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The Phonetics of Yucatec Maya and the Typology of Laryngeal Complexity*

Abstract

We examine the known typology of laryngeal complexity (SILVERMAN 1997a,b) in light of phonetic research (FRAZIER 2009) showing that Yucatec Maya uses contrastive tone and phonation type. The phonetic patterns in YM suggest that articulatory incompatibility is the most important factor in enforcing the phasing of tone and non-modal phonation, but that perceptual factors account for the distribution of phasing patterns. Furthermore, YM is similar to the unrelated languages Danish and Acoma which show that creaky voice conditions preceding high pitch. We motivate future research on cross-linguistic differences in the production of creak and its interaction with pitch and gender.

1. Introduction

Yucatec Maya (YM) is one of the few Mayan languages that is unambiguously tonal. Additionally, this language, like many other Mayan languages, has words such as *ta'ab* 'salt' and *a'al* 'speak' (see BRICKER ET AL. 1998) that have traditionally been described as having a "rearticulated" vowel (e.g. [vʔv]). Recent phonetic research on YM (FRAZIER 2009, 2011) shows that these vowels are best analyzed as long vowels that are marked for both high tone and creaky voice (such that the production of high pitch precedes the production of creak). According to SILVERMAN'S (1997a: 236) definition of *laryngeal complexity* – "vowels that possess both contrastive phonation and contrastive tone" – YM's "rearticulated" vowels (henceforth referred to as GLOTTALIZED, see §2.1) are laryngeally complex.

In this paper I discuss how YM fits in with the known typology of laryngeal complexity. YM is compatible with the patterns identified for other laryngeally complex languages in that tone and non-modal phonation are phased with respect to each other. However, the phasing pattern found in YM – post-tonal non-modal phonation – is predicted to only occur in languages that also have pre-tonal non-modal phonation. I argue that the phonetic patterns of YM show that articulatory incompatibility accounts for the existence of phasing, while perceptual factors account for the attested phasing patterns.

This paper is organized as follows. I first present the relevant aspects of the phonetics and phonology of YM in §2. This section includes details about the phonetics of pitch and glottalization as first documented in FRAZIER (2009, 2011),

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which show that GLOTTALIZED vowels are contrastive for pitch and glottalization. I then discuss the typology of laryngeal complexity in §3. This section looks at the phasing pattern of YM, the cross-linguistic tendency for high pitch to precede creaky voice, and the possibility of laryngeal complexity in other Mayan languages. Conclusions are presented in §4.

2. The Phonetics and Phonology of Yucatec Maya

In this section I present relevant background information on the phonemic inventory of YM, and I summarize the results of phonetic experimentation with regard to the production of pitch and glottalization. It is the results of this production experiment that indicate that YM is laryngeally complex.

2.1 Phonemic Inventory

Five vowel qualities are contrastive in YM: [i e a o u]. Additionally, each vowel quality is produced with one of four *vowel shapes*, which are bundles of suprasegmental features involving length, tone, and glottalization, yielding 20 contrastive syllable nuclei. The vowel shapes are described in (1) with an example minimal quadruplet presented in standard orthography.[1] Vowel shapes are identified by small capital letters throughout this paper so that these terms will not be confused with the same terms that refer to general phonetic and/or phonological properties (e.g. "GLOTTALIZED" is a phonological vowel shape in YM, whereas "glottalized" refers to the phonetic property of glottalization).

(1) vowel shape in YM (BRICKER ET AL. 1998, BLAIR & VERMONT SALAS 1965)

SHORT	/v/	chak 'red'	short, no tone, modal voice
LOW TONE	/v̀v/	chaak 'boil'	long, low tone, modal voice
HIGH TONE	/v́v/	cháak 'rain'	long, high tone, modal voice
GLOTTALIZED	/v́v̰/	cha'ak 'starch'	long, high tone, creaky voice

GLOTTALIZED vowels have traditionally been called "rearticulated" and represented by /vʔv/. The phonetic data presented in §2.2.1 shows that these vowels are most often produced with creaky voice and not a full glottal stop. For this reason, I refer to this vowel shape as GLOTTALIZED (rather than REARTICULATED) and use /v́v̰/ as the abstract phonological representation.[2, 3]

The consonantal inventory of YM includes the laryngeals [h ʔ]. Both laryngeal consonants can appear in onset and coda position: e.g. [ʔam] 'spider',

[1] BRICKER ET AL. (1998) and BLAIR & VERMONT SALAS (1965) refer to the SHORT vowels as "neutral" (indicating that these vowels are not tonal). I prefer SHORT because vowel length is the one factor that clearly distinguishes this vowel shape from the others.

[2] It is traditional in the literature on YM to use the term "glottalized" and not "laryngealized", and so this is the term I adopt for these vowels. In the discussion of laryngeal complexity in §3, I use "glottalized" and "laryngealized" interchangeably in describing this phonetic property.

[3] The tonal marker on GLOTTALIZED vowels is justified in §2.2.2.

[siʔ] 'firewood', [hun] 'one', [koh] 'tooth'. These consonants can appear before or after any vowel shape, though lexical items with a long vowel (HIGH TONE, LOW TONE, or GLOTTALIZED) followed by a glottal stop are rare and are most often found in dialects where [ɓ] becomes [ʔ] word-finally (e.g. *ta'ab* [táa̰ɓ] ~ [táa̰ʔ] 'salt', *tsuub* [tsùuɓ] ~ [tsùuʔ] 'agouti', *tsáab* [tsáaɓ] ~ [tsáaʔ] 'rattlesnake'). [4]

2.2 Production Experiment

In this section, I review the results of a production experiment designed to examine the phonetics of vowel shape in YM. This experiment was conducted in Yucatan, Mexico and involved 24 participants from Mérida (6 males – ages 33, 39, 40, 41, 47, 47 and 1 female - age 39), Santa Elena (5 males – ages 22, 25, 43, 63, 68 and 7 females – ages 19, 20, 25, 30, 33, 35, 63, and Sisbicchén (2 males – ages 30, 41 and 3 females – ages 24, 29, 30), Yucatan, Mexico. All participants except for the 3 females from Sisbicchén are fluent in Spanish; these 3 females understand Spanish but do not use it. Two participants are also fluent in English. All participants use YM in the home and in daily life.

The participants were recorded while they read 100 words in isolation, mostly of the form CVC. They were presented with a note card that displayed a word in Yucatec Maya along with its Spanish translation (due to the fact that many participants did not regularly read Yucatec Maya) and were asked to say aloud the Yucatec Maya word. The word list used for speakers from Santa Elena differed slightly from the word list for speakers from Mérida and Sisbicchén in that the former included some polysyllabic forms such that measurements are taken from a vowel in a non-final syllable.[5] Both word lists included 25 words with each vowel shape. Some of the words were nonce forms, and these words are excluded from analysis here. Measurements from non-final syllables (Santa Elena speakers only) are included in the data on glottalization in §2.2.1 but they are not included in data on pitch in §2.2.2. The full word list (excluding nonce forms) is in Appendix A.

Dialect variation in terms of the sound system of this language is not well documented. FRAZIER (2009, 2011) presents significant differences in the production of pitch and vowel length between speakers from Sisbicchén (on the eastern side of Yucatan) and speakers from Mérida and Santa Elena (on the western side of Yucatan). Speakers from the Mérida and Santa Elena produce pitch contours that closely resemble the claims about tone in the previous literature, whereas the speakers from Sisbicchén that I recorded did not produce different pitch values for HIGH TONE and LOW TONE vowels. To what extent these differences represent broader dialectal trends is unknown at this time. Due to their unique pronunciations, participants from Sisbicchén are excluded from the analysis of pitch presented in §2.2.2.

To summarize, after excluding the appropriate tokens, the data on glottalization comes from 19 tokens with GLOTTALIZED vowels as spoken by each

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[4] One example of a word with a long vowel followed by a glottal stop is *ti'i'* [tíḭʔ] 'there'. This word is bimorphemic in origin – *ti'-i'* 'there-LOCATIVE'.

[5] This word list difference was due to the fact that speakers from Santa Elena do not pronounce the labial implosive in word-final position (see FRAZIER 2009, 2011 for further discussion).

of the 24 participants. The data on pitch comes from 19 tokens with GLOTTALIZED vowels, 20 with HIGH TONE, 21 with LOW TONE, and 22 with SHORT vowels as spoken by each participant from Mérida and from 15 tokens with GLOTTALIZED vowels, 16 with HIGH TONE, 18 with LOW TONE, and 20 with SHORT vowels as spoken by each participant from Santa Elena.

The reader is referred to FRAZIER (2009) for the full methodology and results of this experiment.

2.2.1 Production of Glottalization

The GLOTTALIZED vowels of YM have traditionally been assumed to be of the form /vʔv/. However, the results of this experiment show that a full glottal stop is rarely produced. Instead, the canonical production of this vowel shape is one where creaky voice occurs during the medial portion or final half of the long vowel.[6]

Some examples of waveforms for tokens that are produced with creaky voice are shown in Figure 1. Here we see a great deal of variability in terms of the visible indicators of creak. The tokens in the top row show all the canonical signs of creaky voice (aperiodicity and widely and irregularly spaced glottal pulses (see GORDON & LADEFOGED 2001)). These two tokens differ in the placement of creak: the token on the left shows a return to modal voice before the end of vowel production, while, in the token on the right, creaky voice continues to the end of vowel production. The tokens in the middle row show a significant decrease in intensity but the waveform is periodic throughout and there is only a slight F0 decrease (with the latter not visible in this figure). Such tokens are quite common in YM. FRAZIER (2009) found that a decrease in intensity is the most consistent cue to a departure from modal voice in YM.[7] The token in the bottom row shows only a brief dip in intensity. It is clear in this token that there is some portion of the vowel produced with non-modal voice, but the main indicators of creaky voice are not present and the dip in intensity is very short. In §3.1.1, I return to the different acoustic patterns of creaky voice in YM.

[6] In FRAZIER (2009), creaky voice is divided into two categories: creak and “weak glottalization”. Both categories represent a departure from modal voice. Because the distinction between these two categories is not relevant here, I have conflated the two groups into one, identifying both as “creaky voice”.

[7] This acoustic pattern is similar but not identical to that found for creak in Coatzospan Mixtec (GERFEN & BAKER 2005).

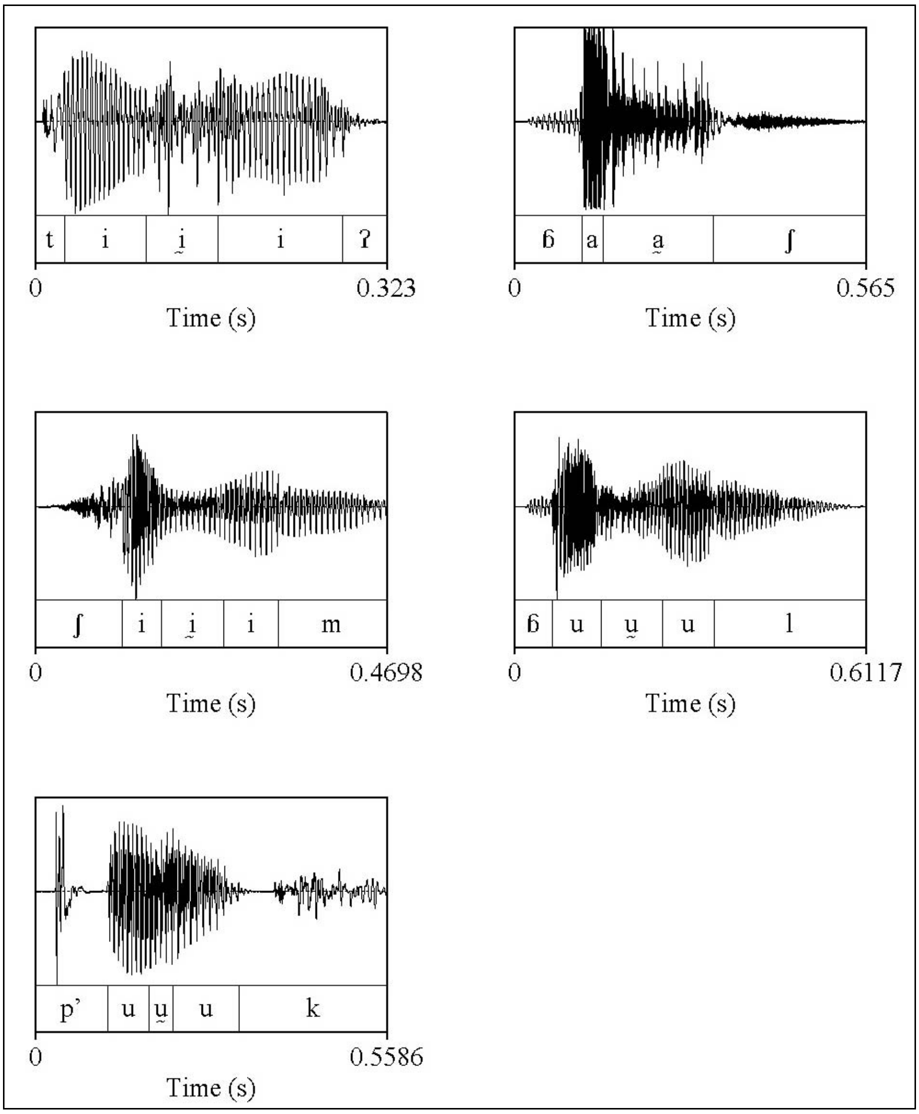

Figure 1: Example tokens of GLOTTALIZED vowels produced with creaky voice
top row: *ti'i'* 'there', *ba'ax* 'what'; middle row: *xi'im* 'corn', *bu'ul* 'bean'; bottom row: *p'u'uk* 'cheek'

While GLOTTALIZED vowels are most often produced with creaky voice, they can also be produced with a full glottal stop or with no glottalization at all (modal voice throughout vowel production). The tokens of GLOTTALIZED vowels collected in this production study (*n* = 456) were coded for glottalization type, and the distribution of each type is as follows: 37.5% modal voice only, 56.8% creaky voice, and 5.7% full glottal stop. It is thus the case that a large portion of GLOTTALIZED vowels are actually unglottalized. The exact positioning of creaky voice in the production of GLOTTALIZED vowels is somewhat variable. Of the 259 tokens of GLOTTALIZED vowels that were produced with creaky voice 81% were produced with creaky voice in the middle of vowel production (modal voice at the beginning and end of vowel production), 17% were produced with initial modal voice and with creaky voice that started at some point in the middle of vowel production and continued to the end of vowel production, while 2% were produced with some other pattern (i.e. initial creaky voice only or creaky voice throughout vowel production.)

There is no correlation between lexical item and glottalization type. For any lexical item with a GLOTTALIZED vowel, that vowel can be variably produced with any one of the glottalization types: full glottal stop, creaky voice, or no glottalization. There is substantial speaker-specific variation in terms of the type of glottalization produced with GLOTTALIZED vowels. For example, one female from Santa Elena (age 25) produced no tokens with a full glottal stop and 80% of GLOTTALIZED vowels with no glottalization at all, whereas another female from Santa Elena (age 35) produced 20% of GLOTTALIZED vowels with a full glottal stop and only 8% with no glottalization at all. Given such variability, we are in need of more data before speculating on the degree of dialect/gender/age-specific variation in the production of glottalization.

2.2.2 Production of Pitch

Figure 2 presents the average pitch contours for the four vowel shapes in YM as spoken by the 7 participants from Mérida and the 12 participants from Santa Elena. This figure represents averages from 313 tokens with a GLOTTALIZED vowel, 332 tokens with a HIGH TONE vowel, 363 tokens with a LOW TONE vowel, and 394 tokens with a SHORT vowel. Pitch is measured in *semitones over the baseline* (s/b), which is used to scale pitch values relative to a speaker's natural pitch range so that pitch values can be averaged across speakers in a meaningful way. A pitch value of, e.g., 2 s/b indicates a pitch value that is 2 semitones above that speaker's baseline.

(2) calculation of semitones over the baseline (s/b):
$s/b = 12 * \log_2(Hz/\text{baseline Hz})$, where baseline Hz = the average pitch value produced at the mid point of LOW TONE vowels for a given speaker.

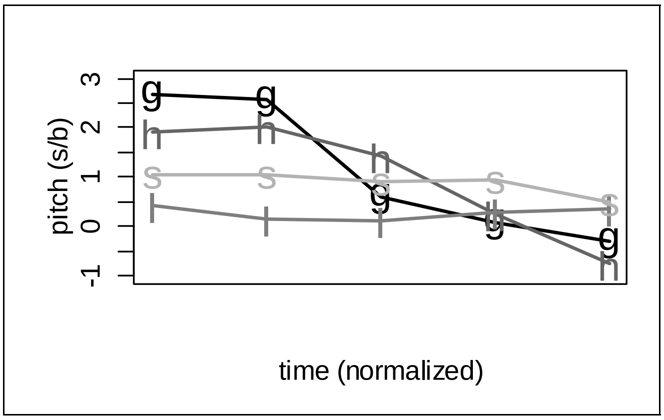

Figure 2: Average pitch contours by vowel shape
'g' = GLOTTALIZED; 'h'= HIGH TONE; 'l' = LOW TONE; 's' = SHORT

As shown above, both HIGH TONE and GLOTTALIZED vowels begin with high pitch and end with low pitch, but the initial portion of GLOTTALIZED vowels has higher pitch than the initial portion of HIGH TONE vowels.[8]

Furthermore, GLOTTALIZED vowels are produced with high pitch even when they are not produced with glottalization. Figure 3 shows the average pitch contours of GLOTTALIZED vowels produced with creaky voice and GLOTTALIZED vowels produced with modal voice for each gender. Productions with a full glottal stop (*n* = 24) are excluded from this graph as the glottal stop interrupts pitch production and, in many cases, allows for pitch measurement to be obtained at only the initial and final time points. It should be noted, though, that high pitch does occur on the initial portion of a GLOTTALIZED vowel when produced with a full glottal stop. Figure 3 thus presents averages from 57 tokens with modal voice and 116 tokens with creaky voice as spoken by males and 51 tokens with modal voice and 65 tokens with creaky voice as spoken by females.

There are two important aspects of the phonetics of YM displayed in this graph. First, we see that the initial high pitch of GLOTTALIZED vowels cannot be solely conditioned by the following creaky voice, as GLOTTALIZED vowels are produced with initial high pitch regardless of whether creaky voice or modal voice follows. This is the motivation for including a tonal marker on the representation of GLOTTALIZED vowels in (1). Given that a third of GLOTTALIZED vowels are produced without glottalization, it is clear that pitch is an important cue to this vowel shape. Second, we see that creaky voice has a different effect on the production of pitch by females than it does on the production of pitch by males. Specifically, creaky voice causes females to produce pitch value that are much lower than their baseline, while the pitch produced during creaky voice is right at the baseline for males. The implications of this result are discussed further in §3.1.1.

[8] The pitch of GLOTTALIZED vowels is significantly higher than the pitch of HIGH TONE vowels at time point 1 ($t(584) = 4.3$, $p < .01$) and time point 2 ($t(597) = 3.0$; $p < .01$, using a mixed linear regression model to account for multiple observations within subjects).

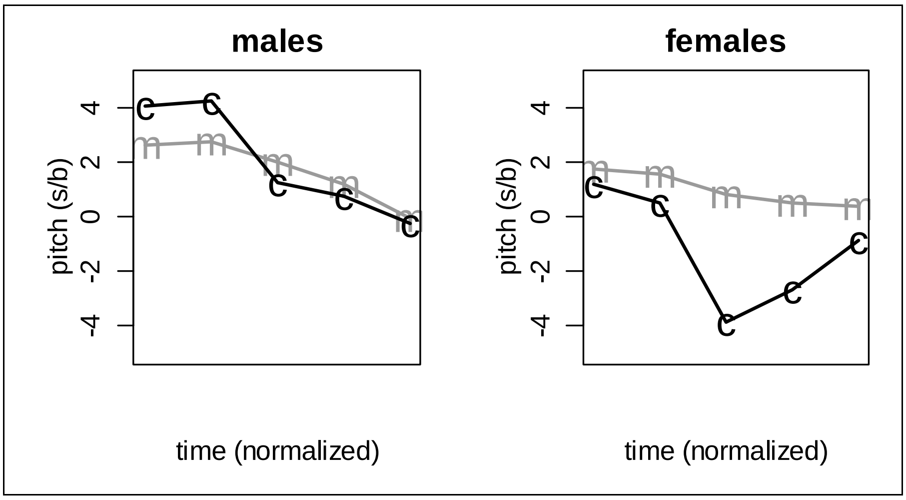

Figure 3: Average pitch contours of GLOTTALIZED vowels by gender and glottalization type
'c' = creaky voice; 'm' = modal voice

2.3 Local Summary

GLOTTALIZED vowels are best represented by the form /v́v̰/. These vowels are most often produced with creaky voice and least often with a full glottal stop, and they are produced with initial high pitch regardless of whether or not creaky voice is produced.

3. Laryngeal Complexity

SILVERMAN (1997a,b) introduces the term *laryngeal complexity* to refer to the contrastive use of pitch and phonation type within a single nucleus or syllable. The Otomanguean languages that he analyzes display a high degree of laryngeal complexity. For example, in Jalapa Mazatec, there are multiple level and contour tones that can occur in combination with breathy or creaky voice. While it is clear that YM is not as laryngeally complex as Jalapa Mazatec, the fact that GLOTTALIZED vowels must be marked for tone and non-modal phonation shows that YM should be considered in any discussion of the typology of laryngeal complexity.

It is common in laryngeally complex languages that tone and non-modal phonation are not produced simultaneously, but rather are *phased* with respect to each other. In Jalapa Mazatec, non-modal phonation is always associated with the first portion of the vowel, while the tonal contrast appears on the latter portion of the vowel. As will be discussed in more detail below, SILVERMAN identifies three phasing patterns (pre-tonal laryngealization, post-tonal laryngealization, and interruptive laryngealization (e.g. /vʔv˥/)) and proposes an implicational hierarchy among these patterns: interruptive laryngealization implies the presence of post-tonal laryngealization, which implies the presence of pre-tonal laryngealization (see §3.1 for further discussion).

There are laryngeally complex languages that do not realize phasing. Both Mpi (SILVERMAN 1997a) and Zapotec (HERRERA Z 2000) allow tone and non-modal phonation to be produced simultaneously, and both are claimed to be exceptions because creak is weakly implemented (i.e. the glottis is less constricted).

Before continuing on to further discussion of the typology of laryngeal complexity, it is important to note that laryngeal consonants and laryngeal gestures on vowels are often conflated in the literature. SILVERMAN (1997a,b) uses different symbols for laryngeal consonants and phonation type but treats them the same: Jalapa Mazatec has breathy or creaky voice before tone, while Comaltepec Chinantec has [h] or [ʔ] before or after tone, and both languages are analyzed as laryngeally complex. YM has laryngeal consonants that occur pre- and post-vocalically and contrastive creaky voice that only occurs post-vocalically. In YM, laryngeal consonants and laryngealization on vowels pattern differently (see §3.1.2), and this suggests that it may be important to more carefully distinguish between laryngeal consonants and laryngealized vowels in other languages.[9]

3.1 Phasing

There are many plausible reasons for why phasing of tone and non-modal phonation is so common. SILVERMAN (1997a,b) identifies both perceptual and articulatory factors: acoustic distance, articulatory compatibility, and auditory salience. In the discussion, SILVERMAN (1997a: 257) emphasizes the role of perception, saying "the sequencing of contrastive laryngeal configurations is often observed so that all contrastive information is rendered recoverable by the listener." Thus, tonal contrasts are not easily recovered during the production of non-modal phonation, and so they are normally produced during modal voice.

In considering the implicational universals with regard to the placement of non-modal phonation, SILVERMAN (1997a: 251) again looks to the perceptual advantages of each pattern by showing how "different timings of a given set of articulatory gestures may produce a stronger or weaker neurochemical response in the inner ear." In this regard the optimal timing pattern is pre-tonal laryngealization (which is also the most common pattern cross-linguistically). If only two phasing patterns are utilized, the post-tonal pattern is maximally distinct from pre-tonal, making these patters well suited for contrast. Finally, if three phasing patterns are utilized, the interruptive pattern is maximally distinct from both pre- and post-tonal laryngealization. In this way, SILVERMAN'S hierarchy is functional in that it is a direct response to articulatory and auditory properties of speech.

In the following two subsections, I discuss phasing in YM in order to answer two questions. Is phasing in YM best analyzed as articulatorily or

[9] There is currently no literature on how robust SILVERMAN'S hierarchy is. Part of the problem with identifying laryngeal complexity and phasing patterns may be that there is no consensus on how to treat laryngeal consonants versus laryngeal vowels.

perceptually motivated (§3.1.1)? Why is post-tonal non-modal phonation the only phasing pattern in YM (§3.1.2)? I propose that there are different motivations for why phasing happens in the first place in YM and for why the attested YM pattern is an exception to the implicational hierarchy. Specifically, YM presents evidence that articulatory incompatibility is a primary factor in ensuring the existence of phasing. Cross-linguistically, auditory salience predicts the implicational hierarchy of phasing patterns, but YM is an exception to this hierarchy because it is *minimally laryngeally complex*. There is no pressure to develop the optimal phasing pattern of pre-tonal laryngealization.

3.1.1 Articulatory Incompatibility in YM

It is well known that creaky voice is associated with lower fundamental frequency. In the production of creak, the thyroarytenoid muscles are contracted but the cricothyroid muscles are relaxed (MCGLONE & SHIPP 1971; see comprehensive discussion in KINGSTON 2005). This means that there is glottal closure but that the vocal folds are not stiff, which results in low F0. Extremely low F0 with creaky voice (often called "vocal fry") has been repeatedly documented for English speakers (MCGLONE 1967, MCGLONE & SHIPP 1971, BLOMGREN ET AL. 1998).

However, the fact that "lower fundamental frequency" may mean something different for males and females has not been systematically addressed in the literature. We know that tone (or intonation) is a function of a speaker's natural pitch range; high tone produced by females will be on average higher than high tone produced by males. In this section I present evidence that pitch produced during creaky voice does not work this way in YM.[10]

We saw in Figure 3 that when GLOTTALIZED vowels are produced with modal voice, they have the same pitch contours for both genders. However, when GLOTTALIZED vowels are produced with weak glottalization or creaky voice, the pitch contours are quite different for the two genders. When females produce creaky voice, the resulting pitch is much lower than their natural pitch range, whereas the pitch produced during creaky voice is well within the normal pitch range for males. In fact, there are many cases where males produce creaky voice during the medial portion of the vowel, and where the final pitch of the vowel (during modal voice) is lower than the pitch produced during creaky voice.

This result is further demonstrated in Figure 4, where we see the average pitch contours of those GLOTTALIZED vowels that were actually produced with creaky voice (and not modal voice only or a full glottal stop) as produced by each gender and measured in Hz and s/b (see (2)). Here we see that Hertz values are similar for both genders at the middle time point (where creaky voice is normally produced). In fact, the difference between the mean pitch values (in Hz) produced

[10] The only other study I have been able to find that presents relevant F0 measurements for males and females shows a similar result. BLOMGREN ET AL. (1998) measured F0 during productions of "modal register" and "vocal fry" and found that the average F0 for females was much higher than males during modal register (211.0 Hz for females as compared to 117.5 Hz for males) but not during vocal fry (48.1 Hz for females and 49.1 Hz for males).

at the middle time point by each gender is not statistically significant (t(113) = 1.74, p = .085, using a mixed linear regression model to account for multiple observations within subjects). It is only when pitch during creak is relativized to a speaker's baseline that the pitch values differ between the genders.

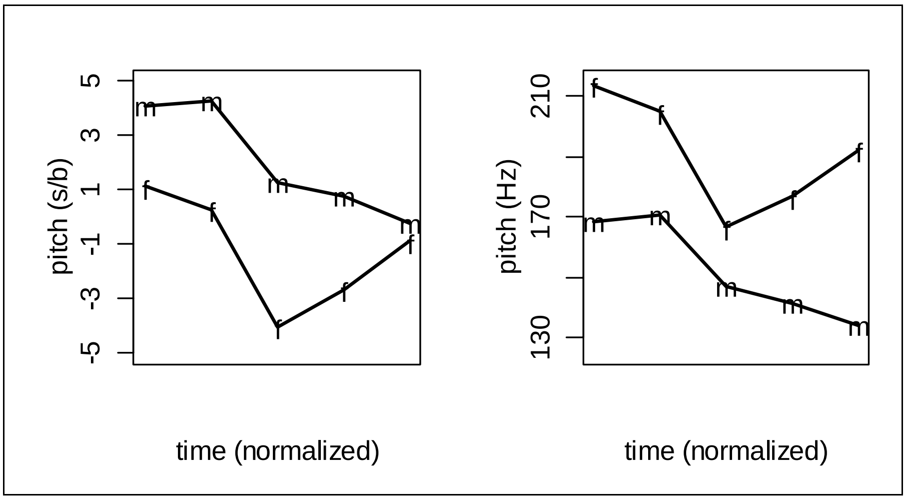

Figure 4: Average pitch contours of GLOTTALIZED vowels produced with creaky voice by gender when pitch is measured in semitones over the baseline (left) and Hz (right)
'm' = males; 'f' = females

The above graph shows that pitch during creaky voice is not a function of a speaker's natural pitch range. In fact, the data suggests that there is some fundamental frequency that is an inherent byproduct of creaky voice. In other words, these speakers are not targeting a particular F0, but rather there is a specific small range of F0 values that results from the production of creak such that other F0's would be articulatorily incompatible with creaky voice. Figure 4 thus presents evidence that articulatory incompatibility of creak and tone ensures phasing in YM. Further support for this claim comes from the fact that there is no obvious perceptual advantage to having pitch contours that have significantly different shapes for each gender.

The result presented in Figure 4 is perhaps surprising when we consider that creaky voice is often "weak" in YM. As discussed in §2.2.1, creaky voice in YM is most often realized by a drop in intensity alone. Additionally, the anatomy of the larynx is such that vocal fold adduction and vocal fold stiffness can be independently controlled (by the thyroarytenoid and cricothyroid muscles, respectively). KINGSTON (2005: 152) summarizes, "This independent control permits the speaker to vibrate the vocal folds at different rates while maintaining the same glottal constriction."

In order to determine exactly why tone and creak are incompatible in YM, we will need to identify exactly which articulatory maneuvers are required to produce the acoustic patterns shown in Figure 1. Given the results of EDMONDSON

& ESLING (2006) showing which *valves of the throat* are involved in the production of creak (namely Valve 1, which controls vocal fold abduction and adduction, and Valve 3, which involves thyroarytenoid contraction), one wonders if the different acoustic patterns result from different degrees of engagement of these valves or from the use of different valves altogether. The same questions should be asked of languages like Mpi and Zapotec, which allow the simultaneous production of tone and creak. In order to fully understand to what degree tone and non-modal phonation are articulatorily incompatible, we must determine the exact articulations involved in each of these languages.

3.1.2 The YM Phasing Pattern

In YM, the only phasing pattern is post-tonal. While there is variation with regard to whether or not a GLOTTALIZED vowel ends with modal voice, the creaky portion of the vowel always occurs after the tonal portion of the vowel. The fact that laryngeal consonants can occur pre- and post-vocalically and hence pre-and post-tonally does not lead to more phasing patterns. Laryngeal consonants and vocalic creaky voice are phonologically different in YM. The consonants function like any other consonants in the language, while creaky voice is a phonetic property that is only associated with one particular vowel shape. It would be a mistake to treat laryngeal consonants and non-modal phonation equally and thus to conclude that YM uses both pre-tonal and post-tonal phasing patterns.

I propose that the reason YM is an exception to the implicational hierarchy of phasing patterns is because YM is minimally laryngeally complex. There is only one vowel shape that must be specified for both tone and non-modal phonation. Thus, sufficient auditory salience can be achieved with post-vocalic creak. It seems that if the tonal system is less complex and if the use of non-modal phonation is kept to a minimum, contrast can be maintained even without the use the of the optimal phasing pattern.

There is still an open question regarding *why* the single phasing pattern of YM involves post-tonal laryngealization. After all, even if there is not a strong motivation to develop the optimal phasing pattern, there is certainly no synchronic motivation for a suboptimal phasing pattern. I suggest that the diachronic development of GLOTTALIZED vowels can shed some light on this question.

There is ample reason to believe that at some point in its history the GLOTTALIZED vowels really were generally produced as [vʔv]. First, Proto-Mayan and Proto-Yucatecan are proposed to have this form (KAUFMAN 1969, FISHER 1973). Second, modern day Mayan languages have this form. Unfortunately, for most Mayan languages, there is no phonetic data to verify that transcriptions of the form [vʔv] are accurate (and not better represented with creaky voice instead of a full glottal stop).[11] Finally, early linguists working with YM (e.g. PIKE 1946, BLAIR & VERMONT SALAS 1965) describe the GLOTTALIZED vowels as being of the form [vʔv]. Thus, we do not know *when* creaky voice replaced a glottal stop as

[11] BAIRD (2010) has recently shown that, in K'ichee' words of the form /CVʔC/ can be produced as [CVʔC], [CVʔV̰C], or [CVV̰C], with [CVʔC] being the most common realization.

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the canonical production, but it seems clear that this change did happen. Furthermore, it seems likely that we are witnessing a change in progress and that we should keep an eye on YM to see how the change develops and specifically to see whether or not post-vocalic creak becomes pre-vocalic.

The first analyses of YM also recognized that the GLOTTALIZED vowels were produced with initial high pitch (see PIKE 1946). There are thus two things that had to happen in order to for *[vʔv] to develop into modern day [v́v̰]: a full glottal stop becomes more rarely produced, with creaky voice in its place, and the initial high pitch (which starts as an intrinsic correlate of the following glottal stop) is reinterpreted as tonal (i.e. pitch has been phonologized and then phonemicized in the sense of HYMAN (1976)). Since the vowel has been reanalyzed as starting with tone, non-modal phonation must occur on the medial or latter portion of the vowel, thus leading to post-tonal laryngealization instead of the optimal pre-tonal laryngealization. Because there are no minimally contrastive forms such as [v̀v̰] in YM, there is no pressure for the suboptimal [v́v̰] to develop into the optimal [v̰v́].

According to HYMAN (1976: 412), the phonologization of a phonetic parameter generally leads to a collapse in the contrast that conditioned the phonetic differences in the first place: “The development of a phonological rule carries the seeds of its own destruction.” In this regard it is interesting to note that it was creaky voice (or a full glottal stop) that conditioned the pitch differences that were reinterpreted as tonal, and that, while creaky voice is still phonemic in YM, a large percentage of GLOTTALIZED vowels are actually produced without it. Given HYMAN’S explication of the phonologization process, one might expect creaky voice to lose its phonemic status in the future. If the GLOTTALIZED vowels do indeed loose their phonological creaky voice, a merger would occur as both HIGH TONE and GLOTTALIZED vowels would be long vowels with initial high pitch: [v́v]. On the other hand, a reviewer points out that such a pending merger could exert the pressure needed for YM to develop the optimal phasing pattern of pre-tonal laryngealization. If GLOTTALIZED vowels had the realization [v̰v́], they would be distinguishable from HIGH TONE vowels even without the production of creaky voice. Only time will tell if either of these scenarios plays out in the language.

3.2 A Cross-Linguistic Correlation between High Pitch and Creaky Voice

I have argued above that the initial high pitch of GLOTTALIZED vowels must be a tonal and not an intrinsic consequence of the following glottalization because GLOTTALIZED vowels are produced with initial high pitch even if they are not produced with glottalization (see Figure 3). Cross-linguistically, it is common for high pitch to precede creaky voice or a glottal stop. Acoma has a “glottal accent” (MILLER 1965) that is produced with a falling pitch contour and with creaky voice. The Danish *stød* is well-documented as being produced with initial high pitch and following creaky voice. While no one has studied the phonetic facts regarding Acoma’s glottal accent, the literature on *stød* in Danish is quite robust. FISCHER-JØRGENSEN (1989) presents a thorough acoustic analysis showing how the first and last portion of *stød* differ: the initial portion is produced with high pitch and intensity, while the latter portion shows decreased intensity and pitch as well as aperiodicity and longer closure time for each vibration (which are all characteristics of creaky voice). Furthermore, analysis of vocal fold movements by means of fiberoptics shows that *stød* is produced with a greater degree of vocal fold constriction and sometimes constriction of the ventricular folds. Phonological accounts differ as to whether or not *stød* is tonal, though it is historically related to word accents in Swedish and Norwegian (e.g. FISCHER-JØRGENSEN 1989, RIAD 2000). RIAD (2000) says that *stød* should be represented as a HL contour tone, while BASBØLL (2003) argues against a tonal treatment of *stød*. Whether or not a tonal representation is the best approach, it is clear that high pitch and creak are connected in some sense.

Further evidence for the idea that creaky voice conditions preceding high pitch comes from Coatlán-Loxicha Zapotec, where vowels before glottalized sonorants are produced with high pitch (PLAUCHÉ ET AL. 1998). Finally, it is well known that a coda glottal stop can condition a rising pitch contour in the preceding vowel (HOMBERT 1978).

In Acoma and Danish, it is possible to claim that creaky voice conditions preceding high pitch. It is thus not necessary to mark high pitch in the phonological form as high pitch could be analyzed as a consequence of the phonetic grammar. This means that neither Danish nor Acoma are properly analyzed as laryngeally complex. However, the phonetic forms in these languages for glottal accent and *stød* are equivalent to YM's GLOTTALIZED vowel. The difference between YM on one hand and Danish and Acoma on the other is that high pitch has been phonemicized in YM. The intrinsic high pitch that occurs before creaky voice or a glottal stop has been reinterpreted as tonal. It would be notable if exceptions to SILVERMAN'S implicational hierarchy could be explained in a similar fashion. It would thus be beneficial for future research to explore this relation between pitch and creak: Why is high pitch before creaky voice so common?

3.3 Other Mayan Languages

There are three other Mayan languages that are claimed to have tone: Uspanteko, Mochó, and the San Bartolo dialect of Tzotzil (CAN PIXABAJ 2006, KAUFMAN 1972: 31, FOX 1978). Unfortunately, there is no documentation as to whether or not these languages might make contrastive use of non-modal phonation. As noted above, the literature on Mayan languages is neither consistent nor explicit in its use of glottal stops. For example, FISHER (1973: 137) discusses the fact that each Yucatecan language (Yucatec, Mopan, Itzaj, and Lakantun) has surface forms represented by /CVʔVC/ and /CVʔC/ though there is no evidence that these forms are ever contrastive. There is thus no consensus in the literature as to the placement of glottal stops in particular Mayan languages. Furthermore, whether or not the glottal stop is actually realized with full glottal closure is seldom addressed. It would thus be fruitful for future work to investigate the role of the glottal stop in Mayan languages generally, and especially in Mayan languages that use tone. If there are other Mayan languages that are laryngeally complex, the phonetic facts about these languages can not only expand our understanding of laryngeal complexity but can also help tease apart some of the diachronic developments of tone and glottalization in YM.

4. Conclusions

The phonetic data from YM emphasizes the role of articulatory incompatibility in enforcing the existence of phasing in laryngeally complex languages. Even though creaky voice is often weakly implemented in this language, females and males produce nearly identical F0 values during creaky voice. The fact that this leads to dramatically different overall pitch contours for GLOTTALIZED vowels across genders suggests that there is no perceptual benefit to this pattern, but rather that specific F0 values are intrinsically tied to the production of creak. On the other hand, it is likely that auditory salience does account for the distribution of phasing patterns in the world's languages. YM is an exception to the implicational hierarchy (which says that post-tonal non-modal phonation implies the presence of pre-tonal non-modal phonation) because of its minimal use of contrastive phonation type. There is no pressure for YM's GLOTTALIZED vowels to develop from /v́v̰/ to /v̰v́/.

There are still many open questions about the interaction of pitch, creaky voice, and gender that cannot be answered at this time. This paper has thus motivated future research on a variety of topics. What are the exact differences in the production of creak in YM, where F0 is an intrinsic correlate of creaky voice, and in a language like Mpi, where tonal contrasts can be produced simultaneously with creaky voice? Why does creaky voice condition preceding high pitch? Are there other Mayan languages that are laryngeally complex? These questions must be answered in order to further our understanding of the typology of laryngeal complexity.

Appendix: Word List

The following wordlist includes the YM words that were used the in the production experiment as reported on here. Words followed by a superscript [se] were presented to only those participants from Santa Elena; words followed by a superscript [m/s] were presented to only those participants from Mérida or Sisbicchén; and all other words were presented to all participants. For all polysyllabic words, measurements were taken from the first syllable, except for *k'aaba'* 'name' as presented to all participants, for which measurements were taken from the final syllable.

YM word	***English***	**YM word**	***English***	**YM word**	***English***
i'	*hawk*	peek'	*dog*	k'at	*clay*
ich	*in*	púuts'	*needle*	p'u'uk	*cheek*
e'es	*show*	chab [m/s]	*anteater*	k'aas	*ugly*
ook	*foot*	chabo' [se]	*that anteater*	k'áax	*forest*
óox	*three*	ta'ab [m/s]	*salt*	k'an	*ripe*
am	*spider*	ta'abo' [se]	*that salt*	k'a'an	*strong*
a'al	*speak*	xiib [m/s]	*man*	k'iin	*day, sun*

oon	*avocado*	xiibo' [se]	*that man*	k'áan	*hammock*
éem	*descend*	píib [m/s]	*under-ground roasting pit*	ch'och'	*cicada*
uk’	*louse*	píibo' [se]	*that under-ground roasting pit*	k'i'ik'	*blood*
eek’	*star*	ni'	*nose*	t'uut'	*parrot*
éets’	*echo*	laa'	*old*	k'áak'	*fire*
abal [se]	*plum*	lak	*clay cup*	k'ab [m/s]	*arm*
u'ub [m/s]	*listen*	na'at	*intelligent*	k'abo' [se]	*that arm*
u’ubik [se]	*hear it*	miis	*cat*	k'a'abéet [se]	*necessary*
iib [m/s]	*bean*	máak	*person*	k'aaba' [se]	*name*
iibil [se]	*bean*	nal	*corn*	ts'íib [m/s]	*writing*
áabil [se]	*grand-child*	mo'ol	*paw*	k'óoben [se]	*kitchen*
ka'	*metate*	maan	*buy*	k'aaba'	*name*
ti'i'	*there*	néen	*mirror*	bix	*how*
tsuu'	*aguti*	mak'	*cork*	ba’ax	*what*
tsáa'	*rattle*	ma'ats'	*hull (corn)*	beet	*make, do*
chak	*red*	neek'	*seed*	báat	*axe*
tso'ots	*hair*	láak'	*other*	bin	*go*
tsaap	*fuzz that causes itching*	ya'ab [m/s]	*a lot*	bu'ul	*bean*
cháak	*rain*	ya'abo' [se]	*a lot*	beel	*road*
kan	*four*	yeeb [m/s]	*fog*	bíin	*future aspect*
xi'im	*corn*	yaabilaj [se]	*love*	bak’	*meat*
tseem	*chest*	náab [m/s]	*hand span*	bi’ik’	*wiggle*
chéel	*rainbow*	náabo' [se]	*that hand span*	beech’	*quail*
pak'	*wall*	ch'o'	*mouse*	bóoch’	*shawl*
pi'its'	*slightly (sweet)*	t'uu'	*side (of hammock)*	be'eb [m/s]	*a type of vine*
				báab [m/s]	*swim*

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