Tone Spread Decomposed

Sung-A Kim
The University of Texas at Austin

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1. Introduction

This paper seeks a phonetic assessment of a phonological analysis of the tonal alternation in Yao (Guthrie 21), a Bantu language spoken mainly in Malawi, Tanzania, Mozambique and some parts of Zimbabwe. Based on the experimental data obtained from native speakers of Malawian Yao, I argue in this paper that the facts that have been considered as a phonological process in Yao deserve a phonetic account. More specifically speaking, the tonal alternation in Malawian Yao, the phenomenon previously described as post-lexical rightward tone spread, results from physiological constraints of f0 (fundamental frequency) realization, rather than a phonological rule of tone spread.

Tonal phenomena have long been at the center of generative phonology, guiding our understanding of the nature of cross-linguistic sound patterns. The tonal phenomena, however, have mostly been studied from an abstract perspective; little attention has been paid to the way tone is phonetically realized. The assumption crucially adopted in the non-linear tonology is that phonetic realization of tones is determined *a priori* by linguistic factors such as types of tone and phonological rules. Consequently, it has been commonly assumed that allophonic variation of a tone should suggest distinct entities or a presence of another phonological rule. This assumption is often merely implicit in the discussions of phonological analyses. For example, the phenomenon known as "downstep", which refers to the decrease of pitch values of high tone immediately preceded by another high tone, has been given various phonological interpretations: The first phonological interpretation is to posit a separate phonological entity such as the exclamation marker (i.e., HH---> H!H). The second phonological interpretation views the downstep as a result of 'floating' low tone between the two high tones, which thus triggers lowering of the next high tone (Clements and Ford 1979, Pulleyblank 1986). The third view proposes a different phonological rule called 'register lowering mechanism' by which pitch values of high tones are assumed to be lowered whenever a new phonological entity is confronted (Clark 1990). In other words, that downstepped sequence may be viewed as the expression of two distinct high tones (i.e., phonological entities), whereas HH sequence is viewed as a single high tone associated with two syllables.

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As pointed out by Laniran (1993) and Liberman et al (1993), such complications of phonological analyses arise from the serious gap in our understanding of tonology. It is not clear how the representations presented in the phonology of tone languages are interpreted in the phonetic realizations. Researchers in non-linear phonology have a tendency to assume a phonological entity without considering the presence of the mapping process. As a result, many and sometimes very different phonological rules have been proposed without being empirically tested. The only approach to sound patterns that can yield solid results is a "hybrid" approach in which instrumental data is analyzed (Liberman and Pierrehumbert 1984).

With the aid of computer-based pitch tracking devices that provide precise, objective measurement of fundamental frequency (f0 henceforth), a property that is difficult to pin down in terms of impressionistic categories, instrumental studies of f0 have recently been accumulated. These studies and others have shown that not all the phonological rules previously proposed necessarily correspond to the phonological representation of the language. Pierrehumbert (1980) demonstrates this point convincingly in her characterization of English intonational contours. She shows that, in combination with a small set of principles of phonetic implementation, the specifications which need to be included in the phonological representation of intonation contours in English are simpler and more limited in number than was previously assumed. In the most often cited work by Pierrehumbert and Beckman (1988), they show that syllables previously described as targets of tone spreading are in fact toneless and the f0 values are determined by phonetic implementations rather by phonological rules in Japanese.

This paper develops this line of inquiry further by conducting phonetic assessments of a phonological analysis of the tone pattern of Yao. I demonstrate in this paper that a better understanding of the relationship between phonetic implementation and phonological representation provides another description of the facts that have been considered as a phonological process in Yao.

The paper is structured as follows: facts of the tone pattern in Yao and previous phonological analysis are introduced in section 2. After examining the pitfalls of the phonological analyses in section 2, a brief sketch of the literature on phonetic sstudies on f0 realization will be presented in section 3. The experimental method and the statistical analysis of f0 will be addressed in sections 4 and 5, respectively. Implications of this study will be discussed in the conclusion.

2. Tonal phenomenon in Yao

Yao has a tone system with two level tones, H (high) and L (low). It is assumed that underlying representations contain only single high tones. Low tones play no active role in the language and thus are assumed to be absent in the phonological component, with the possible exception of a boundary low tone found in pre-pausal position (Odden 1998:267). The tone contrast is illustrated in minimal pairs in (1). The acute marker over a vowel shows a high tone and low tones are unmarked.

(1)	a. lisó	'yesterday'	(Mtenje 1993:180)
	b. liisó	'eye'	

Tone alternation in Yao is of significant interest because it is sensitive to positions where a lexical high tone appears in a phrasal boundary. High tones generally spread forward one mora as in (2). Tone, however, does not spread onto a pre-pausal mora or within the bimoraic penultimate syllable as in (3). High-toned vowels by tone spread are underlined in (2).

(2)	a. liciingá	'a byre'
	b. liciingá lʃla	'that byre'
	c. liijelá	'a hoe'
	d. liijelá lʃla	'that hoe'
	e. liijelá lʃgwiʃle	'a hoe has fallen'
	f. liciingá lʃgwiʃla	'a byre has fallen'
	g. chitúúmbili	'a monkey'
	h. chitúúmbili chila	'that monkey'
	i. chitúúmbili chigwiʃle	'that monkey has fallen'

In (2b) (2d), (2e), and (2f), the underscored vowels are supposed to bear a high tone because they are preceded by a high tone at the final mora of the noun, *'liijelá'*. A comparison of those cases with the (2h) and (2i) shows that toneless mora in the demonstrative *'lila'* becomes high toned when it is immediately preceded by a high tone. Namely, tone spreads to the following mora. Now, let us consider the data in (3).

(3) Suspension of high tone spreading

Pre-pausal positions

a. nga-ni-ju-teléka	'he did not cook'
b. nga-ni-ju-teléká cilo	he did not cook at night'

Phrase-penultimate long vowels

c. nga-ni-ju-valáanga	'he did not count'
d. nga-ni-ju-valáánga cilo	'he did not count at night'

It should be noted that there is no tone spreading in (3). We can easily see that tone does not spread onto a pre-pausal mora in (3a), but it does spread as soon as the target mora is not in the pre-pausal position. In addition, tone spread does not occur in bimoraic penultimate syllable as in (3c), although the target mora is not in the pre-pausal position at all. In general, the suspension of the high tone at phrase final position occurs regardless of whether a high tone belongs to a noun stem or a verb stem at the phrasal level.

In order to account for this seemingly position-sensitive tone alternation, Mtenje (1993:182) assumes extraprosodicity of the pre-pausal mora as in (4a) and formulates the position-sensitive tone spread rule for the data in (3) as a post lexical tone doubling rule, as in (4b).

(4) Tone spreading rule in Yao

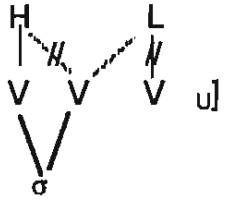
a. Pre-pausal Extraprosodicity: V-----> [+ext]/ _____$_U$]

b. Tone doubling:

A similar tone doubling rule is also observed by Hyman and Ngunga (1994) in Mozambican Yao. This rule spreads a high tone onto the following mora unless the target mora is in the pre-pausal position. The high tone in (3b) spreads to the next mora since the target mora is not in the pre-pausal position. On the other hand, the high tone in (3a) does not spread to the following mora because the target mora is extraprosodic. Positing an extraprosodicity, however, does not account for the suspension of tone spread in (3c).

Mtenje (1993) proposes a post lexical rule called 'Penultimate Fall' as shown in (5) to account for the non-occurrence of tone spreading in a long penultimate syllable.

(5) Penultimate fall (Mtenje 1993:184)



Penultimate fall in (5) is assumed to apply after the tone-doubling rule in (4b). The rule in (5) states that, if the penultimate syllable is long, then the association line on the second mora is disassociated.

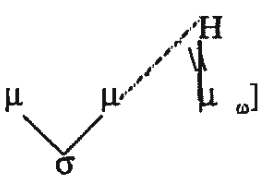
With regard to this rule, Odden (1998:272) makes an insightful comment, which I will cite:

> "This can be explained in terms of a phonetic boundary tone low tone presented in pre-pausal position, and the tendency of that low tone to extend its domain to the non-head mora of the penult. It is possible that the falling tone in this position is not due to phonology at all but rather is handled in the phonetic component."

The phonological rule of post-lexical tone spread calls for several questions. First, a drawback of the tone spreading rule as described above arises from the special reference to the presence of an additional mora. According to the phonological analysis, the penultimate fall rule in (5) must refer to three moras ahead before the delinking process is applied. It makes this rule typologically peculiar in the sense that the application of the rule is triggered by the third element associated with a special type of a boundary tone. This pattern leads to a violation of an otherwise well-motivated generalization: the locality condition. Phonological rules are usually assumed to be subject to conditions of locality where the rule should not refer to any element other than the trigger and the target that are structurally adjacent to each other (McCarthy and Prince 1986). The delinking process as described certainly requires the presence of a third element. In this sense, it is a violation of the locality condition. Some might suggest that reference to the third element can be justified as long as it is adjacent to the target element. However, this line of reasoning can be problematic as well. If grammars have the ability of counting up to three, then in principle they have the ability to count up to any number desired. The counting capability is a too powerful device to introduce into the theory of phonology (Sietsema 1989:244).

More importantly, there is another piece of evidence that supports the absence of any type of phonological process in the long penultimate syllables. In Yao, there is another phenomenon called 'High tone retraction' that applies to the long penultimate syllables. It is formulated as in (6):

(5) High tone retraction



This rule states that when a phrase final high tone is preceded by a long syllable, then the high tone shifts to the preceding mora. Kim, S-A (in preparation) shows that the high tone retracted to the preceding long syllable is not realized on the second mora of the long syllable as proposed by the rule in (6). The high tone is constantly aligned with the first half of the preceding long vowel, departing from what is expected by the phonological rule of high tone retraction. Due to the space limit, I will not go further into the discussion of high tone retraction (refer to Kim S-A, in preparation, for details). Such a disparity between a phonological rule and the phonetic realization in f0 calls for several questions. If the tonal phenomenon in phrase-penultimate long syllables is indeed phonetic in nature, why do we complicate the grammar of the language by postulating post-lexical rules such as tone spread, penultimate delinking, and high tone retraction in Yao? If the phenomenon were phonetic rather than phonological, what would be the phonetic principle to cause it?

An instrumental analysis of the facts previously described as tone spread suggests another description of the facts and another analysis. I claim that such a tone spreading does not exist in Yao and that the phenomenon previously analyzed as post-lexical tone spreading is in fact a consequence of f0 peak delay.

3. A Phonetic Perspective: f0 peak delay

Compared to the pitfalls of the phonological analysis given in section 2, the position-sensitive process is not typologically unusual from the perspective of phonetic timing of f0 peak. A number of studies on the phonetic realization of accent and tone have found that pitch prominence may not align with the onset of the accented or tone-bearing syllable and is delayed onto the next syllable (Steele 1986, Silverman and Pierrehumbert 1990 for English, Prieto et al. 1995 for Mexican Spanish, Liberman 1996 for Yoruba, Grimm 1997 for Oneida, Arvaniti et al 1998 for Modern Greek, Kim 1998 for Chichewa, Hata and Hasegawa 1988 for Japanese, Barteles 1995 for Czech).

For example, Steele (1986) and Silverman and Pierrehumbert (1990) show that two factors, rhyme duration and upcoming prosodic contexts, are the main source of peak location variation in English. That is, when a rhyme is lengthened because of slow speech, the f0 peak is correspondingly delayed. The f0 peak corresponding to a stress is preferentially aligned "past the end of the high tone-bearing rhyme and delayed into the following unaccented syllable" (Silverman and Pierrehumbert 1990:87). Given an identical phrase position, there is a positive correlation between rhyme duration and f0 peak delay relative to the vowel onset. In contrast to this, the f0 peak is aligned early in the syllable where the syllable is close to a prosodic edge in English. More specifically, where the syllable is prosodically lengthened, and f0 peak is aligned in an early portion of the syllable.

Unlike Pierrehumbert and Silverman (1990), Kim S-A (in preparation) investigates the f0 alignment where the syllable duration is extremely shortened in fast speech at phrase medial positions. In the study, speakers were asked to speak '*say minimize again*' with a neutral intonation. It turns out that the f0 peak corresponding to the stress in '*minimize*' tends to be realized even at the onset of the following vowel. The duration of the stressed syllable, peak delay relative to the release of [m] in '*mi*', and the duration between the onset of the next vowel relative and the onset of the stressed syllable '*mi*' were measured. Let us call these measurements Tsyll, Peak delay, and Ons-to-Next vowel respectively. As I have mentioned earlier, f0 peak tends to be realized in the next syllable and even at the onset of the next rhyme. This observation is supported in figure 1 below. Figure 1 provides a histogram of a relative peak delay where values of peak delay are divided by values of Ons-to-Next vowel. If a value of the relative peak delay is higher than 1.0, it indicates that f0 peak is realized

beyond the onset of the next vowel. Figure 1 is a result of the relative peak delay obtained from a male speaker out of four speakers participated in the experiment.

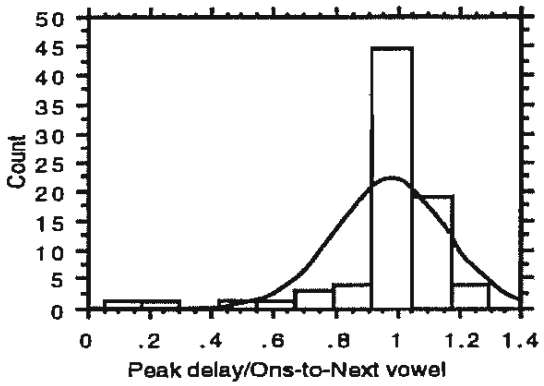


Figure1: Distribution of peak delay divided by Ons-to Next vowel

Notice that majority of the values are plotted between 0.9 and 1.2 in figure 1. This indicates that the f0 peak is frequently delayed and realized at the beginning of the following syllable when the stressed syllable is shortened. What mechanism of speech production would cause this peak delay pattern? Ohala (1978) and Fujisaki (1988) present a potential answer for this question. They argue that the f0 peak delay appears to be due to sluggish cessation of an f0 movement. In other words, f0 is a function of the strain of the muscles such as cricothyroid, mass of the thyroid cartilage and stiffness of the cricothyroid joint. Although the neural commands for producing a pitch target are issued simultaneously with those for producing the syllable that carries it, it would take more time to attain the pitch target than the segmental targets. Therefore, it is possible that f0 peak is realized at the following syllable.

It should be emphasized that no theory of phonology embodies peak delay in English as a phonological rule of accent spread or accent shift. Instead, all of the theories posit a categorical core and rely on phonetic implementation rules to explain the regularities as shown in the pattern of peak delay. In the later part of the paper, I will show that a similar pattern of peak delay is also observed in Yao.

So far I have mentioned an underlying mechanism that may cause the f0 peak delay pattern. That may sound as if f0 peak delay is an irregular and unpredictable pattern. However, another line of studies on f0 realization has shown that there is a tight temporal relation between f0 peak and landmarks of the syllables. The peak delay pattern represents regular timing with landmarks in the syllable (syllable onset, syllable offset). Arvaniti and Ladd (1998) observe that F0 peak tend to stay close to the accented syllable in Modern Greek. The notion of regular and proportional timing between gestures of different articulators has been well established in the works within the framework of task dynamics (Tuller and Kelso 1984, Löfqvist and Yoshioka 1984 among others). A similar type of stability is observed elsewhere as well. For instance, Huffman (1993) shows that syllable landmarks are important in the timing of velar gestures.

To sum up, I have discussed in this section that pitch change requires a relatively longer time than formant changes because of laryngeal inertia. More importantly, the f0 peak is constantly timed with the offset of the tone-bearing syllable.

Although more experimental studies on f0 realization pattern are required, if the pattern of a lagging f0 peak is widely attested, it definitely has implications that need to be tested. Probably the most important one regards its relation to tone spreading in

phonology. If the lagging f0 peak is due to the limited speed of pitch change, and the f0 peak is spilled over to the next syllable when desired pitch change is too large to be completed within the particular syllable, does the presence of f0 peak in the next syllable mean tone spreading as assumed in phonology of tone languages? This suspicion has been widely shared by phoneticians. For example, Ohala (1978) has already noticed the potential relation between the lagging f0 peak and the tonal patterns described as tone spreading. However, this idea has not been systematically pursued since then. This study seriously takes up this so far neglected idea.

4. Methodology

4.1. Subject

The experiment was designed to compare the f0 alignment of the so-called spreading context to the non-spreading context in Yao. Two male Malawian Yao speakers participated in the experiment. Demographic information of the speakers is tabulated in (7). They were all born and grew up in the area of a Yao tribe and their parents spoke Yao. In addition to the first language Yao, they are fluent in English and Chewa (or Chichewa), an official language of Malawi. They are in the thirties and none of them reported a history of hearing or speech problems.

(7) Demographic information of the speakers

Speaker	Birth place	Period of residence in US
DT	Zomba, Malawi	3 and half years
FY	Zomba, Malawi	6 months

4.2. Corpus

The speakers uttered the sentences in (8). Among those, the high tones underlined are the main concern here. In order to minimize segmentally induced perturbation on f0, the target words indicated by italics are composed of sonorants in general. Also note that the vowels in the target word are all [a] to control the intrinsic f0 of vowels.

(8) Corpus in Yao

a. Target word in pre-penultimate positions:
Ajiigéle *mbavalá* makumi nsáno.
"S/he takes fifty bushbucks."

b. Target word in penultimate positions:
Nambó *nganavaláanga.*
"But s/he does not count (them)."

The words indicated by italics in (8a) includes a high tone in a pre-penultimate position, while the one in (8b) contains a high tone in a long penultimate syllable. Therefore, the target word in (8a) corresponds to the spreading context, whereas the one in (8b) corresponds to the non-spreading context.

To induce a broad range of f0 values and syllable duration, the speakers were asked to vary loudness and speech rate. There were three conditions with respect to loudness as used in Liberman et al. (1993): loud (as if shouting to a person in the hall), normal (as if speaking to a person across the booth), and soft (as if speaking quietly to a person right next to the speaker). Loud speech tends to have a higher and broader pitch range (Liberman and Pierrehumbert 1984). With respect to speech rate, the conditions were normal and fast. In the normal condition, they were asked to speak at

a normal conversation rate, while in the fast condition they were asked to speak as quickly as possible while still speaking clearly. Also, they uttered the sentence in two different ways: statements and questions. There were four sessions in the recording with a 10-12 minute break between sessions. In each session the speaker read 144 sentences. A total of 1134 tokens was obtained from the two speakers. The utterances were all recorded on Sony portable minidisc recorder MZ-R30, after which the speech signals were digitized and analyzed by using *xwaves* (Entropic, Inc). F0 extraction was conducted on a Sun Sparc 20 workstation. The segmentation was carried out using the *xlabel* program (which runs as an attachment to *xwaves*).

One such example is displayed in figure 2.

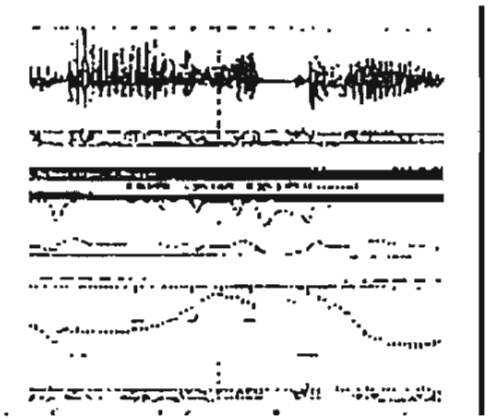


Figure 2: A pitch track of the target word *mbavalá* in Yao

The vertical line indicates an f0 peak corresponding to a high tone in *mbavalá* in pre-penultimate positions. Notice that the f0 peak is realized in the onset of the syllable next to the tone-bearing syllable. Segment labels for each target word were saved by the *xlabel* program in a text file (in ASCII format). The text files were processed by a computer program.

4.3. Hypotheses

The hypotheses being tested in the experiment are as follow:

(9) The hypotheses:

a. There is no tone spread in Yao.

a'. In penultimate positions, the tone-bearing syllable and the following syllable have like f0 values.

a". The temporal locations of the f0 peak are determined by reference only to high tone-bearing syllables in both penultimate and pre-penultimate contexts.

b. The difference between penultimate and pre-penultimate positions results from the fact that f0 peak alignment is relatively reduced in prosodically long syllables.

The hypothesis in (9a) is directly relevant to the issue of what is expected by the phonological analysis of tone spreading. In autosegmental phonology, tone spread is represented by a tone associated with multiple tone-bearing units. Therefore, a clear

difference between tone spreading and non-spreading contexts is expected in either the vertical (i.e., f0 values) or the horizontal (i.e., f0 alignment) dimension of phonetic realization of f0, as posited in various phonological studies. Before proceeding to the discussion of predictions borne out of the phonological analysis of tone spread, let us first assume that [X] represents a phonetic realization of a phonological element X. Goldsmith (1976) suggests that if feature X is associated with segment Y, then [X] [Y] are simultaneous in temporal terms. Sagey (1988) states that [X] overlaps with [Y] in physical space. Keating (1988) and Cohn (1990) show that [X] is realized at a steady-state level throughout most of [Y]. In the same line with Keating (1988) and Cohn (1990), Pierrehumbert and Beckman (1988) propose that the phonological analysis of tone spreading predicts that there are two tonal targets for high tones and the consequent f0 plateau is laid upon two syllables. The predictions made by phonological analysis of tone-spreading are summarized in (10):

(10) Predictions borne out of phonological analysis of tone spread

	Predictions of Phonological Analyses	Number of Associated Tone-bearing Units
Spreading	1. f0 plateau laid upon two syllables	two
	2. f0 peak has a constant relation with the target syllable (i.e., the syllable next to the tone- bearing syllable)	two
Non-spreading	1. no plateau (single F0 peak)	one
	2. No relation between F0 peak and the target syllable	one

The hypothesis in (9a') is relevant to the vertical dimension in f0 realization. In Yao, the hypothesis is supported if the f0 values of the tone-bearing syllable are not significantly different from those of the target syllable in pre-penultimate position.

In comparison, the hypothesis in (9a") concerns the horizontal dimension in f0 realization. A crucial difference between spreading and non-spreading cases is whether there is a tone target at the syllable next to the underlying high tone-bearing syllable. As shown in (10), the so-called spreading case is characterized by the existence of an additional tone target. In order to test the prediction borne out of the phonological analysis of tone spreading, I compared the f0 peak alignment in the two target words in (8). As shown in many studies on proportional timing among articulatory gestures, having a constant timing relation between *a* and *b* means that there is a positive correlation between the duration of *a* and that of *b*: the longer the duration of *a* becomes, so does the duration of *b*. Likewise, if there is a tone spread in pre-penultimate positions, then we would find f0 peak is most constantly timed with the duration of the syllable following the high tone-bearing syllable (i.e., target syllable), while the f0 peak has a constant relation with the duration of the high tone-bearing syllable itself if there is no tone spread. Simple regression will show with which syllable f0 peak has a more regular relation. As outlined in (9a"), if there is no tone spread, f0 peak is expected to be determined by reference to the tone-bearing syllable in both penultimate and pre-penultimate positions.

The following measurements were taken in order to test the hypotheses.

(11) Measurement points:
- a. the onset and offset of the tone-bearing syllable,
- b. the onset and offset of the tone-bearing rhyme,
- c. the onset and offset of the syllable following the tone-bearing syllable,
- d. the onset and offset of the rhyme in the syllable following the tone-bearing syllable,
- e. the f0 peak corresponding to high tones in both pre-penultimate and penultimate contexts,
- f. the frequency values of the f0 peak corresponding to high tone,
- g. the f0 values at the mid and end points of rhyme in both the tone-bearing syllable and the following syllable.

5. Results and discussions: evidence against tone spreading

The idea being tested in the present study is that the facts previously analyzed as a tone spread are in fact results from the f0 alignment patterns: f0 peak is delayed unless the host syllable is prosodically lengthened as outlined in (9b). Before moving onto this hypothesis, let us first discuss the hypothesis in (9a).

5.1. In pre-penultimate positions, f0 values of the two tone-bearing units are significantly different each other?

As mentioned earlier, the hypothesis in (9a') concerns the issue of the f0 values in the two syllables in pre-penultimate positions: the tone-bearing syllable and the following syllable. Because f0 values of the tone-bearing unit are accomplished in a later portion of the tone-bearing unit, f0 values were measured from the mid-point and end-point of the rhyme. The two values are averaged out and schematically shown in table 2 below.

Table 2: F0 values of the tone-bearing syllable and the next syllable

F0 values	Mean	Std. Dev	Speaker
Tone-bearing syllable	169.585	42.528	FY
Next syllable	158.950	47.416	FY
Tone-bearing syllable	169.691	43.40	DT
Next syllable	162.010	45.80	DT

As shown in table 2, the mean of f0 values of the tone-bearing syllable is about 10 Hz higher than that of the following syllable. Unpaired t-test confirms that the difference in the f0 values is statistically significant ($p<0.05$, $df=572$ for each speaker). Therefore, the hypothesis that the two syllables would exhibit like f0 values is rejected.

5.2. In pre-penultimate positions, is f0 peak delay constantly timed with the syllable next to the tone-bearing syllable?

In the previous section, we have seen that f0 values of the tone-bearing syllable are significantly different from those in the following syllable in the context in which a tone spread is expected. We now move on to the next question as to f0 alignment. Would it display a constant relation with the syllable next to the tone-bearing syllable in the pre-penultimate position as expected by the tone spreading analysis? In order to answer this question, a simple regression is conducted. In the simple regression, the dependent variable is Peak delay (i.e., the temporal distance between the onset of the tone-bearing syllable and the time at which f0 maximum was attained). The independent variables are the duration of the tone-bearing syllable and the duration of

the following syllable. The result shown in table 3 is from speaker FY. In the simple regression equations in table 3, Tsyll and Nsyll represent the two independent variables respectively. Due to the space limit, let us focus on the result of a one speaker FY for the time being.

Table 3: Simple regression

Independent variables	Simple regression equations	R
Tone-bearing syllable	Peak delay=0.099+0.585*Tsyll	0.808
Next syllable	Peak delay=0.135+0.223*Nsyll	0.179

Table 3 shows that Peak delay has a higher correlation with the duration of the tone-bearing syllable in pre-penultimate position. It turns out that Peak delay has almost no relation to the duration of the following syllable as suggested by the very low R value. This indicates that the tone-bearing syllable rather than the following syllable mainly determines the temporal location of the f0 peak. Although the f0 peak is often realized in the following syllable, the f0 peak is a function of the tone-bearing syllable.

To sum up the results so far mentioned, the phonological analysis of tone spreading cannot be supported in any aspect of f0 realization in the context where spreading is supposed to occur. Neither f0 values nor f0 peak alignment has anything to do with the target syllable (i.e., the syllable next to the tone-bearing syllable).

When Peak delay (i.e., time point of f0 peak relative to the onset of the tone-bearing syllable) is plotted against the duration of the tone-bearing syllables, as shown in figure 3, there is a broad range of values for Peak delay. This means that there is not a constant absolute time interval between the onset of the syllable and the onset of the f0 peak.

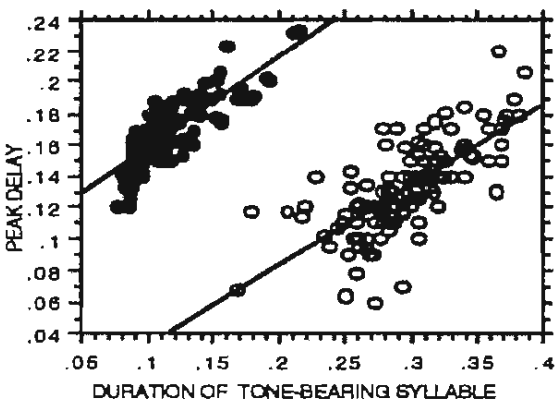


Figure 3: Peak delay as a function of duration of the tone-bearing syllable

The most important aspect of figure 3 is the occurrence of two separate groups of data corresponding to the two phrase positions. The penultimate points (filled circles) are spotted to the right of the penultimate points (empty circles), indicating that duration of the penultimate syllables is greater than the one of the pre-penultimate syllables. They are in general about two times long as shown in table 4:

Table 4: Speaker FY's mean duration of syllable

Positions	Mean duration of syllable (sec)
Pre-penultimate	0.113
Penultimate	0.296

In each position group, there is a clear linear correlation between peak delay and syllable duration: the longer the syllable, the greater the peak delay. However, the presence of the two clearly defined groups of data suggests that there is also another factor affecting the peak delay: phrase positions. The second most important aspect in figure 3 is the degree of the slope. The slopes of the regression lines for the two groups are almost the same: the slope for the pre-penultimate position =0.585, the slope for the penultimate position =0.512.

It is clear from figure 3 that two factors, phrasal position and the duration of the tone-bearing syllable, are major factors affecting the temporal location of the f0 peak. The identification of the two factors leads us to the question of how the two factors affect the location of the f0 peak.

To answer this question, a stepwise multiple regression analysis is conducted. The multiple regression will find out the best equation to predict the location of the f0 peak. The relevant variables used in the multiple regression are given in (12):

(12) Variables in the multiple regression
- a. Peak delay: time point of f0 peak relative to the onset of the tone bearing syllable,
- b. Tsyll: duration of the tone-bearing syllable,
- c. Vsyll: duration of the tone-bearing rhyme,
- d. Position: phrasal position.

In the stepwise multiple regression, Peak delay is the dependent variable, while the duration of the tone-bearing syllable, duration of the tone-bearing rhyme, and positions are the independent variables. Penultimate position was coded "0" and the pre-penultimate position was coed "1". The best regression equations to predict the location of f0 peak are summarized in table 5 below.

Table 5: Multiple regression equations

speakers	Multiple regression equations	R^2
FY	Peak delay=0.103-0.132*Position+0.544(Tsyll)	0.717
DT	Peak delay=0.58-0.102*Position+0.575(Tsyll)	0.725

In these equations, the location of the f0 peak is dependent on both of Tsyll and Position. The R^2 values reflect the fact that 70-73 % of the variations in the location of the f0 peak is captured by these equations. Further, it should be noted that the independent variable 'Tsyll' is positively related with 'Peak delay', indicating longer duration of the tone-bearing syllable causes more peak delay, as was observed in figure 3. To the contrary, the other independent variable 'Position' is inversely related with 'Peak delay', indicating that the f0 peak aligns at an earlier portion of a prosodically lengthened syllable, as attested in other languages mentioned in section 3.

Putting together the experimental results, I propose that the phenomenon viewed as an instance of tone spread could be a by-product of f0 peak alignment pattern: f0 peak delay. In this paper, I have explored a phonetic assessment of the facts previously analyzed as a phonological process. Based on instrumental data, I have shown that a tonal phenomenon at phrasal level in Yao does not support phonological analysis of tone spread. Instead, the tonal phenomenon can be better accounted for by resorting to phonetic principles based on relative timing with segmental landmarks and prosodic positions

The findings in the study have both empirical and theoretical importance. Empirically, they provide instrumental data about a little studied f0 peak delay phenomenon in African tone languages. Theoretically, the experimental results for Yao indicate that the tone alternation in the language deserves a phonetic account rather than a phonological analysis. Therefore, the phonetic account proposed in this paper does not require Yao be an exception to phonological constraint on locality.

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Sung-A Kim
Department of Linguistics
University of Texas at Austin
Austin, TX 78712

skim@ccwf.cc.utexas.edu