The Interaction of Pitch and Creaky Voice: Data from Yucatec Maya and Cross-Linguistic Implications

Melissa Frazier
University of North Carolina at Chapel Hill

Using examples from Yucatec Maya, I present new methodologies with regard to coding glottalization and measuring pitch. I show that lower intensity is the most consistent cue to creaky voice in YM, and I develop a new measurement for scaling individual pitch values to a speaker-specific constant so that these measurements can be compared across speakers. Additionally, I address the interaction of pitch and creaky voice in YM, showing that males and females produce the same pitch values during creaky voice (meaning that pitch during creaky voice is not a function of a speaker's natural pitch range).

1 Introduction

Yucatec Maya (YM, a Mayan language of Mexico) uses pitch and glottalization to signal contrast in its vowel system (see §1.1). Recent production studies have documented the phonetic realization of these properties (which are discussed in detail in Frazier (2009a,b)). In analyzing the results of these production studies, new methodologies have been developed with regard to coding glottalization and measuring pitch.[1] The first goal of this paper is to present these methodologies so that other researchers can use and improve upon them. The second goal of this paper is to identify important areas for future work in the phonetic analysis of pitch and glottalization. Finally, we will see that pitch and creaky voice interact in a gender-specific way in YM, and the third goal of this paper is to document this interaction and to address its cross-linguistic implications.

In reviewing the acoustic correlates of modal and creaky voice in YM, I have found that there are at least three distinct patterns in spectrograms and waveforms that indicate a departure from modal voice and that lower intensity is the most consistent (and often only) indicator of glottalization. Given recent

I would like to thank the native speakers of Yucatec Maya who participated in this project and Jesse Saba Kirchner, Jennifer L. Smith, and Elliott Moreton for helpful feedback. This work was supported by the Jacobs Research Fund (Whatcom Museum, Bellingham, WA) and the Luis Quirós Varela Graduate Student Travel Fund (supplemented by the ISA Mellon Dissertation Fellowship at UNC-CH).

[1] The results of the phonetic studies are not presented in detail here; those interested in phonetic analysis of YM should consult Frazier (2009a,b) and other references therein.

work by Edmondson and Esling (2006), who show that two different "valves of the throat" are involved in the production of creaky voice (see §2), this result prompts future work in determining how the valves of the throat relate to these three acoustic patterns.

With regard to pitch, I develop a new method of scaling pitch values of individual speakers so that pitch measurements can be compared across speakers in a meaningful way. I identify a speaker-specific constant (following Pierrehumbert 1980) and transform pitch values (obtained in Hertz) into semitones above this constant (henceforth called *semitones over the baseline* (s/b)). This transform is successful in minimizing the differences among speakers when pitch measurements are obtained during the production of modal voice.

Finally, we will also see that, in YM, phonation type interacts with pitch in a way that is gender-specific. Pitch produced during creaky voice has the same frequency for both males and females and is thus not a function of a speaker's natural pitch range (cf. pitch during modal voice, which is higher for those with a higher natural pitch range).

This paper proceeds as follows. I first discuss the vowel system of YM in §1.1 and the procedures for the collection of data from native YM speakers in §1.2. Methodologies with respect to coding glottalization type are presented in §2, while in §3 I discuss the new method of measuring pitch. The interaction between pitch and creaky voice is addressed in §4, which includes discussion on the cross-linguistic implications of this result. Conclusions follow in §5.

1.1 Yucatec Maya Vowels

In YM, the suprasegmental properties of length, pitch, and glottalization contribute to contrast in the vowel system (see Bricker et al. 1998 for a concise description of YM phonemes). There are four contrastive sets of these properties (each set is henceforth referred to as a *vowel shape*), as defined in (1) with an example minimal quadruplet. Each vowel quality ([i e a o u]) can appear as any of the vowel shapes. Throughout this paper, small capital letters denote a vowel shape, such that GLOTTALIZED (for example) denotes a specific underlying phonemic category of YM, whereas "glottalized" or "glottalization" denote generic articulatory properties (applicable to any language).

(1) vowel shapes in Yucatec Maya

SHORT	short, mid pitch	/v/	*chak*	'red'
LOW TONE	long, low pitch	/v̀v/	*chaak*	'boil'
HIGH TONE	long, initial high pitch	/v́v/	*cháak*	'rain'
GLOTTALIZED	long, initial high pitch, medial or final creaky voice	/v́v̰/	*cha'ak*	'starch'

The phonological forms in (1) are proposed in Frazier (2009b:Table

2.21) as the forms that best account for the phonetic data on length, pitch, and glottalization in YM. As suggested by these forms, the HIGH TONE, LOW TONE, and GLOTTALIZED vowels are all about twice as long as the SHORT vowels. There is a tonal contrast on long vowels only: the LOW TONE vowels have steady low pitch, and the HIGH TONE and GLOTTALIZED vowels have initial high pitch and final low pitch.[2] The GLOTTALIZED vowels tend to be produced with either creaky voice (during the middle or final part of the vowel) or with a glottal stop (in the middle of the vowel). Traditional sources have used /vʔv/ or /v́ʔv/ as the phonological representation of this vowel shape, but recent phonetic research (Frazier 2009a,b; Avelino et al. 2007) shows that a glottal stop is rarely produced and that creaky voice is the primary manifestation of glottalization in YM.

1.2 Collection of Data

Phonetic data on YM was obtained from a production experiment conducted in Yucatan, Mexico (Frazier 2009a and production study 1 in Frazier 2009b; see these sources for the full methodology of this study). Twenty-four participants (both genders, ages 19-68) were recorded while they read 100 words (mostly of the form CVC) in isolation. Participants are from the towns of Santa Elena, Mérida, and Sisbicchén, Yucatan, Mexico. The results of this study show that Santa Elena and Mérida form a dialect group that is distinct from Sisbicchén. In Frazier (2009a,b), I refer to Santa Elena and Mérida as the "western dialect", and vowel shape in this dialect is produced mostly as it is described in the literature (e.g. Bricker et al. 1998, Blair and Vermont Salas 1965). For this reason, only data from Santa Elena (12 participants) and Mérida (7 participants) is reported on here, though the methodological points of the paper are relevant to all data. Furthermore, the phonological forms given in (1) are only relevant for the western dialect.

All measurements were taken with PRAAT (Boersma and Weenink 2006). For each target word, the spectrogram was used to demarcate the vowel and determine the mode of phonation (during vowel production). Pitch measurements were extracted in Hertz at 10 ms intervals throughout the vowel, and pitch values at 5 normalized time points are used to define the pitch contours of each vowel.

2 Glottalization in Yucatec Maya

Spectrograms and waveforms were observed in order to determine the mode of phonation for each GLOTTALIZED vowel; this vowel shape can be produced with modal voice only (no glottalization), with creaky voice during

---

[2] I assume that the fact that all long vowels end with low pitch (in phrase-final context) is a consequence of the demands of the intonational contour, and hence this property is not marked in the phonological forms in (1). The production of pitch in non-phrase-final context is discussed in Frazier (2009b).

either the middle or final half of vowel production, or with a full glottal stop interrupting vowel production. In the process of coding glottalization type, I found that, for many vowels with an auditory indication of creaky voice, the waveforms did not show all the canonical properties of creaky voice. In this section, I present the articulatory and acoustic properties of creaky voice, show three different acoustic realizations of creaky voice in YM, and discuss questions for future research on how the different acoustic patterns are related to different articulations.

2.1 Articulatory and Acoustic Properties of Creaky Voice

Creaky voice is produced with tight adduction of the vocal folds, though they remain loose enough for voicing. This places creaky voice near one end of a glottal stricture continuum:

(2) glottal stricture continuum (Gordon and Ladefoged 2001):
[open] voiceless – breathy – modal – creaky – glottal closure [closed]

Recent work by Edmondson and Esling (2006) show that, in addition to vocal fold adduction (Valve 1 in their terminology), creaky voice is produced with compression of the arytenoids and aryepiglottic folds, which they refer to as the engagement of Valve 3. It is thus the case that, while vocal fold adduction is one laryngeal maneuver that is used in creaky voice, it is not the only articulatory property of this phonation type.

Gordon and Ladefoged (2001) summarize the characteristics of creaky voice that are identifiable from waveforms and spectrograms: compared to modal voice, creaky voice is aperiodic and has lower intensity and lower fundamental frequency (F_0).[3]

2.2 Identifying Creaky Voice in Yucatec Maya

In this section we will see various manifestations of creak, and these will suggest that future research would benefit from determining which articulatory gestures account for each glottalization type. In particular, a pattern I call "weak glottalization" is indicated by a brief dip in intensity in the middle portion of the vowel which is often correlated with a dip in F_0. It is an open research question as to just which laryngeal maneuvers – just which valves of the throat – cause this pattern of glottalization.

The primary characteristics of creaky voice are seen in the middle of the vowel in Fig. 1. In the portion of the vowel marked as [ḭ], the glottal pulses are irregularly and widely spaced (denoting aperiodicity and low F_0,

[3] Gordon and Ladefoged (2001) also note that creaky voce is associated with higher formant frequencies, longer duration, and spectral tilt that is more steeply positive (i.e. the intensity of the second harmonic is greater than the first). These criteria are not discussed in this paper.

respectively) and are produced with lower intensity. It is clear from the observance of this waveform/spectrogram that this vowel is produced with creaky voice surrounded by modal voice.

Another notable detail in the middle portion of the vowel in Fig. 1 is that there are sporadic differences between the peak intensity of consecutive glottal pulses. This is possibly caused by diplophonia, where the vocal folds vibrate at different rates and hence produce different tones simultaneously. While other sources have observed this pattern in the waveforms of productions of creaky voice (e.g. Redi and Shattuck-Hufnagel 2001), I know of no source that measures individual vocal fold rates of vibration during the production of creaky voice. In YM, sporadic changes in the peak intensity of glottal pulses are often present in productions of creaky voice.

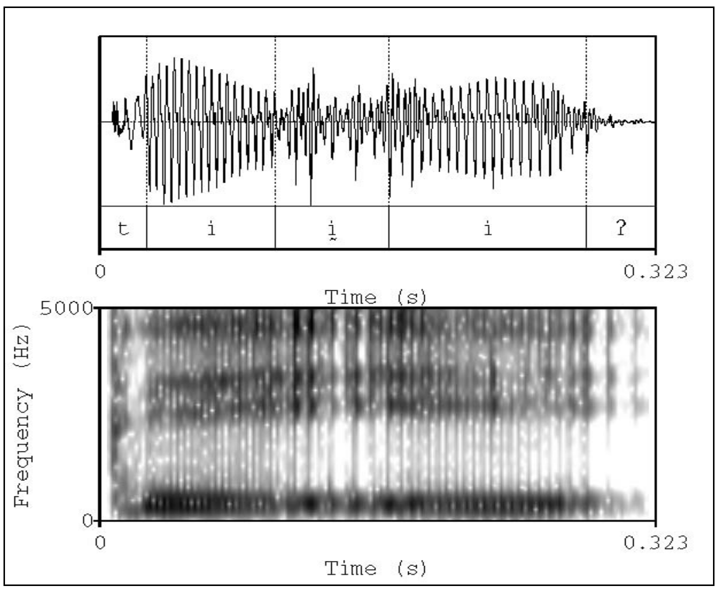

Figure 1. Prototypical creaky voice

The central portion of this vowel shows irregularly and widely spaced glottal pulses and low intensity. This token of ti'i' *'there' was produced by a female from Mérida.*

In Fig. 2 we see an example of a vowel that is not so easy to classify. The central portion of this vowel certainly shows some departure from modal voice, but the only indicators of creaky voice are lower intensity and somewhat lower F_0. The line through the spectrogram tracks F_0, which shows that the spacing of glottal pulses is regular enough to allow for the measuring of fundamental frequency.

When listening to the token below, there is an auditory indication of creaky voice, and the dramatic decrease in intensity coupled with a slight decrease in F_0 leave no doubt that this vowel is not consistently produced with modal voice.[4] In my study, I found that lower intensity was the visual cue that was most consistently present when the stimulus sounded like it was produced with creaky voice. There were no cases where creaky voice showed irregular and widely spaced glottal pulses without a decrease in intensity.

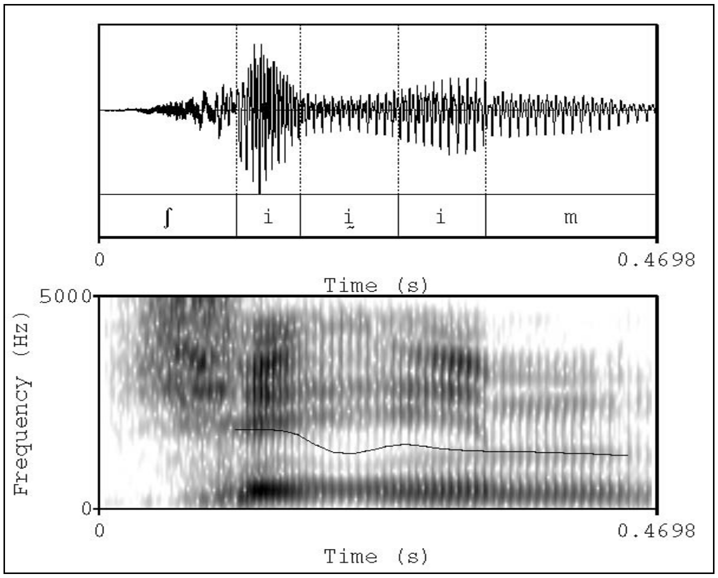

Figure 2. Creaky voice as indicated by lower intensity
The central portion of this vowel shows low intensity. This token of xi'im *'corn' was produced by a male from Mérida.*

There were also many productions of GLOTTALIZED vowels that give an auditory impression of creaky voice but for which the only visual cue to a departure from modal voice is a brief dip in intensity, as shown in Fig. 3. This dip in intensity is also correlated with a decrease in F_0, as indicated by the F_0 contour on the spectrogram. I classify such tokens as having the glottalization type of "weak glottalization".

[4] Such vowels were coded as being produced with creaky voice in this production study.

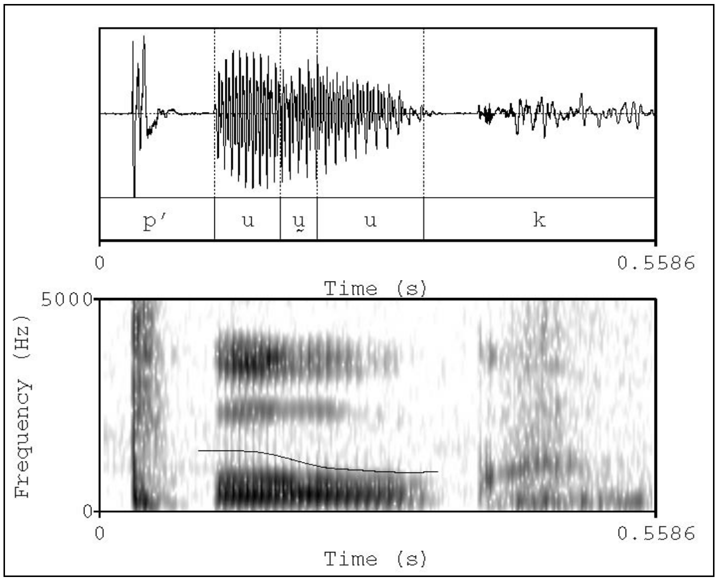

Figure 3. Weak glottalization
The central portion of this vowel shows only a slight dip in intensity. This token of p’u’uk *‘cheek’ was produced by a male from Mérida.*

2.3 Future Work: Which Articulations Cause the Acoustic Patterns?

In the previous section, we saw three different acoustic patterns that indicate a departure from modal voice in the production of GLOTTALIZED vowels in YM: creaky voice that shows all the canonical properties of creaky voice, creaky voice that shows only a decrease in intensity (and a slight decrease in F_0), and creaky voice that shows only a brief dip in intensity. These patterns indicate that decreases in intensity are the most consistent cue to creaky voice in YM, which is a departure from the standard focus on widely and irregularly spaced glottal pulses.[5] Thus, it would be beneficial for future research to compare the productions of creaky voice in YM with productions of creaky voice in other languages in order to determine if intensity is always a more reliable cue or if YM is cross-linguistically rare in this regard.

Furthermore, given Edmondson and Esling’s (2006) identification of the engagement of Valves 1 and 3 in creaky voice, an important question for future research is exactly how articulatory maneuvers differ among the vowels of Figs. 1 – 3. Are both Valves 1 and 3 involved in the production of weak glottalization? Is creaky voice accompanied by all canonical cues produced in a different manner than creaky voice accompanied by only lower intensity?

[5] For example, Gordon and Ladefoged (2001:387) cite aperiodicity as an indicator of creak and then say that “creakiness also triggers a reduction in intensity … in *certain* languages” (emphasis added). The implication is that aperiodicity is linked with creaky voice in all languages but that lower intensity is not.

Finally, it remains to be determined whether or not diplophonia really is the cause of the sporadic changes in peak intensity of consecutive glottal pulses.

3 Measuring Pitch: Semitones over the Baseline

It is notoriously difficult to compare measurements of F_0 across genders because of the physiological differences that result in females having a higher natural pitch range than males. This problem is not solely gender-related; any two speakers with different natural pitch ranges will produce considerably different pitch values for the same phonological tone. One way to abstract away from these differences is to measure a *pitch span* (the difference between the high and low points of a pitch contour), instead of a single pitch value. However, Hertz is still a problematic measurement of pitch spans, because a person with a higher natural pitch range will also produce larger pitch spans.

In perception, pitch spans at the low end of the Hertz scale are perceived as more different than pitch spans of equal length at the high end of the Hertz scale. This phenomenon has lead to the development of a variety of psycho-acoustic scales to measure pitch, including semitones, mels, Bark, and ERB-rate. According to Nolan (2003), semitones provide the best measurement for pitch spans in intonational contours, such that differences among speakers are minimized.

In YM, not every vowel shape has a pitch span that is meaningful. For example, LOW TONE vowels are produced with fairly steady low pitch. There are of course minimum and maximum pitch values produced during any pitch contour, but, with this vowel shape, these extreme values cannot be expected to occur in stable positions within the vowel nor can the difference between them be expected to be meaningful. For this reason, I do not measure a traditional pitch span, but instead I use a constant relative to each speaker to scale pitch values from that speaker. This method is based on Pierrehumbert's (1980) work with English intonation. In her dissertation, Pierrehumbert found that peaks in an intonational contour varied relative to the pitch value produced for the final low boundary tone. She calls this value for the low boundary tone a *baseline*, which is unique for each speaker, and measures pitch with the formula: (pitch – baseline)/baseline.

There are differences between Pierrehumbert's target of analysis (intonational contours) and my own (pitch measurement of both level and contour tones), such that I cannot measure a baseline in the same way. I will, however, make use of her identification of speaker-specific baseline. I define the baseline for each speaker of YM as the average pitch value produced at the middle point of LOW TONE vowels (as spoken in a particular context), and I pick this point because it is both low and relatively stable. I thus measure pitch according to the formula in (3). As mentioned in §1.2, pitch values are first extracted in Hertz. After calculating the baseline for each speaker, these pitch values are then transformed into *semitones over the baseline* (s/b). Thus, a pitch value of 3.4 s/b denotes a pitch value that is 3.4 semitones above *that speaker's* baseline. In this way, pitch values from different speakers can be averaged together and those averages will have meaning.

(3) transformation of Hertz to semitones over the baseline (s/b)

$$s/b = 12*\log_2(\text{Hz}/\text{baseline Hz})$$

where baseline Hz is the average pitch value produced at the mid point of LOW TONE *vowels* ***for a given speaker***

Fig. 4 shows the average pitch contours of HIGH TONE vowels for males and females as measured in Hz and s/b.[6] When pitch is measured in Hz, the pitch contours are considerably different for the two genders, but these differences are not substantial when pitch is measured in s/b. The difference between the average pitch value in s/b produced by females and that produced by males is statistically significant for the three middle time points ($p < .05$, using a mixed linear regression model to account for multiple observations within subjects.) However, the actual differences are fairly small. For example, at time point 2, the average pitch value for males is 1.2 semitones higher than the average pitch value for females when pitch is measured in semitones over the baseline. On the other hand, when pitch is measured in Hz, the average pitch value for females at time point 2 is 4.8 semitones higher than the average pitch value for males.[7] Thus, at this time point, the s/b transform decreases the distance between the male and female average by a magnitude of 4.

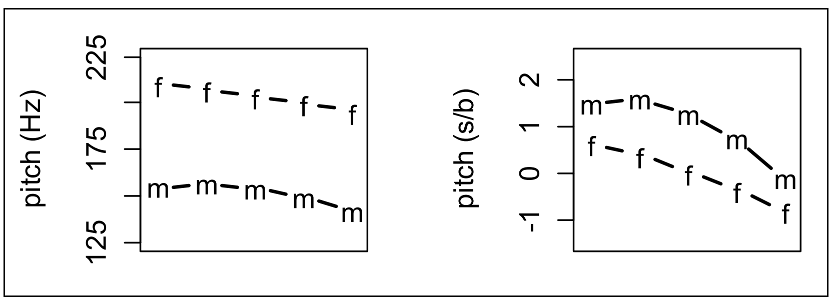

Figure 4. Average pitch contours of HIGH TONE vowels
f = female; m = male; only participants from Santa Elena

It seems that the semitone transform is successful in measuring the pitch of HIGH TONE vowels in YM such that measurements can be averaged together across speakers and genders in a way that gives these averages meaning – they can be used to predict the pitch contour that will be produced by some

[6] Because of dialect variation in the production of pitch (see Frazier 2009a,b), only data from the 12 participants from Santa Elena is used to create the average pitch contours shown in this paper.
[7] The average pitch value at time point 2 is 207.7 Hz for females and 156.9 Hz for males. The difference between these two values in semitones is calculated with the equation $12*\log_2(207.7/156.9)$.

other speaker. As we see in Fig. 5, however, the semitone transform is not as successful with the GLOTTALIZED vowels. Most notably, at the middle time point the measurements from males and females are more similar when pitch is measured in Hz than when pitch is measured in s/b.

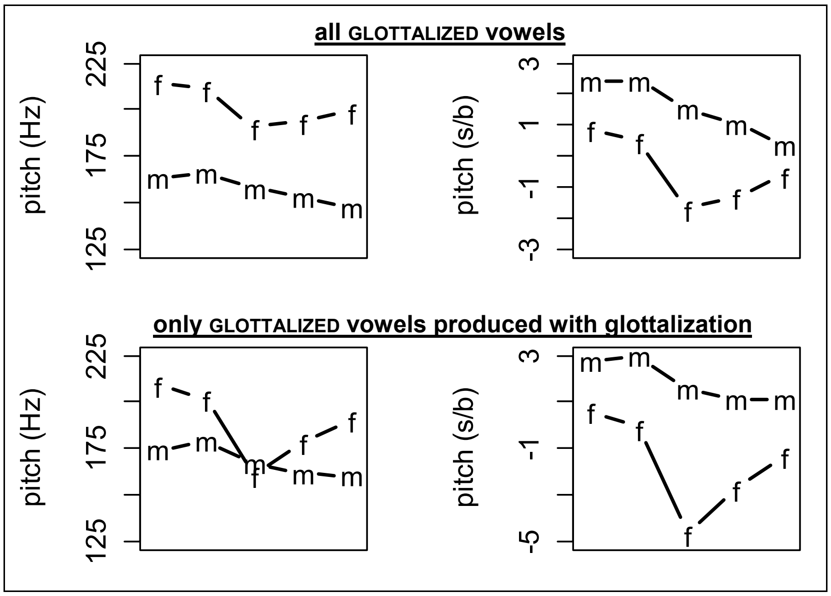

Figure 5. Average pitch contours of GLOTTALIZED vowels
f = female; m = male; only participants from Santa Elena

While HIGH TONE vowels are produced with modal voice throughout, GLOTTALIZED vowels tend to be produced with creaky voice in the middle or last half of the vowel. This means that the middle time point usually occurs during creaky voice. The effects of creaky voice on pitch are made clear when we compare the top graphs, which include all GLOTTALIZED vowels, with the bottom graphs, which show only those GLOTTALIZED vowels that were coded as being produced with some form of glottalization (weak glottalization, creaky voice, or a full glottal stop).[8]

In those tokens that are produced with glottalization the pitch values produced by males and females are nearly identical in Hz at the middle time point (where creaky voice generally occurs). Thus, if we transform these values into semitones over the baseline, we get a negative number for females and a positive one for males (because the baseline is relatively high for females and relatively low for males). Furthermore, because the pitch associated with creaky voice is so low relative to the natural pitch range for the average female, it

[8] Of the tokens averaged together in Fig. 5, the breakdown of glottalization types is as follows: for women – 40% modal voice, 13% weak glottalization, 37% creaky voice, 10% glottal stop; for men – 56% modal voice, 22% weak glottalization, 20% creaky voice, 2% glottal stop.

seems that this affects the rest of the pitch contour for females, such that females are not producing pitch that is as high (relative to their baseline) before or after creaky voice because this would result in too much of a change in fundamental frequency between successive time points.

We have thus seen that, while the semitone transform allows us to compare pitch measurements across speakers when those pitch measurements are extracted from modal voice, it is less successful when pitch measurements are extracted from creaky voice. We will explore this interaction between pitch and creaky voice further in the next section. Fig. 4 has provided evidence that the semitone transform, as defined for YM, provides us with a way to measure individual pitch values and compare those values across speakers. I believe it would be beneficial for future work to investigate how speaker-specific baselines can be used in other languages so that pitch measurements can be compared across genders.

4 The Interaction of Pitch and Creaky Voice

4.1 Gender-Specific Effects of Phonation Type on Pitch

As shown in Fig. 5, creaky voice is produced with a constant F_0 by both males and females.[9] This is a surprising result given that pitch is generally a function of a speaker's natural pitch range: a person with a higher natural pitch range will produce the same melody with a higher F_0 than a person with a lower natural pitch range. The results for YM suggest that this is not true during creaky voice.

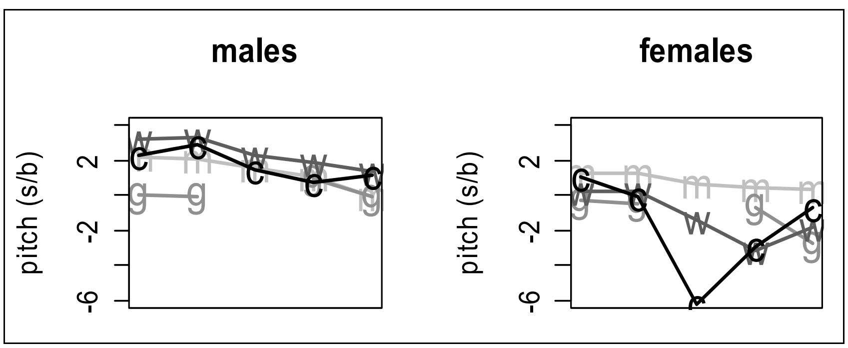

Figure 6. Average pitch contours of GLOTTALIZED vowels by gender and glottalization type
m = modal voice; w = weak glottalization; c = creaky voice; g = glottal stop; only participants from Santa Elena

In order to further explore the gender-based differences in the

[9] I do not know of any other source that specifically compares measurements of pitch during creaky voice across genders. Hence, I do not know if this result is anomalous to YM.

production of pitch, Fig. 6 shows pitch contours for GLOTTALIZED vowels by gender and glottalization type. In this figure we see that the pitch contours for males are not significantly affected by glottalization type, while for females there are drastic differences among the glottalization types. Specifically, creaky voice and weak glottalization cause a severe decrease in pitch for females but not for males. This is the result discussed above. What this graph additionally shows us is that, when GLOTTALIZED vowels are produced with modal voice only, the pitch contours (measured in s/b) are the same for males and females. Again, we see that the semitone transform is successful during productions of modal voice.

Another important point illustrated by Fig. 6 is that weak glottalization and creaky voice have about the same effect on pitch – causing a dramatic decrease for females – though the effect is stronger with creaky voice. I believe this evidence provides support for the claim that weak glottalization is a type of creaky voice. It is clear that, at least in YM, when females produce creaky voice, the resulting pitch is much lower than their natural pitch range, whereas the pitch produced during creaky voice is within the normal pitch range for males.

4.2 Implications for Languages with Laryngeal Complexity

Many languages of Mesoamerica are known to be laryngeally complex (e.g. Jalapa Mazatec, Comaltepec Chinantec, Copala Trique (Silverman 1997), Yalálag Zapotec (Avelino 2004)), meaning that pitch and phonation type contribute to contrast in the vowel system. Because the GLOTTALIZED vowels of YM have commonly been described as vowel – glottal stop – vowel sequences, this language has not previously been classified as laryngeally complex. However, given that the GLOTTALIZED vowels bear tone and that new phonetic data that shows that creaky voice is the primary correlate of glottalization, it is reasonable to include YM when looking at the typology of laryngeal complexity.

In his analysis of laryngeal complexity in Otomanguean languages, Silverman (1997) shows that tone and non-modal phonation are sequenced with respect to each other (i.e. the realization of tone and creaky/breathy voice do not occur on the same portion of the vowel). He argues that this sequencing allows for the listener to recover information with respect to both tone and voice quality. I support Silverman in his assessment that this sequencing aids the listener, but I believe the results presented in this section indicate that there could be an articulatory explanation as well. It could be the case that tone and non-modal phonation have to be sequenced in this way because pitch is linked to creaky voice. If the speaker is physically incapable of producing different tones while producing creaky voice, then such sequencing is the only way to maintain laryngeally complex contrasts. It is thus important to determine if the gender-specific interaction between pitch and creaky voice is a cross-linguistic principle or a language-specific fact about Yucatec Maya.

4.3 The Cross-Linguistic Correlation between Creaky Voice and Preceding High Pitch

With YM's GLOTTALIZED vowels, the initial portion of the vowel is produced with high pitch and the final portion is produced with creaky voice. Interestingly, this pattern is found in many other languages. Acoma (a Keresan language of New Mexico) has a 'glottal accent', which is described in a manner that resembles YM's GLOTTALIZED vowel; it is produced with a falling pitch contour and creaky voice (Miller 1965). The Danish *stød* begins with high pitch and ends with creaky voice (Fischer-Jørgensen 1989), and vowels before glottalized sonorants are produced with high pitch in Coatlán-Loxicha Zapotec (Plauché et al. 1998). The correlation between creaky voice and preceding high pitch is thus found synchronically in multiple language families, and diachronically it is widely believed that a coda glottal stop (which is likely correlated with creaky voice in the vowel) can condition a rising pitch contour in the preceding vowel (Hombert 1978). The cause of this correlation remains to be determined. Future work in this area could shed some light on diachronic questions about tonogenesis in YM.[10]

5 Conclusions

In YM, lower intensity is the most consistent (and sometimes only) cue to creaky voice. Furthermore, in many productions of GLOTTALIZED vowels, the only indication of non-modal voice is a brief dip in intensity. This result prompts future work in determining which articulatory maneuvers (or which of Edmonson and Esling's (2006) valves of the throat) are responsible for the different glottalization types of YM.

In measuring pitch in YM, I use a speaker-specific baseline to scale pitch measurements (in semitones). Individual pitch values in *semitones over the baseline* do not show much inter-speaker variation, however, this method is only effective when pitch measurements are obtained from modal voice. Pitch produced during creaky voice has a constant frequency across speakers and is hence not a function of a speaker's natural pitch range. This result shows that there may be articulatory motivations for the sequencing of tone and non-modal phonation in languages with laryngeal complexity.

References

Avelino, Heriberto. 2004. Topics in Yalálag Zapotec, with Particular Reference to Its Phonetic Structures. Doctoral dissertation. UCLA.

Avelino, Heriberto, Eurie Shin, Sam Tilsen, Reiko Kataoka, and Jeff Pynes. 2007. The Phonetics of Laryngealization in Yucatec Maya. Paper

[10] Most Mayan languages are not tonal, and it is widely believed that tone is an innovation in YM (see e.g. Fox 1978 and Justeson et al. 1985:15 for competing theories about tonogenesis in YM).

presented at the LSA annual meeting in Anaheim, California.
Blair, Robert W. and Refugio Vermont Salas. 1965. *Spoken Yucatec Maya* Book I: Lessons 1-6, with revisions by Salas (1968), N. A. McQuown (1994), and Salas (1994); 1995 version. Chapel Hill, NC: Duke University-University of North Carolina Program in Latin American Studies.
Boersma, Paul and David Weenink. 2006. Praat: Doing Phonetics by Computer (Version 4.4.05) [Computer program]. Available at http://www.praat.org/
Bricker, Victoria, Eleuterio Poʔot Yah, and Ofelia Dzul Poʔot. 1998. *A Dictionary of the Maya Language As Spoken in Hocabá, Yucatán.* Salt Lake City: University of Utah Press.
Edmondson, Jerold A. and John H. Esling. 2006. The Valves of the Throat and their Functioning in Tone, Vocal Register, and Stress: Laryngoscopic Case Studies. *Phonology* 23: 157-191.
Fischer-Jørgensen, Eli. 1989. Phonetic Analysis of the Stød in Standard Danish. *Phonetica* 46:1-59.
Fox, James Allan. 1978. *Proto-Mayan Accent, Morpheme Structure Conditions, and Velar Innovations.* Ph.D. dissertation. University of Chicago.
Frazier, Melissa. 2009a. Tonal Dialects and Consonant-Pitch Interaction in Yucatec Maya. In H. Avelino, J. Coon, and E. Norcliffe (eds.), *New Perspectives in Mayan Linguistics, MIT-WPL 59, 59-82.*
Frazier, Melissa. 2009b. The Production and Perception of Pitch and Glottalization in Yucatec Maya. Ph.D. dissertation. University of North Carolina at Chapel Hill.
Gordon, Matthew and Peter Ladefoged. 2001. Phonation Types: A Cross-linguistic Overview. *Journal of Phonetics* 29: 383-406.
Justeson, John S., William M. Norman, Lyle Campbell, and Terrence Kaufman. 1985. *The Foreign Impact on Lowland Mayan Language and Script.* New Orleans: Middle American Research Institute, Tulane University.
Miller, Wick R. 1965. *Acoma Grammar and Texts.* Berkeley: University of California Press.
Nolan, Francis. 2003. Intonational Equivalence: An Experimental Evaluation of Pitch Scales. *Proceedings of the 15th International Congress of Phonetic Sciences, Barcelona*. 771-774.
Pierrehumbert, Janet. 1980. The Phonology and Phonetics of English Intonation. Ph.D. dissertation, MIT.
Redi, Laura and Stefanie Shattuck-Hufnagel. 2001. Variation in the Realization of Glottalization in Normal Speakers. *Journal of Phonetics* 29: 407-429.
Silverman, Daniel. 1997. Laryngeal Complexity in Otomanguean Vowels. *Phonology* 14: 235-261.

Melissa Frazier
melfraz@gmail.com