Phonetic Duration Effects on Contour Tone Distribution

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0. Introduction

In some tone languages, pitch changes within a syllable may serve lexical or grammatical functions. These pitch changes are usually referred to as contour tones. In these languages, it is often the case that contour tones are restricted to certain syllable types or prosodic positions. Two of the common restrictions are: contours occur only on phonemic long vowels, as in Somali (Saeed 1993) and Navajo (Hoijer 1974, Young and Morgan 1987); and contours occur only on stressed syllables, as in Xhosa (Lanham 1958, 1963, Jordan 1966) and Jemez (Bell 1993).

To account for the first type of contour restriction, analysts have traditionally taken three assumptions. First, the mora is both the contrastive length unit and tone-bearing unit. Second, a contour tone is structurally composed of two level tones. Third, each mora can only be associated with one tone (Trubetzkoy 1939, Newman 1972, Hyman 1985, McCarthy and Prince 1986, Duanmu 1990, Odden 1995, etc.). In an Optimality-Theoretic framework (Prince and Smolensky 1993), the restriction can then be captured by a constraint banning many-to-one mappings between tones and moras, and ranking this constraint higher than the tonal faithfulness constraint(s), as in (1).

(1) $\begin{array}{c} *T_1 \quad T_2 \\ \backslash\ / \\ \mu \end{array}$ » FAITH(TONE)

The restriction of contour tones to stressed syllables can be captured in OT using *Positional Faithfulness* (Beckman 1998), as in (2). The first ranking pair ensures that contour tones will surface on a stressed syllable, while the second ranking pair ensures that they will not surface on a stressless syllable.

(2) IDENT-STRESS(TONE) » *CONTOUR » IDENT(TONE)

So far, we have seen that the two distributional properties of contour tones have received distinct accounts: the former by reference to the contrastive length unit (the mora), the latter by incorporating the prosodic feature *stress*. I ask the following questions

regarding the current analyses: can we, and should we, provide a unified approach to both phenomena?

I argue that the answers for both questions are positive. The outline of the arguments is as follows: since the tone bearing ability of a syllable is closely related to rime duration, and both [+long] and stress may induce a longer rime duration, a unified account *can* be provided for both phenomena; since other factors that affect contour tone distribution are also duration-related (e.g., final position, syllable count in word), and when multiple durational factors are at play, the one that induces greater lengthening is also the one that is more likely to license contour tones, a unified account *should* be provided for contour tone distribution in general.

1. Phonetic Overview

Both the production and perception of tone suggest that there is a close correlation between duration and tone-bearing ability. Articulatorily, a pitch change requires changes in the vocal fold tension and involves the contraction and relaxation of laryngeal muscles (Lindqvist 1972, Ohala and Ewen 1973, Ohala 1978). Therefore, a complicated tonal contour which involves more pitch targets will involve more complicated muscle state changes, and thus will prefer to have a longer duration for the implementation. A tonal contour with farther-apart pitch targets will require the muscles to contract or relax to a greater degree, and thus will also prefer a greater duration of its carrier (Sundberg 1979).[1] Moreover, Sundberg (1979) documents that it takes longer to implement a pitch rise than a pitch fall with the same pitch excursion. Auditorily, the perceived tonal contour depends on the duration of the tone carrier. Black (1970) and Greenberg and Zee (1979) document that when given the same distance of pitch movement, a longer vowel duration induces a more 'contour-like' tonal perception by the listeners.

Tone-bearing ability is also correlated with sonority. Studies by Plomp (1967) and Ritsma (1967) show that the spectral region containing the second to fourth harmonics is crucial in the perception of fundamental frequencies. Since the crucial second to fourth harmonics are usually present in sonorants, but not in obstruents, sonorants are better tone bearers than obstruents.

Lastly, there is no correlation between syllable onset duration and tone-bearing ability, since articulatorily, onset serves as a transitional period between distinct tonal targets and displays erratic pitch patterns (Kratochvil 1970, Xu 1997, 1998, 1999), and perceptually, rapid spectral changes significantly decrease hearers' sensitivity to pitch movement (House 1990).

We thus conclude that tone-bearing ability is directly related to the sonorous portion of the rime of a syllable: the longer the sonorous rime, the higher the tone-bearing ability.

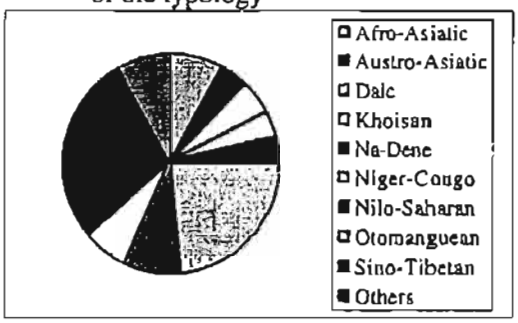
Four factors affect the sonorous duration of a rime: segmental composition, stress, proximity to prosodic boundaries, and syllable count of the word. Obviously, all else being equal, VV>V, VR>VO (R=sonorant, O=obstruent), and $\sigma_{[+stress]}>\sigma_{[-stress]}$. Less obviously, $\sigma_{final}>\sigma_{non\text{-}final}$, and $\sigma_{in\text{-}short\text{-}word} > \sigma_{in\text{-}long\text{-}word}$, the former due to final lengthening (Oller 1973, Klatt 1975), and the latter is documented in a series of phonetic literature including Lehiste 1972 and Lindblom and Rapp 1973. We predict that all these factors may affect the distribution of contour tones in a language.

[1] Unlike Sundberg (1979), Ohala and Ewan (1973) does not find a significant difference in response time between falling pitches of different intervals. But even Ohala's observation is correct, since the experiment requires the subjects to produce the pitch changes at a *maximum* speed, we cannot infer that there is no difference in the *preferred* response time for different intervals of pitch changes.

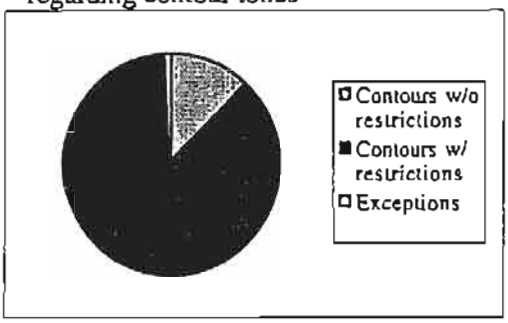
2. A Cross-linguistic Typology on Contour Tone Distribution

A cross-linguistic typology on the distribution of contour tones was carried out. The purpose of the typology is to show that the distribution of contour tones is influenced by all the durational factors identified in section 1. The typology is composed of 182 genetically diverse languages with contour tones, as shown in (3a). Among these languages, 158 have restrictions on contour distribution related to the four durational factors in the expected direction, and two languages have restrictions in the opposite direction, as shown in (3b).

(3) a. Genetic composition of the typology



b. Composition of the typology regarding contour tones



All four durational factors turn out to be relevant in the distribution of contour tones. These effects can be stated as the implicational hierarchies in (4).

(4) All else being equal,
- a. if CV can carry contours, then CVV can carry contours with equal complexity;
- b. if CVO can carry contours, then CVR and CVV can carry contours with equal complexity;
- c. if an unstressed syllable can carry contours, then a stressed syllable can carry contours with equal complexity;
- d. if non-final syllables in a word or utterance can carry contours, then the final syllable of the same prosodic unit can carry contours with equal complexity;
- e. if syllables in an n-syllable word can carry contours, then syllables in an (n-1)-syllable word can carry contours with equal complexity.

These implicational hierarchies are established through observations in (5). "Occurs more freely" includes the following situations: (a) contour tones can occur in one context but not the other; (b) more contour tones can occur in one context than the other; (c) the pitch excursion of a contour tone is greater in one context than in the other context.

(5) Contour tones occur more freely:
- a. on CVV in 44 languages;
  e.g., Somali, Navajo, Ju|'hoasi;
- b. on CVV and CVR in 60 languages;
  e.g., Kiowa, Nama, Fuzhou Chinese;
- c. on stressed syllables in 21 languages;
  e.g., Xhosa, Jemez, Lango;
- d. on the final syllable of words or utterances in 41 languages;
  e.g., Etung, Luganda, Beijing Chinese;
- e. on syllables in shorter words in 17 languages;
  e.g., Mende, Ngamambo, Shanghai Chinese.

We can also imagine languages in which contours with higher complexity simply do not occur. These phenomena may also be durationally based. Contour tones with higher complexity are disfavored since they place a higher demand on the sonorous rime duration. To this end, three implicational hierarchies were identified in the typology, as shown in (6).

(6) a. If a language has contour tones, then it also has level tones.
b. If a language has complex contour tones, then it also has simple contour tones.
c. If a language has rising tones, then it also has falling tones.

The support for these implicational hierarchies is as follows. First, of all the 182 languages in the typology, only two do not have level tones—Guiyang (Li 1997) and Pingyao (Hou 1980), both Chinese dialects. Second, of the 45 languages that allow complex contours, all allow simple contours. Third, the number of languages that have stricter surface restrictions on rising tones far exceeds the number of languages that do for falling tones. Thirty-nine languages belong to the former category and only three belong to the latter.

We are thus led to the following conclusions. First, the typological data support the hypothesis that factors which systematically influence the duration of the sonorous portion of the rime also influence contour tone distribution. Second, not only factors that serve contrastive functions, such as segmental composition of a syllable, can influence the distribution of contour tones. Phonetic factors such as final lengthening and durational differences induced by syllable count in the word can also have such an effect.

The typology thus establishes a close correlation between the sonorous duration in the rime and contour tone distribution. It now seems that in order to give a principled account for contour tone distribution, we need to appeal to a unified durational scale that encompasses all factors that systematically influence the sonorous rime duration, contrastively or not. Referring to contrastive length unit such as the mora or prosodic unit such as stress independently in the analysis misses a more general picture and is unsatisfactory in this respect.

3. The Role of Language Specific Phonetic Patterns on Contour Tone Distribution—Instrumental Studies

3.1. Languages and Hypotheses

Another argument for using a unified durational scale in the analysis of contour tone distribution comes from languages in which multiple durational factors are at play. I show in this section that in these languages, the factor that induces greater lengthening is also the one that is more likely to license contour tones. A durational approach makes exactly this prediction and no others, while a structure-only approach that refers to independent parameters cannot make predictions as to which parameter favors contour bearing, since there is no common ground on which these parameters can be compared.

Phonetic results from four languages—Xhosa, Beijing Chinese, Cantonese, and Navajo—are reported here. Xhosa is a southern Bantu language which has penultimate word stress. It generally restricts its contour tones to the penult, even though the word-final syllable also benefits from a lengthening parameter—final lengthening. In Beijing Chinese, all syllables are equally stressed, but some monosyllabic functional morphemes can be destressed, and they can occur word-finally. Contour tones are restricted to regular-stressed syllables in Beijing, despite the potential lengthening effect that word-final destressed syllables can benefit from. Both Cantonese and Navajo have vowel length and coda sonorancy contrasts, both of which can influence the sonorous duration of the rime.

Phonemic long vowels naturally give rise to phonetically long vowels, and sonorant codas on the one hand add to the sonorous duration of the rime itself, on the other hand do not have the vowel shortening effect that often comes with obtruent codas as in many Chinese dialects. But Cantonese and Navajo make different decisions with regard to contour distribution: Cantonese restricts its contours to non-checked syllables (open or sonorant-closed), whether they have a long or a short vowel; but Navajo restricts its contours to long-voweled syllables, even when they have an obstruent coda.

I set up the hypotheses regarding the durational patterns of these languages based on the durational approach, as shown in (7). The statements refer to the comparison between syllable types with regard to their sonorous duration of the rime.

(7) a. Xhosa: $\sigma_{penult} > \sigma_{final}$.
b. Beijing Chinese: $\sigma_{non\text{-}final,stressed} > \sigma_{final,destressed}$.
c. Cantonese: CVR > CVVO.
d. Navajo: CVVO > CVR.

The data sources for these languages are summarized in (8). To avoid circularity, all syllables used in the measurements have level tones. Data analyses were carried out on Kay Elemetrics CSL. Relevant durations were measured from the spectrograms.

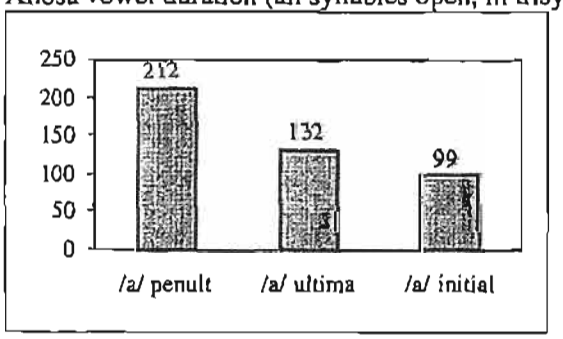
(8)

Language	Source	No. of speakers
Xhosa	UCLA Language Archive	1
Beijing Chinese	Data collection	2
Cantonese	Gordon (1998)	1
Navajo	Data collection	1

3.2. Results and Discussion

The duration results from the four languages are given in (9)—(12). The unit of duration in the graphs is *ms*. The analyses of variance show the effect of position or syllable type on the sonorous rime duration. Fisher's PLSD tests were used for posthoc comparisons. Two-tail paired t-tests were used for the Beijing data.

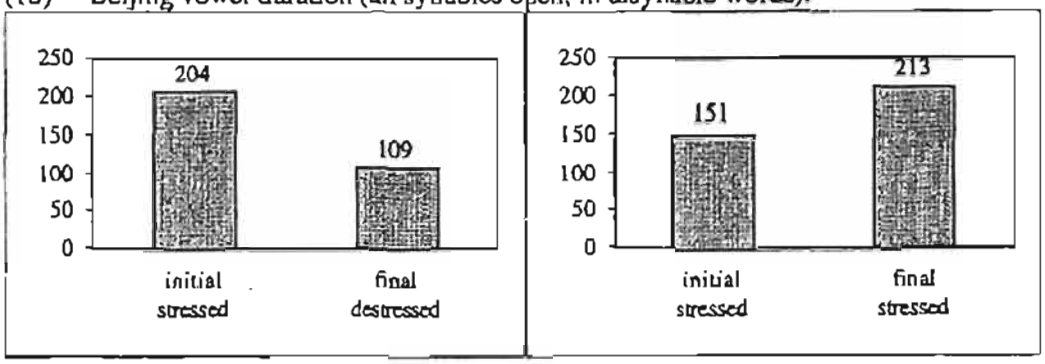
(9) Xhosa vowel duration (all syllables open, in trisyllabic words):



ANOVA: $F(2,131)=242.98$, $p<.0001$;

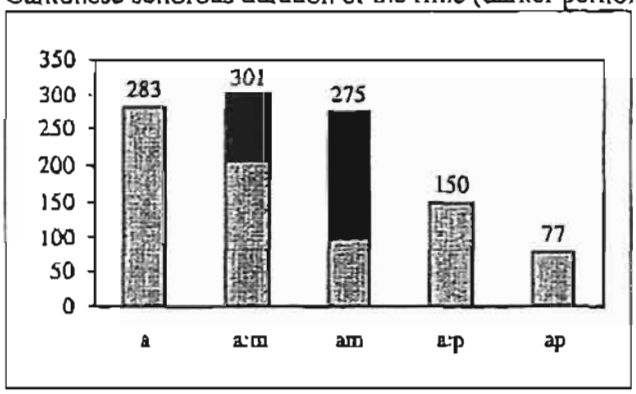
Posthoc: $\sigma_{penult} > \sigma_{final} > \sigma_{initial}$ ($p<.0001$ for both pairs).

(10) Beijing vowel duration (all syllables open, in disyllabic words):



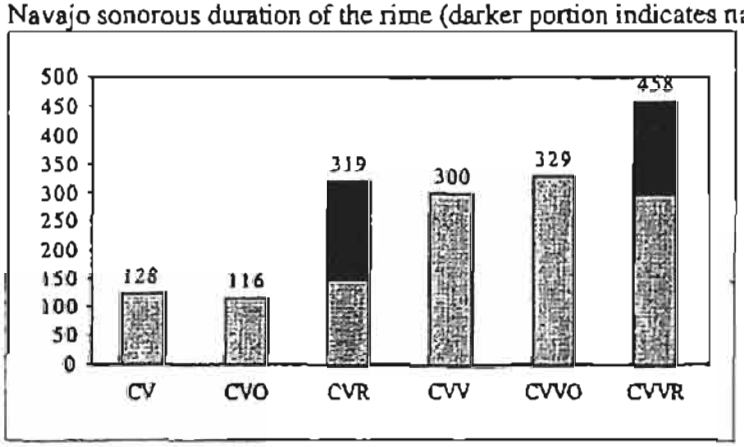
t-test: df=15, t=12.986, p<.0001 *t-test: df=15, t=-13.39, p<.0001*

(11) Cantonese sonorous duration of the rime (darker portion indicates nasal duration):



Gordon (1998) does not give statistical results.

(12) Navajo sonorous duration of the rime (darker portion indicates nasal duration):



ANOVA: F(7, 216)=458.0, p<.0001;
Posthoc: CVR>CVV (p<0.05), CVR=CVVO (p=n.s.).

The phonetic results clearly support the hypotheses for Xhosa, Beijing Chinese and Cantonese in (8). In Xhosa and Beijing Chinese, even though the effect of final lengthening is shown to be present, the stressed syllables in non-final position still have a longer sonorous rime duration than the unstressed final syllables. In Cantonese, CVR has

a considerably longer duration in the rime than CVVO (a 125ms difference). The Navajo data do not directly support the hypothesis, as the sonorous duration of a VR rime is not shorter than, but has a comparable duration to, that of a CVVO or CVV rime. Given that a sonorant consonant is not as good a tone carrier as a vowel because it has low energy in the harmonics crucial to tonal perception, the Navajo results are still consistent with the durational approach. We simply need to encode vowel as a better tone bearer than sonorant consonant (see Zhang 2000 for details). This does not always play a crucial role in contour distribution, especially when VR has a considerably greater duration than VV. But when VR has a comparable duration to VV, it may be a relevant factor.

The fact that the durational parameter that induces the greatest lengthening is always more likely to license contour tones supports the durational approach, since this is exactly its prediction. But for a structure-only approach that refers to individual parameters, there is no principled reason why the parameter that induces less lengthening effect cannot be a more privileged contour licenser, since there is no common ground on which parameters can be compared. We thus conclude that the durational approach is superior since it makes more restrictive, yet more accurate, predictions.

4. Analysis Sketch

This section briefly sketch out the necessary formalism for capturing the relation between duration and contour realization. For detailed formalism and analyses, see Zhang (2000).

We first define *Tone Slope* as in (13). It refers to the magnitude of pitch change within a single unit of time. The *Tone Slope* can be further divided into *Fall Slope* and *Rise Slope*.

(13) For a contour tone with two pitch targets T_1 and T_2 and duration D, the *Tone Slope* of this contour is $\frac{|T_1 - T_2|}{D}$.

Two series of markedness constraints on *Tone Slope* are defined as in (14).

(14)

a.	b.
FALLSLOPE≤x_1	RISESLOPE≤y_1
FALLSLOPE≤x_2	RISESLOPE≤y_2
FALLSLOPE≤x_3	RISESLOPE≤y_3
⋮	⋮
FALLSLOPE≤x_n	RISESLOPE≤y_n
($x_1<x_2<x_3<...x_n$)	($y_1<y_2<y_3<...y_n$)

These constraints penalize pitch changes that are faster than certain values. Under the assumption that the role of phonetics in phonology can be captured by intrinsic rankings of constraints governed by phonetic scales (Prince and Smolensky 1993, Steriade 1997, Jun 1995, etc.), three sets of intrinsic rankings are identified for the constraints in (14), as in (15). The ranking in (15c) encodes the fact that a rising tone requires a longer duration than a falling tone with comparable pitch excursion.

(15) a. FALLSLOPE≤x_n » FALLSLOPE≤x_{n-1} » ... » FALLSLOPE≤x_1
b. RISESLOPE≤y_n » RISESLOPE≤y_{n-1} » ... » RISESLOPE≤y_1
c. If $x_j=y_k$, then RISESLOPE ≤y_k » FALLSLOPE≤x_j. ($1\leq j\leq n$, $1\leq k\leq n$)

Two faithfulness constraints PRESERVE(TONE) (abbr. PRES(T)) and PRESERVE(RIMEDURATION) (abbr. PRES(RD)) are defined as in (16). The tonal

faithfulness constraint requires the tonal specifications to be realized in the output, while the durational faithfulness constraint requires the output duration of a certain syllable type under a certain prosodic condition to conform to the canonical duration of this syllable type under this prosodic condition (see Zhang 2000 for detailed discussion on this point).

(16) a. PRES(T): an input tone T_I must have an output correspondent T_O, and T_O must preserve all the pitch characteristics of T_I.
b. PRES(RD): an input rime R_I must have an output correspondent R_O, and R_O must preserve the duration of R_I.

The factorial typology of the constraints in (14) and (16) predict three different strategies when an excessive contour falls on an insufficient duration. Assuming that the relevant TONESLOPE constraint is undominated, when PRES(RD) outranks PRES(T), contour flattening occurs; when PRES(T) outrank PRES(RD), rime lengthening occurs; and when PRES(RD) and PRES(T) are equally lowly ranked, free variation between contour flattening and rime lengthening occurs. All three language types are attested: Xhosa does not allow its only contour tone—Fall—on stressless syllables; Mitla Zapotec lengthens syllables that carry the rising tone, but does not do so when the syllables carry the falling tone (Briggs 1961); Ngizim accommodates its only contour—Fall—on CVV, but *optionally* simplifies it to H on CVC (Schuh 1971).[2]

To schematically sketch an analysis for Xhosa, I assume that its canonical duration for the final vowel and the penultimate vowel is d and $d+d_0$ respectively, and its falling pitch excursion is ΔF. The relevant TONESLOPE constraint is FALLSLOPE≤x ($\frac{\Delta F}{d+d_0} < x < \frac{\Delta F}{d}$). Then the ranking FALLSLOPE≤x, PRES(RD) » PRES(T) derives the contour distribution pattern. On the penultimate syllable, the falling contour can surface without violating the TONESLOPE constraint. But on the final syllable, the falling contour must be flattened. This is shown in the tableau in (17).

(17) $\sigma_{\Delta F,d} \longrightarrow \sigma_{0,d}$

$\sigma_{\Delta F,d}$	FALLSLOPE≤x	PRES(RD)	PRES(T)
$\sigma_{\Delta F,d}$	*!		
$\sigma_{\Delta F,d+d0}$		*!	
☞ $\sigma_{0,d}$			*

A schematic analysis for Mitla Zapotec can be similarly given. Assume that its falling pitch excursion is ΔF and its rising pitch excursion is ΔR; its canonical sonorous rime duration is d, and it undergoes a lengthening of d_0 when it carries the rising tone. The relevant TONESLOPE constraints are FALLSLOPE≤x ($\frac{\Delta F}{d} < x$), and RISESLOPE≤y ($\frac{\Delta R}{d+d_0} < y < \frac{\Delta R}{d}$). The ranking FALLSLOPE≤x, RISESLOPE≤y, PRES(T) » PRES(RD) derives the contour distribution pattern. A syllable does not need to lengthen to carry the falling tone, as the FALLSLOPE constraint is not violated in this case. But when it carries the rising tone, a duration of d is not sufficient. Given the high ranking of PRES(T), the rime must be lengthened by d_0, which suffices to satisfy the RISESLOPE constraint. This is shown in (18). If $\Delta F \geq \Delta R$, then Mitla Zapotec is an example of rising tones having a

[2] Another scenario emerges if the faithfulness constraints are split into families of intrinsically ranked constraints: contour flattening and rime lengthening can be both employed to a mild degree. This pattern is attested in Hausa (Gordon 1998). See Zhang (2000) for detailed discussion of Hausa.

stricter surface restriction than falling tones, as with $y < \frac{\Delta R}{d} \leq \frac{\Delta F}{d} < x$, the RISESLOPE≤y constraint places a stricter requirement than the FALLSLOPE≤x constraint, yet they are ranked on a par.

(18) $\sigma_{\Delta R,d} \longrightarrow \sigma_{R,d+d0}$

$\sigma_{\Delta R,d}$	FALLSLOPE≤x RISESLOPE≤y	PRES(T)	PRES(RD)
$\sigma_{\Delta R,d}$	*!		
☞ $\sigma_{\Delta R,d+d0}$			*
$\sigma_{0,d}$		*!	

Finally, we give a schematic analysis for Ngizim. Assume that its falling contour has a pitch excursion ΔF. The canonical sonorous rime duration for CVC is d, and it is lengthened to $d+d_0$ when the falling tone surfaces on it. The relevant TONESLOPE constraint is the same as in Xhosa: FALLSLOPE≤x ($\frac{\Delta F}{d+d_0} < x < \frac{\Delta F}{d}$). But the ranking here is FALLSLOPE≤x » PRES(RD), PRES(T). Without a fixed ranking between PRES(RD) and PRES(T), free variation between contour flattening and rime lengthening occurs, as shown in the tableau in (19). As for CVV, even though its sonorous rime duration might not be longer than C_1VC_2 when C_2 is a sonorant, it will still have a stronger tone bearing ability than C_1VC_2, as discussed in 3.2. With additional formalism that encodes the vowel as a better tone carrier than a sonorant consonant (see Zhang 2000), that the falling tone can always surface on CVV, probably without lengthening, can be explained.

(19) $\sigma_{\Delta F,d} \longrightarrow \sigma_{\Delta F,d+d0}$ or $\sigma_{0,d}$

$\sigma_{\Delta F,d}$	FALLSLOPE≤x	PRES(RD)	PRES(T)
$\sigma_{\Delta F,d}$	*!		
☞ $\sigma_{\Delta F,d+d0}$		*	
☞ $\sigma_{0,d}$			*

5. Conclusion

Two points have been made in this paper. First, the distribution of contour tones in a language correlates closely with the duration of the sonorous portion of the rime of different syllable types. Syllable types which have longer sonorous duration of the rime, e.g., long-voweled, sonorant-closed, stressed, final in a prosodic domain, are more likely to carry contour tones. This is illustrated by the cross-linguistic typology which shows that systematic factors that influence the sonorous duration of the rime have strong effects on the distribution of contour tones. Second, to account for the distribution of contour tones, an analysis that refers to the durational properties of different syllable types makes more restrictive and accurate predictions than an analysis that does not. This is illustrated by the phonetic studies which show that, when two different parameters lengthen the sonorous duration of the rime, the one that induces the greater effect is the one that is more likely to license contour tones.

To capture the tone-duration interaction in an Optimality-Theoretic grammar, I appeal to phonetically based TONESLOPE constraints, which penalize fast pitch changes, and their intrinsic rankings. Interacting with faithfulness constraints on tone and duration, the system generates a factorial typology that is well matched with attested patterns of contour realization.

Finally, the duration and pitch values under discussion here all refer to the standard speaking rate and style. I assume that durational categories and tonal contrasts are formed under this condition and speakers' behavior under other rates and styles are derivable given their ability to normalize across different modes of speech (Perkell and Klatt 1986, Leather 1983, Moore 1995, Moore and Jongman 1997).

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