TONE ASSOCIATION AND F0 TIMING IN CHICHEWA[*]

Scott Myers
University of Texas at Austin

In Chichewa (Bantu, Malawi), a high tone is realized as a peak in fundamental frequency (f_0). In this study, the timing of f_0 peaks relative to the duration of the high-toned syllable was measured for high tones in phrase-medial, -penultimate and -final positions. No phonetic support was found for the assumption in the literature that a phrase-medial high tone is spread over two syllables. Instead, it was found that such a high tone is realized with a significantly later f_0 peak than a high tone in the last two syllables. On the other hand, support was found for Kanerva's proposal that a phrase-final high tone is shifted in phonological representation to the phrase-penultimate syllable.

1. Introduction

There are two tone patterns in Chichewa (Bantu, Malawi) which have been described as depending on position in the phrase [Moto 1984, Louw 1987, Mtenje 1987, Kanerva 1989].

First, according to these descriptions, a high tone spreads rightward onto the following syllable *only if the high tone is not in the last three syllables of a phrase*. This is illustrated in the transcriptions from Kanerva [1989] in (1) and (2). The penultimate vowel of a phrase in Chichewa is always lengthened; all other vowels are short. A high tone in the last three syllables of a phrase, as in (1a) and (2a), is associated with just one syllable, but if a high tone occurs earlier in the phrase, it is associated with two syllables, as in (1b) and (2b).

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(1) a. *mtsíkaana*   'girl'
   b. *mtsíkána uuyu* 'this girl'

(2) a. *zidzábeera*   'they will steal x for/ with you'
   b. *zidzábéraana*   'they will steal x for each other'

The second restriction on tone association is that a lexical (i.e., non-intonational) high tone is disallowed in phrase-final position [Kanerva 1989].[1] A lexical high tone that would be expected to occur in phrase-final position is realized instead on the second half of the lengthened phrase-penultimate syllable, as illustrated in (3) and (4) [Kanerva 1989: 59]. In non-final position in the phrase, as in (3a) and (4a), the words *mlendo* and *peza* have a high tone on the final syllable. But in phrase-final position, as in the isolation forms in (3b) and (4b), these words have a high tone on the penultimate mora of the phrase, so that the lengthened penult syllable has rising tone. To account for this shift, Kanerva proposes a phonological rule retracting a high tone from phrase-final position (p. 58).

(3) a. *mle^{n}dó uuyu*   'this visitor
   b. *mleé^{n}do*   'visitor'

(4) a. *pezá nyaama*   'find the meat!'
   b. *peéza*   'find!'

Avoidance of high tone in phrase-final position, as in (3)-(4), is common across languages. Among Bantu languages, a high tone is disallowed in phrase-final position in Makua [Cheng & Kisseberth 1979: 34], Haya [Byarushengo, Hyman & Tennenbaum 1976: 186], Rimi [Schadeberg 1979: 289], Ndanda Yao [Odden, 1998: 308)], Ruciga [Cassimjee & Kisseberth 1998: 69], Tetela [Stevick 1969: 340], Chasu [Stevick 1969: 339], and Kukuya [Hyman 1987: 318]. Utterance-final high tone is also disallowed in non-Bantu languages such as Serbo-Croatian [Inkelas & Zec 1988], and Tangale [Kenstowicz & Kidda 1987]. This incompatibility of high tone with phrase-final position is presumably related to the fact that a tone in such a position is generally realized at a lower pitch than in other positions, an effect known as *final lowering* [Liberman & Pierrehumbert 1984, Pierrehumbert & Beckman 1988, Herman 1996].

The tone spread pattern in (1)-(2) above is unusual though. Tone spread from one syllable to the following one is common crosslinguistically, reported in Bantu in such languages as Shona [Odden 1981, Myers 1990], Bemba [Sharman & Meeussen 1955: 394], Kikuyu [Clements 1984: 318], and Chimaraba Makonde [Odden 1990: 69], and outside of Bantu in Navajo [Kari 1976: 59], Sanskrit [Whitney 1896], and Yoruba [Hyman & Schuh 1974: 88]. But there is no other

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[1] The only high tone that can occur in phrase-final position is the boundary tone H%, marking the end of a question or a nonfinal phrase [Myers 1996].

case in the literature in which tone spread from one syllable to the next is subject to the condition that the trigger syllable be further than three syllables from the end of a phrase. Such a pattern would represent a counterexample to the otherwise well-motivated generalization that phonological patterns always involve elements that are structurally adjacent [Myers 1990, Odden 1994, Archangeli & Pulleyblank 1994], since the string of three syllables that must be counted off at the end of the phrase need not be close to the trigger and target of the spread.[2]

An alternative view of this pattern arises from work on the timing of changes in fundamental frequency (f_0), the acoustic manifestation of tone. A high tone corresponds to a period of relatively high f_0. The f_0 peak corresponding to a high-toned syllable generally occurs not in that syllable itself, but rather early in the next syllable. Such a pattern of f_0 peak timing has been described for English [Steele 1986; Silverman & Pierrehumbert 1990], Spanish [Prieto, van Santen & Hirschberg 1995], Danish [Thorsen 1978], Navajo [de Jong & McDonough 1993], Czech [Bartels 1995], Modern Greek [Arvaniti, Ladd & Mennen 1998], and Brazilian Portuguese [Madureira et al. 1999].

The interval from the beginning of the tone-bearing unit to the f_0 peak is called *peak delay* [Silverman & Pierrehumbert 1990]. Experimenters have found, however, that the more stable measure of f_0 timing is *relative peak delay*, which is the peak delay divided by the duration of the tone-bearing syllable. The f_0 peak does not occur at a constant period after the onset of the syllable, but it does tend to occur at a constant percentage of the syllable duration.

Relative peak delay is not, however, absolutely invariant. One important source of variation is that relative peak delay is systematically reduced in prosodically lengthened syllables, i.e., syllables that are longer due to their position in the phrase. Silverman and Pierrehumbert [1990] found that relative peak delay in English is reduced in two contexts in which a syllable is lengthened: (a) in phrase-final or word-final position (final lengthening), and (b) in a stressed syllable immediately preceding another stressed syllable (stress clash). Prieto, van Santen, and Hirschberg [1995] found the same result in Spanish. In Oneida, Grimm [1997] found that while the f_0 peak of a short accented vowel occurred in the next syllable, the f_0 peak of an accented long vowel occurred in the accented syllable itself.

Consider, then, how these general patterns of f_0 timing might apply to Chichewa. A high tone in an unlengthened syllable is expected to be realized with f_0 rising through the high-toned syllable up to a peak near the beginning of the next syllable. This could easily be interpreted as tone spread, since both the high-toned syllable and its successor include regions of high f_0 (cf. de Jong & McDonough [1993] on such a case in Navajo).

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[2] Kanerva [1989] proposes that the high tone spreads one mora to the right if the target mora is not included in a foot, relying on arguments that the final two syllables in a phrase are included in a trochaic foot. This formulation does not require reference to nonadjacent material, but it is just as anomalous in a typological sense. No other instance of such a condition on local tone spread has been noted in the literature.

The last two syllables in the phrase, on the other hand, are lengthened. The penult is lengthened because it is stressed, and the final syllable is subject to phrase-final lengthening. We thus would expect the f_0 peak to occur relatively early in such syllables. If it is substantial relative peak delay that leads transcribers to hear the high tone on two syllables, then such an early f_0 peak would systematically fail to give that impression. It could even give the impression that the high tone has been retracted to an earlier mora.

The phonetic hypothesis, then, is that there is no tone spread or tone retraction, but rather a gradient pattern of f_0 timing sensitive to vowel length and phrase-final position. This paper presents the results of an instrumental study of f_0 timing in Chichewa, aimed at testing the phonetic hypothesis. The timing of f_0 peaks for high tones in phrase-medial, -penultimate and -final positions was examined and modelled. The results do not support the claim in the literature that high tone in medial position is spread, but are consistent with a phonetic timing account of that position. The results do, on the other hand, support Kanerva's [1989] proposal of phonological phrase-final high tone retraction. The analysis contributes to the general discussion of the distinction between phonetic and phonological patterns [Liberman & Pierrehumbert 1984, Keating 1988, Pierrehumbert 1990], and specifically addresses the phonetic interpretation of autosegmental association.

2. Experiment 1: F0 timing in lengthened and unlengthened vowels

In the first experiment, the timing of f_0 peaks for high tones in phrase-medial (pre-antepenultimate) position was compared to that for high tones in lengthened phrase-penultimate syllables. According to the phonological account in the literature, the f_0 peaks should be longer (i.e., more plateau-like) in the phrase-medial case than in the phrase-penultimate case, due to tone spread. According to the phonetic alternative, the difference between the two phrase positions lies in the timing of the f_0 peak, rather than its duration.[3]

2.1. Methods and Materials. The test sentence was the following. The tone marking here abstracts away from the tone spread that is at issue.

(5) *mlónda   ámayenéra kuɲéeɲa.*
     watchman must   INF.goof-off
     'The watchman must goof off.'

Measurements were made for the two underlined syllables: the high-toned phrase-medial syllable *né* and the high-toned phrase-penultimate syllable *ɲée*. This sentence was chosen because it has nasals and liquids in the neighborhood of the relevant f_0 peaks. These consonants induce minimal disturbance of f_0, and are clearly distinguishable from the neighboring vowels in spectrograms and waveforms.

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[3] We focus on high tones and f_0 peaks, since Myers [1998] has shown that non-high-toned syllables in Chichewa are toneless, lacking any phonetic target for f_0.

Three speakers of Chichewa produced the test sentence: SM, DJ, and CJ. All three speakers are adult native speakers of Chichewa from Malawi. SM is a male from Nkhotakota in the Central region, DJ is a male from Blantyre in the South, and CJ is a female from Mzuzu in the North. Due to a failure in the labeling of tokens, all data from Experiment 1 for speaker DJ had to be omitted. Only results from speakers SM and CJ are reported in this section.

To induce a broad range of f_0 values, speakers were instructed to vary loudness and sentence type. F_0 peaks are higher in louder speech than in less emphatic speech [Liberman & Pierrehumbert 1984], and higher in questions than in statements in Chichewa [Myers 1996]. There were three levels of loudness: *loud* (as if shouting to someone in the next room), *normal* (as if speaking to someone across a table), and *soft* (as quietly as possible without whispering). The speakers produced the sentence both as a *question* and as a *statement* .

To induce a broad range of syllable durations, speakers also varied their rate of speech. There were two self-selected speech rates: *normal* and *fast* (as fast as possible while still speaking clearly).

Speakers read the sentence from a sheet where the printed sentence was accompanied by instructions as to how loudly and quickly it was to be produced. Each speaker produced twenty repetitions of the sentence (in blocks of six) in each combination of loudness and rate conditions, for a total of 240 tokens per speaker (3 loudness conditions X 2 rate conditions X 2 sentence types X 20 repetitions).

The utterances were recorded on a Sony DAT tape recorder in a sound-treated booth in the Phonology Laboratory of the University of California at Berkeley. The recordings were redigitized and analyzed using Soundscope, a Macintosh-based sound analysis system produced by GW Instruments. Using synchronized waveform, spectrogram and f_0 displays, the following time intervals were measured in the phrase-medial syllable *né* and the lengthened penultimate syllable *ɲée*.

(6) *Measurements*

a. *Syllable duration*. The interval from the beginning of the onset nasal in the test syllable (as indicated by marked drop in amplitude in the waveform and a fall to a minimal value of F1 in the spectrogram) to the onset of the next syllable (as marked by the same indications).

b. *F_0 peak delay*. The interval from the beginning of the test syllable (as indicated in (6a)) to the onset of the f_0 peak (the first instance of the local maximum value in f_0, excluding discontinuous values during consonants).

c. *F_0 plateau*. The interval from the onset of the f_0 peak (as indicated in (6b)) to its offset (i.e., the last instance of the local maximum value in f_0).

High tones were realized as a rise in f_0 up to a peak value, followed by a fall. The f_0 peak (the highest f_0 value in the region) sometimes consisted of a single point, and sometimes was held for some time. *F_0 peak delay* in (6b) is a measure

of when the peak is attained, relative to the beginning of the tone-bearing syllable. F_0 *plateau* in (6c) is a measure of how long that peak is held.

A sample display for speaker SM is given in Fig 1, with measurement points indicated. Vertical lines mark off the two syllables, and arrows mark the onset and offset of each of the two f_0 peaks. Note that the first peak, in medial position, comes after the high-toned syllable marked off by vertical lines, while the second peak lies well within the vertical lines marking the penultimate syllable. In this example, then, f_0 relative peak delay is greater in medial position than in the lengthened penult, consistent with the pattern described above for English and Spanish.

Fig. 1. Sample display with measurement points (speaker SM)
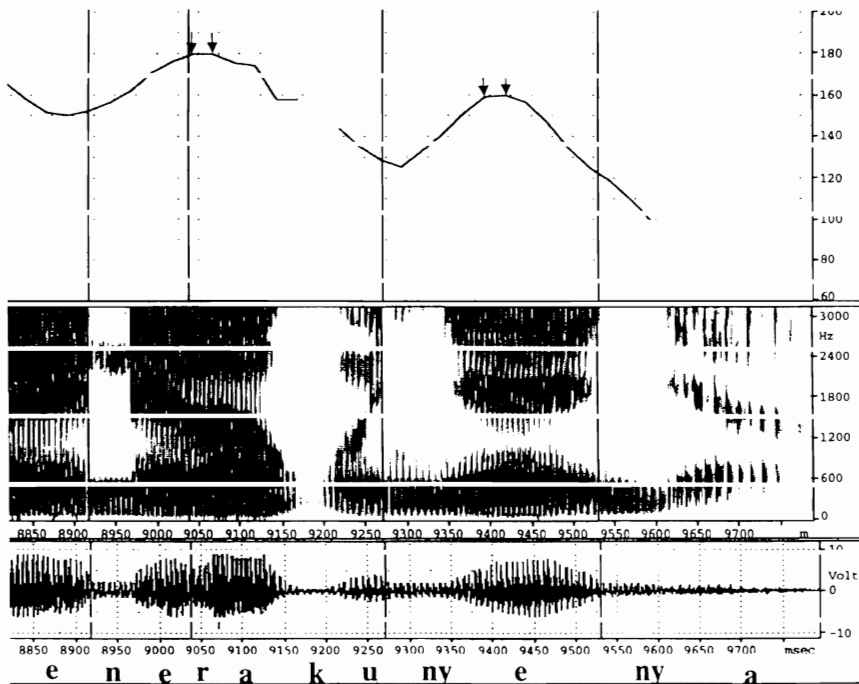
2.2. Results

2.2.1. F_0 peak delay. The data are plotted in Fig. 2, where the x-axis represents the syllable duration and the y-axis the f_0 peak delay. Datapoints from the lengthened penult syllable are plotted with squares, while those from the unlengthened phrase-medial syllable are plotted with triangles.

Fig. 2. Peak delay relative to syllable duration.

(a)

(b)
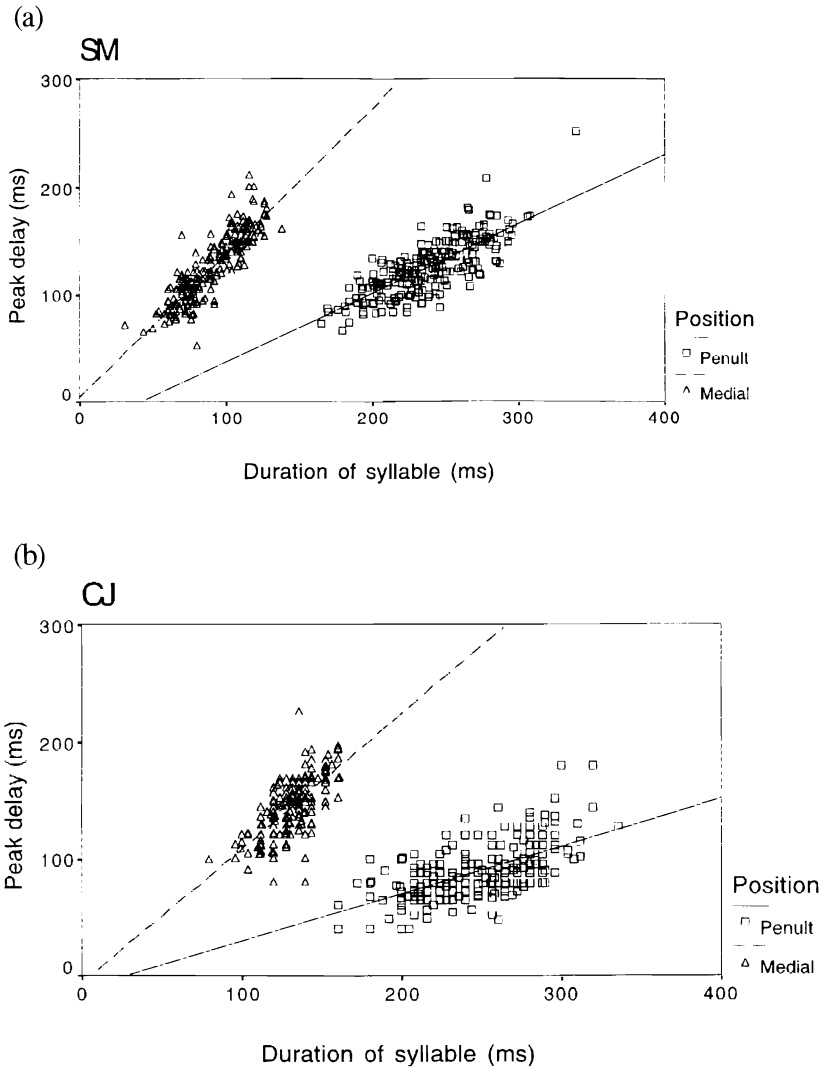
The squares in Fig. 2 are grouped to the right of the triangles, indicating that the penult syllables are longer than the medial ones. The mean duration of the penult syllables was generally about twice that of the medial syllables, as shown in (7). These differences were statistically significant, as shown by the t-tests in the fourth column (in which medial and penult syllables of each token were paired together).

(7) Mean syllable duration by phrase position (ms)

Speaker	Medial	Penult	Paired t-test
a. SM	90	238	$t_{239} = -88.4$, $p < .01$
b. CJ	131	247	$t_{239} = -55.0$, $p < .01$

Within each group in Fig. 2, the points display a strong linear trend, with f_0 peak delay being greater for longer syllables, as represented by the regression lines through each set of data. The fact that these lines are sloped rather than horizontal indicates that peak delay is not constant, but varies systematically as a function of syllable duration.

The dashed line for the medial datapoints is steeper than the solid line for the penult datapoints. This means that any given increase in syllable duration corresponds with a greater increase of peak delay in medial syllables than in penultimate ones. In other words, the peak is later in the syllable in the medial than in the penultimate syllables.

These trends can be modeled quantitatively by means of multiple linear regression, a statistical technique for calculating the linear trends that best fit the data. The model equations are given in (8) together with R^2, which represents the percentage of the variance in the data that is accounted for by the equation.

(8) Linear models of peak delay
(P (Position) = 0 for medial, 1 for penult; S = syllable duration)

Speaker	Regression equation	R^2
a. SM	Peak delay = (((−.88 P) + 1.43) * S) − 3.89	.70
b. CJ	Peak delay = (((−.77 P) + 1.18) * S) − 9.67	.75

The model equations are formulated so that *position* is reflected in the co-efficient of *syllable duration*, since it is clear in Fig. 2 that the two position groups differ chiefly in the slope of the line. This position coefficient is large and negative for both speakers, indicating that the f_0 peak is earlier in penult position (P = 1) than in medial position (P = 0). The R^2 values in the last column indicate that most of the variance in peak delay is accounted for in terms of these two factors.[4]

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[4] The models in (8) had significantly better fit than alternative models that were tried with other mathematical forms or other syllable landmarks as reference points (e.g. the beginning of the vowel, the beginning of the following vowel, the end of the following syllable). All models were compared by means of paired t-tests with absolute value of the residuals as the dependent variable. Such tests also showed that the models in (8) had significantly better fit than a model based on a suggestion of a reviewer, according to which peak delay is a constant, rather than sensitive to syllable duration.

These models indicate that the f_0 peak in medial syllables occurs later, relative to the tone-bearing syllable, than in penult position. To focus on this point, we look at *relative peak delay* (f_0 peak delay divided by syllable duration). The mean values for this measure are given in (9).

(9) Mean relative peak delay by phrase position.

Speaker	Medial	Penult	Paired t-test
a. SM	1.39	.53	$t_{239} = 68.0$, $p < .01$
b. CJ	1.10	.36	$t_{239} = 76.6$, $p < .01$

The mean relative peak delay in medial position is over 1 for both speakers, indicating that the f_0 peak generally occurred after the end of the high-toned syllable. It is considerably less than 1 in the penult position, indicating that the peak in that position occurred well within the high-toned syllable. The paired t-tests summarized in the last column establish that this difference in f_0 timing between the two positions is significant. As in (7), each medial measurement was paired with the penult measurement for the same utterance token.

We conclude that f_0 peak delay is significantly greater in medial position than in penult position for these speakers of Chichewa.

2.2.2. F₀ peak plateau. According to Kanerva's [1989] phonological analysis, the penultimate syllable is represented with two moras, while all other syllables have just one. Tone spread leads to a configuration in which any high tone in medial position is associated with two moras in two successive syllables, while a high tone in penult position is associated with only one mora. If moras are taken to be timing units [Hubbard 1995, Broselow et al. 1997], we then expect the f_0 plateau (as defined in 6c) to be longer in the case of the two-mora medial tone span than in the one-mora penultimate tone span. Such a comparison is summarized in (10).

(10) F₀ plateau duration by phrase position (ms)

Speaker	Medial	Penult	Paired t-test
a. SM	26.2	21.3	$t = 3.32$, $p < .01$
b. CJ	23.0	25.1	$t_{239} = -1.42$, $p = .16$

It can be seen that the duration means for the two positions are very close, distinguished only by a few milliseconds. For CJ this small difference is insignificant and goes in the wrong direction. For SM the effect is significant, but too small to be expressed through tone spread, since then we would expect the difference to approximate the duration of a syllable (compare (7)).

The f_0 data therefore do not support the view that a medial high tone covers two moras while a penultimate high tone covers just one.

2.3. Implications of Experiment 1. The phonetic evidence, then, does not support the claim that tone is spread in certain phrase-positions in Chichewa, but does indicate a significant difference in f_0 timing for these two speakers between phrase-medial and phrase-penultimate high tones. This is a welcome result, since the phonetic timing pattern is cross-linguistically well-attested while the proposed phonological tone spread pattern is anomalous compared to tone spread patterns in other languages.[5]

The pattern of f_0 peak delay might shed light on a number of reported tone patterns in Bantu languages. In a number of languages in that family, high tone is described as being shifted one syllable to the right of its underlying position: Rimi [Olson 1964], Chiruri [Massamba 1984], Jita [Downing 1996], Kikuyu [Clements & Ford 1979], Eerati Emakhua [Cassimjee & Kisseberth 1998: 34], and Chaga [McHugh 1990]. It is possible that some or all of these cases are actually instances of the phonetic pattern of f_0 peak delay we have described here. Quantitative instrumental analysis would be needed in order to decide whether these patterns are gradient or categorical. The crucial question would be whether the f_0 peak is timed with respect to the original high-toned syllable, or to the syllable following that one (see Section 3 below).

If some or all of these cases are found to involve a genuine shift in the syllable with which the tone is associated, then it is likely that f_0 peak delay forms the phonetic basis for that shift. It is striking that shift to the right is reported much more frequently than shift to the left, described in Bantu languages only for Kinyarwanda [Kimenyi 1979] and Kinande [Hyman & Valinande 1985]. Moreover, the leftward tone shift in Kinyarwanda is disputed on the basis of f_0 data by Furere and Rialland [1985].

One might ask why a high tone should be realized *after* the syllable that it is associated with. One hypothesis might be that the vocal fold adjustments that determine f_0 modulation are more sluggish than the supralaryngeal gestures that define the syllable. Another possible explanation would be in terms of perception. House [1990] has shown that f_0 cues are more easily perceived in regions of relative spectral stability, as in the midpoint of a vowel, than in regions of rapid spectral transition, as in the consonant-vowel transition. A rapid rise in f_0 is a salient cue in identifying a high tone ['t Hart 1981]. Thus alignment of the f_0 peak with the end of the high-toned syllable insures that the f_0 rise is centered over the spectrally most stable portion of the syllable.

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[5] A preliminary report of the data for speaker SM was presented in Kim [1998] without permission of the experimenter. That paper suffers from the following problems. (a) The data on which Kim's report was based included some measurement errors, which had to be corrected before the data could be used for the present study. (b) Kim's dataset was not balanced across conditions. (c) The statistical analysis is flawed, being based on an invalid comparison of R^2 values across different populations. (d) The report only considers peak delay, a measure which provides no information about whether the peak is associated with one syllable or two.

One limitation of the experiment was that only two phrase positions were included: penultimate and pre-antepenultimate. The impressionistic descriptions, however, include the antepenultimate position as one in which a tone does not spread. I have not done a controlled study of the timing of f_0 peaks in this position, but my preliminary and informal observation suggests that f_0 peaks are earlier in antepenultimate position than in pre-antepenultimate positions. The antepenultimate syllable is not lengthened, unlike the penultimate and final, so a lessening of peak delay in this position would not be expected on that basis. However, the literature has shown that upcoming f_0 peaks or phrase-boundaries can also have the effect of diminishing peak delay, and that this effect can hold even for high tones a few syllables away from those conditioning factors [Silverman & Pierrehumbert 1990, Prieto, van Santen & Hirschberg 1995]. If the f_0 peak is indeed early in the antepenultimate syllable, it could be due to such an effect. If so, one would expect the peak to be significantly later in antepenultimate than in penultimate and final positions, since the conditioning factors would be one syllable more distant.[6]

3. F0 timing in phrase-final position

According to Kanerva [1989], when a high-tone-final Chichewa word such as *mwaná* 'child' occurs in phrase-final position, the word-final high tone is not realized on the phrase-final syllable, but rather is shifted to the second mora of the lengthened phrase-penultimate syllable (e.g., ...*mwaána*.).
    An alternative view would be that the high tone is not shifted to a nonfinal tone-bearing unit, but rather that the f_0 peak realizing the high tone occurs relatively early relative to the phrase-final syllable. Steele [1986], Silverman and Pierrehumbert [1990], and Prieto, van Santen, and Hirschberg [1995] found that an f_0 peak occurred earlier in a word- or phrase- final syllable than in a syllable further from the edge of such a prosodic domain. Since word- and phrase-final syllables tend to be longer than comparable nonfinal syllables, this could be seen as an instance of the reduction of peak delay in lengthened syllables. An earlier f_0 peak in phrase-final position could also be induced by the intonational boundary tone on the phrase-final syllable, since f_0 peak delay is reduced if another f_0 target immediately follows, an effect known as "tonal crowding" [Silverman & Pierrehumbert 1990; Engstrand 1997; Arvaniti, Ladd & Mennen 1998].
    Thus, as in the comparison between medial and penultimate position treated in Section 2, there are two hypotheses regarding the distinction between final and nonfinal position. According to Kanerva's phonological analysis, a phrase-final syllable cannot bear a high tone, and any potential phrase-final high tone occurs

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[6] It is important to note that no result about f_0 timing in antepenultimate position could support the tone spread analysis and refute the phonetic timing analysis provided in this section. Finding that there was tone spread in antepenultimate position would be incompatible with either analysis. On the other hand, the tone spread analysis makes no predictions about the timing within the syllable of f_0 peaks that are not spread. Thus including antepenultimate high tones in the experiment would have told us something about f_0 timing, but would not have provided evidence about tone spread, the main focus of this study.

instead in the penultimate syllable. According to the phonetic alternative, a high tone can occur in phrase-final position, but it occurs earlier relative to that syllable than in other positions.

To distinguish the two hypotheses, we must first decide how to determine on the basis of phonetic data which syllable a given tone is associated with. In the original formulation of autosegmental phonology, Goldsmith [1976] proposed that association of a tone with a vowel is phonetically interpreted as meaning that the two were simultaneous. Sagey [1988] amended this proposal, suggesting instead that the phonetic instantiations of two elements associated with each other must merely overlap in time.

Neither proposal specifically addressed phonetic data, and neither is, in fact, realistic as a proposal about phonetic timing. For example, if the f_0 peak is taken to be the phonetic instantiation of a high tone, we have seen that it need not overlap at all with the phonetic instantiation of the syllable it is associated with. Similarly, Browman and Goldstein [1990] point out that the peak of glottal spreading in an aspirated stop is timed to occur just after the end of the closure for that stop. The phonetic literature abounds with evidence that the various acoustic cues for a segment need not be either simultaneous or overlapping [e.g., Liberman et al. 1967].

Browman and Goldstein [1990] propose that autosegmental association between phonological elements *a* and *b* is to be interpreted as stating that there is a regular phasing relation between the phonetic realizations of *a* and *b*. In other words, if two things are associated, then one can predict the timing of the phonetic realization of one based on the timing of the phonetic realization of the other. This definition is consistent with the regularities of interarticulator timing [Browman & Goldstein 1990, Huffman 1993, Sproat & Fujimura 1993]. Applied to tone, it implies that we can tell which syllable a high tone is associated with by finding which syllable provides the best prediction of the timing of the f_0 peak (cf. Ladd [to appear]). This test is applied in this section to the issue of which syllable a high tone is associated with in Chichewa.[7]

3.1. Methods. The same speakers and recording procedures were used as in experiment 1 (see Section 2). The two sentences compared, listed in (11), were identical except for the final word.[8]

(11) a. *mlónda ámaiwála kuɲééɲa.*
       watchman he-forgets   INF.goof-off

      'The watchman forgets to goof off.'

   b. *mlónda ámaiwála mwaaná.*
       watchman he-forgets child

      'The watchman forgets the child.'

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[7] I have benefited in writing this section from reading Doran [1997], an analysis of CJ's data for Experiment 2.

[8] As above in (5), the tonal transcription in (11) abstracts away from the tone retraction and tone spread in question.

Measurements were made in the last two syllables of each phrase. The sentences were produced as a statement and as a question, and at three different loudness levels (soft, normal, loud). Speaking rate was a self-selected "normal" one. The first 20 tokens of each sentence in each condition were selected for measurement, yielding 20 tokens X 2 sentences X 2 sentence types X 3 loudness levels = 240 total tokens.

In Experiment 1, speakers produced both questions and statements in order to generate variation in f_0 level. In Experiment 2, the same distinction is exploited as an independent variable to test whether the final boundary tone marking the distinction between question and statement would have an effect on the timing of high tones in the last two syllables of the word. Myers [1996] showed that questions and nonfinal phrases in Chichewa generally end in an abrupt rise (or rise-fall) in f_0 on the final syllable, while utterance final statements end in a fall. This difference can be represented in terms of a contrast between the boundary tones H% and L% [Pierrehumbert 1980]. One question in Experiment 2 is whether the f_0 peak realizing a high tone occurs earlier in the syllable if another f_0 peak follows, as has been reported in other languages [Silverman & Pierrehumbert 1990; Engstrand 1997; Arvaniti, Ladd & Mennen 1998].

Measurements were made, as in Section 2, of the following intervals:

(12) a. *Syllable 1 duration.* The interval from the beginning of the penultimate syllable to the end of that syllable (as indicated by the criteria in (6)).

  b. *Syllable 2 duration.* The interval from the beginning of the final syllable to the end of that syllable.

  c. *Syllable 1 peak delay.* The time of the beginning of the f_0 peak (the first of the local maximum f_0 values) minus the time of the beginning of the penult syllable.

  d. *Syllable 2 peak delay.* The time of the beginning of the f_0 peak (the first of the local maximum f_0 values) minus the time of the beginning of the final syllable.

Because of the tendency to reduction and laryngealization in the final syllable, it was sometimes impossible to obtain one of these measurements for a given token, in which case that token had to be omitted from analysis. Two tokens were omitted from SM's dataset, giving a total of 238 utterances. In DJ's data, lowering of the final high tone in the *mwaná* statements was great enough that generally no f_0 peak could be distinguished, f_0 falling in a relatively uninterrupted straight line from the high tone on *yenéra*. As a result, the whole *mwaná* statement condition had to be omitted from his dataset, since there was no f_0 peak to measure the timing of. Comparisons for DJ are only made among the remaining pairs of conditions (180 tokens). CJ also displayed final lowering in the case of *mwaná*
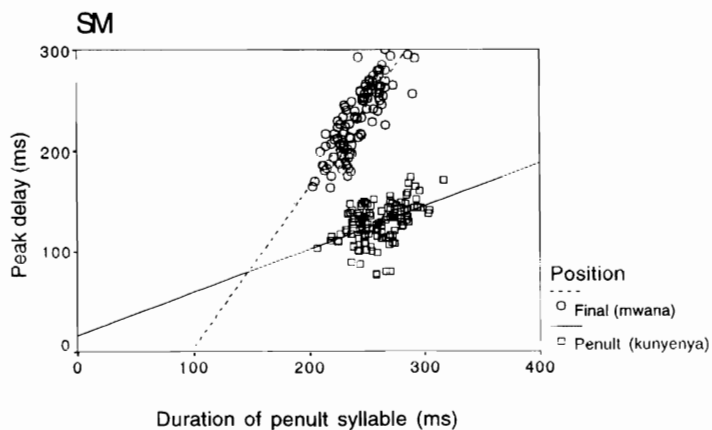
statements, but 49 instances of that condition had a measurable peak. Her total dataset included 218 tokens.
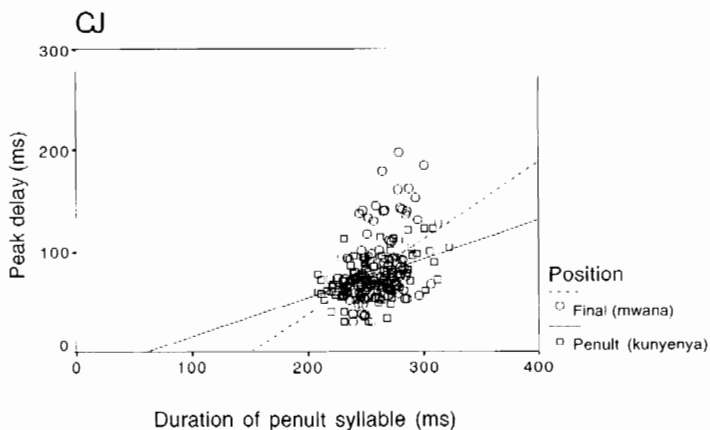
3.2. Results

3.2.1. Linear regression models. The graphs in Figure 3 display the timing of the f_0 peak with respect to the penult syllable. Circles mark "final" high tones in

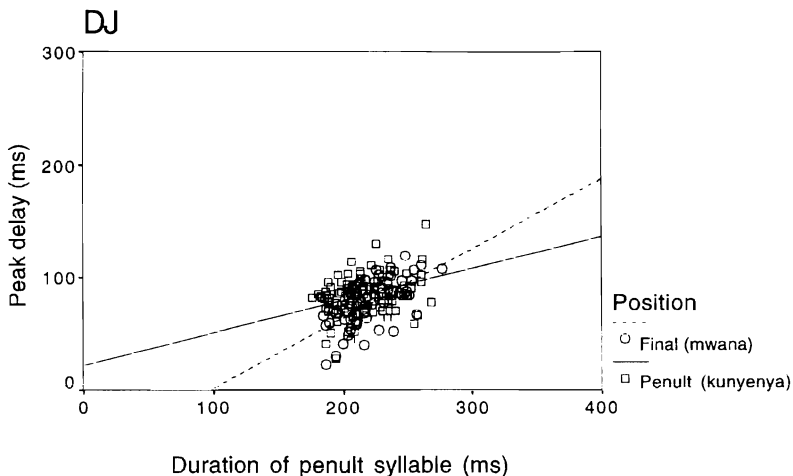Fig. 3. Peak delay relative to penult syllable duration
   (a)

   (b)

(c)

Duration of penult syllable (ms)

mwaná, while squares mark the penult high tones in *kupépa*. For all three speakers, the value on the y-axis for f0 peak delay is considerably less than the x-axis value for penult syllable duration. This means that for all speakers, the f0 peak for both classes of word normally lay within the penult syllable.

This tendency can be expressed more precisely through relative peak delay, as in (13). For all speakers, the mean values of relative peak delay are less than 1 for both position groups, indicating that the f0 peak generally begins within the penult syllable. For speaker SM, the two position groups remain distinct (cf. the two distinct clouds of points in Fig. 3a), while for speakers CJ and DJ, the two groups are close to identical (cf. the overlapping of circles and squares in Figs. 3b and 3c). According to a t-test (for independent samples of unequal variance) reported in the last column of (13), the difference between the two groups is significant for SM but not for CJ or DJ.

(13) Mean relative peak delay by phrase position

Speaker	Penult (*kupépa*)	Final (*mwaná*)	t-test
a. SM	.49	.95	$t_{210.6} = -43.0$, $p < .01$
b. CJ	.29	.32	$t_{150.0} = -1.6$, $p = .11$ (n.s.)
c. DJ	.39	.35	$t_{118} = 0.2$, $p = .87$ (n.s.)

Thus, for all three speakers, the f_0 peak in *mwaná* occurs in the penult, not the ultima. For speakers CJ and DJ, the f_0 peak is indeed timed just as in the *kupépa* forms, neutralizing the timing distinction between the two classes.

To compare a gradient phonetic analysis of this pattern with the phonological one, we compare two classes of multiple linear regression models. In the first class of model, the phonological models, the assumption is that the high tone in both the final and the penult tone classes is associated with the phrase-penultimate syllable, i.e., that the high tone of *mwaná* is shifted to the penult. In these models, the timing of the f_0 peak is predicted on the basis of the penult syllable, regardless of the underlying position of the high tone. The dependent variable is *syllable 1 peak delay*, and the independent variables are *position*, *sentence type*, and *syllable 1 duration*. If these models are successful in predicting the location of the f_0 peak, this supports the phonological account of high tone retraction, as posited by Kanerva [1989].

In the second class of model, the phonetic timing models, the assumption is that the high tone remains in underlying position, so that the H in *kupépa* is associated with the penult, and that of *mwaná* is associated with the final syllable. In these models, the timing of the f_0 peak is predicted on the basis of the penult syllable for penult high tones and the final syllable for final high tones. The dependent variable in these models is *syllable n peak delay*, which is *syllable 1 peak delay* for penult high tones (*kupépa*) and *syllable 2 peak delay* for final high tones (*mwaná*). The crucial independent variable is *syllable n duration*, which is the duration of the penult syllable for penult high tones and the final syllable for final high tones. The other independent variable is *sentence type*, as in the phonological models.

Because the dependent variables in the two models are different, it would be inappropriate to compare R^2 values between them. Instead, we compare the absolute value of the residual, which is the amount by which the predicted value differs from the actual value for each token. We can compare the two sets of residuals using a paired t-test.

By this measure, the phonological models outperformed the phonetic timing models for all three speakers. The results are laid out in (14). The average of the amount by which each model was off was considerably less in the phonological models than in the phonetic timing models (third column), and this difference in fit was significant according to the paired t-tests (fourth column). Thus the more accurate prediction of the timing of the f_0 peak takes as its reference value the duration of the penult syllable, not the syllable to which the high tone belongs underlyingly. The penult, then, must be the syllable with which the high tone is associated, according to the phonetic test proposed above.

In the phonological models, the effect of *position* (the difference between *mwaná* and *kupépa*) is proportional to the size of the coefficient of *P*. For speaker SM, this coefficient is .47, which means that the f_0 peak occurs 47% later in the syllable in the final-high words than in the penult-high words. For speakers CJ and DJ, on the other hand, the coefficient of *P* is very small, indicating that there was effectively no contrast between the two position classes for these speakers.

(14) Linear models of peak delay in final and nonfinal positions

   S1P = Syllable 1 peak delay
   SnP = Syllable n peak delay
   S1dur = Syllable 1 duration
   Sndur = Syllable n duration
   P = position (0 = penult, 1 = final)
   T = sentence type (0 = statement, 1 = question)

Speaker	Regression equation	Mean absolute residual (ms)	Paired t-test
a. SM	Phonological model S1P = ((.47 P + .55) * S1dur) − (9.33 T) − 11.35	15.6	$t_{237} = -15.3$, $p < .01$
	Phonetic timing model SnP = (.95 Sndur) + (9.24 T) − 177.09	51.2	
b. CJ	Phonological model S1P = ((.03 P + .35) * S1dur) − (12.42 T) − 7.56	19.3	$t_{217} = -9.0$, $p < .01$
	Phonetic timing model SnP = (1.79 Sndur) + (54.71 T) − 430.56	44.4	
c. DJ	Phonological model S1P = ((-.04 P +.42) * S1dur) − (1.49 T) − 7.13	12.7	$t_{179} = -9.4$, $p < .01$
	Phonetic timing model SnP = (1.49 Sndur) − (33.79 T) − 236.77	38.2	

One way to make sense of this is in terms of Kanerva's [1989] phonological analysis of the tone patterns of speaker SM. Kanerva proposed that the penult syllable is the only one with two moras, and that final-high words have the high tone retracted only to the phrase-penultimate mora, i.e., the second mora of the lengthened penult, while penult-high words have the high tone on the first mora of the penult. Thus, the surface distinction between the two classes in phrase-final position would be as in (15). If we assume that each mora in the penult takes up

(15) a.   H   b.   H
            | |
        μ μ μ μ   μ μ μ
        | V | V |
    ... ku. ɲe. ɲa   ... mwa. na.

50% of that syllable's duration, then we would expect that the f_0 peak in (15b) to be about 50% later than that in (15a). That is in good agreement with the 47% found as the coefficient of P in Model A for SM.

This pattern can be expressed in Optimality Theory with the following two constraints:

(16) a. NONFINALITY: A high tone associated with a phrase-final mora is forbidden [Cassimjee & Kisseberth 1998: 66].

b. ANCHOR-R: If an input tone T has an output correspondent T', then the rightmost mora associated with T corresponds with the rightmost mora associated with T'.

The constraint FINAL in (16a) expresses the general avoidance of phrase-final high tones, documented above in Section 1. The constraint ANCHOR-R is a faithfulness constraint [McCarthy & Prince 1999], requiring that the right edge of a tone not be moved in the input-output mapping (cf. Cassimjee & Kisseberth [1998: 44]). A violation is assigned for each mora that separates the rightmost mora of output tone T' from the output correspondent of the rightmost mora of input tone T.

FINAL must dominate ANCHOR-R, as illustrated in the tableau in (17). The faithful candidate (17a) violates FINAL and so is less harmonic than either (17b) or (17c). Shift of the high tone to the penultimate mora, as in (17b), is preferred to further shift, as in (17c), because the former violates ANCHOR-R less. The optimal candidate is thus (17b), with H shifted from the final to the penultimate mora.

(17) Input: / ...mwaná./

Candidates	FINAL	ANCHOR-R
a. ...mwaa.ná.	*!	
b. ☞ ...mwaá.na.		*
c. ...mwáa.na.		**!

For the other two speakers, the neutralization of the timing distinction between the two classes can be represented by shifting the high tone in *mwaná* all the way to the first mora of the penult, as in (18). The extra shift of the high tone to the an-

(18) a.   H   b.   H
           | |
        μ μ μ μ   μ μ μ
        | V | V |
      ... ku. ɲe. ɲa   ... mwa. na.

tepenultimate mora could reflect the general tendency for high tone to occur at the beginning of the syllable, as reflected in the constraint NORISE [Poletto 1998: 347, Cassimjee & Kisseberth 1998: 72]:

(19) NORISE: Align the left edge of every high tone with the left edge of some syllable.

Both NORISE and FINAL must dominate ANCHOR-R for these speakers, as in the tableau in (20). This ranking selects the third candidate, with the final H shifted to the antepenultimate mora. As a reviewer notes, such a shift of tone over two moras could be considered a non-local process. But we see that in this analysis, it falls out from the interaction of strictly local constraints, i.e., constraints on structurally adjacent elements.

(20) Input: / …mwaná./

Candidates	FINAL	NORISE	ANCHOR-R
a. …mwaa.ná.	*!		
b. …mwaá.na.		*!	*
c. ☞ …mwáa.na.			**

    We have been mainly considering the effect of position class on the timing of the f0 peak. The effect of the contrast between question and statement is very small for all three speakers, as reflected in the very small coefficients for the variable T in (14). These coefficients indicate that the f0 peak is earlier in questions by 1.49 to 12.42 milliseconds (depending on the speaker). For speakers CJ and DJ, one could attribute this small effect to "tonal crowding" repelling the lexical H from the H% marking questions. But speaker SM produced all the questions in this dataset without a final rise, marking them as questions just with their higher pitch range [Myers 1996]. It is unclear, therefore, why this speaker showed the same sort of timing distinction between statements and questions.

4. Conclusion

We have investigated for three speakers of Chichewa the timing of f0 peaks in three phrase positions: medial, penultimate, and final. We have found that the f0 peak realizing a medial high tone occurs early in the syllable following the high-toned syllable, while a high tone in a lengthened penult occurs well within the penult syllable. This follows the pattern of f0 timing found in previous work on English, Spanish and other languages. No evidence was found supporting the claim in the literature that a high tone in medial position is subject to tone spread. Thus,

there was no support from the data for these three speakers for the claim that Chichewa has an instance of tone spread subject to the non-local condition that the trigger tone be at least four syllables from the end of the phrase.

A high tone in phrase-final syllable is shifted to the penultimate syllable, in particular to either the second mora (SM) or the first mora (CJ and DJ) of that syllable. This is an instance of the general avoidance of high tones in phrase-final syllables. It was argued that the shift must be reflected in the phonological representation, since the f_0 peak realizing a final high tone was timed with respect to the phrase-penultimate syllable, not the phrase-final one.

These results, obtained through quantitative analysis of instrumental acoustic data, support a revision of the basic facts of Chichewa tonology as they have been described on the basis of impressionistic tone transcriptions. Such transcriptions have, of course, provided a great deal of important information about Chichewa and other tone languages. But the present study provides new evidence as to the inherent vagueness of transcription data, and supports the view that tonology is put on a firmer foundation when tone transcriptions are augmented with objective experimental methods (cf. Bruce [1977] on Swedish, and Pierrehumbert & Beckman [1988] on Japanese). Only such quantitative data can allow us to distinguish categorical phonological patterns from gradient phonetic ones [Liberman & Pierrehumbert 1984].

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Department of Linguistics
University of Texas
Austin, TX 78712-1196
s.myers@mail.utexas.edu