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Exceptional Tone Spreading and F0 Peak Alignment

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Kim, Sung-A. 2008. Exceptional Tone Spreading and F0 Peak Alignment. *Linguistic Research* 25(1), 1-23. The paper seeks to conduct a phonetic assessment of exceptional tone spreading by comparing tone spreading cases in Yoruba, Yao, and South Kyeongsang Korean. The tone alternations in the three languages have been analyzed as a rightward tone spreading in previous studies. A major finding in the present study is the asymmetric behavior of high tones in the languages: Unlike the tone alternation in Yoruba, those in Yao and South Kyeongsang Korean deserve an account in terms of phonetic implementation of high tone rather than phonological analysis of tone spreading with exceptional conditions. In the experiments, native speakers'speech data were pitch tracked and measurement was conducted on fundamental frequency (f0 henceforth) of pitch peak and on the time points of offset and onset of tone bearing syllables. A regression model revealed that there were no significant differences between non-spreading and spreading contexts with regard to the prediction of the location of f0 peak in Yao and South Kyeongsang Korean, while there was a significant difference in the case of Yoruba. The result evidences the claim that there is no spreading in Yao and South Kyeongsang Korean. The phenomenon previously considered as a phonological spreading in the two languages may result from f0 peak lagging. **(Kyung Hee University)**

Keywords tone spreading, f0 peak lagging, phonetic assessment, Yoruba, Yao, South Kyeongsang Korean

1. Introduction

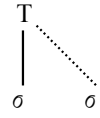
The alignment of fundamental frequency contour with other units in speech is an important issue not only for modeling f0 contour in speech analysis, but also for theoretical understanding of tone and intonation systems. The studies on the f0-syllable alignment have been investigated by two lines of researchers from different perspectives. The first line of research has been conducted in tone studies within a framework of theoretical linguistics. Tones can be spread, shifted, or copied, all involving changes of alignment of tones with their host units (Hyman and Schuh 1974, Schuh 1978). Major portions of metrical and autosegmental phonology of tone / accent languages are devoted to

various complex tone-syllable alignment issues. The f0-syllable alignment has been formalized by resorting to the notion of 'association lines' in autosegmental phonology (Goldsmith 1979, 1990, among others).

The second line of research has been mainly conducted in the field of phonetics. It concerns physical aspects of alignment of f0 contour with the segmental units in speech. For example, Bruce (1977) found that f0 realizations in Swedish are characterized by the relative stability of certain tonal targets. However, the review of these tone/accent studies displays a general lack of communications on either part. The paper tries to fill this gap by investigating one of the most common tone alternations: tone spread.

Tone spread is described as a phonological process whereby "a tone moves beyond its original segmental domain to replace or displace the tone of the following syllable or syllables" (Schuh, 1978: 231). In autosegmental phonology, the tone spread is formalized as the process in which two tone-bearing units share the same tone, as schematically shown in (1).

(1) Phonological analysis of tone spreading



Recent works on f0 henceforth realization cast a doubt about the nature of the phonological analysis of tone spreading. It is agreed that f0 peak corresponding to high tone tends to be delayed till the later part of the tone-bearing unit or the onset of the next syllable (Silverman and Pierrehumbert 1990, Prieto et al 1995, Arvaniti et al 1998, 2000, Kim 1999, among others) because of a sluggish cessation of f0 movement (Ohala 1978, Fujisaki 1988). Furthermore, phonetic studies on implementation of tones have shown that only a single peak is found in the context of tone spreading (Xu and Wang 1997, Kim 1998). Findings of the phonetic studies raise a serious question of how tone spread is distinguished from f0 peak lagging described above. Will the f0 peak lagging and the tone spreading be isomorphic in nature? This issue has not been seriously addressed before, simply assuming that phonological spreading would be realized by f0 plateau laid upon two tone-bearing units at the phonetic implementation level (Pierrehumbert and Beckman 1988). This paper attempts to answer this question and

proposes a phonetic assessment for the facts previously described as tone spreading in three unrelated languages: Yoruba, Yao, and South Kyeongsang Korean.

The remainder of the paper is organized as follows: Facts of the tone alternation in Yoruba, Yao, and South Kyeongsang Korean are introduced in section 2. A brief sketch of the previous literature on f0 peak realization will be presented in section 3. The experimental method and the result will be addressed in sections 4 and 5, respectively. Implications of this study will be discussed in section 5 as well.

2. Tone Alternatin in Yoruba, Yao, and Kyeongsang Korean

Yoruba has a three-tone system, which is composed of high, mid, and low tones. Among the three tones, mid tone is phonologically inert in the sense that it does not interact with adjacent high or low tones. It is not subject to tone spreading rules (Pulleyblank 1988, Laniran 1992). In comparison, high tone spreads to the next low-toned syllable but not to the mid-toned syllable as shown in (2).

(2) a.	/ layo /	[layo]	‘a personal name for male’
	/ debo /	[debo]	‘a personal name for male’
b.	/ loko /	[loko]	‘a farm’

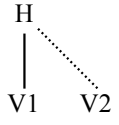
In (2a), high tone on the first syllable spreads to the next low-toned syllable and the second syllable bears a contour tone. On the other hand, such a contour tone does not occur where the high tone is followed by a mid tone, as shown in (2b). The tone alternation described above occurs regardless of the position in which the high tone occurs in a phrase.

The tone alternation in Yao, a Malawian language with high and low tones, differs from the tone alternation in Yoruba in the sense that it is position-sensitive. In this language, low tones are assumed to be phonologically inert and thus low tones do not play a role in tone patterns. It is a high tone that spreads and deletes. In Yao, high tones generally spread forward one syllable as in (3a) and (3c), but not onto or within the phrase-penultimate vowels as in (3b) and (3d). High-toned vowels created by tone spread are underscored in (3).

(3) a.	nga-ni-ju-teléká̲ cilo	‘he did not cook at night’
b.	nga-ni-ju-teléka	‘he did not cook’
c.	nga-ni-juvaláánga cilo	‘he did not count at night’
d.	nga-ni-ju-valáanga	‘he did not count’

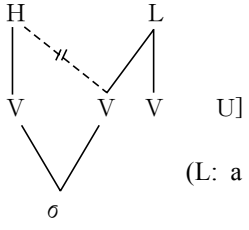
Mtenje (1993) formulates the position-sensitive tone spread rule for the data in (3) as tone doubling and penultimate fall as depicted in (4) and (5)

(4) a. Tone-doubling:



(Condition: V2 is not in a phrased final foot)

b. Penultimate Fall (Mtenje 1993)



(L: a low boundary tone, U: utterance final)

According to these rules, a high tone spreads onto the following vowel if the vowel is not in the phrase-penultimate syllable. In (3a) and (3c), there occurs a high tone spreading because the target vowel is not in the phrase-penultimate position. On the other hand, the high tone in (3b) and (3d) does not spread to the following vowel since the target vowel is included in the phrase-penult syllable. The phonological analyses of the tone alternation in Yao can be summarized as follows: Tone spreading occurs in pre-penult positions, while it does not in penult positions in Yao.

South Kyeongsang Korean, a pitch accent dialect spoken in the southeastern

part of Korea, has lexical tones as illustrated in the minimal pair such as *nál* (H) ‘blade’ and *nal* (L) 'day.' Traditional studies have reported that there are two types of high tones and that their distributions depend on the tone alternation patterns in suffixed words(Ramsey 1975[1]) Hashimoto, 1973). Let us arbitrarily refer to the two

1) Ramsey (1975) did not use terms such as ‘spreading’ which has been used since the rise of the

types of high tones as *uniquely linked H* and *doubly linked H* respectively. The tonal differences are well illustrated when a monosyllabic root is followed by suffixes. The examples in (5) contain words consists of non-spreading H root followed by a toneless suffix. High tone occurs in the root. In comparison, when *spreading H* is followed by a toneless suffix, the high tone occurs both in the root and in the initial syllable of the suffix as in (6) (the suffixes are underlined).

(5) Uniquely linked H in South Kyeongsang Korean

a. k'ot	'flower'
b. k'ot + i	k'ot i 'flower (nom.)'
c. k'ot + man	k'otman 'flower only'

(6) Doubly linked H South Kyeongsang Korean

a. mul	'water'
b. mul+ i	muli('water (nom.)
c. mul + man	mulman 'water only'

At this point, we should inform the readers of the disagreement over the number of lexical tones in South Kyeongsang Korean. A majority of traditional Korean linguists (Kim C-K 1970, Park 1980, Moon H-G 1974) still argue that South Kyeongsang dialect is a remnant of Middle Korean and preserves three distinct tones (H, M, L) or a rising tones (H, L, R) (Chung 1963).[2] Others claim that South Kyeongsang dialect has two way contrasts (Moon G-S 1986, Park 1979, Kim S-A 2005). More importantly, there is an observational discrepancy in the tones of words in (5). They are sometimes described as a sequence of HM (Kim C-K 1970) and HH (Hashimoto 1973) in other times. This descriptional discrepancy was the starting point of this experimental study on thetone alternation in South Kyeongsang Korean. Kim S-A (2005) reports absence of mid tone in the language and suggests that South Kyeongsang Korean be a pitch accent dialect with two tones. From the theory internal perspective, the distinction between L and M is hard to justify as both L and M play

autosegmental phonology. Yet, he provided similar data and the data were confirmed in Kim S-A (2005).

2) R refers to a rising tone. The tonal differences between more (HL) 'sand' and more (RH) 'the day after tomorrow' have been used to support the presence of the rising tone in South Kyeongsang Korea. Yet, it appears that the tonal difference between the two words may stem from the vowel length in the first syllable of each word. Obviously, the first vowel in more (RH) is longer than that in more (HL) (Chung 1963).

no active role in tone alternation.

Departing from the 3-way contrast hypothesis, this paper is based on the idea that South Kyeongsang Korean have two-way tonal contrast. Given the two-way contrast account, whether the high tone on the root spreads onto the next syllable or not is lexically determined. Some roots allow their high tones on the root syllable to be doubly linked by the following single syllable and others don't. It is a matter of lexical specification.

Before moving on to the next section, let us briefly discuss a problem of the spreading analyses for Yao and South Kyeongsnag Korean. The problem in the phonological spreading analysis in Yao arises from the special reference to the phrase-final element. According to the phonological analysis, the spreading rule must refer to three syllables ahead before tone-spreading takes place. It makes this rule typologically peculiar in the sense that local tone spreading is triggered by an element at the end of a phrase and by counting the syllables from the end of the phrase. This pattern leads to a violation of the locality condition, an otherwise well motivated generalization. Phonological rules are usually assumed to be subject to conditions of locality where the trigger and the target should be structurally adjacent to each other (McCarthy and Prince 1986, Odden 1994). The tone-spread as described is a violation of this well-motivated constraint.

Another type of typological peculiarity is found in South Kyeongsang Korean. In addition to its disagreeing tonal descriptions, the presence of two different types of high tones in a single language is cross-linguistically extremely rare. Splitting high tones into two subtypes of high tones may satisfy the observational adequacy,[3] and yet it is still hard to find such a case in other tone languages.

The summary of tone alternations in the three languages is tabulated in (7). In Yoruba, high tone spreading is assumed to occur in high-low context (henceforth, HL context), but not in high high-mid context (henceforth, HM context). In Yao, high tone spreading is supposed to occur in pre-penult positions but not in penult positions. In South Kyeonsang Korean, one type of high tone is supposed to spread to the next syllables, while the other isn't.

3) To our knowledge, Sukuma, a Bantu language spoken in Tanzania, is reported to be the only language with two sub-types of high tones (Matondo 2002).

(7) Summary of phonological analysis of tone alternation

Languages	Locality	Condition	So-called Spreading Case
Yoruba	local	None	HL contexts
Yao	non-local	Position Sensitive: Spreading only in pre-penult positions	Pre-penult positions
South Kyeongsang Korean	local	Disagreeing descriptions	Lexically specified high tones

We explore an instrumental analysis of the facts previously described as tone spread, which suggests another description of the facts and another analysis. This ultimately proposes that the exceptional tone alternations in the languages in concern are not tone spreading, but by-products of f0 peak alignment.

3. Theoretical Background: F0 Peak Lagging

Compared to the unusualness of the phonological analysis in Yao given in section 2, the position-sensitive processes are 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 phonetic prominence, specifically pitch prominence, may not always align with the accented or tone-bearing syllable (Steele 1986, Silverman and Pierrehumbert 1990 for English, Prieto et al. 1995 for Mexican Spanish, Liberman et al. 1993 for Igbo, and Liberman 1996 for Yoruba).

Also, it has already been well established that the f0 lagging does not occur where the syllable is close to a prosodic phrase edge. 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 vowel is lengthened because of slow speech, the f0 peak is correspondingly delayed. Given an identical phrase position, there is a positive correlation between vowel duration and f0 peak lagging 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. Prieto et al. (1995) report a similar result for Mexican Spanish. In addition, they observe that the same finding is obtained when f0 peak lagging is measured

relative to accented syllable onset as well as vowel / rhyme onset.[4] Of particular interest is the lack of correlation between the syllable duration and distance between syllable offset and f0 peak (offset-to-f0 peak) in Chichewa. This means that offset-to-f0 peak does not systematically vary with any consistency. In other words, the f0 peak simply stays close to the syllable offset. The high correlation between f0 peak relative to the tone-bearing syllable onset and the syllable duration indicates that the f0 peak is moving closely with the syllable offset. Let us call this pattern 'f0 peak lagging.' As Ohala (1978) and Fujisaki (1988) argue, the f0 peak lagging appears to be due to a function of sluggish cessation of an f0 movement. In other words, f0 is a function of the strain of the muscles such as cricothyroid and sternohyhoid, mass of the thyroid cartilages and stiffness of the cricothyroid joint. Even if the neural commands for producing a pitch target is issued simultaneously with those for producing the syllable that carries it, the pitch target would be attained more slowly than the segmental targets. Therefore, it is possible that f0 peak is realized at the following syllable.

The peak lagging pattern in f0 represents a regular timing relation between the laryngeal gesture that leads to the f0 peak and landmarks in the syllable (syllable onset, syllable offset). Since the ground breaking work of Bruce (1977) on Swedish, it has been known that at least some f0 patterns are characterized by relative phonetic stability of certain tonal targets. Bruce finds that the local f0 peak corresponding to Swedish word accent is constantly aligned with the segmental material and the f0 value is constant across multiple repetitions of the same utterance by the same speaker. Bruce interprets this to mean that, for the Swedish accentual distinction, "reaching a certain pitch level at a particular point in time is the important thing, not the movement (rise or fall) itself (1977:132)." The same kind of stability is observed elsewhere as well. For instance, Huffman (1993) shows that syllable landmarks are important in the timing of velar gestures. The regular and proportional timing between gestures of different articulators is also founded in the works within the framework of task dynamics (Tuller and Kelso 1984, Browman and Goldstein 1990 among others).

4) Kim S-A (1998) reveals that the distance from syllable onset and f0 peak highly correlates with the duration of tone-bearing syllables in Chichewa. Of particular interest is the lack of correlation between the syllable duration and distance between syllable offset and f0 peak (offset-to-f0 peak) in Chichewa.

4. Eeperimental Design

The experiment was designed to compare the f0 alignment of the so-called spreading case with the non-spreading case in each language. Consider the sentences in (8), which are the Yoruba corpus used in the experiment.

(8) Corpus in Yoruba

a. Ó <u>mòómò</u> lò ìyen
"He intentionally uses that one."

b. <u>Màmámia</u> lè lò ìyen.
"My mother is able to use that one."

The two sentences in (8) are almost identical to each other except for the target words, indicated by underlines. The underscored word in (8a) contains a sequence of a high tone followed by a low tone (henceforth, HL), while the one in (8b) has a sequence of high tone followed by a mid tone (henceforth, HM). Therefore, the target word in (8a) corresponds to the spreading case, whereas the one in (8b) corresponds to the non-spreading case. If there is a tone spread only in (8a), clear differences in the f0 realization between the spreading and non-spreading cases are predicted by the phonological analysis. The predictions made by phonological analysis of tone-spreading are summarized in (9).

(9) Prediction born out of phonological analysis of tone spread

	Determiner of f0 peak	Number of Associated Syllable(s)
Spreading	Both tone-bearing and target syllables	2
Non-spreading	Only tone-bearing syllable	1

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 at (9), the so-called spreading case is characterized by the existence of an additional tone target. In order to test the prediction born out of the phonological analysis of tone spreading, we compared the f0 peak alignment in the two target words in (8). If there is a tone spread in pre-penult positions, then we would find f0 peak is timed with the syllable following the high tone-bearing syllable, while the f0 peak is timed

with the high tone-bearing syllable itself, if there is no tone spread.

The same reasoning applies to the tone spreading case in Yao. For Yao, the following corpus in (10) was used in the experiment. Notice that the sentences in (10) have multiple high tones. Among those, the second high tone underlined in each sentence is the main concern here. It is the second high tone that is located in the phrase-final foot in (10b) but not in (10a). For the sake of convenience, let us call the second high tones in (10a) and (10b) the pre-penult and penult tones respectively. It should be noted that the pre-penult and the penult tone-bearing vowels are identical (i.e., *a*) to control the intrinsic f0 of vowels.

(10) Corpus in Yao

a. Target words in pre-penultimate positions:
Ajiigéle *mnavalá makumi* nsano.
"S / he takes fifty bushbucks."

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

If there is a spreading only in pre-penult positions in Yao, then the f0 alignment in the pre-penult positions should differ from the one in penult positions. If there is no tone spread, f0 is expected to be determined by reference to the tone-bearing syllable regardless of the positions.

In the same context with the experiments in Yoruba and Yao, a similar reasoning is applied to South Kyeongsang Korean. We investigate whether there is any reliable f0 timing difference between the non-spreading H (i.e., a uniquely linked H) and the spreading H (i.e., a doubly linked H). H in the non-spreading case is expected to be timed with the first syllable, while the H in the spreading case is predicted to reveal different timing relationship. Eight target words, listed in (11) were inserted in the carrier sentences: _____ *masista* "_____ is delicious." And _____ *masisna* "_____" Is_____ delicious?"

(11) target words

k'ótman	múlman
k'óti	múli
súlman	pápman
súli	pápi

In the experiments, a male Yao speaker and a female Yoruba speaker and 7 South Kyeongsang Korean speakers participated at the recording.[5] The speakers uttered the sentence in (8), (10) and (11) respectively. 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). A total of 576 tokens (1 speaker × 2 sentence types × 3 loudness levels × 2 speech rates × 2 target words × 24 repetitions = 576) was obtained for Yao. Because of lesser number of repetitions (5 repetitions), a total of 120 tokens was obtained for Yoruba.

For South Kyeongsang Korean, relatively greater number of speakers (i.e., 7 speakers) participated in the experiment. They were all born and grew up in Busan and the vicinities of Busan. They were in their 20's and 30's and nobody reported any hearing or speaking problems. All speakers were not aware of the purpose of the experiment and they participated in the recording session as a part of their academic activities. The recording was made in a quiet room at D University in Korea. As in the case of experiment for Yoruba and Yao, they were asked to produce stimuli in two different speech rates (normal and fast) and in three loudness conditions. Each speaker had 6 repetitions of 8 target words. The stimuli were randomly presented in Korean on a portable computer in a timed Powerpoint presentation. There were 12 conditions (2 speech rates × 3 types of loudness × 2 sentence types) and 6 repetitions for each condition, yielding 576 tokens per speaker. A total of 4032 tokens were collected in the experiment. The speech signal recorded on a digital audio tape-recorder was digitized at a sampling rate of 22 kHz and segmented from waveform and spectrogram display, using PCQuirerer (Scicon R&D Inc).Pitch tracking samples are displayed in figures 1 and 2.

5) For Yao and Yoruba, only one speaker could participate in the experiment. The Yao speaker was in his twenties and the Yoruba speaker was in the thirties. The recording was conducted in quiet rooms at the University of Arizona and the University of Texas at Austin respectively. We acknowledge that the small number of speakers can be a limit of the present study.

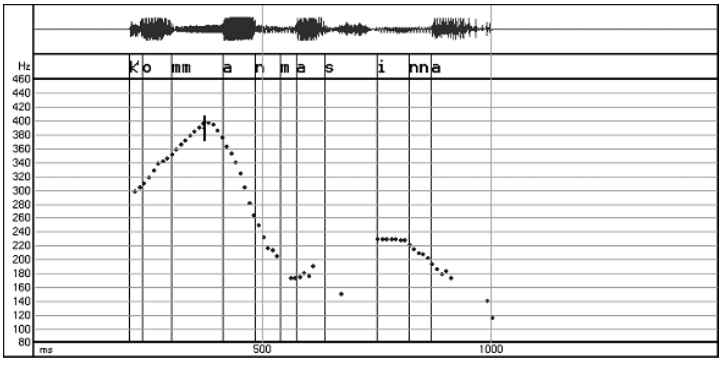


Figure 1. A pitch track of so-called non-spreading high tones in South Kyeongsang

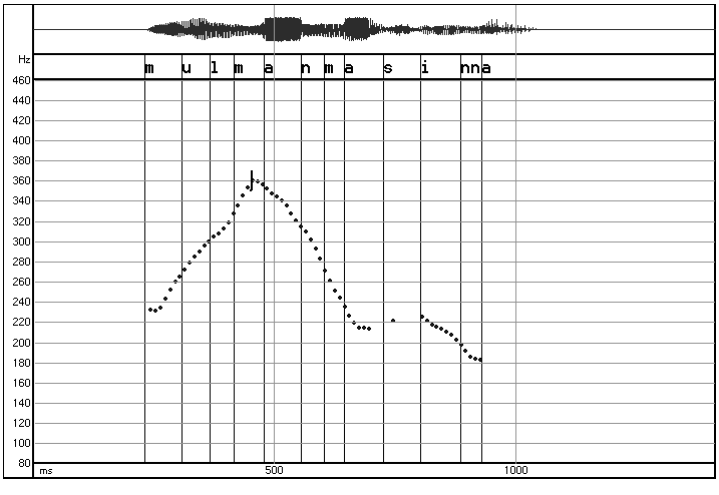


Figure 2. A pitch track of so-called spreading high tones in South Kyeongsang

Figures 1 and 2 show the waveform display and f0 contour. Segmental transcription is given at the top of each figure. The short vertical line on pitch track in Figure 1 indicates the time point of f0 peak of the target root and the one in Figure 2 the time point of f0 peak of *múl*.

The following measurements were taken on the target words in spreading and non-spreading cases in each language.

(12) 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 spreading and non-spreading contexts.

The following hypotheses are tested in the study. If they are rejected, then it can be said that tone spreading analysis is not confirmed in each language.

(13) The Hypotheses:
a. In Yoruba, there is a difference in the timing of f0 peak between HL (i.e., spreading) and HM (i.e., non-spreading) contexts: the temporal locations of the f0 peak are determined by reference to both tone-bearing and target syllables in HL contexts but not in HM contexts.
b. In Yao, there is a difference in the timing of f0 peak between pre-penult (i.e., spreading) and penult (i.e., non-spreading) contexts: the temporal locations of the f0 peak are determined by reference to both tone-bearing and target syllables in pre-penult positions but not in penult positions.
c. In South Kyeonsang Korean, there is a difference in the timing of f0 peak between doubly linked H and uniquely linked H contexts: the temporal locations of the f0 peak are determined by reference to both tone-bearing and target syllables in doubly linked H contexts but not in uniquely linked H contexts.

In order to test these hypotheses, we compared regression models for the prediction of f0 peak location. The relevant variables used in the regression analysis are given in (14):

(14) Variables
a. Peak: Temporal distance between f0 peak and the onset of the tone-bearing syllable.
b. T-Syllable duration: Duration of the tone-bearing syllable.
c. N-syllable duration: Duration of the syllable following the tone-bearing syllable.

F0 peak relative to the onset of the tone-bearing syllable in (14a) is the dependent

variable and the syllable durations in (14b) and (14c) are the independent variables in the regression analysis.

5. Experimental Results and Discussions

5.1 Yoruba

First, let us discuss the results of Yoruba. With regard to the f0 peak in pitch tracks, only a single f0 peak is observed in both HM and HL contexts. There was no f0 plateau laid upon the two syllables in general. The f0 peak is delayed on to the syllable following the high tone-bearing syllable. As a result, the longer the high-toned syllable, the more f0 peak is delayed. At first glance, it appears that there is no difference in f0 timing between the HL context (i.e., spreading case) and HM context (i.e., non-spreading cases) with regard to the f0 peak alignment. A close examination, however, reveals that the two contexts differ from each other in the syllable with which the f0peak has a constant relation. Consider the table in (15) where the results of simple regression models in HM context are summarized. The one in (15a) indicates the regression model where the peak is assumed to be timed with the tone-bearing syllable itself, while the one in (15b) represents the regression model where the peak is supposed to be timed with the syllable next to the tone-bearing syllable. We can compare models using relative measures of goodness of fit. One of such measures is the Pearson R^2 values, which are indicated in the second column in the table. For example, the R^2 value of 0.68 indicates that the model accounts for 68% of the variation in the data. In the table, the equation with significant R^2 value is indicated by ☞.

(15) Regression models for the prediction of f0 peak location

☞ a. Peak = 0.049+ 0.676*Tsyll duration	R^2 .68	HM context (non-spread)
b. Peak = 0.001+0.022*Nsyll duration	R^2 .002	HM context (non-spread)

In the table in (15), higher R^2 value in (15a) indicates that f0 peak is timed with the tone-bearing syllable in non-spreading context. The extremely low R^2 value in (15b) shows that the f0 peak has almost no relation with the syllable following the tone-bearing syllable.

In the spreading context, however, the opposite result is obtained, as shown in (16).

The equation in (16b) shows the result of the case where the f0 peak is assumed to be timed with the next syllable in the spreading context. That equation model has higher R^2 value than the one in (16a). This means that the temporal location of f0 peak is best predicted by reference to both the tone-bearing syllable and the syllable next to the tone-bearing syllable in spreading cases.

(16) Regression models for the prediction of f0 peak location

☞ a. Peak = 0.134+0.901*Tsyll duration	R^2 .59	HL context (spread)
☞ b. Peak = -0.027+0.823*Nsyll duration	R^2 .62	HL context (spread)

If we compare the tables in (15) and (16), it is clear that there is an asymmetry between HM and HL contexts. In non-spreading context, f0 peak has a constant relation with the high tone-bearing syllable itself. On the other hand, in spreading context, it is timed both with the tone-bearing syllable and the syllable next to the tone-bearing syllable. In short, both syllables play roles in determining location of f0 peak.

To sum up, the hypothesis in (13a) is accepted as they display a difference in f0 timing between spreading and non-spreading cases. Indeed, the temporal locations of the f0 peak are determined by reference to both syllables (i.e., tone-bearing syllable and the following syllable) in spreading context but not in non-spreading context.

5.2 Yao

In the previous section, Yoruba results show that there is a clear difference in f0 timing between spreading and non-spreading cases. In comparison, Yao results show that there is no difference in f0 timing between spreading and non-spreading cases. F0 peak is timed with the high tone-bearing syllable in both cases in Yao. The table in (17) shows two regression models in pre-penult positions whereas the one in (18) contains two regression models in penult positions. It should be noted that regression equations in (17a) and (18a) have higher R^2 values than the ones in (17b) and (18b), which suggests that f0 peak is only determined by the tone-bearing syllable itself regardless of the phrase position. If there is an articulatory target on the syllable next to the tone-bearing syllable, the target syllable itself is expect to play a role in predicting the location of f0 peak as observed in Yoruba. In fact, it is not the case in Yao.

(17) Regression models for the prediction of f0 peak location

☞ a. Peak = 0.12+0.561*Tsyll duration	R^2 .83	pre-penult (i.e. spread)
b. Peak = 0.166+0.034*Nsyll duration	R^2 .02	pre-penult (i.e. spread)

(18) Regression models for the prediction of f0 peak location

☞ a. Peak = -0.028 + .684 *Tsyll duration	R^2 .68	penult (i.e. non-spread)
b. Peak = 0.061 + .253 *Nsyll duration	R^2 .21	penult (i.e. non-spread)

Put differently, if there is a tone spreading only in penult positions as suggested by the phonological rules of tone spreading, then it is predicted that f0 peak in pre-penult positions has most constant relation with the syllable next to high tone-bearing syllable, as we found in Yoruba cases. Notice that the R^2 value in the N-syllable based model (i.e., equations in 17b and 18b) is much lower than the one in the T-syllable based model (i.e., equations in 17a and 18a). In both pre-penult positions, it is the target syllables' duration that shows a better fit to indicate the location of f0 peak. In other words, when the peak lagging is plotted against the duration of the high tone-bearing syllable, the tone-bearing syllable is a better indicator for the location of f0 peak. Therefore, the hypothesis in (13b) is rejected. We will discuss the full significance of this result after we present the South Kyeongsang Korean result. For the time being, let us point out the fact that Yao does not pattern together with Yoruba.

5.3 South Kyengsang Korean

In order to normalize variations across the multiple speakers for the experiment in South Kyeongsang Korean, we calculated the normalized f0 peak lagging shown in (19):

(19) Normalized f0 peak lagging

$$\left(\sum_{k=1}^{m} \text{f0 peak lagging}^{6)} / \text{duration of the tone-bearing syllable}\right) / \text{m}$$

(m: the total number of the tokens)

6) F0 peak lagging refers to the temporal distance between the onset of the tone-bearing syllable and f0 peak.

The normalized f0 peak lagging enables us to remove the speaker variations as the f0 peak lagging is normalized by the duration of the tone-bearing syllable per speaker. Speakers may have different speech rates and inherent segment durations and different f0. Once raw value of f0 peak lagging is relativized by the duration of the tone-bearing syllable, speaker variations are eliminated because the value could range somewhere around 1 regardless of the speaker. If the normalized f0 peak lagging is 1, it indicates that the f0 peak is precisely at the offset of the tone-bearing syllable, while 'greater than 1' signals that the f0 peak is located after the offset of the tone-bearing syllable and 'less than 1' indicates that the peak is before the offset of the tone-bearing syllable. When the data were pooled across the speakers, the normalized f0 peak lagging in both contexts: doubly is shown in figure 3.

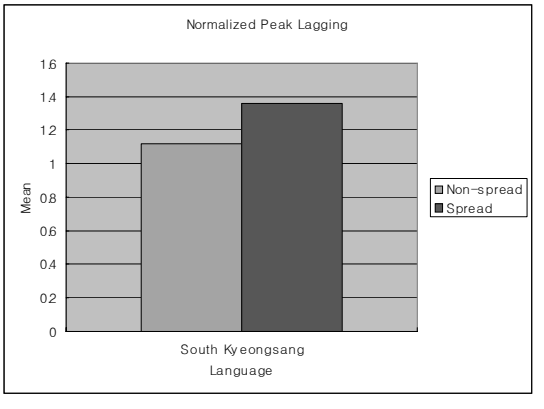


Figure3. Normalized f0 peak lagging (pooled across the speakers)

A close look at figure 3 reveals that both contexts have normalized f0 peak lagging greater than 1 in common. In other words, f0 peak tends to be located after the offset of the tone-bearing syllable. Normalized f0 peak lagging in spreading context (i.e., doubly linked H) appears to be slightly greater than the one in non-spreading context (i.e., uniquely linked H):1.36 and 1.12 for spreading and non-spreading contexts respectively. A paired t-test result, however, confirms that the difference was statistically insignificant ($p<.05$).

As in the cases of Yoruba and Yao, regression equations are acquired for each speaker and they are summarized in (20).

(20) Regression models for the prediction of f0 peak location

a. Speaker M

☞ a. Peak = 0.102+0.635*Tsyll duration	R^2 .75	Doubly linked H (i.e., spread)
b. Peak = 0.028+0.561*Nsyll duration	R^2 .21	Doubly linked H (i.e., spread)
☞ c. Peak = 0.008+0.699*Tsyll duration	R^2 .77	Uniquely linked H (i.e., non-spread)
c. Peak = 0.019+0.584*Nsyll duration	R^2 .28	Uniquely linked H (i.e., non-spread)

b. Speaker P

☞ a. Peak = -0.033+0.795* Tsyll duration	R^2 .88	Doubly linked H (i.e., spread)
b. Peak = -0.041+0.521* Nsyll duration	R^2 .27	Doubly linked H (i.e., spread)
☞ c. Peak = -0.017+0.695* Tsyll duration	R^2 .79	Uniquely linked H (i.e., non-spread)
d. Peak = -0.084+0.621* Nsyll duration	R^2 .18	Uniquely linked H (i.e., non-spread)

c. Speaker C

a. Peak = 0.166+0.535*Tsyll duration	R^2 .57	Doubly linked H (i.e., spread)
☞ b. Peak = 0.093+0.661*Nsyll duration	R^2 .61	Doubly linked H (i.e., spread)
☞ c. Peak = 0.142+0.535*Tsyll duration	R^2 .64	Uniquely linked H (i.e., non-spread)
d. Peak = 0.087+0.661*Nsyll duration	R^2 .33	Uniquely linked H (i.e., non-spread)

d. Speaker Ch

☞ a. Peak = 0.035+0.666*Tsyll duration	R^2 .62	Doubly linked H (i.e., spread)
b. Peak = 0.048+0.571*Nsyll duration	R^2 .59	Doubly linked H (i.e., spread)
☞ c. Peak = 0.025+0.592*Tsyll duration	R^2 .64	Uniquely linked H (i.e., non-spread)
d. Peak = 0.036+0.514*Nsyll duration	R^2 .48	Uniquely linked H (i.e., non-spread)

e. Speaker Y

☞ a. Peak = -0.03+0.635*Tsyll duration	R^2 .75	Doubly linked H (i.e., spread)
b. Peak = -0.028+0.561*Nsyll duration	R^2 .21	Doubly linked H (i.e., spread)
☞ c. Peak = -0.03+0.635*Tsyll duration	R^2 .77	Uniquely linked H (i.e., non-spread)
d. Peak = -0.021+0.461*Nsyll duration	R^2 .26	Uniquely linked H (i.e., non-spread)

f. Speaker L

☞ a. Peak = 0.083+0.635*Tsyll duration	R^2 .69	Doubly linked H (i.e., spread)
b. Peak lagging = 0.079+0.561*Nsyll duration	R^2 .38	Doubly linked H (i.e., spread)
☞ c. Peak = 0.051+0.439*Tsyll duration	R^2 .65	Uniquely linked H (i.e., non-spread)
d. Peak lagging = 0.068+0.461* Nsyll duration	R^2 .42	Uniquely linked H (i.e., non-spread)

g. Speaker K

☞ a. Peak = 0.73+0.775*Tsyll duration	R^2 .76	Doubly linked H (i.e. spread)
b. Peak lagging = 0.67+0.561* Nsyll duration	R^2 .19	Doubly linked H (i.e. spread)
☞ c. Peak = 0.76+0.742*Tsyll duration	R^2 .83	Uniquely linked H (i.e. non-spread)
d. Peak = 0.56+0.431*Nsyll duration	R^2 .27	Uniquely linked H (i.e. non-spread)

In (20), a controller of the temporal location of f0 peak is indicated by ☞. A comparison of the regression models in (20) shows that tone-bearing syllables rather than target syllables serve as the reference point for f0 peak in both doubly linked and uniquely linked H cases. For most of the speakers other than Speaker C, it was the tone-bearing syllables that show a better fit. Target syllables are barely relevant to the temporal location of f0 peak in either case. This suggests that the syllable next to the tone-bearing syllable does not serve as a tone target. Namely, there was no f0 timing difference

between uniquely linked and doubly linked Hs. Therefore, the hypothesis in (13c) is rejected. For the ease of comparison, results from the regression equations are summarized in (21).

(21) A summary of the experimental results

Language	Difference in F0 peak timing between Spreading and non-spreading contexts	Determiner of the F0 peak	Phonological analysis of tone spreading
Yoruba	Yes	Both syllables	accepted
Yao	No	Tone-bearing syllable	rejected
South Kyeongsang Korean	No	Tone-bearing syllable	rejected

In Yoruba, f0 peak in HL context behaved differently from the one in HM sequence. In HL context, both tone-bearing and the following syllable played roles in determining the location of F0 peak but not in HM context: f0 peak is timed with both tone-bearing and the following syllable in spreading context but not in non-spreading context. This was the asymmetry between the spreading (i.e., HL sequence) and the non-spreading (i.e., HM sequence) contexts. Therefore the experimental results support the phonological analysis of tone spreading in Yoruba.

In contrast to Yoruba, Yao and South Kyeongsang Korean showed no difference in f0 peak timing in both so-called spreading and non-spreading contexts. Regardless of the contexts, it was tone-bearing syllable that explains the distribution of f0 peak. The following syllable hardly played a role. This leads us to cast a strong doubt about the authenticity of the peculiar phonological rules in Yao and categorization of doubly linked H in South Kyeongsang. The experimental results evidence the claim that these seemingly spreading-like phenomena in the two languages do not result from phonological tone spreading. They appear to be instances of f0 peak lagging.

To sum up, the findings of this study are important both empirically and theoretically. Empirically, they provide instrumental data about little studied f0 peak lagging phenomenon in African and Asian tone languages. Theoretically, the experimental results in Yao and South Kyeongsang Korean indicate that the tone alternation in the language deserves a phonetic account rather than a phonological analysis. The phenomenon previously analyzed as a tone spreading turned out not to

be a phonological process. This shows a clear contrast with Yoruba tone spreading where the tone-bearing syllable rather than the target syllable (i.e., the syllable next to the tone-bearing syllable) has a control over the f0 peak location. A phonetic account of f0 peak lagging may be more appropriate account for the patterns of f0 peak. The phonetic account does not require that Yao be an exception to phonological constraint on locality. Likewise, it enables us to resolve the controversies over the disagreeing observations about the tone patterns in South Kyeongsang Korean have been presented.

More importantly, the contrast between tone alternations in the three languages provides an empirical ground to tease apart phonetic implementation of tone (e.g. tone alternation in Yao and South Kyeongsang Korean) from true phonological rule of tone spreading (e.g. tone alternation in Yoruba).

References

Arvaniti, A.; D. R. Ladd and I. Mennen. 1998. Stability of tone alignment: The case of Greek pre-nuclear accents. *Journal of Phonetics*, 26, pp. 3-25.

Arvaniti, A.; D. R. Ladd and I. Mennen. 2000. What is a starred tone? Evidence from Greek. In M. Broe & J. Pierrehumbert(eds.), *Papers in Laboratory Phonology V: Acquisition and the Lexicon,* 119-131. Cambridge, MA: Cambridge University Press

Browman, C., and L. Goldstein. 1990. Tiers in articulatory phonology, with some implications for casual speech. In J. Kingston & M. Beckman (eds.) *Papers in Laboratory Phonology I*, pp. 341-376. Cambridge, MA: Cambridge University Press.

Bruce, G. 1977. *Swedish Word Accents in Sentence Perspective*. Lund: Gleerup.

Chung, Y-C. 1976. *Kukeo Seongjoey Kwanhan Yeonku*. Seoul: Ilchokak.

Fujisaki, H. 1988. A note on the physiological and physical basis for the phrase and accent components in the voice fundamental contour. In Osamu Fujimura (ed.) *Vocal Physiology: Voice Production*, *Mechanisms and Functions*, pp. 347-355. New York: Raven Press.

Goldsmith, J. 1979. *Autosegmental Phonology*. New York: Garland.

Goldsmith, J. 1990. *Autosegmental and Metrical Phonology*. Oxford: Blackwell Publishers.

Hashimoto, M. 1973. Hamkwuk-e accentuy umwun-non. *Hanku,* pp. 151, 3-34.

Huffman, M. 1993. Phonetic patterns of nasalization and implications for feature specification. In M. Huffman & R. Krakow (eds.), Phonetics *and Phonology 5: Nasals, Nasalization and the Velum*, pp. 303-327. New York: Academic Press.

Hyman, L. M, and R. G. Schuh. 1974. Universals of tone rules: Evidence from west Africa. *Linguistic Inquiry*, 5. pp. 81-115.

Kim, C-K. 1970. Kyeongnam bangen-uy seongjo chekye. *Hankul,* 145. pp. 109-149.

Kim, S-A. 1998. Position-sensitive tone alternation in Chichewa: phonological analysis vs. phonetic timing. *Proceedings of CLS* 34, pp. 278-290.

Kim, S-A. 2005. How many tones in South Kyeongsang dialect? A phonetic perspective. MS. Paper presented at the Annual Colloquium of Humanities in Busan. Pusan National University.

Laniran, Y. 1992. Intonation in Tone Languages: The Phonetic Implementation of Tones in Yoruba. Unpublished Cornell University doctoral dissertation

Liberman, M. 1996. Tone, accent and relative prominence. Talk given at the University of Texas at Austin.

Liberman, M; J. Schults; S. Hong; and V. Okeke. 1993. The phonetic interpretation of tone in Igbo. *Phonetica,* 50, pp. 147-160.

Matondo, M. 2002. Sukuma tone: a preliminary report. *UCLA Working Papers in Linguistics*, 8, pp. 107-130.

McCarthy, J., and A. Prince. 1986. Prosodic morphology. Amherst and Waltham, Cambrdige MA: University of Massachusetts, and Brandeis University, MS.

Moon. H-G. 1974. *Analysis of Korean Tones*. Seoul: Sejongchulpan Kongsa.

Moon, G-S. 1986. Kyeongnnam bangeonuy soengjo gochal. *Kyeongnam Eomun*, 18, pp. 94-119.

Mtenje, A. 1993. Verbal Structures and Tone in CiYao. In S. Mufwene and L. Moshi, (eds.), *Topics in African Linguistics*, pp. 179-190. Philadelphia: Benjamins.

Odden, D. 1998. Principles of Tone Assignment in Tanzanian Yao. In L. Hyman and C. Kisserth (eds.), *Theoretical Aspects of Bantu*, pp. 195-230.

Ohala, J. J. 1978. The production of tone. In Victoria Fromkin (ed), *Tone: A linguistic Survey*, pp. 5-39. New York: Academic Press.

Park, M-S. 1982. Kyengnam Kyechang pangen yengu. *Cheongjusadae Nonmuncip* 11, pp. 36-57.

Pierrehumbert, J. and M. Beckman. 1988. *Japanese Tone Structure*. Cambridge, MA: MIT Press.

Prieto, P.; J. V. Santen; and J. Hirschberg. 1995. Tonal alignment patterns in Spanish. *Journal of Phonetics*, 23, 429-451.

Pulleyblank. D. 1988. Vocalic underspecification in Yoruba. *Linguistic Inquiry*, 19, pp. 233-270.

Schuch, R. G. 1978. Tone rules. In Victoria Fromkin (ed), *Tone: A linguistic Survey*, pp. 221-256. New York: Academic Press.

Silverman, K. 2003. Hypothesis concerning phonetic and functional origins of tone displacement in Zulu. *Proceedings of CLS* 39, pp. 111-128.

Silverman, K., and J. Pierrehumbert. 1990. The timing of prenuclear high accents in English. In J. Kingston & M. Beckman (eds.), *Papers in Laboratory Phonology I*, pp. 72-106. Cambridge, MA: Cambridge University Press.

Steele, S.A. 1986. Nuclear accent f0 peak location: Effects of vowel, rate, and the number of syllables following. *Journal of the Acoustical Society of America Supplement 1*, 80; s 51.

Tuller, B., and S. Kelso. 1984. The timing of articulatory gestures: Evidence for relational invariants. *Journal of the Acoustical Society of America* 76, pp. 1030-1076.

Xu, Y, and E. Wang. 1997. Intonation contours decomposed: From bottom up. Evanston, IL: Northwestern University, MS.

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