Pitch accent timing and scaling in Chickasaw

Abstract

Questions in Chickasaw, an endangered Muskogean language of Oklahoma, display a transition from a high pitch accent (H*) to a low boundary tone (L%) within a three-syllable window at their right edge. The location of H* has been reported to be sensitive to the weight of the final three syllables. It falls on the final syllable if it contains a long vowel. If the final syllable has a short vowel, the pitch accent falls on a heavy penultimate syllable (CVV or CVC), and otherwise on the antepenultimate syllable. Phonetic investigation of the timing and scaling of the pitch accent in the production of Chickasaw questions by three speakers confirms these phonological patterns, but also reveals considerable variability across speakers and accent locations in phonetic aspects of pitch accent realization. H* occurs progressively earlier in accented syllables the closer the syllable is to the end of the question. This leftward shifting of the pitch accent may be viewed as an instance of tonal repulsion attributed to crowding of H* and L%. Final vowels, which support both H* and L%, are not lengthened and scaling effects on H* and L% are less consistent across speakers, suggesting that the primary means for minimizing tonal crowding in Chickasaw is through timing changes in the location of the pitch accent rather than other means such as tonal undershoot or segmental lengthening.

Keywords: Chickasaw, intonation, pitch accent

1. Introduction

1.1. Phonetic manifestations of tonal crowding

The realization of tonal events in intonational languages is influenced by many factors, including the temporal proximity of other tones. Many languages try to minimize crowding of multiple tones onto a short string of speech. Responses to tonal crowding avoidance vary depending on the language and the levels of the tones involved. One such strategy for minimizing tonal crowding is to temporally shift adjacent tones away from each other. For example, a prenuclear H* pitch accent in English occurs earlier in a syllable immediately preceding a syllable with a nuclear pitch accent than in a syllable not followed by an accented syllable (Silverman and Pierrehumbert 1990). Tonal crowding may be particularly acute when the adjacent tones differ in their levels. Thus, in yes/no questions in Greek, a H- phrase boundary tone varies in its timing patterns as a function of the proximity of both a preceding L* accent and a following L% boundary tone (Arvaniti 2002): a H- on the phrase-final syllable moves away from a preceding L* realized on the same syllable, but away from a following L% if the L* is realized on a non-final syllable.

Tonal excursions may also be reduced when multiple tonal targets are in close proximity to each other. An example of this phenomenon of tonal undershoot is observed in Greek (Arvaniti and Baltazani 2005), where the second in a sequence of L* + H pitch accents often undergoes undershoot of the L* component.

Another strategy for eliminating tonal crowding is to delete one or more tones. Thus, in Hungarian (Ladd 1983), the question tune consists of a low tone (the nuclear pitch accent) on the primary stressed syllable of the focused word followed by a high plus low boundary tone at the right edge of the question, as in (1a). Although it is possible for a single syllable to support two of the three component tones comprising the question tune (1b), a syllable may not carry more than two tones. The low component of the boundary tone goes unrealized if it were to be realized on the same syllable as the pitch accent (1c).

(1)

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a. L*          H   L%                                   b.      L*HL%
   |           |   |                                            |  |/
 Beszél a miniszter?  'Is the minister talking?'              A tanár?  'the teacher?'

c. L* H (L)%
    |/
  sör?  'beer?'
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Yet another way to reduce tonal crowding is to lengthen the segmental material onto which the crowded tones dock. This strategy is observed in Japanese (Venditti 2005) and Korean (Jun 2005), in which boundary tones consisting of multiple tonal targets, e.g. LH% or HL%, are temporally shorter than singleton boundary tones.

This paper examines phonetic manifestations of tonal crowding in Chickasaw, an endangered Muskogean language spoken in south central Oklahoma. The goal of this study is to determine if, and how, tonal crowding considerations influence the realization of tonal targets in Chickasaw questions, which are characterized by a fall from a high pitch accent, H*, near the right edge of the question to a final low boundary tone, L%, at the end of the question. Impressionistically, the location of the H* pitch accent is confined to one of the final three syllables, where the choice of docking site is a function of the weight of the syllables. This paper seeks to empirically confirm these impressionistic judgments about Chickasaw question intonation through quantitative investigation of the timing and scaling of the terminal pitch excursion. If confirmed experimentally, the conditions governing the location of the pitch accent would be among the more complex ones observed cross-linguistically. Examination of terminal pitch falls in Chickasaw questions thus promises to expand our typological knowledge of intonation systems as well as the phonetic effects of tonal crowding.

1.2. Stress and pitch accents in Chickasaw

Chickasaw is a stress language in which words have a single primary stressed syllable and potentially one or more secondary stressed syllables. In Chickasaw, the location of stressed syllables is predicable on phonological grounds (see Gordon 2004 for detailed discussion). All heavy syllables (CVV or CVC) and all final syllables carry at least secondary stress. Primary stress at the word level falls on the final syllable of words lacking long vowels (2a) and on the long vowel in words containing one (2b). Words with multiple long vowels display variation in which of the long vowels, either the rightmost or the leftmost one, carries primary stress (2c). Stress in Chickasaw is associated with a combination of higher fundamental frequency and increased duration and intensity (see Gordon 2004).

(2)	a.	ˌissoˈba	‘horse’
		ˌbaʃˈpo	‘knife’
		ˌokˌfokˈkol	‘type of snail’
	b.	piˈsaːliˌtok	‘I saw him’
		ˈaːˌtʃomˌpaʔ	‘store’
		ˌbakʃiˈjaːˌmaʔ	‘diaper’
		aˈboːkoˌʃiʔ	‘river’
		ˈʃiːˌki	‘buzzard’
		oˈfõːˌlo	‘screech owl’
	c.	ˌaːjoˈkaːˌtʃiʔ (or ˈaːjoˌkaːˌtʃiʔ)	‘police station’
		ˌaːkiˈlaːʔ (or ˈaːkiˌlaːʔ)	‘wick’

Pitch accents, all phonetically high tone in Chickasaw, are assigned at the phrasal level in Chickasaw. In Chickasaw, the domain of pitch accent placement is the Intonation Phrase (see Gordon 2005 for more on Chickasaw intonation), which may be associated with a boundary tone depending on the semantics of the IP (see below). The final word of an IP has a single pitch accented syllable, akin to the nuclear pitch accent in a language like English. Parallel to other languages (see Ladd 1996 for a typological overview), pitch accented syllables are stressed in Chickasaw. However, unlike many other languages, pitch accents do not predictably dock on the primary stressed syllable of a word in Chickasaw. Rather, the location of the pitch accent in Chickasaw is determined by orthogonal principles from those governing word-level stress.

The simplest case of pitch accent placement occurs in statements, which lack the final tonal fall found in questions. Rather, in statements, f0 is highest on the final syllable, suggesting either a H* pitch accent or a H% boundary tone or a combination of the two. The characteristic f0 plateau rather than a final upstep is consistent with an analysis positing a H* pitch accent followed by no boundary tone (see Grice et al. 2005 for a similar analysis of Intonation Phrases lacking boundary tones in German). Some statements end in a f0 rise, however, suggesting an optional H% boundary tone (see Gordon 2005 for discussion). Crucially, for present purposes, statements differ from questions in lacking the final tonal excursion triggered by two tones of different levels. An example of a statement IP appears in figure 1.

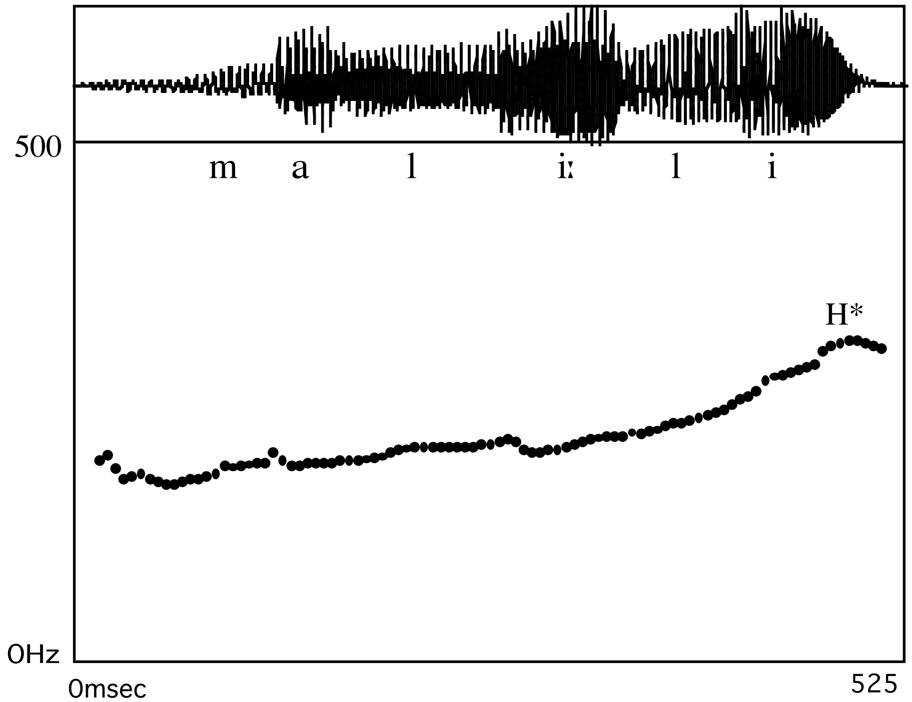

Figure 1. H* on the final syllable of the statement /maliːlǐ/ 'S/he is running.'

The more interesting cases of pitch accent placement and the focus of this paper arise in questions. Question IPs end in a fall in f0 preceded by an f0 peak located within a three syllable window at the right edge of the question (Gordon 2005). The same intonation pattern is found for both wh-questions and yes/no questions.[1] The tonal fall found at the end of wh- and yes/no questions is analyzed most economically within a autosegmental metrical analysis (Pierrehumbert 1980) as a transition from a H* pitch accent to a L% boundary tone.[2]

If the final syllable contains a long vowel, it carries the pitch accent (3a). If the final vowel is short, the penult attracts the pitch accent if it is heavy (i.e. CVV or CVC) (3b). If the penult is light and the final syllable is not CVV, the antepenult carries the pitch accent

[1] Echo questions, on the other hand, are characterized by the same intonational pattern as statements, but with an overall upward scaling of f0 levels.
[2] The H* pitch accent is not consistently preceded by a low pitch target which might be indicative of a bitonal pitch accent. Independent of H*, however, low f0 targets within an IP, due occur at the beginning and end of Accentual Phrases, which characteristically have the tonal pattern [LHHL]. The possibility of a L- phrasal tone before the L% tone in questions cannot be definitively excluded, though there is no compelling evidence in Chickasaw for phrasal tones in addition to boundary tones. The interested reader is referred to Gordon (2005) for further analysis of Chickasaw intonation.

(3c).[3] It may be noted that an antepenultimate syllable with a pitch accent will always be heavy due to an independent phenomenon of rhythmic lengthening that lengthens a short vowel in an open non-final syllable following another CV syllable.[4]

(3) a. Final syllable if CVV:
(katahtãː) t͡ʃihaːʃáː ‘Who are you angry at?’
b. Otherwise, penult if CVV or CVC:
malíːtam ‘Did s/he run?’
(nantaːt) hatáːt͡ʃim ‘What turned color?’
(nantaːt) t͡ʃilákbi ‘What is turning color?’
(nantaːt) istókt͡ʃaŋk ‘What’s a watermelon?’
c. Otherwise, antepenult:
mállitam ‘Did he jump?’
ʃíːpata ‘Is it stretchy?’
(nantaːt) abóːkoʃiʔ ‘What’s a river?’

Figures 2-4 illustrate pitch accents on the final syllable, the penult, and the antepenult, respectively.

[3] Pitch accents are free to fall on suffixes if phonological conditions allow. For example, the 1st person sg. suffix –li (–liː non-finally after a CV syllable) receives the pitch accent in the form tʃipiːsalíːta ‘Do I see you?’ since it contains a long vowel in the penultimate syllable. Furthermore, virtually all suffixes (see Gordon 2005 for exceptions), including those occurring in the data analyzed in this paper, are part of the three syllable window within which the pitch accent falls. Thus, the pitch accent falls on the CVV penultimate syllable in both the morphologically simple form maliːli in the question kataːt malíːli ‘Who’s running?’ and also in the phonologically parallel but morphologically suffixed form pisaː-li in the question katahtãː pisáːli ‘Whom do I see?’.

[4] Rhythmic lengthening targets vowel in even-numbered syllables counting from left to right. For example, the phonemic short vowels in the second and the fourth syllables in the word tʃipiːsaliːtok ‘I saw you’ are lengthened since they since they occur in even-numbered CV syllables preceded by another CV syllable. The lengthened vowels in tʃip**i**ːsal**i**ːtok may be compared with their non-lengthened variants in p**i**saːl**i**tok ‘I saw him’. Rhythmically lengthened vowels may either be identical in length to phonemic long vowels or slightly shorter depending on the vowel quality and the speaker (see Munro and Ulrich 1984, Munro and Willmond 1994, 2005, Gordon et al. 2000, and Munro 2005 for further discussion of rhythmic lengthening).

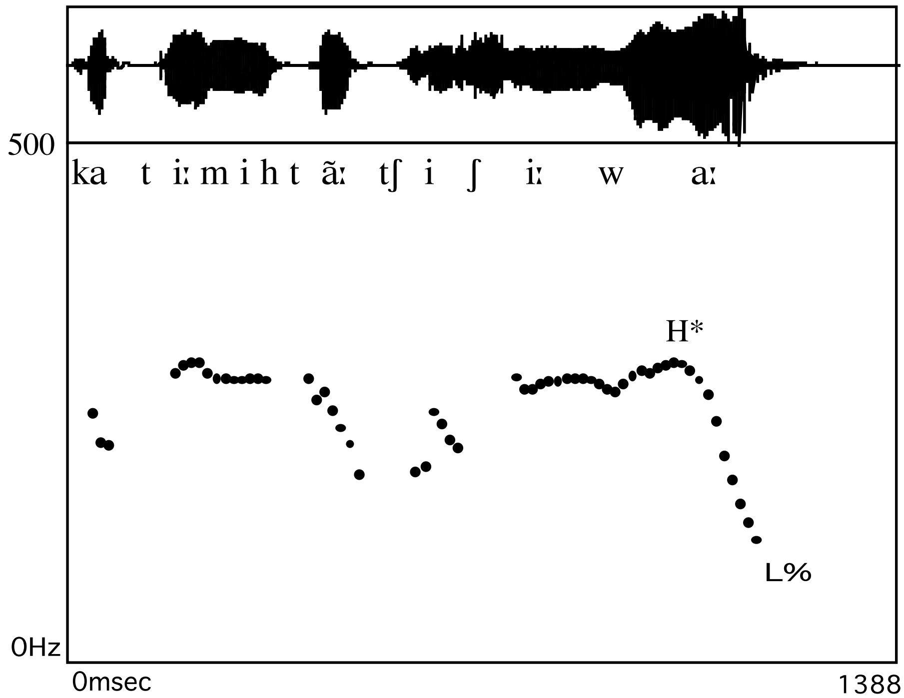

Figure 2. H* on the final syllable of /tʃiʃiːwáː / in the question /katiːmihtãː tʃiʃiːwáː/ ‘Why are you striped?’

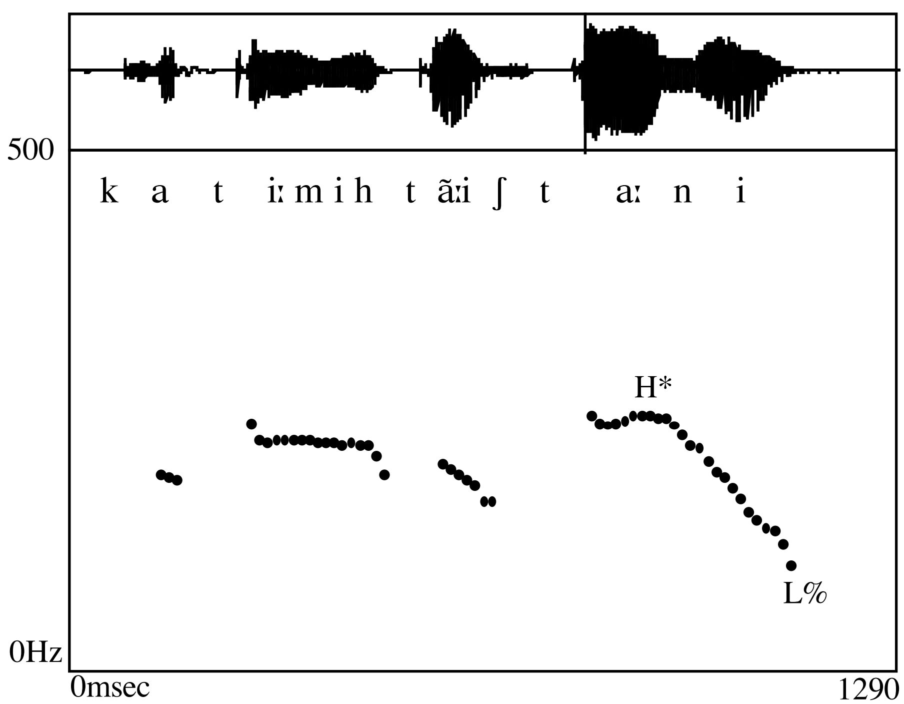

Figure 3. H* on the penultimate syllable of /iʃtáːni/ in the question /katiːmihtãː iʃtáːni/ ‘Why are you getting up?’

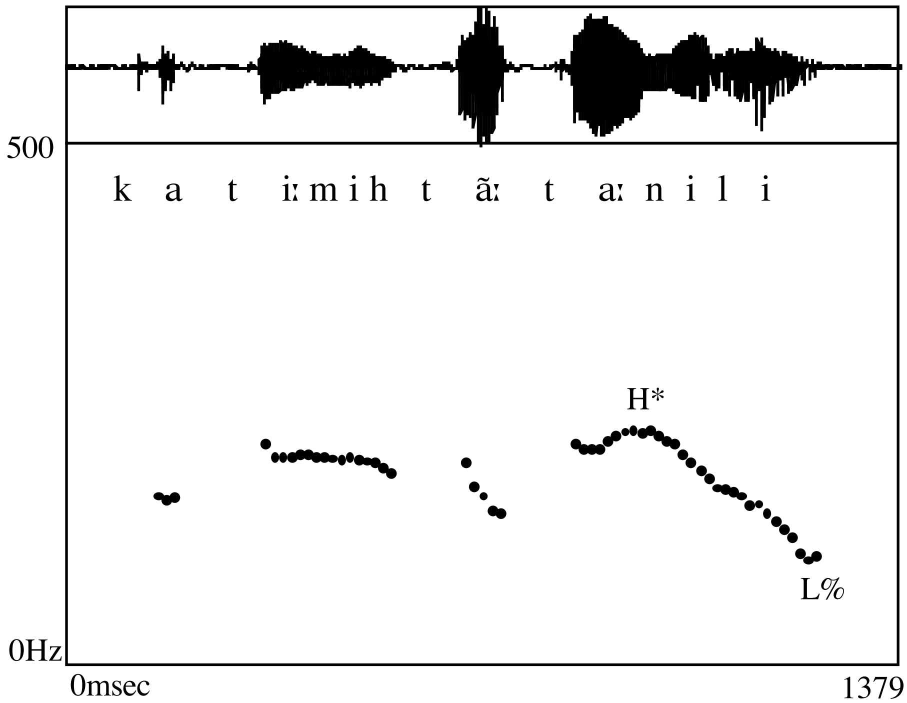

Figure 4. H* on the antepenultimate syllable of /táːnili/ in the question /katiːmihtãː táːnili/ ‘Why am I getting up?

The same pitch accent and boundary tone patterns are observed in wh- and yes/no questions in Chickasaw. Figure 5 shows an example of a yes/no question containing a H* pitch accent on a heavy antepenult followed by a L% boundary tone.

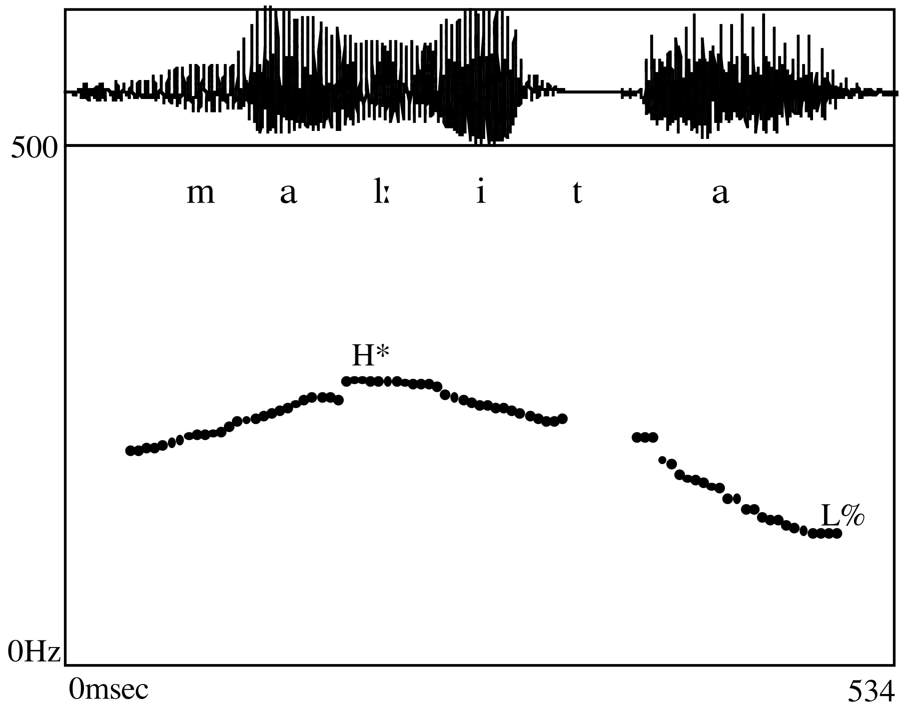

Figure 5. H* on the antepenultimate syllable of the question /mállita/ ‘Is s/he jumping?’

If verified experimentally through quantitative investigation of a controlled corpus recorded from multiple speakers, the system for determining the location of the pitch accent in Chickasaw questions would be typologically unusual in its sensitivity directly to syllable weight. Furthermore, the fundamental frequency excursion from H* pitch accent to L% boundary tone in Chickasaw questions provides a case study of how intonational tones are realized when occurring in close proximity to each other. We might thus ask whether the steepness of the f0 excursion or temporal characteristics of the f0 transition, or both, are influenced by differences in the proximity of the two adjacent tones between the three accent locations: antepenultimate, penultimate, and final.

2. Experiment

2.1. Method

An experiment was designed to investigate the realization of the H* pitch accent plus L% boundary tone sequence in Chickasaw questions. The corpus consisted of questions hypothesized to differ in the location of the pitch accent relative to the right edge of the question. In one group of words, the pitch accent fell on a final long vowel. In another set of words, the pitch accent fell on a heavy penult (either CVV or CVC). In a final group of words, the pitch accent fell on a heavy antepenult (either CVV or CVC). The pitch accented vowel was /a/ in all cases and the pitch accented words were all trisyllabic. All material to the right of the pitch accented vowel consisted of sonorants in order to allow for measurement of the fundamental frequency transition from pitch accent to boundary tone. Furthermore, any vowels after the pitch accent were /i/ to allow for a more controlled comparison of fundamental frequency contours across accent conditions. The corpus of words appears in table 1.

Table 1. Corpus of words containing pitch accents

Location	Syllable Type	
	CVV	CVC
Antepenult	ʃáːlili 'haul sth (1sg.)' táːnili 'get up (1sg.)'	mállili 'jump (1sg.)' nállili 'swallow (1sg.)'
Penult	taláːli 'put sth down (3)' iʃtáːni 'get up (2sg.)'	ʃamálli 'be stuck (3)' iʃnálli 'swallow (2sg.)'
Final	t͡ʃihaːʃáː 'be angry (2sg.)' t͡ʃiʃiwáː 'be striped (2sg)' t͡ʃikiláː 'burn (2sg.)'	Does not occur

Target words were preceded by a wh-word, either nantaːt 'what (subject)', nantahtã́ː 'what (object)', katiːmihtãː 'why', kataːt 'who', or katahtã́ː 'whom' depending on which was most semantically compatible with the target word. In addition, the target words ending in a long vowel were also elicited as a statement. Speakers were asked to give the Chickasaw equivalent to English sentences. Each speaker repeated each Chickasaw sentence four or five times. Data was collected on DAT recorder using a high quality unidirectional head-mounted microphone in a soundproof booth. Data were then converted to .wav format for analysis using the Praat software (www.praat.org). Three native female speakers of Chickasaw, all over the age of 65, participated in the experiment.

The following characteristics were examined using a pitch trace accompanied by a time aligned waveform and wideband spectrogram:

1. the duration of the accented vowel
2. the distance between the f0 peak associated with H* and the beginning of the accented vowel (absolute f0 peak delay)
3. the distance between the f0 peak of H* and the beginning of the accented vowel relative to the duration of the accented vowel (relative f0 peak delay)
4. the fundamental frequency of the f0 peak associated with the H* pitch accent
5. the fundamental frequency of the f0 trough associated with the L% boundary tone
6. the difference between the f0 peak of H* and the f0 trough of L% (f0 fall)

2.2. Results

2.2.1. Pitch accent timing

As a starting point in the investigation, the location of the f0 peak associated with H* was examined across accent locations to determine whether it aligned with syllables hypothesized to carry the pitch accent. Figure 6 depicts the timing of H* within accented long vowels in different syllables for individual speakers. Horizontal bars represent the distance between the beginning of the accented vowel and H* (peak delay) in different accented syllable, while the dark vertical lines represent the mean duration of the accented vowel.

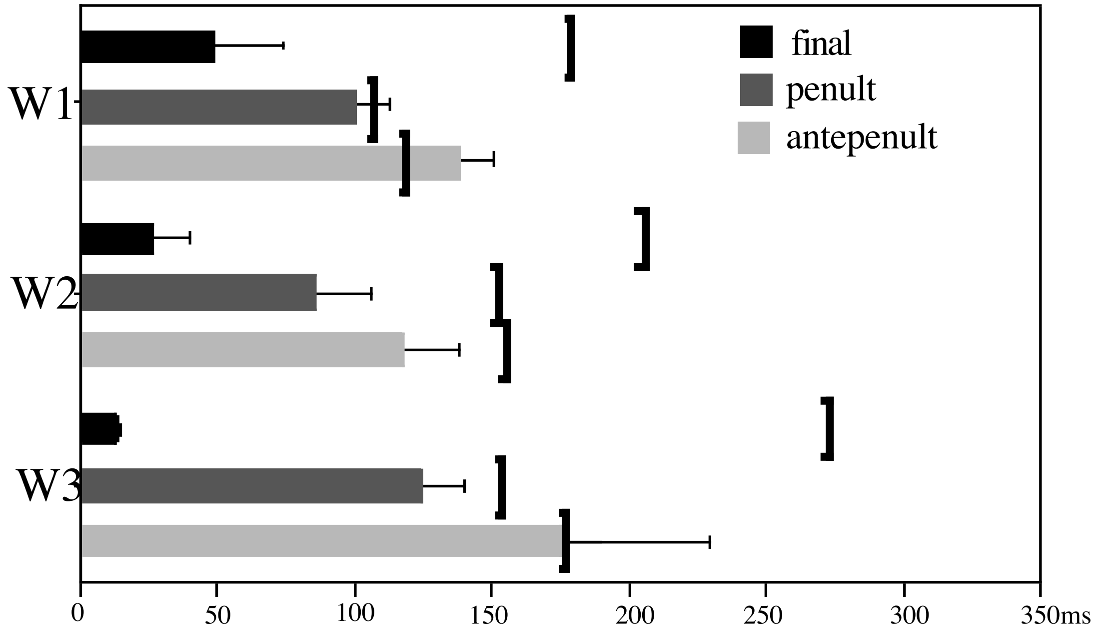

Figure 6. Distance of H* (solid bars) from the beginning of the accented vowel in CVV syllables in final, penultimate, and antepenultimate position for three Chickasaw speakers. The end of the vowel is marked with a black vertical line. Whiskers represent standard deviation.

The results are consistent with impressionistic judgments about pitch accent placement. The f0 peak associated with H* almost always falls within the vowel hypothesized to be associated with the pitch accent. The one exception to this pattern is provided by speaker W1, for whom the f0 peak associated with the antepenult occurs just to the right of the antepenultimate vowel during the coda consonant, i.e. during the first half of the following geminate. The peak delay in this case is part of a more general trend in which the distance from the beginning of the vowel to the f0 peak becomes progressively greater the farther the syllable is from the right edge of the question IP. Thus, the f0 peak occurs closest to the beginning of final vowels, farther away from the beginning of penultimate vowels, and still farther removed from the left edge of vowels in the antepenult. Interestingly, for pitch accented final syllables, the speaker with the shortest final vowels, W1, has the longest peak delay, whereas the speaker with the longest final vowels, W3, has the shortest peak delay. The relationship between final vowel duration and pitch peak timing is discussed further in section 2.2.3.

One-factor ANOVAs were conducted for individual speakers taking *absolute peak delay* (the duration between the onset of the accent vowel and the actual f0 peak associated with H*) as the dependent variable and pitch accent location (antepenultimate, penultimate, or final syllable) as the independent variable. For speaker W1, there was a significant main effect of accent location on peak delay: $F(2, 22) = 57.193$, $p<.0001$. All three accent locations differed from each other according to Fisher's PLSD posthoc tests: final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$; penultimate vs. antepenultimate syllable, $p<.0001$. Speakers W2 and W3 also had significant main effects of accent location on peak delay: for speaker W2, $F(2, 22) = 47.316$, $p<.0001$; for speaker W3, $F(2, 17) = 41.573$, $p<.0001$. Both speaker W2 and W3 made a three way distinction in peak delay between the three accent conditions: for speaker W2, final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$; penultimate vs. antepenultimate syllable, $p=.0022$; for speaker W3, final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$; penultimate vs. antepenultimate syllable, $p=.0061$.

One-factor ANOVAs were also conducted taking *relative peak delay* (the distance between the onset of the accented vowel and H* relative to the total duration of the accented vowel) as the dependent variable and pitch accent location (antepenultimate, penultimate, or final syllable) as the independent variable. All three speakers showed a significant main effect of accent location on relative peak delay: for speaker W1, $F(2, 22) = 118.635$, $p<.0001$; for speaker W2, $F(2, 22) = 69.998$, $p<.0001$; for speaker W3, $F(2, 17) = 50.713$, $p<.0001$. Most pairwise comparisons between accented syllables were statistically robust in posthoc tests pinned to the main ANOVAs; for speaker W1, final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$; penultimate vs. antepenultimate syllable, $p=.0010$; for speaker W2, final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$; penultimate vs. antepenultimate syllable, $p=.001$; for speaker W3, final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$. However, speaker W3 did not distinguish relative peak delay between accented penults and accented antepenults.

It may also be noted that final long vowels are much longer than vowels in penultimate and antepenultimate syllables for all three speakers. A single speaker ANOVA for speaker W1 with vowel duration as the dependent variable and accent location as the independent variable revealed a significant effect of accent location on vowel duration: $F(2, 22) = 186.707$, $p<.0001$. Posthoc tests indicated a significant difference between the final syllable and both the penult and antepenult in vowel duration: $p<.0001$ in both comparisons. However, the penult and the antepenult did not reliably differ from each other in duration. Results for speaker W2 were similar. There was a significant main effect of accent location on vowel duration: $F(2, 22) = 22.521$, $p<.0001$. In addition, pairwise comparisons of vowel duration between the final syllables and both pre-final syllables reached significance: $p<.0001$ in both cases. The penult and the antepenult did not reliably differ in duration. A significant main effect was also observed for speaker W3: $F(2, 17) = 90.717$, $p<.0001$. Unlike for other two speakers, however, this speaker made a three way distinction in vowel duration according to posthoc tests; final vs. penultimate, $p<.0001$; final vs. antepenultimate, $p<.0001$; penultimate vs. antepenultimate syllable, $p=.0148$. For speaker W3, vowels in the final syllable were longest, followed by those in the antepenult, and those in the penult, which were shortest.

The timing of the f0 peak of H* was also compared for CVC syllables in the penult and antepenult. (Recall that CVC final syllables in questions may not carry the pitch accent.) Figure 7 shows the distance between the f0 peak and the left edge of the accented vowel (light bars) as compared to the total duration of short vowels in CVC antepenults and penults (indicated by vertical lines).

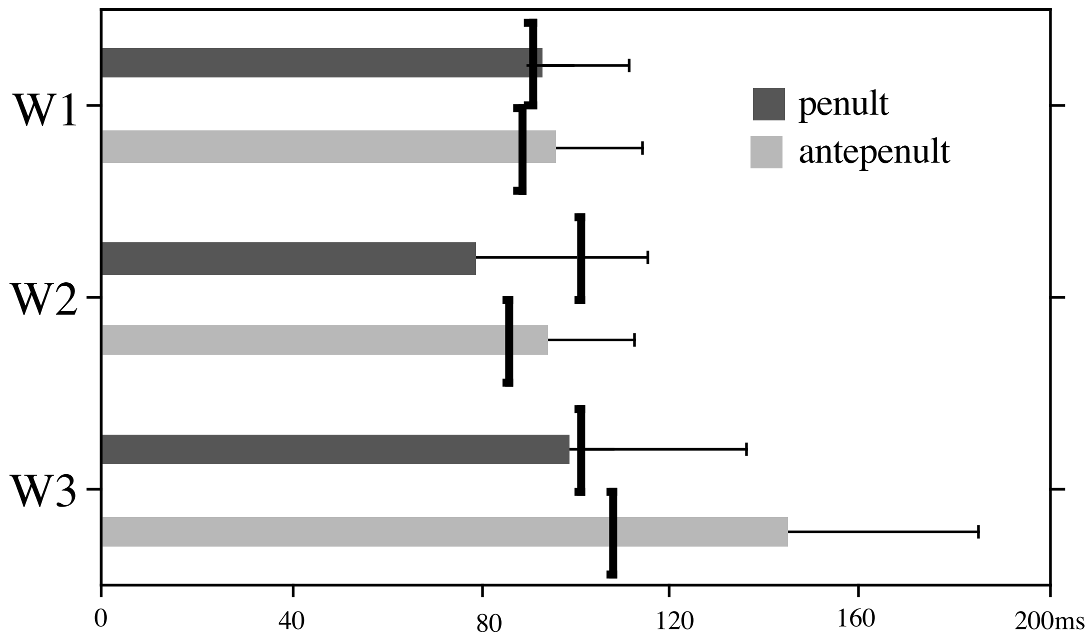

Figure 7. Distance of H* (solid bars) from the beginning of the accented vowel in CVC syllables in penultimate and antepenultimate position for three Chickasaw speakers. The end of the vowel is marked with a black vertical line. Whiskers represent standard deviation.

The f0 peak occurs slightly after the end of the antepenultimate vowel for all speakers and after the end of the vowel in the penult for two of the three speakers. T-tests conducted for individual speakers, however, indicated that only one speaker, W3, had a difference in absolute peak f0 delay between penultimate CVC and antepenultimate CVC: t (*df*=18) = 2.578, p=.0189. The peak occurred later in CVC antepenults (mean peak delay = 144 ms) than in CVC penults (mean peak delay = 98 ms). Two of the three speakers (W2 and W3) showed a difference between the penult and the antepenult in the peak delay relative to the total duration of the accented vowel: for speaker W2, t (df = 15) = 2.288, p=.0371; for speaker W3, t (*df* = 18) = 2.574, p=.0191. This effect went in the expected direction with the f0 peak occurring earlier in the penult than in the antepenult in keeping with the closer proximity of the penult to the low boundary tone.

The fact that only relative peak delay and not absolute peak delay differed for speaker W2 suggests that the source of the difference between the antepenult and penult in relative peak delay for this speaker is a difference in vowel duration between the two syllables. A longer vowel in the penult would mean that an equivalent absolute peak delay would result in a shorter peak delay relative to the entire vowel duration. T-tests for individual speakers confirmed that vowels in the penultimate syllable were longer than those in the antepenult for speaker W2: t (df=15) = 2.660, p=.0178. This may be viewed as a regressive final lengthening effect extending leftward to affect the penult (see Berkovits 1993 for a similar effect in Hebrew). There was no difference in vowel length between penultimate and antepenultimate CVC syllables according to t-test conducted separately for data produced by speakers W1 and W2.

2.2.2. Scaling of peak and trough values

Values for the f0 peak of H*, the f0 trough of L%, and the difference between these two values (f0 fall) were also compared across accent locations and syllable types. Table 2 shows f0 peak values for H*, f0 trough values for L%, and the difference between these values (f0 fall) for questions produced by the three speakers. Values for questions containing an accent on a CVV syllable are separated out from questions with the accent on a CVC syllable due to an effect of syllable structure on f0 falls for certain speakers (see discussion below).

Table 2. F0 peak values for H*, F0 trough values for L% and the difference between the two for three Chickasaw speakers. All values are in Hertz.

		CVV			CVC		
Speaker	Location	Peak	Trough	Fall	Peak	Trough	Fall
W1	Final	261	150	111			
	Penult	212	120	92	209	121	88
	Antepenult	211	105	106	201	111	90
W2	Final	255	150	105			
	Penult	250	139	111	257	133	124
	Antepenult	266	139	127	256	146	110
W3	Final	187	135	52			
	Penult	176	140	36	181	142	39
	Antepenult	172	134	38	183	137	46

Individual speaker ANOVAs with f0 fall as the dependent variable and accent location as the independent variable did not reveal a significant effect of accent location on f0 fall for either speaker W1 or W2. However, a one way ANOVA for speaker W1 with f0 peak as the dependent variable and accent location as the independent variable found an effect of accent location on peak values: $F (2, 22) = 16.441$, $p=<.0001$. Posthoc tests indicated that f0 peaks were higher in final position (mean = 261Hz) than either penultimate (mean = 212Hz) or antepenultimate (mean = 211Hz) position: in both comparisons, $p<.0001$. Another ANOVA with f0 trough as the dependent variable indicated an effect of accent location on trough values: $F (2, 22) = 21.192$, $p<.0001$. Posthoc tests showed that the f0 trough was raised in final syllables (mean = 150Hz) relative to both penultimate (mean = 120Hz) and antepenultimate syllables (mean = 105Hz): final vs. penultimate, $p=.0004$; final vs. antepenultimate, $p<.0001$. Thus, the entire pitch range in final accented syllables is shifted upward for this speaker.

Unlike for speakers W1 and W2, an ANOVA with f0 fall as the dependent variable indicated a significant effect of accent location on f0 fall for speaker W3: $F (2, 17) =$

11.302, p=.0008. Fisher's PLSD posthoc tests indicated that the f0 fall was greater when the final syllable was accented than when either the penult (p=.0003) or the antepenult (p=.0021) was accented. There was no difference between the penultimate and antepenultimate accent conditions. Two follow-up ANOVAs for speaker W3 using f0 peak and f0 trough as dependent variables indicated an effect of accent location on f0 peak values, F (2, 17) = 4.102, p=.0352, but not f0 trough values. Fisher's posthoc tests indicated that f0 peaks were higher in final syllables (187 Hz on average) than both penultimate (176 Hz) and antepenultimate (172 Hz) syllables: final vs. penultimate accents, p=.0361; final vs. antepenultimate, p=.0141. Penultimate and antepenultimate accented syllables did not differ in their f0 peak levels.

Individual speaker ANOVAs limited to CVC accented syllables with f0 fall as the dependent variable and accent location as the independent variable did not indicate any effect of accent location on f0 fall in questions with H* on a CVC syllable.

ANOVAs were also conducted to examine possible interactions between accent location and syllable type for penultimate and antepenultimate accented CVV and CVC. F0 fall was the dependent variable and accent location and syllable type were the dependent variables for these within speaker analyses. The ANOVA for speaker W1 did not reveal an effect of accent location or syllable type on f0 fall nor did it indicate any interaction between the two factors. Results for speaker W2 indicated no effect of accent location or syllable type, but there was an interaction between the two factors: F (1, 29) = 6.838, p=.0140. The source of this interaction was a reversal in patterns for the two accent locations. In the penult, f0 fall values were greater in CVC syllables (124 Hz on average) than CVV syllables (111 Hz), whereas in the antepenult, f0 fall values were smaller in CVC (110 Hz) than CVV (127 Hz). An ANOVA with f0 peak and f0 trough as dependent variables and accent location and syllable type as independent variables indicated that the source of the f0 fall difference between CVC and CVV was a difference in f0 peak between the two syllable types: F (1, 29) = 4.392, p=.0354. In the penult, f0 peak values were greater in CVC syllables (257 Hz on average) than CVV syllables (250 Hz), whereas in the antepenult, f0 peak values were smaller in CVC (256 Hz) than CVV (266 Hz).

For speaker W3, there was no effect of accent location on f0 fall nor was there an interaction between accent location and syllable type as factors. There was an effect of syllable type on f0 peak in a separate ANOVA, F (1, 31) = 5.267, p=.0287, with peaks being higher in CVC than CVV (mean f0 peak = 182Hz vs. 175Hz), p=.0348 according to a Fisher's posthoc test. An ANOVA with f0 trough as the independent variable and syllable type as a factor indicated an effect of syllable type on f0 trough values for this speaker : F (1, 31) = 7.423, p=.0105. Fisher's posthoc tests indicated that trough values were slightly higher in the penult than the antepenult (142Hz vs. 137Hz): p=.0191 in a posthoc test.

2.2.3. Slope of the f0 fall in final syllables

The slope of the fall from H* to L% in final syllables was also calculated and is plotted in figure 8.

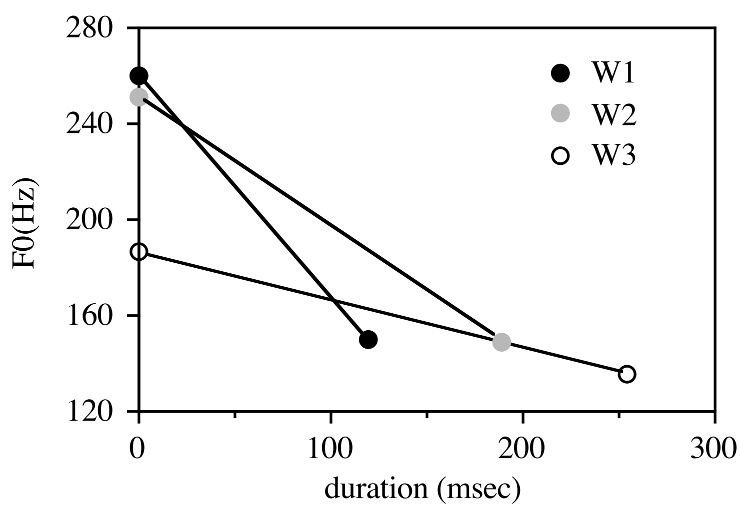

Figure 8. F0 fall from H* to L% in final CVV syllables for three speakers of Chickasaw

Speaker W1 and W2 have similar f0 values for H* and for L%, but they differ in the slope of the fall to L%. The fall is steeper for W1 than for W2 owing to the shorter duration of the vowel for W1. Speaker W3 has considerably lower f0 values than the other speakers for H* and slightly lower values for L%. The substantially lower H* values coupled with the longer duration of the final vowel relative to the other speakers contribute to the very shallow f0 slope for speaker W3.

2.2.4. Vowel duration in final accented syllables

The duration of long vowels in the final accented syllable of questions was compared with the duration of final accented long vowels in statements in order to see whether the final vowel in questions is lengthened in order to alleviate tonal crowding between H* and L%. Statement-final long vowels would be in no need of this lengthening since there is no tonal excursion between tones of different levels. Table 3 shows mean duration values by speaker for final accented vowels in questions and statements.

Table 3. Duration (in milliseconds) for final pitch accented vowels in questions and statements for three Chickasaw speakers

Speaker	Questions	Statements
W1	180	197
W2	206	220
W3	273	276

Single speaker t-tests conducted to see if final vowel duration differed as a function of IP-type revealed no difference between questions and statements. The lack of a duration difference between statement-final and question-final long vowels also indicates that the earlier finding that final long vowels are longer than pre-final long vowels in questions is attributed to the cross-linguistically pervasive phenomenon of final lengthening (Wightman et al. 1992) and is not an effect of the f0 excursion found in questions.

3. Discussion

3.1. Phonetic manifestations of tonal crowding

Results indicate that Chickasaw displays variability in the timing of pitch accents as a function of the proximity of the low boundary tone. Pitch accents are realized relatively early in final syllables, which must support both the pitch accent and the boundary tone. As the distance between the pitch accented syllable and the boundary tone increases, the pitch accent peak occurs progressively later in the accented syllable. In fact, the pitch peak tends to be realized relatively late in both penultimate and antepenultimate accented syllables. Furthermore, in closed syllables, the pitch accent typically occurs slightly after the accented vowel.

The baseline late realization of the pitch accent in non-final syllables in Chickasaw questions is consistent with findings from several other languages, e.g. English (Silverman and Pierrehumbert 1990), Mexican Spanish (Prieto et al. 1995), and Dutch (Ladd et al. 2000). The relatively late timing of the accent in syllables containing a short vowel also has analogs in other languages. For example, Godjevac (2005) reports that the f0 fall associated with the falling tone in Serbo-Croatian is realized in the posttonic syllable in polysyllabic non-utterance-final words. Ladd et al. (2000) and Schepman et al. (2006) report a similar late realization of accents in syllables containing a short vowel in Dutch. Furthermore, the early realization of the pitch accent in final syllables in Chickasaw is consistent with other languages in which intonational tones are temporally shifted in order to increase their distance from neighboring tones. This phenomenon may arise in two different circumstances: when the two crowded tones are the same, i.e. both high or both low, or when the two tones are different, i.e. one high and one low. An example of the former type of timing shift is found in English, which realizes the f0 peak associated with a prenuclear accent earlier when the following syllable is also accented (Silverman and Pierrehumbert 1990). Similarly, in the tone language, Kinyarwanda, a lexical high tone is realized monotonically earlier in a syllable as a function of the distance of a high tone to its right (Myers 2003). Tonal repulsion effects of the latter type triggered by adjacent conflicting tones have also been observed cross-linguistically. For example, the H- phrase tone is repelled from both a preceding L* and a following L% in Greek (Arvaniti 2002). In Kinyarwanda, a high tone phonologically associated with a final syllable is also pushed leftward onto the penultimate syllable before a L% boundary tone (Myers 2003). Other languages displaying tonal repulsion effects involving tones of different levels include Mexican Spanish (Prieto et al. 1995), Cypriot Greek (Arvaniti 1998), and English (Steele 1986).

Chickasaw questions represent a case of tonal repulsion involving conflicting tones, suggesting that the relevant factor is not necessarily the proximity of the two tones but the tonal excursion involved in the execution of both the high pitch accent and the low boundary tone. The gradient nature of tonal repulsion over the last three syllables in

Chickasaw questions mirrors gradience found in other languages with tonal shifts to avoid crowding, e.g. in Kinyarwanda (Myers 1999), and for one of the speakers in Silverman and Pierrehumbert's (1990) study of English.

One of the potential confounds in evaluating the effect of tonal crowding on temporal alignment of tones is the finding that pre-boundary lengthening may also trigger the relatively early realization of tonal targets. Thus, Silverman and Pierrehumbert (1990) found that prenuclear H* is realized relatively early in word-final syllables independent of the proximity of a following accent. Although final lengthening could contribute to the leftward shift of the pitch accent in final syllables in Chickasaw, it is unlikely to account for the extent of the movement. Not only is the timing of the peak early relative to the duration of the final vowel, but the absolute distance from the beginning of the accented vowel to the f0 peak is also much shorter in final syllables than in either penultimate or antepenultimate syllables. Furthermore, the pitch accent occurs earlier in absolute distance when it is associated with a CVV penult than with a CVV antepenult, even though the vowel in a CVV penult is not longer than the vowel in a CVV antepenult. If the early realization of the f0 peak were attributed only to a localized slowing down of gestures at the end of the Intonation Phrase-final vowel, we would expect consistency across accent locations in the absolute distance of the pitch peak from the beginning of the accented vowel. On the other hand, for one speaker, lengthening of the vowel in CVC penults led to a leftward shift of the f0 peak relative to the entire duration of the vowel without affecting the absolute peak delay.

There was no evidence of deletion of either the H* or L% boundary tone due to tonal crowding. Other than the interspeaker consistency in the preservation of both tones, however, proximity of the pitch accent to the boundary tone did not have a consistent effect on f0 levels across speakers. One speaker did not have a difference in the extent of the fall from H* to L% across different accent locations or different syllable types. This speaker did, however, display an overall upward scaling of both H* and L% in final syllables. Another speaker had a greater drop from H* and L% in the final syllable than in either the penult or the antepenult, where this difference was attributed to a higher H* when associated with the final syllable and not to a lowered L%. The interspeaker variability in the scaling of f0 excursions is consistent with results for Greek in Arvaniti et al. (1998). In their study, the found that the difference between the low and high f0 targets in low-high accents was greater in final syllables than non-final accents for one speaker, while two speakers had less of an f0 difference in f0 falls in both accented penults and accented final syllables than accented antepenults.

A possible explanation for the higher f0 values for H* on the final syllable of speaker W3's questions is that raising H* in this context reflects an attempt to enhance the excursion from H* to L% by increasing the difference in f0 values between the two tones. The slope of this speaker's transition from H* to L% is far shallower than that associated with the other speakers, owing to the combination of three factors: the substantially greater lengthening of the final vowel relative to other speakers, the lower absolute H* values, and the early realization of the f0 peak. By scaling H* upward, the slope of the f0 transition from H* to L% steepened thereby bringing it more in line with that of the other speakers, though still substantially shallower. Non-final pitch accents would presumably be in less need of enhancement since they occur in a separate syllable from the final boundary tone, thereby allowing comparison of f0 values across syllables rather than within a single syllable. It is conceivable that the upward scaling of H* and L% on final syllables for speaker W1 also enhances H*, and perhaps L%, without increasing the extent of the f0 fall. This strategy would have the advantage of not exacerbating tonal crowding and is consistent with the cross-linguistic use of heightened f0 to increase the prominence of focused elements (Rump and Collier 1996).

The other scaling effects on f0 observed in the data are more difficult to explain without further data. The raising of H* in accented CVC relative to CVV by one speaker could reflect a strategy for enhancing H* on a syllable type that is inherently less well suited to realizing tonal information. This hypothesis is consistent with the speaker's particularly late (relative to other speakers) realization of H* after the accented vowel and during the following consonant in both the penult and the antepenult. It is unclear why another speaker would asymmetrically raise H* on an accented CVC penult relative to a CVV penult but lower H* on an accented CVC antepenult relative to CVV in the same position.

Final accented vowels in questions were compared with their counterparts in statements in order to determine whether vowels are lengthened in order to increase the distance between a H* and L% associated with the same syllable in questions. No systematic length difference was found, suggesting that vowel lengthening is not employed as a strategy for reducing tonal crowding in Chickasaw.

3.2. The relationship between phonetic timing and phonological pitch accent placement

The phonetic timing patterns associated with H* potentially provide some insight into the complex conditioning factors governing the location of the pitch accent in Chickasaw questions. If we abstract away from cases where an unstressed syllable or an individual segment carries an accent due to contrastive focus, e.g. I said, "REceive not DEceive" (see van Heuven 1994 for discussion), stress languages characteristically restrict pitch accents to syllables carrying primary stress at the word-level. If Chickasaw adhered to this principle, we would expect the final syllable to be accented in question IP-final words not containing a pre-final long vowel (see section 1.2 on Chickasaw stress). In words containing a long vowel, we would anticipate the pitch accent to fall on the long vowel. Instead Chickasaw places the pitch accent on the final syllable of a question only if it contains a long vowel. If the final syllable lacks a long vowel, the pitch accent retracts onto the nearest syllable containing a coda consonant or a long vowel.

It is clear from the asymmetrical ability of final CVV but not final CV(C) to carry a pitch accent that Chickasaw displays a preference for placing the pitch accent accent on long vowels. From a phonetic standpoint, this preference is sensible as long vowels are best suited to carrying tonal information, in particular, tonal excursions (House 1990). A further articulatory advantage in realizing an f0 transition on a long vowel rather than a short vowel is that the long vowel provides a longer span to make the rapid transition from a high to a low articulatory target laryngeal configuration without potential perturbation effects from adjacent consonants.

In keeping with the ability of long vowels to support tonal transitions phonetically, many tone languages restrict falling or rising tones to syllables containing long vowels, e.g. Tubu (Lukas 1953), Somali (Berchem 1993), and others discussed in Zhang (2002).[5]

[5] This does not mean that tonal excursions cannot be perceived or articulated over durations characteristic of short vowels (see, for example, Sundberg 1979, Xu 1999, Xu and Sun 2000 on the articulation of fundamental frequency contours and Black 1970, Greenberg and Zee 1979 on the perception of such contours). Furthermore, there are languages in which contour tones freely occur on short vowels in

The fact that the pitch accent does not preferentially fall on pre-final long vowels over CVC in Chickasaw suggests that the crucial property distinguishing long vowels from other syllable types is the ability of a long vowel to support the transition from high pitch accent to low boundary tone. Syllables to the left of the final one do not bear the burden of realizing both the pitch accent and the low boundary. For this reason, long pre-final vowels do not preferentially attract the pitch accent.

Myers (2003) presents a possible mechanism by which a phonological restriction against tonal excursions on final syllables might develop. In his studies of Kinyarwanda (2003) and Chichewa (1999), he observes that the gradient phonetic shifting in Kinyarwanda of a high tone from the final syllable to the penult in utterance-final position due to tonal crowding between the lexical high tone and the final low boundary tone mirrors a similar categorical phonological displacement of high tone to the penultimate syllable in Chichewa. Myers (2003) suggests that the Chichewa phonological pattern may have originated as a phonetic shifting of tone from the final to the penultimate syllable like that observed in Kinyarwanda. Over generations listeners might have reanalyzed this phonetic timing pattern as a phonological pattern, an instance of a hypocorrective sound change (Ohala 1993, 1994).

A similar account could be extended to Chickasaw incorporating the additional factor of syllable weight. The pitch accent might originally have been phonologically aligned with the final syllable in all questions regardless of syllable structure, in keeping with the pattern observed synchronically in statements. Under this account, the pitch accent would have been phonetically realized, however, only on final syllables containing a long vowel. If the final syllable was short, the accent would have been phonetically shifted to the left of the final syllable. This phonetic displacement of the tone might eventually have been reinterpreted as phonological alignment of the pitch accent with a pre-final syllable. It is conceivable that proximity of the L% boundary tone would have forced the pitch accent very early in a CV penultimate syllable or even at the end of the syllable immediately preceding a CV penult. This early timing of the pitch accent might have been phonologized as antepenultimate accent preceding a CV penult, thereby

addition to long vowels (Zhang 2002). Nevertheless, both the typological rarity of contour tones on short vowels in tone languages and the experimental evidence suggests that a long vowel likely provides a superior backdrop for the realization of a tonal contour (see Zhang 2002 for discussion).

leading to the asymmetric phonological docking of the pitch accent on the penult if CVV or CVC and on the antepenult if the penult was CV. Alternatively, even if the pitch accent were phonetically realized on all types of penultimate syllables, speakers may have avoided accenting a CV penult due to its inherent lack of prominence instead positioning the pitch accent on the nearest *stressed* pre-final syllable. Consistent with this hypothesis is the synchronic observation that the pitch accent in Chickasaw is restricted to syllables that carry some degree of stress.

4. Conclusions

This study has provided phonetic corroboration of the phonological conditions on pitch accent placement in questions in Chickasaw, a structurally and genetically divergent language from others in which intonation has been quantitatively studied. Furthermore, investigation of the timing and scaling of pitch accents has enabled the classification of a North American Indian language within the typology of responses to tonal crowding. Of the various possible strategies for reducing tonal crowding between a high pitch accent and a low boundary tone, Chickasaw speakers consistently opt for early realization of the pitch accent. Other means employed cross-linguistically for minimizing crowding were not observed in the Chickasaw data, including deletion of one of the crowded tones, compression of tone range, or lengthening of the accented vowel.

Chickasaw also represents a case in which phonetic and phonological aspects of tonal crowding avoidance dovetail. The phonetic timing of the pitch accent varies gradiently as a function of the distance between the accented syllable and the right edge of the question. Phonologically, the pitch accent is restricted to final syllables containing a long vowel, in keeping with the greater ability of long vowels relative to short vowels to realize crowded tones. The parallel between phonetic and phonological timing of pitch accents in Chickasaw lends credence to hypotheses that suggest the phonological conditions governing pitch accent placement in Chickasaw may ultimately have their roots in phonetic patterns.

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