was measured are listed in the upper part of Table 3. The lower part of Table 3 lists the words containing the matched, unstressed vowels. For example, the first word ‘my spindle whorl wheel’, pronounced as [nomalaˈka̲teç] in Oapan, was paired with ‘meat (dim.)’ [naka̲ˈt͡siːntɬi]. In two cases, Ahuelicán did not have a cognate word and thus, there were two less word pairs for this dialect. Table 4 lists the words recorded to investigate the production of the high tone in syllables preceding a syllable with a coda **h*. The varieties of Balsas Nahuatl spoken in the villages of Ahuelicán and Oapan are the only ones to have such tones. The upper part of Table 4 lists the words with high tone derived from coda **h* in the following syllable and the lower part lists the words containing the matched, unstressed syllables without high tone. For example, ‘sweet potato’ is pronounced as [ká̲moɦˈt͡ɬi] in Ahuelicán. The underlined, target [a] was paired with the underlined [a] in [ka̲ˈmakt͡ɬi] ‘mouth’.

Tables 3 and 4 approx. here

The vowels used for comparison were selected with a set of criteria designed to minimize confounding effects on the measures. First, as in the case of the target syllables, only the open vowel [a] was used. This was to control effects of spectral resonances on the amplitude of the harmonics and to control variation in vowel length and F0 due to vowel height. Second, all vowels were in open syllables.[10] This was to control variation in duration due to syllable structure. Third, to the extent possible, we controlled the voicing of the onset consonant. This was to control for microprosodic effects of onset consonant voicing on F0. For the stress comparisons, there are even numbers of voiced and voiceless onsets in the two conditions. In the high tone comparisons, there is an imbalance by one word. Fourth, final syllables were not used in any of the comparisons. This was to control for durational effects caused by word final lengthening and other potential confounds of word boundary such as change in voice quality or

F0. Fifth, the comparison vowels were matched with stressed or high tone vowels in terms of position within the word: medial vowels were matched with medial vowels and initial vowels were matched with initial vowels. This was to control for any possible durational effects related to position within the word. While polysyllabic shortening (Lehiste, 1972)—whereby vowels are shortened to a greater extent in longer words—may be at play in Nahuatl, the length of the words in the two comparison groups was comparable, and all target vowels were in pre-stress position, which is known from studies in other languages to be less affected by shortening than post-stress position (Lindbloom & Rapp, 1973; Nooteboom, 1972). Sixth, none of the matched vowels had a high tone or were stressed (including the stress relocated to the final syllable), nor was there a **h* in any of these words. This was to compare vowels with high tone or stress to vowels unaffected by **h* or stress. We know of no other potentially confounding effects to our measures.

The target words were recorded in both phrase-medial and phrase-final position. The nouns were said in the same sentence frame used in Study 1. However, verbs were not accepted in this sentence frame by the speakers. Rather, verbs in the future tense were produced in the sentence frames [ˈmoːst͡ɬa ____ saˈniman] ‘tomorrow ___ early’ and [ˈmoːst͡ɬa saˈniman ____] ‘tomorrow early ___’ and those in the past tense were uttered in the sentence frames [ˈjaːɬwa ____ saˈniman] ‘yesterday ___ early’ and [ˈjaːɬwa saˈniman ____] ‘yesterday early ___’. The same recording procedure was used for the words in this study as that used in Study 1. For this study, 1248 productions were analyzed: 912 for the penultimate accent (20 words x 2 phrasal positions x 4 dialects x 6 speakers – 48 missing) and 336 for the innovated tone (14 words x 2 phrasal positions x 2 dialects x 6 speakers).

3.1.3. Analysis

The sound files were downsampled to 22,050 Hz to facilitate the FFT spectral analysis performed for the amplitude measures.

3.1.3.1. Duration Measure

The duration of the target vowels was measured to determine whether there were systematic differences in duration related to stress or tone. The measures were made using waveform and spectrographic displays in Praat. The duration of the vowel was measured from the onset of the first full glottal pulse to the offset of the last full glottal pulse corresponding with the end of visible energy or a marked change in frequency of the second formant in the spectrogram.

3.1.3.2. Fundamental Frequency Measure

Fundamental Frequency (F0) was measured at the temporal midpoint of the vowel using a Praat script with the autocorrelation method with recommended settings. Through auditory assessment and visual inspection of the waveform for irregularities, creaky-voiced tokens were identified and the F0 measurements for those tokens were eliminated from the data for later analysis. Twenty-one tokens (roughly 1% of the data) were eliminated by this procedure. Two tokens were eliminated for the high tone vowels and one for their matched counterparts. Ten tokens were eliminated for the stressed vowels and eight for their matched counterparts.

3.1.3.3. Spectral Balance Measures

The spectral balance measures estimate differences between the amplitude of the first and second harmonic (H1-H2) and the amplitude of the first harmonic and the second formant (H1-A2). The H1-A2 measure gives an estimate of the overall spectral slope from the low to mid-range frequencies. It is though that with increased vocal effort the harmonic amplitudes in the mid- to high-frequency range (over 500 Hz) increase more than those in the lower part of the spectrum. This is due to the more rapid closure of the glottis during phonation under conditions of increased vocal effort, which produces a change in spectral tilt (Gauffin & Sundberg, 1989; Glave & Rietveld, 1975; Liénard & Di Benedetto, 1999). The H1-H2 measure provides an estimate of the open quotient, or the ratio of the time that the vocal folds are open to the complete duration of the glottal cycle: the greater the open quotient, the greater the H1-H2 difference (Hanson, 2001; Stevens & Hanson, 1995). Additionally, the open quotient has been found to be negatively correlated with vocal effort (Holmberg, Hillman, Perkell, Guiod, & Goldman, 1995). Thus, greater vocal effort is thought to be correlated with smaller H1-A2 and H1-H2 differences.

The amplitude of the source harmonics, as well as the amplitude and bandwidths of vocal tract resonances, varies as a function of formant frequencies (Fant, 1960). Thus, vowels with essentially the same formant frequencies must be compared, or normalizing procedures must be used (e.g. Hanson, 1997, 1999) for spectral amplitude measures. For this reason, the formant frequencies of the matched accented and unaccented vowels will be compared prior to the analysis of the H1-H2 and H1-A2 measures analyzed in this study.

Using software by Scicon Research and Development, PCQuirer, both narrow band FFT and LPC (26 coefficients) spectra were calculated and plotted in a single spectral window. A Hamming window was centered at the temporal midpoint of the vowel to calculate a narrow-band FFT spectrum (1024 point, 21 Hz). The amplitude, in decibels, of the first and second harmonics was measured by hand with a cursor on a time-expanded screen. The location of the first harmonic in the frequency range was verified against the F0 measurement to guard against spurious harmonic resolutions, as the FFT spectrum would sometimes resolve a peak below the H1 for voices with high fundamental frequencies. The amplitude of the second formant was measured as the most prominent harmonic from the narrowband FFT spectrum that was found to be clearly within the second formant band defined by the LPC tracing. These measures only approximate the amplitude of the second formant, as the most prominent harmonic may or may not be at the central frequency of the resonance.

3.1.3.4. First and Second Formant Frequency Measures

Before proceeding with the analysis of the spectral balance measures, we report the formant frequency comparisons for the matched vowels of each group.

The first and second formant frequencies (F1 and F2) were measured at the temporal midpoint of the vowel using a Praat script. LPC analysis was used to determine the formant frequencies. The LPC analysis was obtained using the values recommended by the authors of Praat: 5 formants (10 coefficients) and 25 ms Gaussian window, and pre-emphasis from 50 Hz. The analysis range was set at 5500 for female and 5000 for male speakers to approximate the relative difference in format spacing between genders. The LPC tracks were superimposed on a broadband spectrogram calculated from 0 to 5000 Hz with a 5 ms (260 Hz) Gaussian window.

The F1 and F2 measurements were automatically recorded at the vowel's temporal midpoint. These measurements were verified by visual inspection of the spectrogram. Knowledge of the typical formant structure for an [a] vowel, as well as of the [a] vowel for a given speaker, were employed and spurious formant measures were discarded. The LPC formant tracking values that corresponded to visible formants on the spectrogram were recorded to replace the spurious values.

The individual data points for each speaker for the F1 and F2 measures were submitted to separate repeated measures ANOVAs with the factors of Phrasal Type (medial and final) and Stress (stressed and unstressed) or Tone (high tone and no tone). An alpha level of .05 was used for all tests. The results indicated that F1 and F2 did not vary by phrasal position. The main effect of Phrasal Type and the interaction of Stress or Tone and Phrasal Type were not significant for any of the F1 or F2 comparisons [F-values ranged from > 0.01 to 3.43].

F1 and F2 were also unaffected by stress accent. There was no significant effect on F1 for San Miguel [stressed mean 695 Hz vs. unstressed mean 680 Hz, $F(1,59)=1.78$, $p=.19$], Ameyaltepec [662 Hz vs. 649 Hz, $F(1,59)=1.89$, $p=.17$], Ahuelicán [711 Hz vs. 688 Hz, $F(1,46)=1.83$, $p=.18$], or Oapan [621 Hz vs. 643 Hz, $F(1,57)=1.89$, $p=.17$]. Neither was the effect of Stress on F2 significant for San Miguel [accented mean 1669 Hz vs. unaccented mean 1647 Hz, $F(1,59)=0.94$, $p=.34$], Ameyaltepec [1603 Hz vs. 1584 Hz, $F(1,59)=2.08$, $p=.15$], Ahuelicán [1589 Hz vs. 1558 Hz, $F(1,46)=3.11$, $p=.08$], or Oapan [1568 Hz vs. 1547 Hz, $F(1,57)=1.69$, $p=.20$].

Likewise, F1 and F2 were unaffected by the presence or absence of high tone. There was no significant effect on F1 for either of the tonogenetic villages: Oapan [high tone mean 658 Hz vs. no tone mean 665 Hz, $F(1,40)=0.27$, $p=.60$] or Ahuelicán [710 Hz vs. 728 Hz, $F(1,41)=3.20$, $p=.08$]. Neither was the effect of Tone on F2 significant for Oapan [high tone mean 1486 Hz vs. no tone mean 1495 Hz, $F(1,40)=0.21$, $p=.65$] or Ahuelicán [1537 Hz vs. 1498 Hz, $F(1,41)=3.06$, $p=.09$].

Given the finding that formant frequencies were not significantly affected by either stress or tone, the analysis of the H1-H2 and H1-A2 measures will precede without normalization in the sections below.

3.2. Results

The results for the comparisons are presented by subdialect. In San Miguel and Ameyaltepec, stressed vowels were compared to vowels in matched, unstressed syllables (see Table 3). In Ahuelicán and Oapan, the stress comparisons were made, as well as comparisons of vowels with high tone followed by coda **h* to vowels in matched syllables (see Table 4). For the stress comparisons, acoustic correlates potentially associated with stress accent (duration, H1-H2, and H1-A2) were expected to be constant across the phrasal conditions, if found. F0 differences on the other hand, were thought likely to vary by phrasal position, as they may be indicative of intonational pitch accents (cf. results from Study 1). For the tonal comparisons, F0 differences between high-toned and matched syllables were the only expected effects. The other measures (duration, H1-H2, and H1-A2) were not expected to vary by tonal specification. Additionally, the F0 effects were expected to be found in all phrasal conditions, as the tones are thought to be word-level specifications.

The data from individual speakers were first inspected and compared to other speakers of the same subdialect. Speakers of a given dialect showed consistency in F0 patterning for each word type in each phrasal position. Accordingly, the data has been pooled across the speakers in the analyses reported below.

3.2.1. San Miguel (**h* retained, penultimate stress only)

Figure 5 presents the results for San Miguel speakers comparing penultimate stressed vowels to unstressed vowels. Note that the F0 of stressed vowels was higher than that of unstressed vowels in both phrasal positions (5a). Also, the duration of stressed vowels was longer than that of unstressed vowels in final position (5b). The spectral balance measurements differed in both phrasal positions. The stressed vowels had smaller H1-H2 and H1-A2 differences than the unstressed vowels, indicating a relatively smaller open quotient during phonation and a flatter spectral slope, both of which are thought to be indicative of greater vocal effort (5c-d).

Figure 5 approx. here

The individual data points for each speaker were submitted to separate repeated measures ANOVAs for each of the four measures with the within subject factors of Phrasal Type (medial and final) and Stress (stressed and unstressed). All factors were repeated measures for which a given speaker's productions were compared with their own productions across the conditions. Thus, even though both male and female speakers were in each group, the variance in the cells to be compared was similar, as they contained productions from the same speakers. An alpha level of .05 was used for all tests. For the measure of F0, the accented vowels had a higher F0 than the unaccented vowels in both phrasal conditions, but the effect was stronger for the final than the medial position. The effect of Stress was significant [$F(1,54)=94.75$, $p<.001$, $\eta_p^2=.64$] and it interacted with Phrasal Type [$F(1,54)=19.76$, $p<.001$, $\eta_p^2=.27$]. The main effect of Phrasal Type was not significant [$F(1,54)=0.77$, $p=.38$]. In order to investigate the interaction, two repeated measures ANOVAs tested the effect of Stress on each phrasal position separately (alpha level adjusted to .025 for two comparisons). The analyses returned a significant effect for both positions [medial: $F(1,57)=25.57$, $p<.001$, $\eta_p^2=.31$, final: $F(1,56)=123.34$, $p<.001$, $\eta_p^2=.67$].

For the measure of duration, stressed vowels tend to have longer durations than matched, unstressed vowels in phrase-final position. Also, there is a marginal trend for vowels to be longer overall in phrase-final position. The effect of Stress was significant [$F(1,59)=10.82$, $p=.002$, $\eta_p^2=.16$] and it interacted with Phrasal Type [$F(1,59)=5.41$, $p=.02$, $\eta_p^2=.08$]. The main effect of Phrasal Type was marginally significant [$F(1,59)=3.97$, $p=.051$]. The effect of Stress was significant for the final position [$F(1,59)=18.08$, $p<.001$, $\eta_p^2=.24$], but not the medial position [$F(1,59)=1.81$, $p=.18$].

For both the H1-H2 and the H1-A2 measures, San Miguel speakers had smaller values for the stressed than unstressed vowels. Additionally, the H1-A2 measure tended to increase in phrase final position. The main effect of Stress was significant [$F(1,54)=28.38$, $p<.001$, $\eta_p^2=.34$ and $F(1,54)=47.32$, $p<.001$, $\eta_p^2=.47$]. There was also a main effect of Phrasal Type for the H1-A2 measure [$F(1,54)=6.63$, $p=.013$, $\eta_p^2=.11$]. No other main effects or interactions were significant for these measures [F-values ranged from 0.01 to 2.86].

3.2.2. Ameyaltepec (**h* lost, penultimate stress only)

Figure 6 presents the results for Ameyaltepec speakers comparing penultimate stressed vowels to matched, unstressed vowels. As was the case for San Miguel speakers, the F0 of stressed vowels was higher than that of unstressed vowels in both phrasal positions (6a). Additionally, the duration of stressed vowels was longer in phrase-final position than that of unstressed vowels (6b). Finally, the stressed vowels had smaller H1-H2 and H1-A2 differences than the unstressed vowels in both phrasal positions (6c-d).

Figure 6 approx. here

Each of the four measures was submitted to a repeated measures ANOVA with the factors of Phrasal Type and Stress. For all four measures, the effect of Stress was significant. The F0 was significantly higher in accented syllables [$F(1,52)=26.46$, $p<.001$, $\eta_p^2=.34$], the duration was significantly longer [$F(1,59)=21.82$, $p<.001$, $\eta_p^2=.27$], the H1-H2 was significantly smaller [$F(1,52)=19.40$, $p<.001$, $\eta_p^2=.27$], and the H1-A2 was significantly smaller [$F(1,52)=9.90$, $p=.003$, $\eta_p^2=.16$]. Only one interaction was significant: Stress and Phrase Type interacted for the measure of duration [$F(1,59)=14.97$, $p<.001$, $\eta_p^2=.20$]. Two separate repeated measures ANOVAs found that the effect of Stress on duration was significant (alpha level adjusted to .025 for two comparisons) for phrase-final position [$F(1,59)=30.75$, $p<.001$, $\eta_p^2=.34$], but not for phrase-medial position [$F(1,59)=4.97$, $p=.03$, $\eta_p^2=.08$]. No other interactions or main effects were significant [*F*-values ranged from 0.38 to 2.86]. These results indicate that vowels with a penultimate stress have higher F0 and are produced with more vocal effort than unaccented vowels in both phrasal positions. Duration, on the other hand, was only a significant correlate of stress in phrase-final position.

3.2.3. Ahuelicán (**h* retained, innovated tone)

Figure 7 presents the results for Ahuelicán speakers comparing penultimate stressed vowels to unstressed vowels and Figure 8 presents the results for the same group of speakers comparing vowels with a high tone to vowels with no tone. The stressed vowels have a higher F0 than unstressed vowels, especially in phrase-final position (7a). Duration and H1-H2 measures seem to be roughly the same for the stressed and unstressed vowels (7b-c). However, stressed vowels have a smaller H1-A2 difference (7d), indicating a flatter spectral slope without a change in open quotient. In Figure 8, F0 was the only measure found to differentiate vowels with high tone from vowels with no tone. Furthermore, F0 differences were found in both phrase-medial and phrase-final positions (8a). The other three measures were not correlated with tone (8b-d).

Figures 7 and 8 approx. here

Separate analyses were conducted for the stress and tone data for each of the four measures. Considering the stress analysis first, vowels with penultimate stress in Ahuelicán have a higher F0 and a flatter spectral slope than unaccented vowels, with the F0 effect being greater phrase-finally. The effect of Stress was significant for the F0 [$F(1,44)=53.43$, $p<.001$, $\eta_p^2=.55$] and H1-A2 [$F(1,44)=8.62$, $p=.005$, $\eta_p^2=.16$] measures only. Additionally, for F0, there was a main effect of Phrasal Type [$F(1,44)=24.43$, $p<.001$, $\eta_p^2=.36$] and an interaction between Stress and Phrasal Type [$F(1,44)=28.81$, $p<.001$, $\eta_p^2=.40$]. Investigating the interaction (alpha level adjusted to .025 for two comparisons), it was found that the effect of Stress on F0 was significant for the phrase-final position [$F(1,44)=60.11$, $p<.001$, $\eta_p^2=.58$] and marginally significant for the phrase-medial position [$F(1,44)=5.38$, $p=.025$, $\eta_p^2=.11$]. Thus, the F0 effect was greater in the phrase-final position. No other significant effects or interactions were observed [*F*-values ranged from 0.01 to 2.29].

The analyses investigating tone returned only one significant effect. Vowels with high tone have significantly higher F0 than vowels with no tone [$F(1,41)=55.93$, $p<.001$, $\eta_p^2=.58$]. No other significant main effects or interactions were observed for any of the other measures [*F*-values ranged from 0.04 to 1.52]. These results indicate that high tone is correlated with F0 only and that the effect is similar in phrase-medial and phrase-final position.

3.2.4. Oapan (**h* lost, innovated tone)

Figure 9 presents the results for Oapan speakers for penultimate stress and Figure 10 presents the results for tone. The stressed vowels have a higher F0 than unstressed vowels in both phrasal positions but the difference is greater in phrase-final position (9a). Duration for the stressed vowels is also longer in both positions (9b). Finally, H1-H2 and H1-A2 do not appear to be correlated with penultimate stress in either position (9c-d). For tone, the only acoustic correlate is F0 (10a). This is the case for both phrasal positions. None of the other measures differed by tonal status (10c-d).

Figures 9 and 10 approx. here

Separate analyses were conducted for the stress and tone data for each of the four measures. Considering the stress data first, F0 was higher and duration longer in both phrasal positions for stressed than unstressed vowels, with the F0 effect being relatively greater phrase-finally. There may also be a tendency, based on the H1-A2 measure, for reduced spectral tilt across the board phrase-finally. The effect of Stress was significant for the F0 [$F(1,53)=80.18$, $p<.001$, $\eta_p^2=.60$] and duration [$F(1,58)=15.10$, $p<.001$, $\eta_p^2=.21$] measures only. For F0, there was an interaction between Stress and Phrasal Type [$F(1,53)=13.30$, $p=.001$, $\eta_p^2=.20$]. Separate repeated measures ANOVAs testing the effect of Stress on F0 for each phrasal position returned significant effects (alpha level adjusted to .025 for two comparisons) for both [medial: $F(1,58)=38.25$, $p<.001$, $\eta_p^2=.40$, final: $F(1,53)=104.75$, $p<.001$, $\eta_p^2=.66$]. The effect was simply stronger in phrase-final position. Additionally, there was a marginal main effect of Phrasal Type for the H1-A2 measure [$F(1,53)=4.11$, $p=.048$, $\eta_p^2=.07$].

The analyses investigating tone returned significant effects for the F0 measure only. Vowels with high tone have significantly higher F0 than vowels with no tonal specification [$F(1,39)=102.12$, $p<.001$, $\eta_p^2=.72$]. Additionally there was a Phrasal Type effect for F0. Phrase-final words had lower F0 than phrase-medial words [$F(1,39)=15.21$, $p<.001$, $\eta_p^2=.28$]. No other significant main effects or interactions were observed for any of the other measures [*F*-values ranged from 0.03 to 3.68]. These results indicate that tone is correlated only with F0 and that the effect is similar in phrase-medial and phrase-final position, although the F0 of phrase-final words is lower across the board.

3.3. Discussion

This study investigated potential acoustic correlates to stress and tone: F0, duration, and the spectral balance measures H1-H2 and H1-A2, which are thought to be related to vocal effort. In San Miguel and Ameyaltepec, two villages where historical penultimate stress is preserved and no tone innovated, H1-H2 and H1-A2 reliably distinguished stressed from unstressed syllables in both phrase-medial and phrase-final positions. Vowels with penultimate stress were also longer than unstressed vowels, but this trend was only significant in phrase-final position. In Ameyaltepec, higher F0 reliably distinguished stressed from unstressed syllables in both phrase-medial and phrase-final positions but in San Miguel the F0 effect was only strongly evidenced phrase-finally. Note that the F0 results concur with the data reported in Study 1.

Taken together, these results indicate that San Miguel and Ameyaltepec have a word-level stress accent primarily correlated with acoustic effects of spectral balance. Duration was at best a weak correlate phrase internally. The relatively longer duration in the phrase-final than phrase-internal position may be due to an overall utterance-final lengthening. It does not, however, appear to be a correlate to stress, as it is not found phrase internally. F0 may also be a correlate to stress in Ameyaltepec. However, as mentioned previously, further work manipulating the discourse context is needed to disassociate intonation from stress effects.

Now let us turn to the results from the villages which have developed high tone on syllables preceding **h*, Oapan and Ahuelicán. As seen in the results of Study 1, syllables with high tone had higher F0. In this second study, the possibility of other acoustic correlates to the high tone was investigated. These varieties also preserve penultimate stress in some words. Thus, it was of interest to determine differences in the realization of stress and tone.

In both villages, the penultimate stress accents had different acoustic correlates than tone. In Ahuelicán, the penultimate stresses were produced with a flatter spectral slope (smaller H1-A2 differences) in both phrasal positions. A higher F0 was only reliably found in phrase-final position. Thus, a flatter spectral slope appears to be the primary acoustic correlate to penultimate stress in Ahuelicán; the high F0 appears to be a characteristic of phrase-final intonational prosody. In Oapan, penultimate stress accents were produced with higher F0 and longer duration in both phrasal positions. Thus, greater duration, and possibly higher F0, appear to be the primary acoustic correlates to stress in Oapan. The only acoustic correlate to tone in both subdialects and in both phrasal positions, on the other hand, was F0.

Thus, the penultimate stress accents exhibited acoustic characteristics typical of stress in both villages: flatter spectral slope in Ahuelicán and longer duration in Oapan. However, in neither village did penultimate stressed vowels exhibit smaller H1-H2 differences, which would indicate smaller open quotients. Thus these varieties may use less creaky or tense voicing in producing penultimate stress than the San Miguel and Ameyaltepec varieties.

4. General Discussion and Conclusion

The results of the studies presented here have provided evidence about the origin and development of tone in the Nahuatl subdialects of Oapan and Ahuelicán. Tone seems to have originated in a small lowering of F0 conditioned by a non-final coda breathy [ɦ] (< **h*). We proposed that tone developed as a reinterpretation of the relatively higher F0 on the syllable preceding a syllable with [ɦ]. A high-low F0 contour across the two syllables was phonologized, producing a high tone on the preceding syllable. This account of the sound change may be captured by John Ohala's notion of hypo-correction (see e.g., Ohala, 1993) in which listeners fail to normalize coarticulatory effects (such as the effect of breath voicing on F0) and interpret the coarticulatory effects as intended by the speaker.

Given this analysis, the development of tone in Balsas Nahuatl is similar to the development of low or falling tonal contours found in other languages (Matisoff 1973; Ohala 1973; Svantesson 2001), including the related Uto-Aztecan language, Hopi (Manaster-Ramer, 1986). The results also provide support for Thurgood's (2002) proposal that breathy voicing is the relevant conditioning element in such developments.

Furthermore, once the conditioning environment (i.e., the coda [ɦ]) was lost, and the F0 patterns were phonologized as lexical tones, they were no longer tied to their original location. Thus, in Oapan, high tones are now found on syllables other than those immediately preceding a syllable with coda **h* (see examples (5) and (6) in which a high tone is found on a syllable with **h*). This historical development may be the origin of autosegmenal tonal phenomena in this language in which accents are not tied to certain syllables, but exhibit morphophonological variation. Consider the variation illustrated in examples (9) through (15) in which tonal patterns appear to be associated with roots and vary in their placement depending on affixation. The lack of variation in tonal placement in Ahuelicán indicates that the conditioning environment may need to be lost before variation may enter into the system.

In both the tonal subdialects, the historical penultimate accents interact with the innovated tones. As can be seen in Figures 3 and 4 and in the examples (9)-(11), when a high tone is developed on the antepenultimate syllable, the historical stress accent shifts from the penultimate to the final syllable (unless the penult has a long vowel in Oapan). This indicates that the innovated tones and the historical stress accents interact with each other so that, in some sense, they must form part of the same word-level prosodic system. Whether this interaction is autosegmental at the tonal level or a metrical, accentual phenomenon, is not clear at the present stage of analysis. However, the interaction would seem to require some sort of phonological specification on the same tier or domain for both the innovated tones and historical stress accents.

Although the hybrid stress-tone systems reviewed in the introduction exemplified cases in which stress and tonal systems were independent of each other, there are cases in which stress and tone interact. For example, Van der Hulst and Smith (1988) review many cases of hybrid systems in which tone is dependent on stress or vice versa. Tonal information may be limited to stressed syllables in Scandinavian languages and dialects of Dutch, German, and Croatian. On the other hand, stress placement may be limited to syllables with certain tonal specifications in Kimatuumbi and Ayutla Mixtec. However, we have not yet found a report of a hybrid system in which tone and stress interact in a clash avoidance or dissimilatory process, as is the case in the Nahuatl subdialects studied here.

The finding of phonological interaction between stress and tone led us to question whether the historical stress accents were themselves becoming tonal. Thus, we investigated the phonetic realization of tone and penultimate stress. Tone was found to be uniquely correlated with F0, where stress was found to be correlated with different acoustic characteristics, depending on subdialect. In subdialects that had not developed tone, stress was correlated primarily with spectral balance measures. In dialects that had developed tone, spectral balance measures were less strongly associated with stress. In Oapan, spectral balance measures were not correlates to stress and duration had developed into the primary correlate. In Ahuelicán, spectral balance correlates had been diminished but no new features had been added. Thus, we propose that in these subdialects, stress is changing in its phonetic realization as it interacts with tone. However, the association of F0 with these historical stress accents will need further investigation in more controlled prosodic environments.

The development of duration as a correlate to stress in Oapan is a bit puzzling. If stress were becoming more tone-like, why would a new correlate typical of stress accent be recruited? Likewise, it is a bit puzzling why none of the other subdialects use duration as a major correlate of stress. To tackle these questions, let us begin from a typological context. In many languages characterized as having stress accent, longer duration is considered to be a primary cue to stress (see e.g., Beckman, 1986; Gussenhoven, 2005 and references therein). However, not all languages have been found to use duration as a cue to stress. Berinstein (1979) found that speakers of the Mayan language K'ekchi, which has phonemic vowel length, did not use duration in stress production, nor did they use it as a cue to perception. However, the speakers of the related language Cakchiquel, as well as Spanish and English, none of which have phonemic vowel length, did use duration as a cue to perception. Thus, as Berinstein proposed, the presence of phonemic vowel length may modulate the use of duration as a cue to stress. Although, it must be mentioned that at least some languages with durational contrasts use duration as a cue to stress (e.g., Finnish as described by Suomi and Ylitalo, 2004). Three of the four Nahuatl subdialects investigated here follow this generalization. Only Oapan, which has lost the correlate of spectral balance, employs duration. We suggest that duration, a less common correlate to stress in languages such as Nahuatl that have phonemic length, was developed in Oapan only after the loss of the correlates to spectral balance.

The loss of certain correlates to stress accent and the shift to others may indicate some instability in the word-level prosody of these hybrid systems. It may be that we are witnessing the transition from a tone and stress hybrid system to a purely tonal system. It may also be that the recruitment of duration while other correlates to stress are being lost has reinforced the encoding of stress and served to maintain and resolidify the hybrid system. Though hybrid systems are rare, there has been enough documentation of them (see introduction for review) to consider them a viable prosodic class.

Let us turn now to a consideration of the origin of tone and stress hybrid systems. Earlier we proposed a tentative developmental course for hybrid systems in which tone is acquired through the loss of some phonological contrast in a stress accent language. The stress then remains, as well as the innovated tones. In such languages tones will not necessarily be present on all lexical items, just those containing the earlier phonological contrast. The Nahuatl subdialects investigated here provide another example of such a developmental course.

Overall, the data presented here provide further support for hybrid systems from a typological perspective but also indicate that such systems are perhaps rather unstable. Future work is needed to provide a more complete understanding of how word-level hybrid systems interact with phrase-level prosody and how such systems change over time.

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Endnotes

[1] Remijsen (2002) writes that the tones in Ma'ya are a secondary development, but does not propose a specific account of their innovation.

[2] Shaul (2000) also reports that Northern Tepehaun (Tepiman subfamily of Uto-Aztecan) has developed tonal contrasts related to the loss of /h/. However, the exact nature of this development is not yet fully described.

[3] Some dialects of Nahuatl exhibit different stress locations for some or all words, but these can be attributed to effects of historical processes such as cliticization or loss of a final vowel (Boas, 1917; Brockway, Brockway & Valdés; 2000; Munro 1977). A fuller description of previous work on Nahuatl prosody is presented in Amith (unpublished ms.).

[4] The following abbreviations are used in the morphological parsing of the examples in the text.

1, 2, 3	1st, 2nd, 3rd person
SG	singular
PL	plural
S	subject
O	object
POSSR	possessor
ABS	absolutive (for singular, unpossessed nouns)
AGENT	agentive
ALIEN	alienable
COMPL	completive
DIMIN	diminutive
DUR	durative
FUT	future
IMPERFV	imperfective
INTRA.DIR	intraverse directional
PERFV	perfective
POSSD	possessed
PRES	present
RDP.S/h	monomoraic reduplicant with coda **h*

[5] Word-final **h* has not conditioned tonal innovation and is retained in all subdialects in phrase-final position. It may be elided in some phrase internal positions but we have not yet systematically investigated this patterning.

[6] While Ameyaltepec and Oapan have lost non-word-final coda **h* (historical **h*), /h/ can be found in surface forms in both Oapan and Ameyaltepec. In Oapan and Ameyaltepec geminate /kk/ and /ll/ > /hk/ and /hl/ and in Oapan /w/ > /h/ and /k/ > /h/ before all consonants. However, it is outside the scope of the current paper to investigate the phonetic nature of these /h/ productions, e.g., whether they are breathy or voiceless and whether they affect the F0 of the preceding vowel.

[7] The verb [nikteːnéːwas] was pronounced as [nihteːnéːwas] by speakers in the villages of Oapan and Ameyaltepec.

[8] The partial eta-squared (η_p^2) provides an estimate of the effect size. The eta-squared statistic describes the proportion of total variability attributable to a factor.

[9] The examples in this section are based on transcriptions and consultation with native speakers of the respective subdialects. Words are transcribed as produced in an isolated context. The high tone mark [́] indicates a high tone and the stress mark [ˈ] indicates a high F0 associated with the historical penultimate stress accent that may be found either on the penultimate syllable or the final syllable in the synchronic forms (i.e., those to the left of the ‘<’). The historical forms, to the right of the ‘<’ and marked with ‘*’, are shallow reconstructions of Balsas area Nahuatl based on correspondences with neighboring varieties and informed by the evidence in classical Nahuatl.

[10] The vowels compared in the matched words [teːt͡ʃwiːˈkaskeh] and [kinakaskaˈnaːwas] found in Table 3 may be an exception to the open syllable criteria. However, given the fact that the vowels compared are both followed by a [sk] cluster, possible differences in syllabification were not expected to affect the results.

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Table 1. The four varieties of Nahuatl investigated in the study.

	Penultimate Stress Only	Innovated Tones
Non-word-final *h retained	San Miguel	Ahuelicán
Non-word-final *h lost	Ameyaltepec	Oapan

Note: The Nahuatl varieties are indicated by the name of the village in which they are spoken. All villages are located along the Balsas River in the state of Guerrero, Mexico. The villages of Ahuelicán and Ameyaltepec were offshoots from the village of Oapan in pre-colonial times (Amith, 1995, 2005) and the Nahuatl in all three of these villages has certain differences from the Nahuatl spoken in San Miguel, which is more conservative, preserving the historical non-word-final coda *h and penultimate accent.

Table 2. List of words recorded for Study 1

Historical	San Miguel	Ameyaltepec	Ahuelicán	Oapan	gloss
**h* in coda of first syllable*					
*a**h**ˈmoːlli	aɦˈmoːɬ͡li	aˈmoːɬ͡li	aɦˈmoːɬ͡li	áˈmoːɬ͡li	soap tree (*Ziziphus mexicana* Rose, tree in the Rhamnaceae family)
*ki**h**ˈkiːskeːt͡ɬ	kiɦˈkiːskeːt͡ɬ	kiˈkiːskeːt͡ɬ	kiɦˈkiːskeːt͡ɬ	kíˈkiːskeːt͡ɬ	partygoer
*kʷa**h**ˈkʷawkeːt͡ɬ	koɦˈkohkeːt͡ɬ	kuˈkuw̥keːt͡ɬ	koɦˈkohkeːt͡ɬ	kókohˈkeːt͡ɬ	wood chopper
*tɬa**h**ˈsolli	tɬaɦˈsoɬli	tɬaˈsoɬli	tɬaɦˈsoɬli	tɬásoɬˈli	garbage/ brush
*kʷe**h**ˈtomat͡ɬ	kʷeɦˈtomat͡ɬ	kʷeˈtomat͡ɬ	kʷeɦˈtomat͡ɬ	kʷétoˈmat͡ɬ	pillow
**h* in coda of second syllable*					
*aːˈtʃi**h**t͡siːn	aːˈtʃiɦt͡siːn	aːˈtʃit͡siːn	áːtʃiɦˈt͡siːn	áːtʃiˈt͡siːn	a little
*monˈta**h**t͡ɬi	monˈtaɦt͡ɬi	monˈtat͡ɬi	móntaɦˈt͡ɬi	móntaˈt͡ɬi	father-in-law
*t͡ɬaˈma**h**keːt͡ɬ	t͡ɬaˈmaɦkeːt͡ɬ	t͡ɬaˈmakeːt͡ɬ		t͡ɬámaˈkeːt͡ɬ	hunter
*t͡ʃiːˈta**h**t͡ɬi	t͡ʃiːˈtaɦt͡ɬi	t͡ʃiːˈtat͡ɬi	t͡ʃíːtaɦˈt͡ɬi	t͡ʃíːtaˈt͡ɬi	cradle
*kaˈmo**h**t͡ɬi	kaˈmoɦt͡ɬi	kaˈmot͡ɬi	kámoɦˈt͡ɬi	kámoˈt͡ɬi	sweet potato
*toːˈmo**h**t͡ɬi	toːˈmoɦt͡ɬi	toːˈmot͡ɬi	tóːmoɦˈt͡ɬi	tóːmoˈt͡ɬi	prickly pear
No *h					
*aːˈteːmpan/ *aˈːteːŋko	aːˈteːmpan	aːˈteːŋko[a]	aːˈteːmpan	aːˈtéːmpan	river's edge
*piˈlisaːl	piˈlisaːɬ	piˈlisaːɬ	piˈlisaːɬ	piˈlísaːɬ	blanket
*aːˈkaʃtet͡ɬ/ *aːˈteːnt͡ɬi	aːˈteːnt͡ɬi[a]	aːˈkaʃtet͡ɬ		aːˈkáʃtet͡ɬ	stone watering bowl
*monˈt͡siːnt͡ɬi	monˈt͡siːnt͡ɬi	monˈt͡siːnt͡ɬi	monˈt͡siːnt͡ɬi	monˈtsiːnt͡ɬi	son-in-law (DIMIN.)
*koˈkoʃki	koˈkoʃki	koˈkoʃki	koˈkoʃki	koˈkoʃki	sick person
*t͡ɬaˈpet͡ʃt͡ɬi	t͡ɬaˈpet͡ʃt͡ɬi	t͡ɬaˈpeʃt͡ɬi	t͡ɬaˈpeʃt͡ɬi	t͡ɬaˈpeʃt͡ɬi	bed
*t͡ɬaˈmant͡ɬi	t͡ɬaˈmant͡ɬi	t͡ɬaˈmant͡ɬi	t͡ɬaˈmant͡ɬi	t͡ɬaˈmant͡ɬi	group
*t͡ʃiˈkiwt͡ɬi	t͡ʃiˈkiçt͡ɬi	t͡ʃiˈkɨɰt͡ɬi	t͡ʃiˈkiçt͡ɬi	t͡ʃiˈkiht͡ɬi	basket
*kaˈmakt͡ɬi	kaˈmakt͡ɬi	kaˈmakt͡ɬi	kaˈmaht͡ɬi	kaˈmaht͡ɬi	mouth
*toːˈnalli	toːˈnaɬli	toːˈnaɬli	toːˈnaɬli	toːˈnaɬli	sun
*kʷeˈʃomat͡ɬ	kʷeˈʃomat͡ɬ	kʷeˈʃomat͡ɬ	kʷeˈʃomat͡ɬ	kʷeˈʃomat͡ɬ	wooden tray

[a] = word not cognate with the words in the other dialects and with a different meaning than that expressed in the final column

Table 3. List of words with penultimate accent used in Study 2

Historical	Oapan	Ahuelicán	Ameyaltepec	San Miguel	Gloss
[a] with penultimate accent					
*nomalaˈkatew/ʍ	nomalaˈka̲teç	nomalaˈka̲teʍ	nomalaˈka̲teʍ	nomalaˈka̲teh	my spindle whorl wheel (or bead)
*oːnowiːˈkakeh	oːnowiːˈka̲keh	oːnowiːˈka̲keh	oːnowiːˈka̲keh	oːnowiːˈka̲keh	they left together
*kinakaskaˈnaːwas	kinakaskaˈna̲ːwas	kinakaskaˈna̲ːwas	kinakaskaˈna̲ːwas	kinakaskaˈna̲ːwas	he will thin its handles (lit. ‘ears’) out
*malaˈkatet͡ɬ	malaˈka̲tet͡ɬ	malaˈka̲tet͡ɬ	malaˈka̲tet͡ɬ	malaˈka̲tet͡ɬ	spindle whorl stone (or bead)
*oːmit͡steːˈkakeh	oːmisteːˈka̲keh	oːmisteːˈka̲keh	oːmisteːˈka̲keh	oːmisteːˈka̲keh	they lay you down
*oːpepeˈt͡ɬakak	oːpepeˈt͡ɬa̲kak		oːpepeˈt͡ɬa̲kak	oːpepeˈt͡ɬa̲kak	it glittered
*pepeˈt͡ɬakas	pepeˈt͡ɬa̲kas		pepeˈt͡ɬa̲kas	pepeˈt͡ɬa̲kas	it will glitter
*teːt͡ɬahˈt͡ɬatas	téːt͡ɬaˈt͡ɬa̲tas	téːt͡ɬaɦˈt͡ɬa̲tas	teːt͡ɬaˈt͡ɬa̲tas	teːt͡ɬaɦˈt͡ɬa̲tas	they will have a good time watching things
*oːnomoːˈt͡ɬakeh	oːnomoːˈt͡ɬa̲keh	oːnomoːˈt͡ɬa̲keh	oːnomoːˈt͡ɬa̲keh	oːnomoːˈt͡ɬa̲keh	they threw rocks at each other
*teːt͡ʃwiːˈkaskeh	teːt͡ʃwiːˈka̲skeh	teːt͡ʃwiːˈka̲skeh	teːt͡ʃwiːˈka̲skeh	teːt͡ʃwiːˈka̲skeh	they will accompany us
[a] in matched unaccented syllable					
*nakaˈt͡siːntɬi	naka̲ˈt͡siːntɬi	naka̲ˈt͡siːntɬi	naka̲ˈt͡siːntɬi	naka̲ˈt͡siːntɬi	meat (DIMIN.)
*mit͡st͡ɬapaˈtiliːs	mist͡ɬapa̲ˈtiliːs	mist͡ɬapa̲ˈtiliːs	mist͡ɬapa̲ˈtiliːs	mist͡ɬapa̲ˈtiliːs	he will exchange things for you
*kit͡ɬakaːˈwiliːs	kit͡ɬaka̲ːˈwiliːs	kit͡ɬaka̲ːˈwiliːs	kit͡ɬaka̲ːˈwiliːs	kit͡ɬaka̲ːˈwiliːs	he will leave things for him
*neːt͡ʃt͡ɬakoːˈwiːskeh	neːʃt͡ɬa̲koːˈwiːskeh	neːʃt͡ɬa̲koːˈwiːskeh	neːʃt͡ɬa̲koːˈwiːskeh	neːʃt͡ɬa̲koːˈwiːskeh	they will strike me with a rod
*kinakaskaˈnaːwas	kinakaska̲ˈnaːwas	kinakaska̲ˈnaːwas	kinakaska̲ˈnaːwas	kinakaska̲ˈnaːwas	he will thin its handles (lit. ‘ears’) out
*oːt͡ɬaˈpaːkkeh	oːt͡ɬa̲ˈpaːhkeh		oːt͡ɬa̲ˈpaːhkeh	oːt͡ɬa̲ˈpaːhkeh	they washed clothes
*nomalaˈkatew	nomala̲ˈkateç		nomala̲ˈkateʍ	nomala̲ˈkateh	my spindle whorl wheel (or bead)
*oːneːt͡ʃt͡ɬateːˈmilih	oːneːʃt͡ɬa̲teːˈmilih	oːneːʃt͡ɬa̲teːˈmilih	oːneːʃt͡ɬa̲teːˈmilih	oːneːt͡ʃt͡ɬa̲teːˈmilih	they filled things up for me
*oːneːt͡ʃt͡ɬat͡saˈkwilih	oːneːʃt͡ɬa̲t͡saˈkwilih	oːneːʃt͡ɬa̲t͡saˈkwilih	oːneːʃt͡ɬa̲t͡saˈkwilih	oːneːt͡ʃt͡ɬa̲t͡saˈkwilih	he blocked my way
*kinakaskaˈnaːwas	kinaka̲skaˈnaːwas	kinaka̲skaˈnaːwas	kinaka̲skaˈnaːwas	kinaka̲skaˈnaːwas	he will thin its handles (lit. ‘ears’) out

Table 4. List of words with accent from **h* used in Study 2

Historical	Oapan	Ahuelicán	Gloss
/a/ with accent from following syllable with coda **h*			
*kaˈmoht͡ɬi	ká̲moˈt͡ɬi	ká̲moɦˈt͡ɬi	sweet potato
*(t͡ɬah)t͡ɬaˈmahke:t͡ɬ	t͡ɬá̲maˈke:t͡ɬ	t͡ɬaɦt͡ɬá̲maɦˈke:t͡ɬ	hunter
*te:mat͡ʃˈtihke:t͡ɬ	te:má̲ʃtiké:t͡ɬ	te:má̲ʃtiɦˈke:t͡ɬ	teacher
*t͡ʃalaˈlaht͡ɬi	t͡ʃalá̲laˈt͡ɬi	t͡ʃalá̲laɦˈt͡ɬi	type of tree (*Amphipterygium adstringens* (Schltdl.) Standl., tree in the Julianaceae family)
*tamalaˈjoht͡ɬi	tamalá̲joˈt͡ɬ	tamalá̲joɦˈt͡ɬi	type of squash
*aːˈt͡ʃiht͡siːn	á̲ːt͡ʃiˈt͡siːn	á̲ːt͡ʃiɦˈt͡siːn	a little
*o:t͡ɬakwahtahˈsike	o:t͡ɬá̲kwataˈsikeh	o:t͡ɬá̲kwaɦtaɦˈsikeh	they ate upon arriving there
/a/ in matched unaccented syllable			
*kaˈmakt͡ɬi	ka̲máɦt͡ɬi/ka̲mákt͡ɬi	ka̲mákt͡ɬi	mouth
*malaˈkatet͡ɬ	ma̲lakátet͡ɬ	ma̲lakátet͡ɬ	spindle whorl stone
*te:malˈt͡si:nt͡ɬi	te:ma̲ɬt͡sí:nt͡ɬi	te:ma̲ɬt͡sí:nt͡ɬi	puss (DIMIN.)
*malaˈkatet͡ɬ	mala̲kátet͡ɬ	mala̲kátet͡ɬ	spindle whorl stone
*nomalaˈkatew	nomala̲káteç	nomala̲káteʍ	my spindle whorl wheel (or bead)
*aːˈkaʃtet͡ɬ/*aːteˈpaɬkat͡ɬ	a̲ːˈkaʃtet͡ɬ [a]	a̲ːteˈpaɬkat͡ɬ [a]	stone bowl for giving water to animals
*o:t͡ɬakwa:teˈmo:t͡ɬak	o:t͡ɬa̲kwa:teˈmo:t͡ɬak	o:t͡ɬa̲kwa:teˈmo:t͡ɬak	he threw things at heads

a = These words are not cognate, but do have the same syllable structure for the target vowel.

Figure Legends

Figure 1. Mean F0 at vowel midpoint for each syllable in the target words produced by six participants from San Miguel. Three types of words are presented, those with **h* in the first syllable, those with **h* in the second syllable, and those with no **h*, in phrase-medial (a) and phrase-final (b) position. Note that **h* is preserved in San Miguel as a breathy voiced [ɦ].

Figure 2. Mean F0 at vowel midpoint for each syllable in the target words produced by six participants from Ameyaltepec. Three types of words are presented, those with **h* in the first syllable, those with **h* in the second syllable, and those with no **h*, in phrase-medial (a) and phrase-final (b) position. Note that **h* is lost in Ameyaltepec.

Figure 3. Mean F0 at vowel midpoint for each syllable in the target words produced by six participants from Ahuelicán. Three types of words are presented, those with **h* in the first syllable, those with **h* in the second syllable, and those with no **h*, in phrase-medial (a) and phrase-final (b) position. Note that **h* is preserved in Ahuelicán as a breathy voiced [ɦ], though somewhat weaker than in San Miguel.

Figure 4. Mean F0 at vowel midpoint for each syllable in the target words produced by six participants from Oapan. Four types of words are presented, those with **h* in the first syllable and a long vowel in the second syllable, those with **h* in the first syllable and a short vowel in the second syllable, those with **h* in the second syllable, and those with no **h*, in phrase-medial (a) and phrase-final (b) position. Note that non final coda **h* is lost in Oapan.

Figure 5. Mean and standard error at vowel midpoint for the measures of fundamental frequency (a), vowel duration (b), difference between the first and second harmonic (c), and difference between the first harmonic and the amplitude of the second formant (d) for vowels stressed on the penultimate syllable and for unstressed vowels. Data was produced by six participants from San Miguel.

Figure 6. Mean and standard error at vowel midpoint for the measures of fundamental frequency (a), vowel duration (b), difference between the first and second harmonic (c), and difference between the first harmonic and the amplitude of the second formant (d) for vowels stressed on

the penultimate syllable and for unstressed vowels. Data was produced by six participants from Ameyaltepec.

Figure 7. Mean and standard error at vowel midpoint for the measures of fundamental frequency (a), vowel duration (b), difference between the first and second harmonic (c), and difference between the first harmonic and the amplitude of the second formant (d) for vowels stressed on the penultimate syllable and for unstressed vowels. Data was produced by six participants from Ahuelicán.

Figure 8. Mean and standard error at vowel midpoint for the measures of fundamental frequency (a), vowel duration (b), difference between the first and second harmonic (c), and difference between the first harmonic and the amplitude (d) of the second formant for vowels with high tone from the effect of *h in the coda of the following syllable and for vowels without tone. Data was produced by six participants from Ahuelicán.

Figure 9. Mean and standard error at vowel midpoint for the measures of fundamental frequency (a), vowel duration (b), difference between the first and second harmonic (c), and difference between the first harmonic and the amplitude of the second formant (d) for vowels stressed on the penultimate syllable and for unstressed vowels. Data was produced by six participants from Oapan.

Figure 10. Mean and standard error at vowel midpoint for the measures of fundamental frequency (a), vowel duration (b), difference between the first and second harmonic (c), and difference between the first harmonic and the amplitude of the second formant (d) for vowels with high tone from the effect of *h in the coda of the following syllable and for vowels without tone. Data was produced by six participants from Oapan.

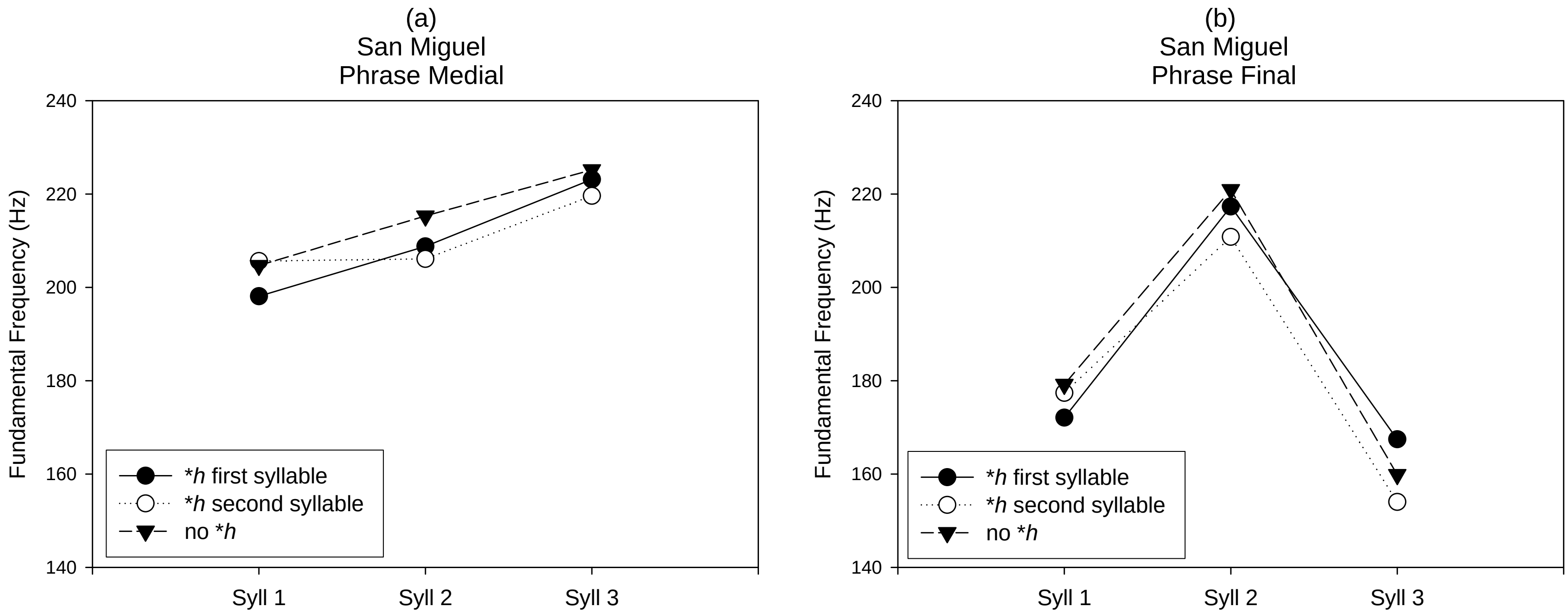

(a)
San Miguel
Phrase Medial
Fundamental Frequency (Hz)
240
220
200
180
160
140
Syll 1
Syll 2
Syll 3
*h first syllable
*h second syllable
no *h
(b)
San Miguel
Phrase Final
Fundamental Frequency (Hz)
240
220
200
180
160
140
Syll 1
Syll 2
Syll 3
*h first syllable
*h second syllable
no *h

Figure 1

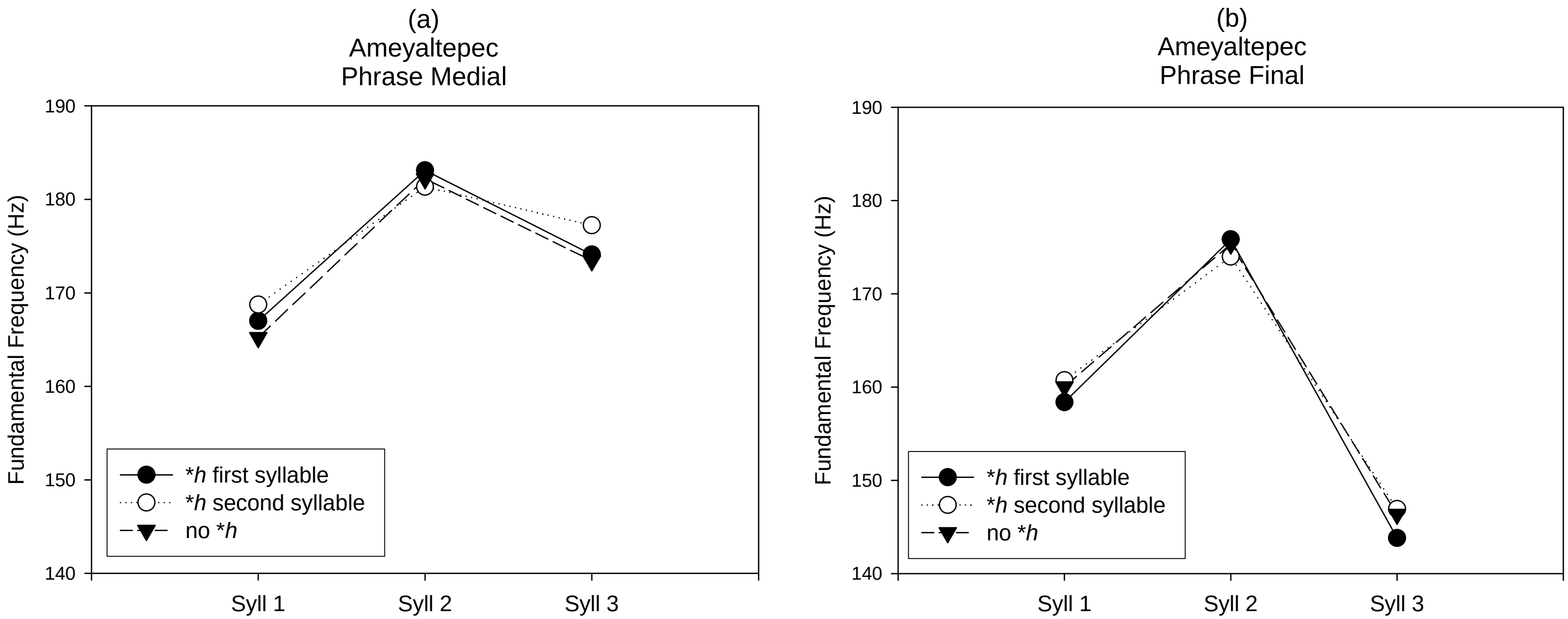

(a)
Ameyaltepec
Phrase Medial
Fundamental Frequency (Hz)
190
180
170
160
150
140
Syll 1
Syll 2
Syll 3
*h first syllable
*h second syllable
no *h
(b)
Ameyaltepec
Phrase Final
Fundamental Frequency (Hz)
190
180
170
160
150
140
Syll 1
Syll 2
Syll 3
*h first syllable
*h second syllable
no *h

Figure 2

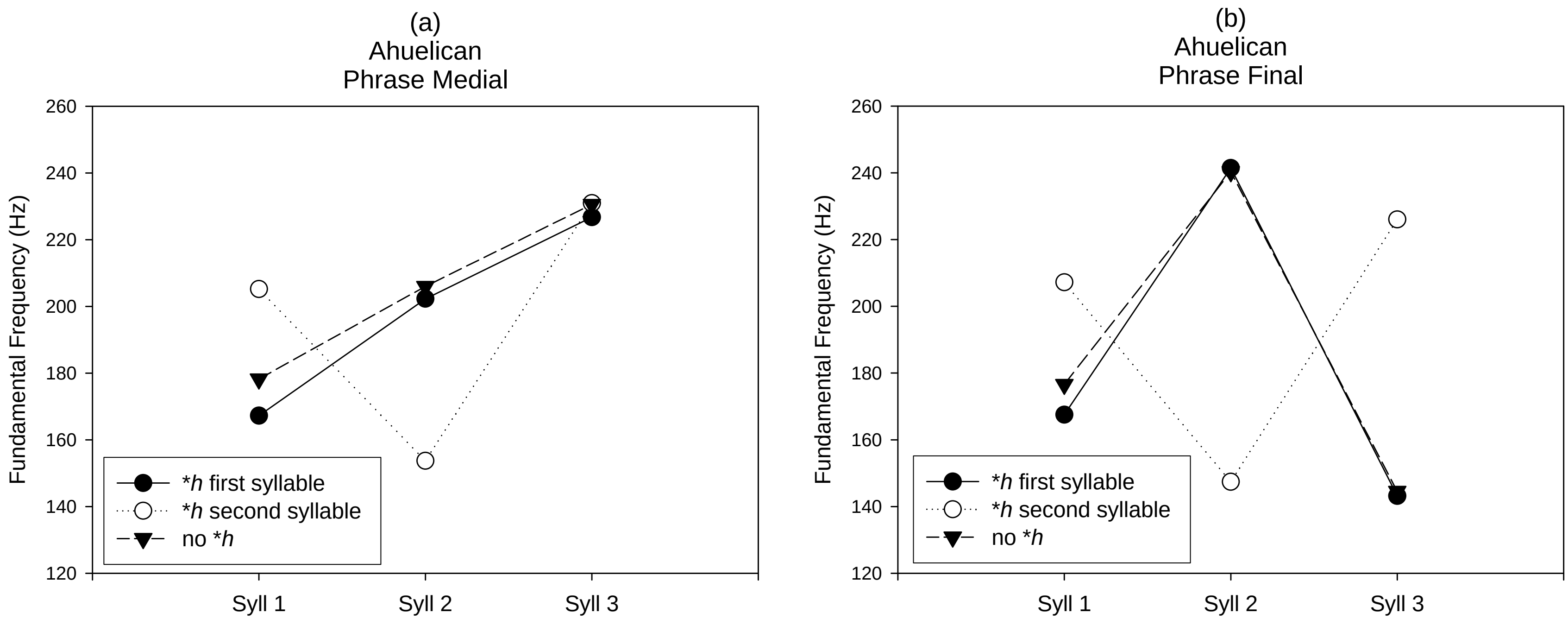

(a)
Ahuelican
Phrase Medial
(b)
Ahuelican
Phrase Final
Fundamental Frequency (Hz)
260
240
220
200
180
160
140
120
Syll 1
Syll 2
Syll 3
*h first syllable
*h second syllable
no *h

Figure 3

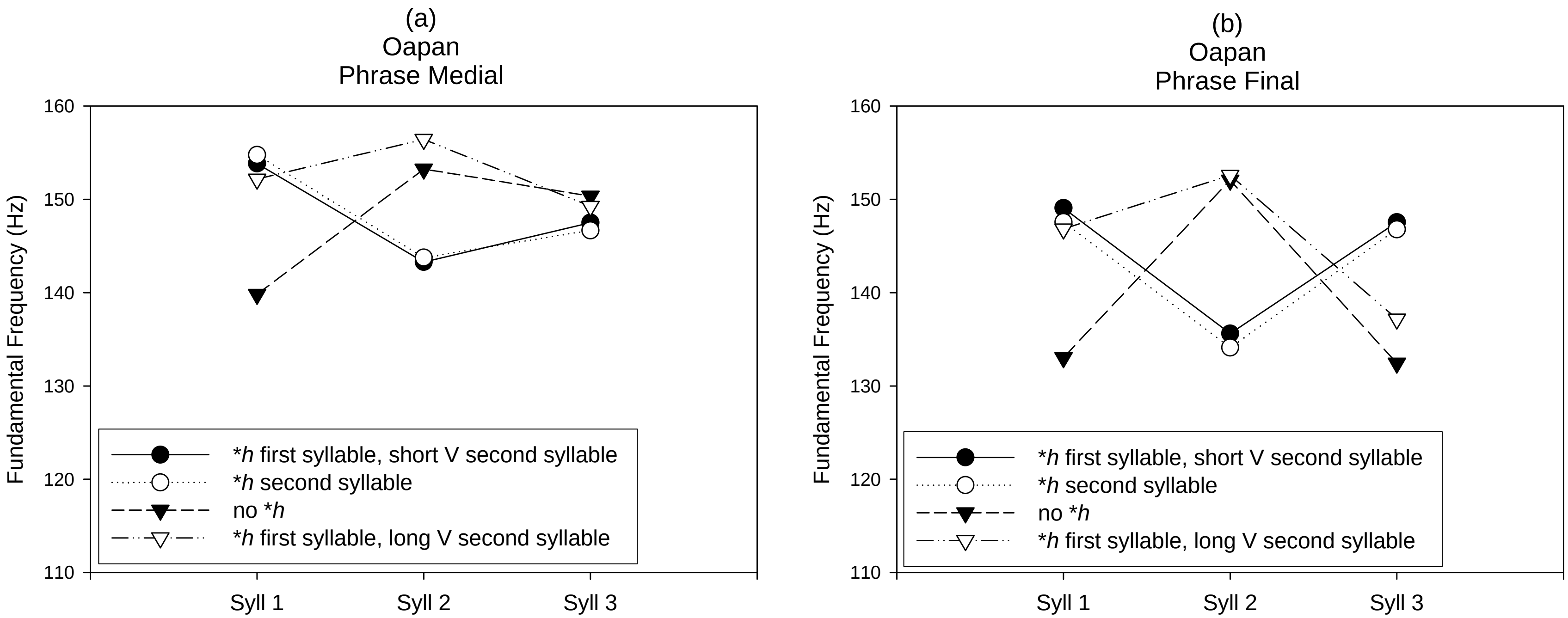

(a)
Oapan
Phrase Medial
Fundamental Frequency (Hz)
160
150
140
130
120
110
*h first syllable, short V second syllable
*h second syllable
no *h
*h first syllable, long V second syllable
Syll 1
Syll 2
Syll 3
(b)
Oapan
Phrase Final
Fundamental Frequency (Hz)
160
150
140
130
120
110
*h first syllable, short V second syllable
*h second syllable
no *h
*h first syllable, long V second syllable
Syll 1
Syll 2
Syll 3

Figure 4

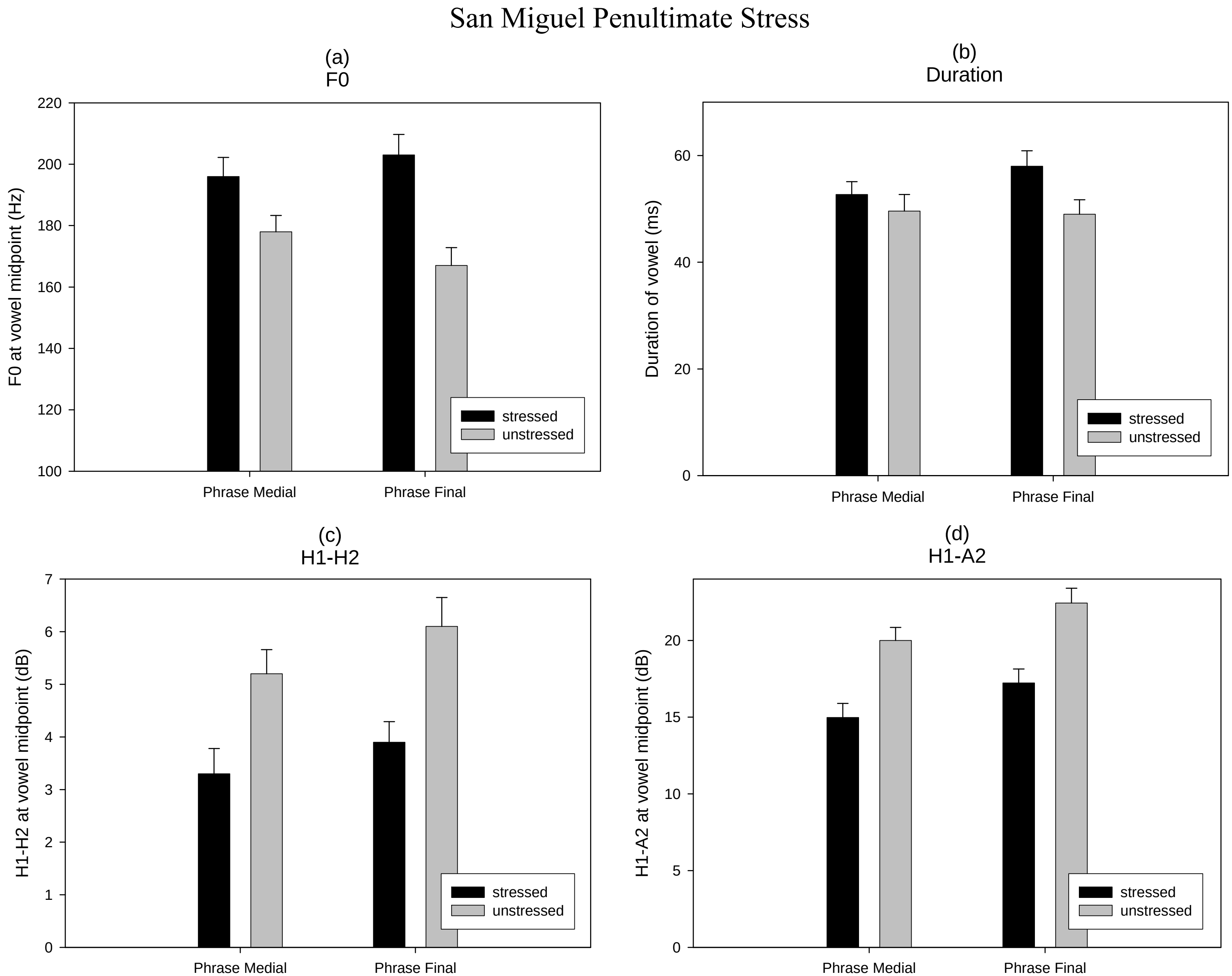

San Miguel Penultimate Stress
(a)
F0
F0 at vowel midpoint (Hz)
220
200
180
160
140
120
100
Phrase Medial
Phrase Final
stressed
unstressed
(b)
Duration
Duration of vowel (ms)
60
40
20
0
Phrase Medial
Phrase Final
stressed
unstressed
(c)
H1-H2
H1-H2 at vowel midpoint (dB)
7
6
5
4
3
2
1
0
Phrase Medial
Phrase Final
stressed
unstressed
(d)
H1-A2
H1-A2 at vowel midpoint (dB)
20
15
10
5
0
Phrase Medial
Phrase Final
stressed
unstressed

Figure 5

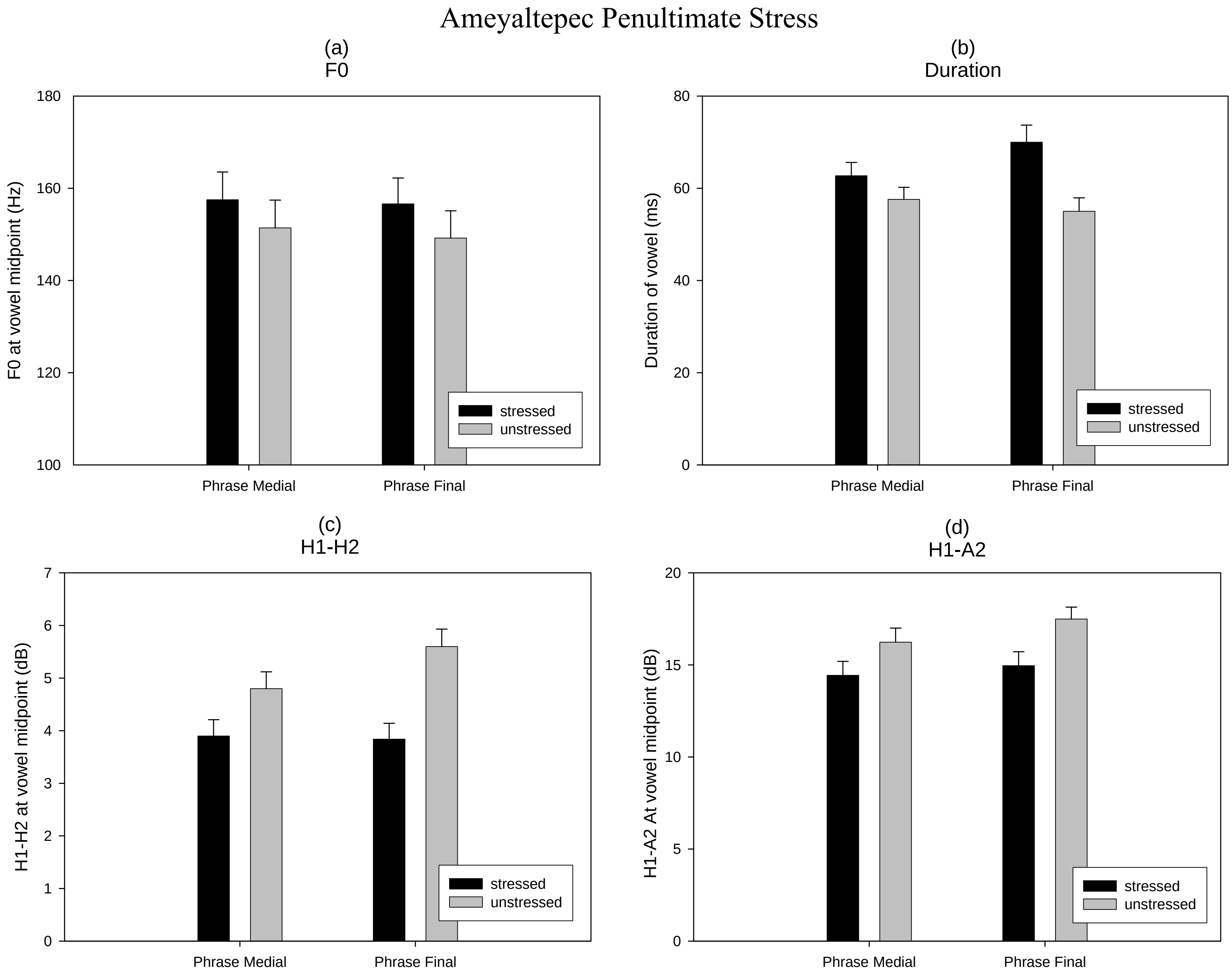

Ameyaltepec Penultimate Stress
(a)
F0
F0 at vowel midpoint (Hz)
180
160
140
120
100
Phrase Medial
Phrase Final
stressed
unstressed
(b)
Duration
Duration of vowel (ms)
80
60
40
20
0
Phrase Medial
Phrase Final
stressed
unstressed
(c)
H1-H2
H1-H2 at vowel midpoint (dB)
7
6
5
4
3
2
1
0
Phrase Medial
Phrase Final
stressed
unstressed
(d)
H1-A2
H1-A2 At vowel midpoint (dB)
20
15
10
5
0
Phrase Medial
Phrase Final
stressed
unstressed

Figure 6

Ahuelicán Penultimate Stress

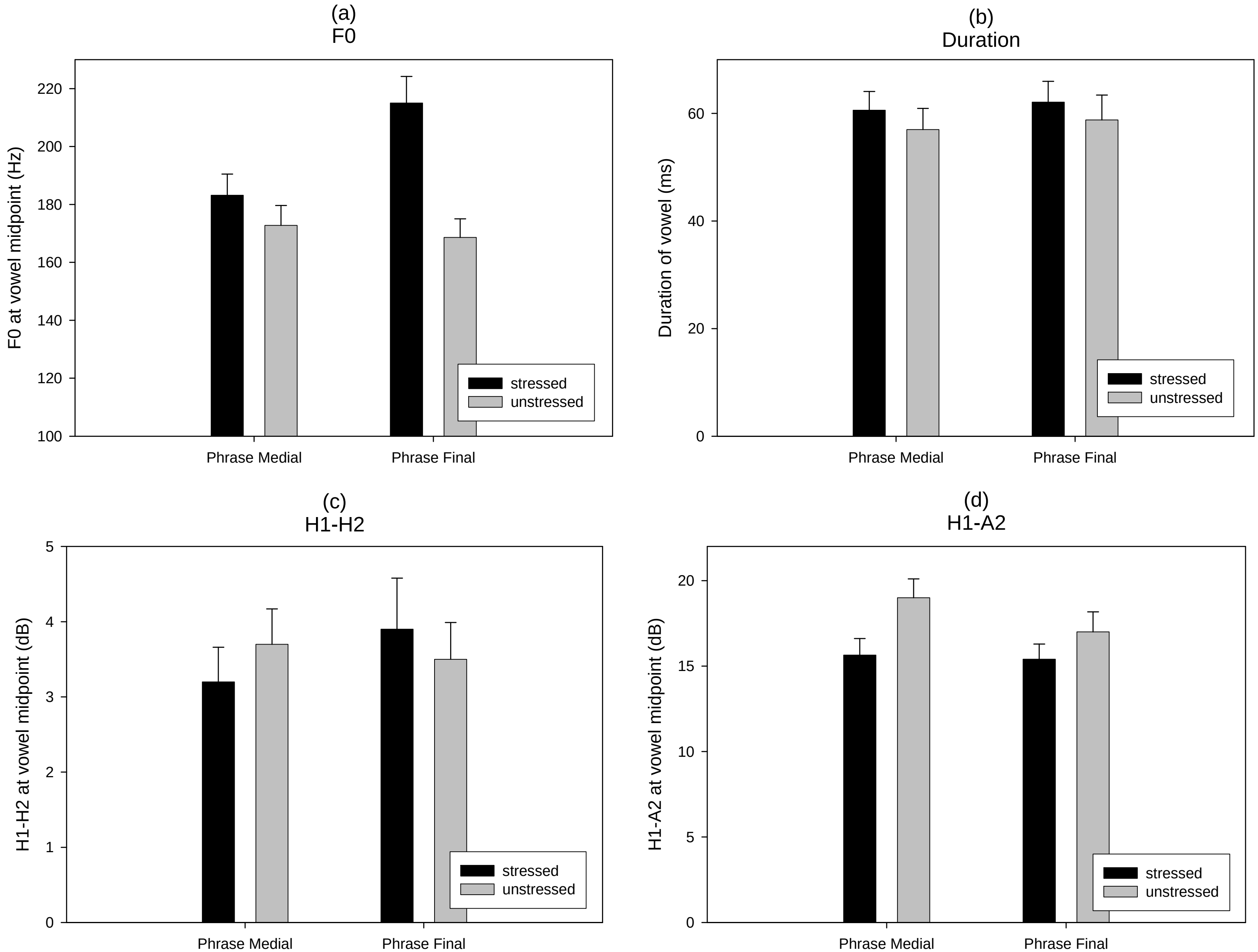


Figure 7

Ahuelicán High Tone on Syllable before Coda *h

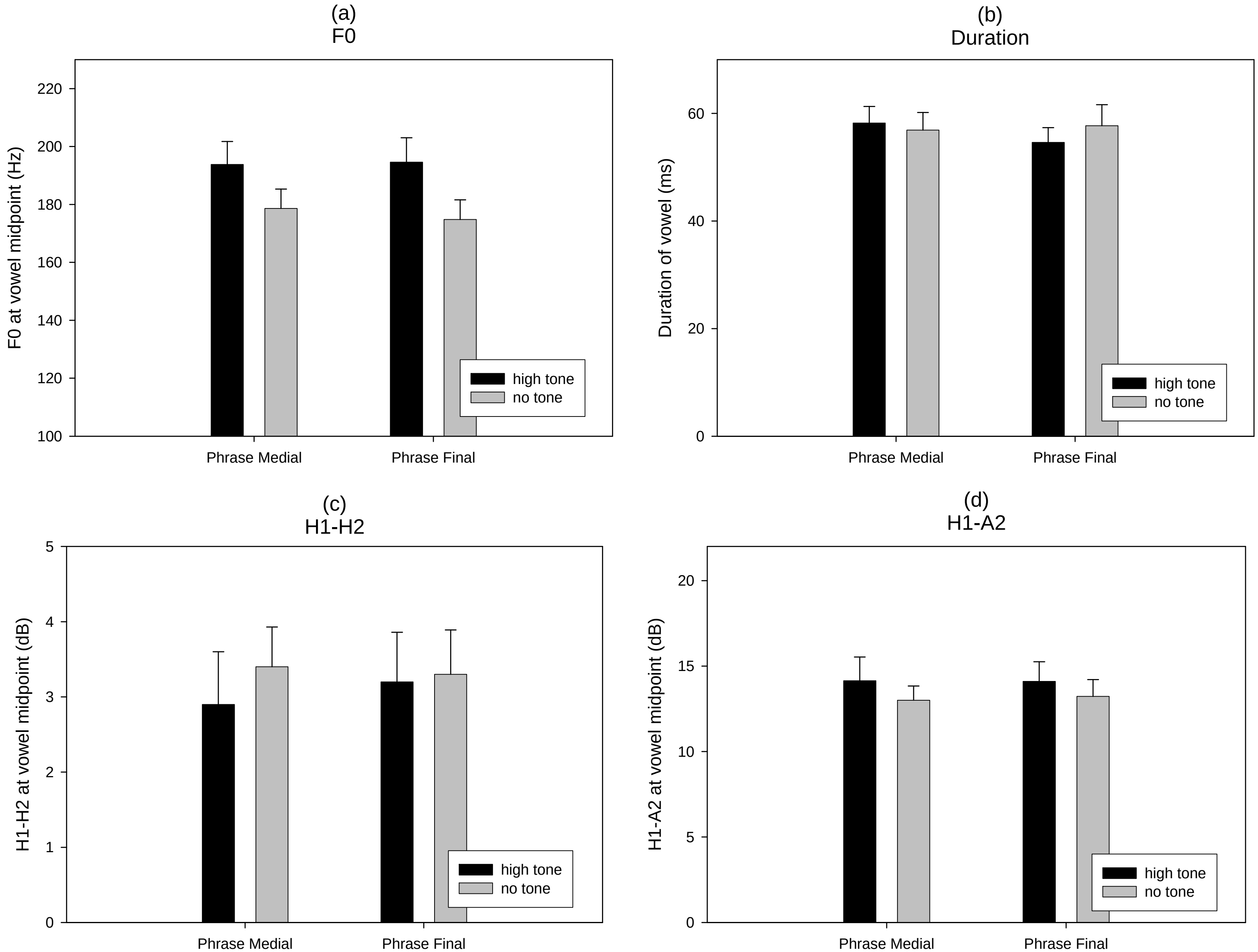


Figure 8

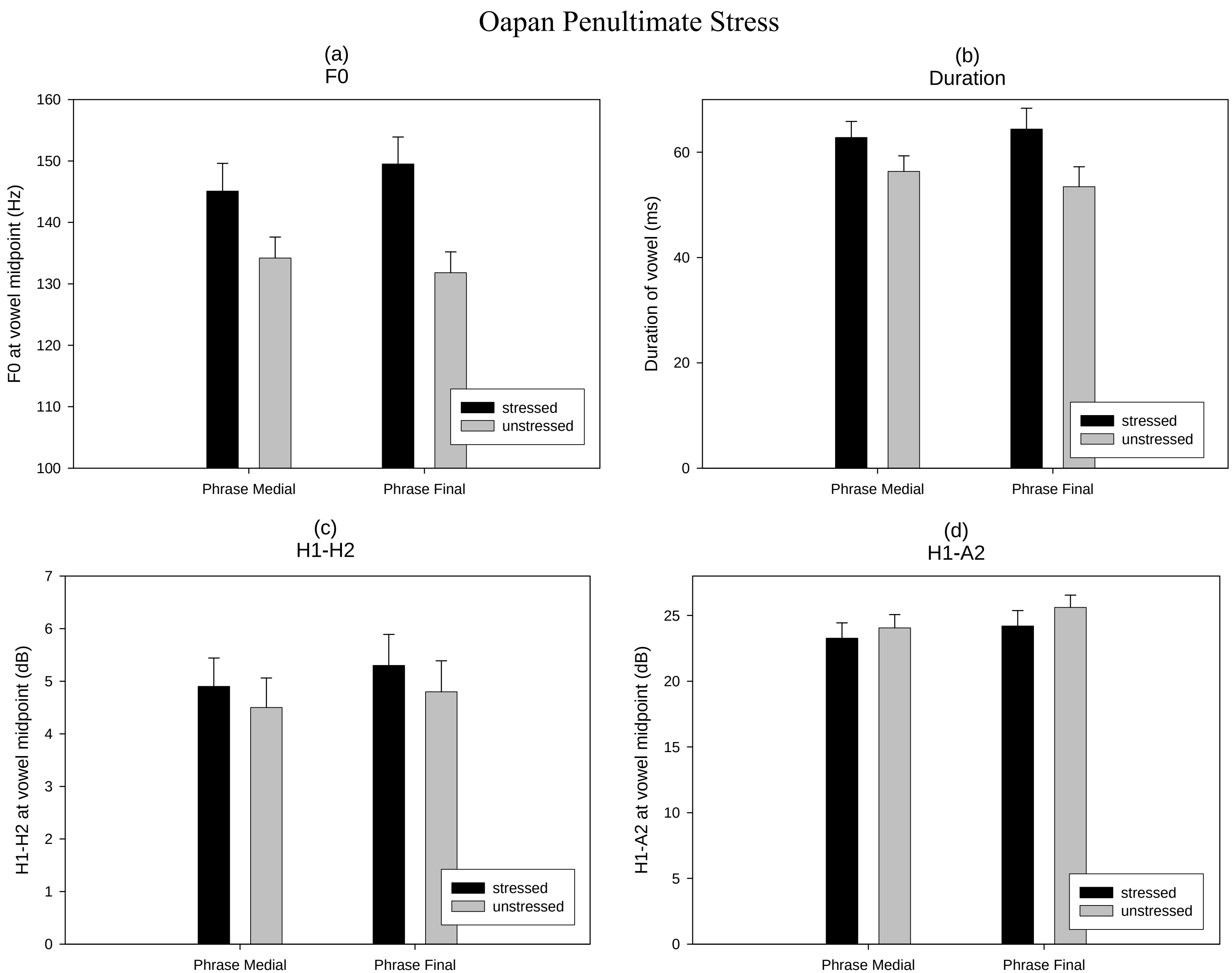

Oapan Penultimate Stress
(a)
F0
F0 at vowel midpoint (Hz)
160
150
140
130
120
110
100
Phrase Medial
Phrase Final
stressed
unstressed
(b)
Duration
Duration of vowel (ms)
60
40
20
0
Phrase Medial
Phrase Final
stressed
unstressed
(c)
H1-H2
H1-H2 at vowel midpoint (dB)
7
6
5
4
3
2
1
0
Phrase Medial
Phrase Final
stressed
unstressed
(d)
H1-A2
H1-A2 at vowel midpoint (dB)
25
20
15
10
5
0
Phrase Medial
Phrase Final
stressed
unstressed

Figure 9

Oapan High Tone on Syllable before Coda *h*

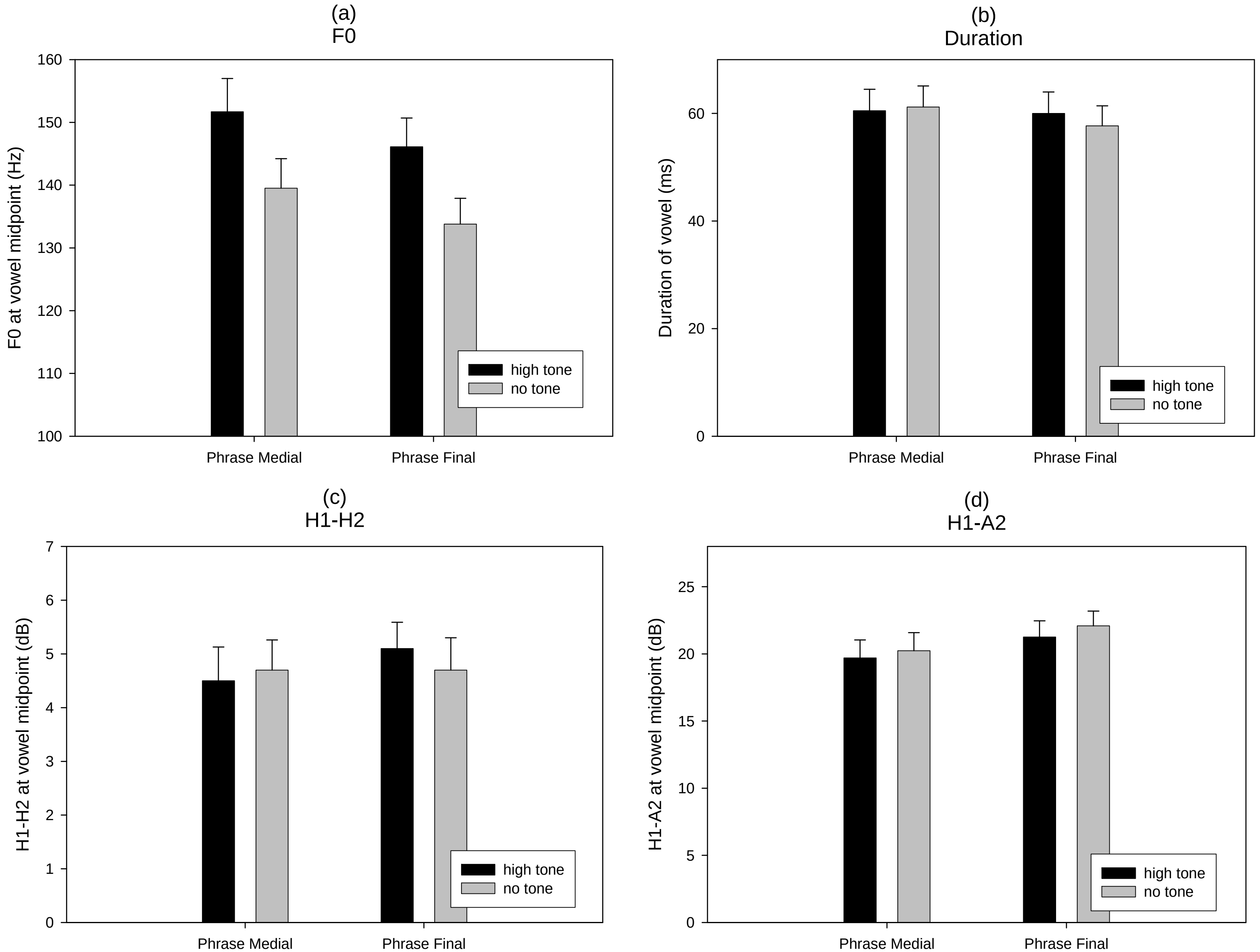


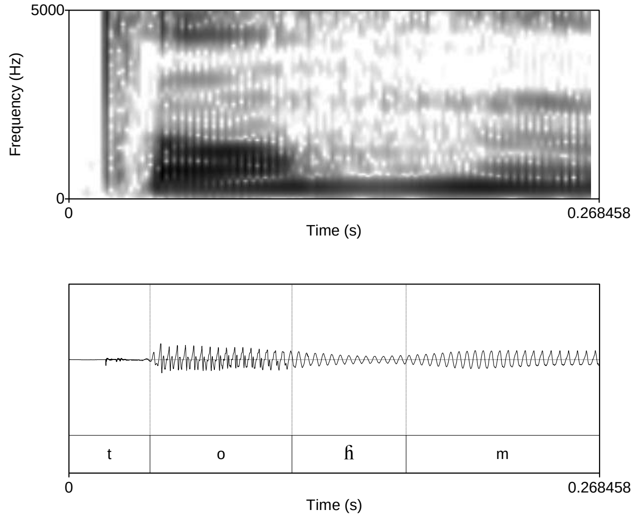
Figure 10

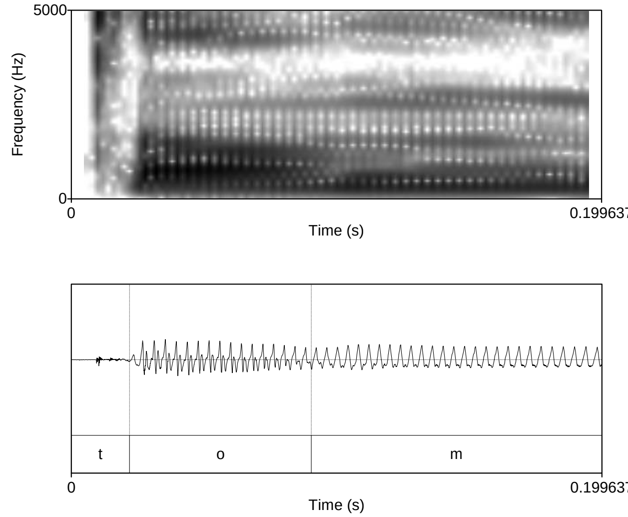
Appendix A

The figures here illustrate the production of a word with a non-word-final coda *h and a matched word spoken by one speaker from each village under investigation. The illustrations on the left are example productions of the beginning of the word **tohmitl* 'body hair' and those on the right, of **tomi:n* 'money'. For clarity of presentation just the beginning of the word through the [m] is illustrated. Note that in San Miguel and Ahuelicán the historical **h* is preserved and produced as a breathy voiced [ɦ] in [toɦmit͡l] < **tohmitl*. There is a clear period of voicing with reduced amplitude at the end of the syllable. Note also that the breathy voicing extends to the beginning of the [m] in these dialects. This can be contrasted with the production of [tomiːn] < **tomi:n*, which has no breathy voicing at the end of the syllable. On the other hand, the subdialects that have lost **h*, Ameyaltepec and Oapan, produce [tomit͡l] < **tohmitl* with no breathy voicing at the end of the syllable and the production is quite similar to [tomiːn] < **tomi:n*.

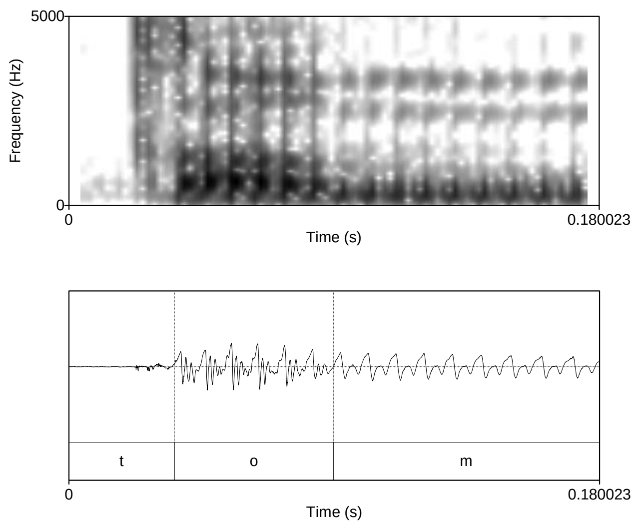
While these figures are representative of all the speakers from each village, it should be noted that the breathy phonation period in speakers from Ahuelicán is sometimes shorter than that in speakers from San Miguel. In San Miguel, the breathy voicing sometimes transitions to voicelessness towards the end of the syllable. Thus, while San Miguel speakers always have a breathy voiced portion as a reflex of **h*, they sometimes have a voiceless period after that. So, for example, the word illustrated here could sometimes be produce as [toɦmit͡l] and sometimes be produced as [toɦ͡hmit͡l].

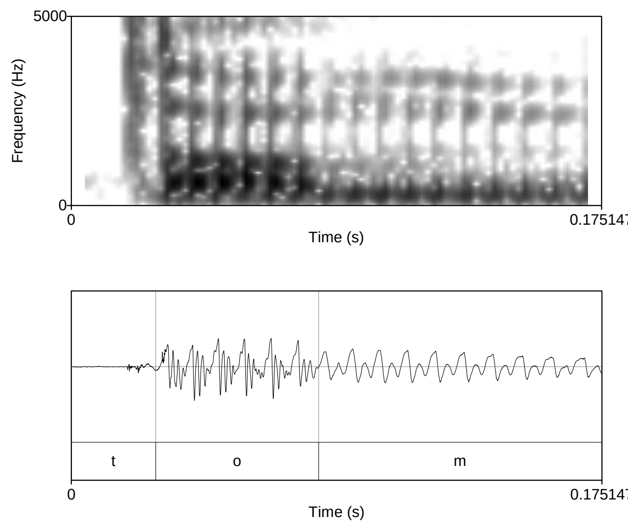
San Miguel (**h* retained, penultimate stress only)



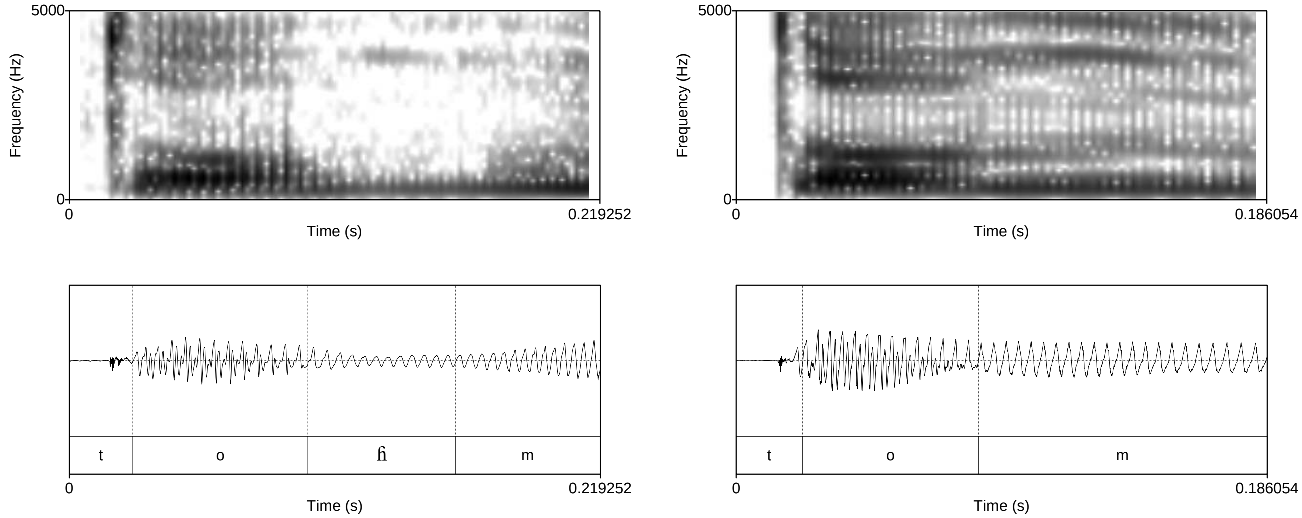


Ameyaltepec (**h* lost, penultimate stress only)

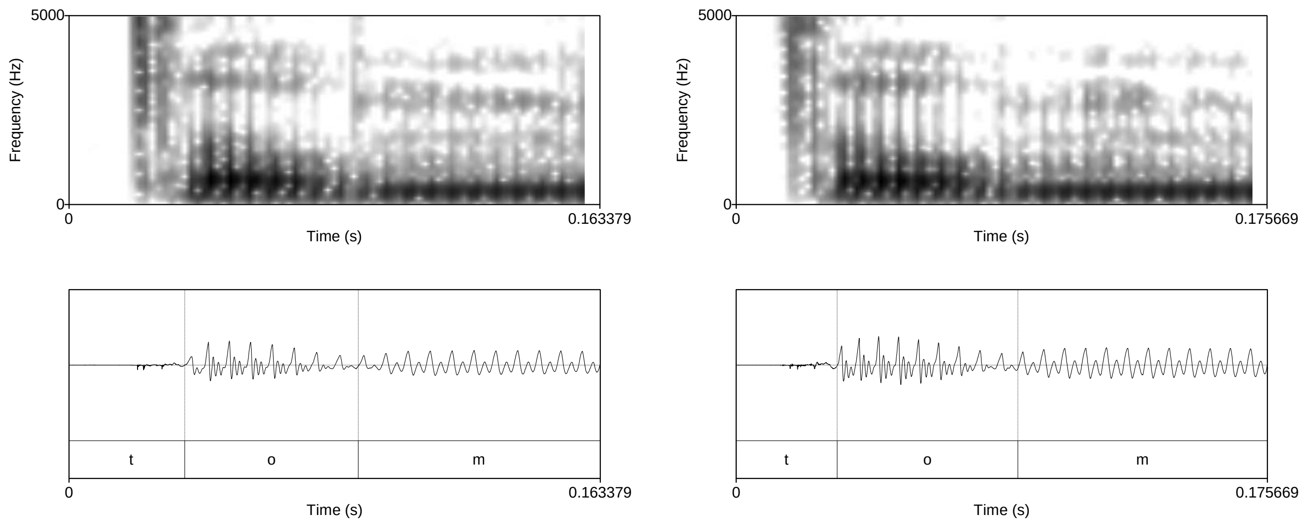




Ahuelicán (**h* retained, innovated tones)



Oapan (**h* lost, innovated tones)



Appendix B

The figures here illustrate the production of the target word [kíˈkiːskeːt͡ɬ] ‘partygoer < *ki**h**ˈkiːskeːt͡ɬ spoken by three speakers from Oapan. The temporal midpoint was measured for each vowel. These F0 tracks are representative of the observation that long and short vowels did not vary qualitatively in their F0 patterns.