6 The role of contrast-specific and language-specific phonetics in contour tone distribution

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1 Introduction

In some tone languages, contour tones (pitch changes within a syllable) may be used contrastively. The phonological distribution of contour tones has been of much theoretical interest, as it sheds light on both the representation of tone (Woo 1969; Leben 1973; Goldsmith 1976; Bao 1990; Duanmu 1990, 1994a; Yip 1989, 1995) and the relation between phonetics and phonology (Duanmu 1994b; Gordon 1998; Zhang 1998, 2002a).

Contour tones are commonly restricted to phonemic long vowels, as in Navajo (Young and Morgan 1987), or to stressed syllables, as in Xhosa (Lanham 1958). I ask the following questions in this chapter: What is the link between these two contexts? Should they be accounted for by independent mechanisms, based on contrastive vowel length and stress respectively, or by some unified mechanism? Drawing from typological and instrumental data, I argue that the unifying factor for contour tone licensing is sonorous rhyme duration, and that the distribution of contour tones is determined by phonetic categories for duration and sonority rather than abstract structural categories based on contrastive vowel length or stress.

The argument goes as follows. The articulation and perception of contour tones determine that they need a sufficient sonorous rhyme duration to be implemented. Thus, a long sonorous rhyme duration is the unifying factor for privileged contour tone licensers. Examining contour tone distribution cross-linguistically, we find that (a) the types of syllables on which contour tones are more likely to occur are exactly those that independently have a longer duration and higher sonority in the rhyme; and (b) the privileged contour tone licensers include not only long-vowelled and stressed syllables, but also syllables in other contexts shown in the literature to undergo lengthening, namely phrase-final position and shorter words. Moreover, instrumental studies show that in languages with two lengthening factors, the factor that induces greater lengthening of the sonorous portion of the rhyme is always the one that is more likely to license contour tones. This could not be explained unless the principles of contour licensing make direct reference to sonorous rhyme duration.

2 The phonetics of contour tones

2.1 Sonorous rhyme duration is the carrier of contour tones

2.1.1 The importance of sonority The main perceptual correlate of tone is the fundamental frequency (FO). All harmonics serve as a cue to f_0, since they occur at integral multiples of f_0. However, as shown by Plomp (1967) and Ritsma (1967), the spectral region containing the second, third and fourth harmonics is especially important in the perception of fundamental frequencies in the range of speech sounds. Since sonorants possess richer harmonic structures than obstruents, including the crucial second to fourth harmonics, sonorants are better tone bearers than obstruents. Moreover, vowels typically have greater energy, and thus stronger acoustic manifestation of harmonics, in the crucial region, than sonorant consonants. These differences will be crucial in the analysis below.

2.1.2 The importance of duration Tone-bearing ability depends not just on sonority, but also duration. This is determined by factors involving both production and perception.

The production of contour tones is different from that of other contour segments (e.g. labial-velars like [k͡p] or clicks) in that for contour tones, the acoustic change results from the state change of a single articulator, the vocal folds. Laryngeal muscle contraction and relaxation, which determine vocal fold tension (Ohala 1978), must be sequenced to produce the pitch variation in a contour tone. Thus, unlike a complex segment whose different oral constrictions can be overlapped, a contour tone requires greater duration to be implemented. This duration depends on the tone's complexity (e.g. MLH[1] vs LH) as well as its pitch range (e.g. MH vs LH) (Sundberg 1979). Moreover, because the muscles responsible for pitch falls are both more numerous and more robust than those that execute a rise, it takes longer to implement a pitch rise than a pitch fall of the same extent (Ohala 1978; Sundberg 1979).

Contour tones also differ from other contour segments such as prenasalised stops and affricates in auditory terms. Although the production of the latter group of sounds also requires an articulator to go from one position to another, the acoustic consequence of such change is sudden; for example, the frication noise is formed the moment the oral occlusion is loosened, and the transition between the two states has no perceptual consequence. But for contour tones, the gradual stretching or relaxation of the vocal folds has a continuous acoustic effect, and the transition from the beginning state to the end state carries a significant perceptual weight in the identification of the tonal contour (Gandour 1978; Gandour and Harshman 1978). Correspondingly, Greenberg and Zee (1979) show that, given the same pitch excursion, the longer the duration of the vowel, the more 'contour-like' the tone is perceived by the listener. They also show that listeners cannot perceived pitch changes reliably when the duration is below 90ms.

2.2 *Two phonetic scales – contour tone-bearing ability and tonal complexity*

We are now in a position to define two relevant phonetic scales: contour tone-bearing ability and tonal complexity. The preceding section established that the realisation of contour tones relies on two aspects of the rhyme: sonority and duration. Therefore, we may hypothesise that it is a weighted sum of these two factors that determines the contour tone-bearing ability of the syllable. I term this weighted sum $C_{CONTOUR}$. Suppose that Dur(V) and Dur(R) represent the duration of the vowel and the sonorant consonant in the rhyme respectively. Then $C_{CONTOUR}$ can be defined as follows:

(1) $C_{CONTOUR} = a \cdot \mathrm{Dur(V)} + \mathrm{Dur(R)}$

Clearly, *a* must be greater than one, since vowels facilitate tonal realisation more than coda sonorants. However, *a* cannot be huge, since the sonorants do make a non-negligible contribution to tone-bearing ability. For more discussion of *a*, see Zhang 2002a.

$C_{CONTOUR}$ can be used to construct a tonal complexity scale, as in (2).

(2) Tonal complexity scale
For any two tones T_1 and T_2, let C_1 and C_2 be the minimum $C_{CONTOUR}$ values required for the production and perception of T_1 and T_2 respectively. T_1 is more tonally complex than T_2 iff $C_1 > C_2$.

From the discussion of contour tone phonetics, we already know that the following three parameters of a tone influence its position in the tonal complexity scale: the number of pitch targets, the pitch excursion between two targets, and the direction of the slope. The influence of these three parameters is stated more rigorously in (3).

(3) For any two tones T_1 and T_2, suppose T_1 has *m* pitch targets and T_2 has *n* pitch targets; the cumulative falling excursions for T_1 and T_2 are Δf_{F_1} and Δf_{F_2} respectively, and the cumulative rising excursions for T_1 and T_2 are Δf_{R_1} and Δf_{R_2} respectively. T_1 has a higher tonal complexity than T_2 iff:
a. $m > n$, $\Delta f_{F_1} \geq \Delta f_{F_2}$, and $\Delta f_{R_1} \geq \Delta f_{R_2}$;

b. $m = n$, $\Delta f_{F_1} \geq \Delta f_{F_2}$, and $\Delta f_{R_1} \geq \Delta f_{R_2}$ ('=' holds for at most one of the comparisons);
c. $m = n$, $\Delta f_{F_1} + \Delta f_{R_1} = \Delta f_{F_2} + \Delta f_{R_2}$, and $\Delta f_{R_1} \geq \Delta f_{R_2}$.

Condition (3a) states that if T_1 has more pitch targets and T_1's cumulative falling excursion and rising excursion are both no smaller than those of T_2's, then T_1 is more tonally complex than T_2 (cf. section 2.1.1); for example, 534 is more complex than 53.[2] Condition (3b) states that if T_1 and T_2 have the same number of pitch targets, and one of T_1's cumulative falling excursion and rising excursion is greater than that of T_2's, and the other one is no smaller than that of T_2's, then T_1 is more complex than T_2. For example, 535 has a higher tonal complexity than 545, 534, or 435. Condition (3c) states that if T_1 and T_2 have the same number of pitch targets and the same overall pitch excursion, but the cumulative rising excursion in T_1 is greater than that in T_2, then T_1 is more complex than T_2 For example, 435 is more complex than 534, since $m = n = 3$, $\Delta f_{F_1} + \Delta f_{R_1} = \Delta f_{F_2} + \Delta f_{R_2} = 3$, and $\Delta f_{\mathrm{R}_1} = 2 > \Delta f_{R_2} = 1$.

2.3 *Phonological factors that influence $C_{CONTOUR}$*

Since C_{CONTOUR} has a major effect on tonal complexity, it is important to discuss the phonological factors that influence it. I identify four such factors here: segmental composition, stress, phrase-final position, and the number of syllables in the word to which the rhyme belongs.

Segmental composition factor refers to the length of vowels and the [sonorant] value of coda consonants. According to (1), all else being equal, VV has a greater C_{CONTOUR} value than V; a VR (R = sonorant) has a greater C_{CONTOUR} value than VO (O = obstruent); and VV has a greater C_{CONTOUR} value than VR, provided they have comparable duration.

Together with pitch and amplitude, duration is often one of the key phonetic correlates of stress; for references see Gordon's chapter (this volume) and Zhang 2002a. Therefore it is reasonable to assume that all else being equal, a stressed syllable has a greater C_{CONTOUR} value than an unstressed one.

Final lengthening is the basis for considering the phrase-final position as a relevant parameter. The phonetic literature has shown that the final syllable of a prosodic unit is subject to lengthening (Klatt 1975; Wightman et al. 1992, among others). We thus expect that, all else being equal, a final syllable in a prosodic unit has a greater C_{CONTOUR} value than a non-final syllable in the same prosodic unit.

Lastly, a syllable in a shorter word has a greater C_{CONTOUR} value than an otherwise comparable syllable in a longer word. This is motivated by a series of phonetic studies (Lehiste 1972; Lindblom et al. 1981; Lyberg 1977, among others) that documents that a syllable has a longer duration when it is in a shorter word than in a longer word.

2.4 Predictions about contour tone distribution by two competing approaches

As discussed in the introduction to this book, if we acknowledge that constraints on speech production and perception have an effect on phonological markedness, then typological research in phonology can proceed deductively; that is, we may lay out specific hypotheses about possible phonological patterns or implicational laws based on our knowledge of articulation and perception, and test these hypotheses against language data.

If the typology of contours is entirely determined by ease of articulation and perception, we are led to the predictions in (4).

(4) a. The only syllables that selectively license contour tones are those with greater C_{CONTOUR}, i.e. long-vowelled, sonorant-closed, stressed, phrase-final, or found in shorter words.

b. Within a language, multiple factors can together induce a greater C_{CONTOUR} value, and their contour tone licensing ability corresponds to the degree of C_{CONTOUR} increase.

These predictions are made within a general view of the role of phonetics in phonology that I will call the *direct approach*. This approach embodies two assumptions. The first is that positional licensing is contrast-specific. Since different contrasts require the support of different phonetic properties, they are preferentially licensed in different positions, which reflects the phonetics (Steriade 1993). Specifically, positional licensing of contour tones is tied to the duration and sonority of the rhyme, which are crucial to their production and perception. This may be contrasted with an alternative view, which I will call the *structure-only approach*, in which certain specified phonological positions are hypothesised to host phonological contrasts of any sort, rather than just the contrasts that they are phonetically well suited to host. On this view we expect, for instance, that contour tones should in some languages have a special license to occur on word-initial syllables, since this context has been shown to be privileged for many other phonological features (Steriade 1993, 1995; Beckman 1997). Moreover, since short words and phrase-final position are not contexts that license phonological contrast in general, a structure-only approach predicts that they should be not licensers for tonal contrasts either.

The second assumption of the direct approach is that, for a particular contrast, its positional licensing behaviour should be tuned to language-specific phonetics. That is, a language that has a greater quantitative amount of the relevant phonetic property in a position is expected to be more able or likely to use that position to license the relevant contrast. The structure-only approach differs in predicting that language-particular quantitative differences should play no role in phonological licensing.

A clear way to compare the direct and structure-only approaches is to consider cases in which there are multiple factors present that induce a greater C_{CONTOUR}. In such a case, the direct approach predicts which one should be the better contour tone licenser, but the structure-only approach does not. Let me spell out the argument in detail. Consider a language L in which two distinct properties of a syllable, P_1 and P_2, can both induce a greater C_{CONTOUR} value. Assume further that L has contour tones with distributional restrictions related to P_1 and P_2, and that $C_{\text{CONTOUR}}(P_1) > C_{\text{CONTOUR}}(P_2)$. Let us first see what predictions the structure-only approach makes. Since P_1 and P_2 are properties that increase the syllable's contour tone-bearing ability, we may posit two positional Markedness constraints that penalise the realisation of contour tones on syllables without these properties, as defined in (5).

(5) a. *CONTOUR($\neg P_1$): no contour tone is allowed on syllables without property P_1.
    b. *CONTOUR($\neg P_2$): no contour tone is allowed on syllables without property P_2.

Since P_1 and P_2 are distinct properties of the syllable, there are two possible scenarios for the ranking of (5a) and (5b). Either: (i) there is no universal ranking between them; or (ii) there is such a universal ranking, but it is not based on the phonetic characteristics of P_1 and P_2, so there is no a priori reason to believe that this ranking agrees with the C_{CONTOUR} comparison between P_1 and P_2. In either case, we cannot rule out the ranking *CONTOUR($\neg P_2$) $\gg$ *CONTOUR($\neg P_1$) in a principled way.

To explore this question further, let us complete the analysis by adding more constraints and computing the factorial typology (Prince and Smolensky 1993), which is the full set of language types that are possible under any ranking of the constraints. We first need the two general constraints given in (6).

(6) a. *CONTOUR: no contour tone is allowed on a syllable.
    b. IDENT(Tone): let α be a syllable in the input, and β be any syllable corresponding to α in the output; if α has tone T, then β has tone T.

Calculating the factorial typology of the four constraints given so far, we find that it include five distinct patterns of contour tone realisation:

(7) Factorial typology (structure-only approach)

	Constraint ranking	Contour tone restriction predicted
a.	*CONTOUR(¬P_1), *CONTOUR(¬P_2), *CONTOUR ⇓ **IDENT(Tone)**	No contour tone on any syllable
b.	*CONTOUR(¬P_1), *CONTOUR(¬P_2) ⇓ **IDENT(Tone)** ⇓ *CONTOUR	Contour tone only on syllables with both P_1 and P_2
c.	*CONTOUR(¬P_1) ⇓ **IDENT(Tone)** ⇓ *CONTOUR(¬P_2), *CONTOUR	Contour tone only on syllables with P_1
d.	*CONTOUR(¬P_2) ⇓ **IDENT(Tone)** ⇓ *CONTOUR(¬P_1), *CONTOUR	Contour tone only on syllables with P_2
e.	**IDENT(Tone)** ⇓ *CONTOUR(¬P_1), *CONTOUR(¬P_2), *CONTOUR	Contour tone on all syllable types

When IDENT(Tone) is ranked at the bottom, no contour is allowed on any syllable ((7a)); when IDENT(Tone) is ranked between the positional Markedness and general Markedness constraints, contours are only allowed on syllables with P_1&P_2 simultaneously ((7b)), since all other combinations (¬P_1&P_2, P_1&¬P_2, ¬P_1&¬P_2) violate at least one of the highly ranked *CONTOUR(¬P_1) and *CONTOUR(¬P_2); when IDENT(Tone) is ranked between the two positional Markedness constraints, contours are only allowed on syllables with P_1 ((7c)) or on syllables with IDENT(Tone)P_2 ((7d)); and finally, when IDENT(Tone) is ranked on top, contours are allowed on all syllable types ((7e)).

A slight complication, which will be relevant later on, is the possibility that the grammar could include the disjoined constraint *CONTOUR($\neg P_1$) $\cup$ *CONTOUR($\neg P_2$), which is violated only when both *CONTOUR($\neg P_1$) and *CONTOUR($\neg P_2$) are violated (for the theory of constraint disjunction, see Smolensky 1995; Kirchner 1996; and Crowhurst and Hewitt 1997). If such a constraint is included, the factorial typology will expand slightly, to include cases in which contours are licensed by the presence of either P_1 or P_2; the critical ranking is *CONTOUR($\neg P_1$) $\gg$ *CONTOUR($\neg P_2$) $\gg$ IDENT(Tone) $\cup$ *CONTOUR($\neg P_1$), *CONTOUR($\neg P_2$), *CONTOUR. For simplicity, I will assume this six-member factorial typology in the comparison below; for further discussion of this pattern, see Zhang 2002b.

The really crucial prediction made by the structure-only approach is (7c): contour tones could in principle surface only on syllables with P_2, despite the fact that syllables with P_1 are phonetically better contour tone bearers.

Consider now the predictions the direct approach makes for the same situation in which $C_{CONTOUR}(P_1) > C_{CONTOUR}(P_2)$. I assume that the effect of the $C_{CONTOUR}$ value increase is additive; that is if a syllable has both properties P_1 and P_2, then its $C_{CONTOUR}$ value is even greater.[3] Therefore, we arrive at the following phonetic scale: $C_{CONTOUR}(P_1\&P_2) > C_{CONTOUR}(P_1) > C_{CONTOUR}(P_2)$. This gives rise to the following positional Markedness constraints:

(8) Positional Markedness constraints in a direct approach
  a. *CONTOUR($\neg C_{CONTOUR}(P_1\&P_2)$): no contour tone is allowed on syllables whose $C_{CONTOUR}$ value is less than $C_{CONTOUR}(P_1\&P_2)$.
  b. *CONTOUR($\neg C_{CONTOUR}(P_1)$): no contour tone is allowed on syllables whose $C_{CONTOUR}$ value is less than $C_{CONTOUR}(P_1)$.
  c. *CONTOUR($\neg C_{CONTOUR}(P_2)$): no contour tone is allowed on syllables whose $C_{CONTOUR}$ value is less than $C_{CONTOUR}(P_2)$.

Since these constraints refer to a unified phonetic scale, $C_{CONTOUR}$, and we know that $C_{CONTOUR}(P_1\&P_2) > C_{CONTOUR}(P_1) > C_{CONTOUR}(P_2)$, we can project a universal constraint ranking (cf. Prince and Smolensky 1993: 67), as shown in (9).

(9) *CONTOUR($\neg C_{CONTOUR}(P_2)$) $\gg$ *CONTOUR($\neg C_{CONTOUR}(P_1)$) $\gg$
  *CONTOUR($\neg C_{CONTOUR}(P_1\&P_2)$)

The basis of this ranking is that *CONTOUR constraints for lower $C_{CONTOUR}$ values are always ranked above *CONTOUR constraints for higher $C_{CONTOUR}$ values.

With this ranking and the general constraints *CONTOUR and IDENT(Tone), the factorial typology predicted by the direct approach can be computed in (10).

(10) Factorial typology (direct approach)

	Constraint ranking	Contour tone restriction predicted
a.	$*\textsc{Contour}(\neg C_{\textsc{contour}}(P_2))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1\&P_2))$, $*\textsc{Contour}$ $\Downarrow$ **IDENT(Tone)**	No contour tone on any syllable
b.	$*\textsc{Contour}(\neg C_{\textsc{contour}}(P_2))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1\&P_2))$ $\Downarrow$ **IDENT(Tone)** $\Downarrow$ $*\textsc{Contour}$	Contour tone only on syllables with $P_1\&P_2$ simultaneously
c.	$*\textsc{Contour}(\neg C_{\textsc{contour}}(P_2))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1))$ $\Downarrow$ **IDENT(Tone)** $\Downarrow$ $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1\&P_2))$, $*\textsc{Contour}$	Contour tone only on syllables with P_1
d.	$*\textsc{Contour}(\neg C_{\textsc{contour}}(P_2))$ $\Downarrow$ **IDENT(Tone)** $\Downarrow$ $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1\&P_2))$, $*\textsc{Contour}$	Contour tone only on syllables with P_1 or syllables with P_2
e.	**IDENT(Tone)** $\Downarrow$ $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_2))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1))$, $*\textsc{Contour}(\neg C_{\textsc{contour}}(P_1\&P_2))$, $*\textsc{Contour}$	Contour tone on all syllable types

This factorial typology turns out to be smaller (five members instead of six). In particular, it is lacking the case in which contours are allowed on only syllables with property P_2. For this outcome to arise, we would need some constraint in the system that penalised contours on P_1 but not P_2. However, no such constraint exists. Indeed, there could be no such constraint, since the constraints are based not on phonological contexts per se, but rather on the values for $C_{CONTOUR}$; and by hypothesis $C_{CONTOUR}(P_1) > C_{CONTOUR}(P_2)$.

In summary, the direct approach and the structure-only approach make two different predictions. First, the direct approach predicts that contour tones specifically gravitate to positions with greater $C_{CONTOUR}$ values, that is, ones with longer sonorous rhyme duration, and in the case of equal sonorous rhyme duration, the position with a longer vocalic component. The structure-only approach, however, is insensitive to phonetic properties specific to contour tones, and thus predicts that word-initial position should be privileged for contour tones, while phrase-final syllables and syllables in shorter words should not be. Second, the structure-only approach predicts that it is possible to have contour tones only on syllables with P_2, despite the fact that syllables with P_1 have a greater contour tone-bearing ability; the direct approach, however, predicts an implicational relation that allows contour tones on P_2 only if contour tones on P_1 are allowed.

To test these different predictions, I carried out a typological survey of contour tone distribution to see if contour tones are indeed more likely to surface on syllables with a greater $C_{CONTOUR}$ value. In addition, I conducted phonetic studies of duration in languages with multiple lengthening factors to see if there is an implicational relation between the stronger and weaker lengthening factors in their contour tone licensing ability.

3 The role of contrast-specific phonetics in contour tone distribution: a survey

3.1 Overview of the survey

The survey was composed of 187 genetically diverse tone languages with contour tones. The full details of the survey are reported in Zhang 2002a; here I will only give a very brief summary. Of the 187 languages, 22 have no restrictions on the distribution of contour tones; 159 have restrictions on contours that accord with the predictions of the direct approach; that is, they were related to the factors given in section 2.3 that increase the $C_{CONTOUR}$ value of the rhyme. Five languages have restrictions in both the expected and unexpected directions. These languages are Lealao Chinantec, Margi, Zangcheng Chinese, Lao, and Saek; for full discussion of these cases, see Zhang 2002a.[4] No languages imposed restrictions solely in the unexpected direction.

3.2 Implicational laws

More specifically, we can make the following observations regarding contour tone distribution from the survey, as in (11). 'Occurs more freely' in a context here means any of the following: (a) contour tones can occur in this context, but not other contexts; (b) the contour tones that occur in this context are a superset of those that occur in other contexts; (c) the pitch excursion of the contour tones that occur in this context is greater than that in other contexts; (d) rising tones can occur in this context, but not others. These scenarios are based on the definition for 'tonal complexity' in section 2.2.

(11) Contour tones occur more freely:

a. on CVV in 38 languages (e.g. Somali, Navajo, Ju|'hoasi)
b. on CVV and CVR in 66 languages (Kiowa, Nama, Fuzhou Chinese)
c. on stressed syllables in 21 languages (Xhosa, Jemez, Lango)
d. on the final syllable of words or utterances in 45 languages (Etung, Luganda, Beijing Chinese)
e. on syllables in shorter words in 19 languages (Mende, Ngamambo, Shanghai Chinese)

Through these observations, the following implicational laws can be established:

(12) All else being equal,

a. if CV can carry contour tones, then CVV can carry contour tones with equal or greater complexity;
b. if CVO can carry contour tones, then CVR and CVV can carry contour tones with equal or greater complexity;
c. if an unstressed syllable can carry contour tones, then a stressed syllable can carry contour tones with equal or greater complexity;
d. if non-final syllables in a prosodic domain can carry contour tones, then the final syllable of the same prosodic domain can carry contour tones with equal or greater complexity;
e. if syllables in a word having *n* syllables can carry contour tones, then syllables in a word having *n–1* syllables can carry contour tones with equal or greater complexity.

The limiting case of contextual limitation is complete absence: there are many languages in which the more complex contour tones simply do not occur. These gaps may also be phonetically based. Contour tones with higher complexity are disfavoured since they place a higher demand on the duration and sonority of the rhyme. The relevant observations are as follows. First, of all the 187 languages in the survey, only two do not have level tones: Guiyang (Li 1997) and Pingyao (Hou 1980), both Chinese dialects. Second, of the 46 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 have them for falling tones. Thirty-seven languages belong to the former category and only three to the latter.

To this end, three strong implicational tendencies can also be established, as shown in (13).

(13) 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.

3.3 Discussion of the survey

Our survey leads to the following conclusion: only factors that systematically influence the duration or sonority of the rhyme can influence the distribution of contour tones; contour tones gravitate to the rhymes with greater C_{CONTOUR} values. The hypothesis in (4a) is supported.[5] Two observations are particularly striking. First, phrase-final syllables and syllables in shorter words are preferred bearers of contour tones, even though they are usually not privileged for other phonological contrasts. Moreover, word-initial syllables, which have been shown to selectively license many other phonological contrasts (Steriade 1993, 1995; Beckman 1997), do not show up on our list of privileged contour tone bearers. The positional licensing behaviour of contour tones is thus sensitive to the phonetic properties that are crucial to contour tones per se, namely duration and sonority. Phrase-final syllables and syllables in short words are privileged contour tone licensers because they are lengthened. Word-initial syllables, on the other hand, fail to license contours because lengthening of the initial rhyme is cross-linguistically very rarely attested.

Contour tones behave like other phonological structures in requiring context-specific licensers. For example, for obstruent place contrasts, Steriade (1993, 2001a) argues that, even though most place contrasts are more likely to be maintained in prevocalic position, the contrast between an alveolar and a retroflex is more likely to be maintained postvocalically, since unlike other place distinctions that primarily benefit from C-to-V formant transitions, their distinction resides in the V-to-C formant transitions. For diphthongs, Zhang (2001) shows that, like contour tones, they gravitate to positions with longer inherent duration, and for essentially the same reasons.

4 The role of language-specific phonetics in contour tone distribution: instrumental studies

This section brings experimental data to bear on the question of whether the formal theory needs to directly encode phonetic properties such as $C_{CONTOUR}$ into the phonological constraints, as the direct approach claims. The data are from languages with contexts whose durational properties fit the description of P_1 and P_2 in the factorial typology study above (section 2.4). To recapitulate the argument, if we find languages in which the privileged factor for contour bearing is P_1, despite the fact that syllables endowed with P_1 but not P_2 have a smaller $C_{CONTOUR}$ value than those endowed with P_2 but not P_1, then we must conclude that the structure-only approach is the correct one. If, however, the privileged factor is always the one that induces a greater $C_{CONTOUR}$, this supports the direct approach.

4.1 Identifying the languages

If we take stress to be P_1 and final position to be P_2, then we can find both syllables with only P_1 and syllables with only P_2, provided the target language includes words with non-final stress. Xhosa is such a language (Lanham 1958), and many Northern Chinese dialects (e.g. Beijing Chinese) also qualify. In these languages, all syllables are equally stressed, but some monosyllabic reduplicative morphemes and functional words can be destressed, and they can occur word-finally.

The second type of relevant languages has both vowel length and coda sonorancy contrasts, both of which influence the sonorous duration of the rhyme. If we take the [+long] feature of the vowel as property P_1 and the [+son] feature of the coda consonant as property P_2, then syllable CVVO has property P_1 but not P_2, and syllable CVR has property P_2 but not P_1. Among the languages that fit this description, Standard Thai (Abramson 1962; Gandour 1974) and Cantonese (Kao 1971) allow fewer contour tones on CVVO, while Navajo (Young and Morgan 1987) does not allow contour tones on CVR.

I summarise the relevant phonetics of these languages next. The detailed methods and word lists are documented in Zhang 2002a.

4.2 Instrumental Studies

4.2.1 Xhosa Xhosa has penultimate word stress. Vowel length is non-contrastive except in a few grammatical morphemes. All syllables are open: the apparent coda /m/ is in fact syllabic. There are three tones: H, L, and HL (falling). There are no distributional restrictions for H and L, but HL is generally restricted to the penult of a content word. A few monosyllabic grammatical

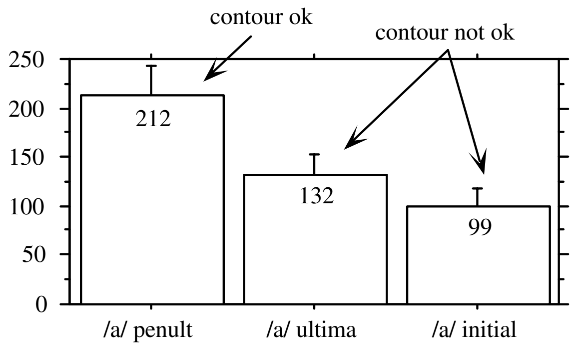

Figure 6.1 Xhosa vowel duration (ms)

prefixes and suffixes can also bear HL, and they do not necessarily occur in penultimate position. But the vowel in these morphemes is lengthened. In an utterance, especially when spoken quickly, some words lose their penultimate stress, creating a tonal alternation HL → H if the penult originally carried a HL (Lanham 1958).

The focus here is on the fact that HL is restricted to the penult of a word. The two relevant durational factors are stress and final position; thus, the two types of syllables of interest are the penult and the ultima. The penult is subject to lengthening by virtue of stress, but not by virtue of being at a prosodic boundary. The opposite is true for the ultima. Given that all syllables are open, the vowel alone constitutes the sonorous portion of the rhyme. The direct approach leads to the hypothesis that in Xhosa, the penult has greater vowel duration than the ultima.

Phonetic data for Xhosa were extracted from a forty-five-minute analogue tape in the UCLA Language Archive. It consists mainly of trisyllabic or quadrisyllabic words read in isolation by one female speaker. Each word has two repetitions. All words extracted for digitisation and measurement were trisyllabic. All target syllables – initial, penult, and ultima – were open with a level-toned /a/ as the nucleus. Forty-four words were used for initial syllables, thirty-four for penultimate, and fifty-four for final.

The mean duration of /a/ for the three positions is shown in figure 6.1. The error bars indicate one standard deviation. One way ANOVA shows that the effect of position is highly significant ($F(2,131) = 242.98$, $p < 0.0001$). Fisher's PLSD post-hoc tests show that all pairs of comparison – penult vs ultima, penult vs initial, and ultima vs initial – have a significant effect at the level of $p < 0.0001$.

The hypothesis that it is the phonetically longest rhymes of Xhosa that support contours is therefore supported by the experimental results. And since it is exactly stress that defines the contour restriction in Xhosa, the data in Xhosa are consistent with the direct approach.

Further experimentation on Beijing Chinese, which likewise permits comparison of stressed and non-final and stressless final syllables, has yielded similar results; for details, see Zhang 2002a.

4.2.2 Standard Thai Consider now the second type of relevant languages, those with both vowel length and coda sonorancy contrasts. We will examine Standard Thai, Cantonese, and Navajo.

Syllables in Standard Thai can be open, closed by an obstruent /p/, /t/, /k/, or /ʔ/, or closed by a nasal /m/, /n/, or /ŋ/. Vowel length is contrastive in closed syllables. I will refer to syllables closed by an obstruent (CVO and CVVO) as checked syllables, and other syllables (CV, CVN, and CVVN) as non-checked syllables. There are five tones in Thai: H, M, L, HL, and LH. On non-checked syllables, all five tones can occur. On CVVO, generally, only HL and L occur, but in rare instances, H can also occur (e.g., *nóot* 'note'; *khwɔ́ɔt* 'quart', both English loanwords). On CVO, generally, only H and L occur, but HL occurs occasionally (e.g., *kɔ̂ʔ* 'then, consequently') (Gandour 1974; Hudak 1987). This tonal distribution is summarised in (14) (adapted from Gandour 1974; parentheses indicate rare occurrence.).

(14) Tonal distribution in Standard Thai (Gandour 1974):

	H	M	L	HL	LH
CV	+	+	+	+	+
CVN	+	+	+	+	+
CVVN	+	+	+	+	+
CVVO	(+)	−	+	+	−
CVO	+	−	+	(+)	−

It can be seen that the distribution of contour tones in Thai is primarily affected by the checked/non-checked distinction, as non-checked syllables can carry both LH and HL whether they have a long or a short vowel. Vowel length is also relevant, since HL can occur on CVVO, but usually not on CVO.[6] However, the crucial distinction for present purposes is that CVVO supports only a subset of the tones supported by CV and CVN, despite its greater phonological vowel length. If the approach taken here is correct, it must be the case that the sonorous rhyme duration of CV and CVN is greater than that of CVVC. In other words, in Thai, the factor *checked vs nonchecked* should outweigh the factor *V vs VV*.

Thai data were collected from two native speakers. For each of the five syllable types – CV, CVVN, CVN, CVVO, CVO–four monosyllabic words

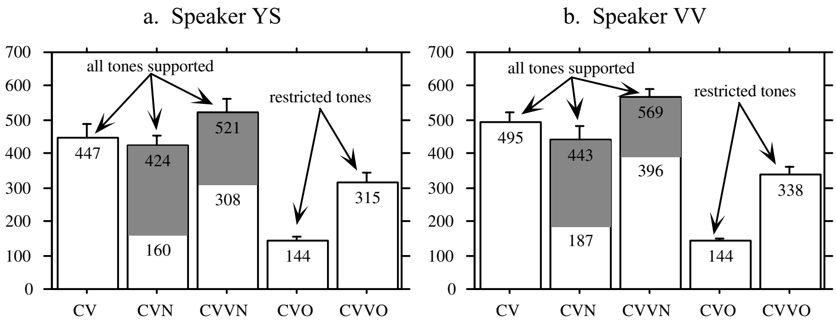

Figure 6.2 Standard Thai sonorous rhyme duration (ms)

were recorded, each with eight repetitions. All words have the nucleus /a/ and had either M or L tone.

The sonorous rhyme duration for the five syllable types are plotted in figure 6.2. The grey portion in the bars indicates sonorous duration contributed by the nasal coda.

For each speaker, a one-way ANOVA with sonorous rhyme duration as the dependent variable and syllable type as the independent variable was carried out. The effect is highly significant for both speakers: for YS, $F(4, 135) = 623.3$, $p < 0.0001$; for VV, $F(4, 135) = 1157.7$, $p < 0.0001$. Fisher's PLSD post-hoc tests show that for both speakers, both CV and CVN have a longer sonorous rhyme duration than CVVO at the significance level of $p < 0.0001$.

The hypothesis CV > CVVO, CVN > CVVO is therefore supported, and the data in Thai are thus consistent with the direct approach. The phonological pattern that more contour tones are allowed on non-checked syllables than checked syllables is in agreement with the phonetic fact that non-checked syllables have longer sonorous rhyme duration.

Gordon (1998) documents a similar pattern for Cantonese. The syllable inventory of Cantonese is the same as Thai: CV, CVN, CVVN, CVO, and CVVO (N = /m, n, w/, O = /p, t, k/). While there is both a vowel length contrast and a checked/non-checked distinction, the distribution of contour tones is only affected by the latter: in CV, CVN, and CVVN, seven different tones, including four contour tones, can occur: 53, 35, 21, 23, 55, 33, 22. But in CVVO and CVO, only the level tones 5, 3, and 2 can occur, even when the syllable contains a long vowel.

Gordon's duration data for different syllable types of Cantonese are shown in figure 6.3. Again, the grey portion in the bars indicates sonorous duration contributed by the nasal coda. As in Thai, Cantonese has a considerably longer sonorous rhyme duration in non-checked syllables than in checked ones, regardless of the phonological length of the nucleus.

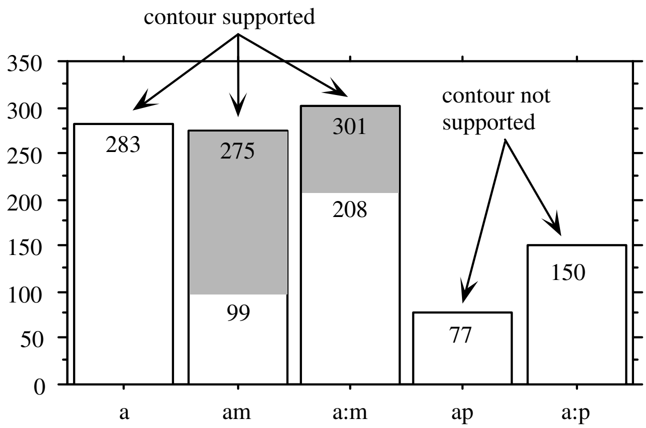

Figure 6.3 Cantonese sonorous rhyme duration (ms)

4.2.4 Navajo Navajo exhibits the opposite pattern to Standard Thai and Cantonese: it restricts contours to long vowels, regardless of the coda. Therefore the crucial question is whether the duration pattern of Navajo is also different from Standard Thai and Cantonese.

Navajo vowel length is contrastive in both open and closed syllables. There are six syllable types (CV, CVO, CVR, CVV, CVVO, and CVVR) and four tones (H, L, HL, LH), with the contour tones restricted to long vowels and diphthongs, that is, CVV, CVVO, and CVVR. Therefore, unlike Thai and Cantonese, the factor that determines the contour distribution in Navajo is vowel length, not coda sonorancy. The tonal distribution of Navajo is summarised in (15).

(15) Tonal distribution in Navajo

	H	L	HL	LH
CV	+	+	–	–
CVO	+	+	–	–
CVR	+	+	–	–
CVV	+	+	+	+
CVVO	+	+	+	+
CVVR	+	+	+	+

The crucial $C_{CONTOUR}$ comparisons are between CVR and CVV and between CVR and CVVO: CVR benefits from having a sonorant coda, while CVV and CVVO benefit from having a long vowel. Given that it is the long vowel that

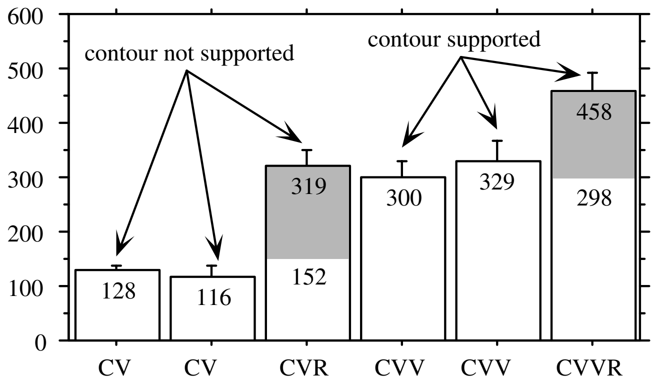

Figure 6.4 Navajo sonorous rhyme duration (ms)

licenses contour tones here, the direct approach leads to a phonetic hypothesis that is crucially different from that for Thai and Cantonese: $\{C_{\text{CONTOUR}}(\text{CVV}), C_{\text{CONTOUR}}(\text{CVVO})\} > C_{\text{CONTOUR}}(\text{CVR})$. Since a vowel is phonetically a better tone-bearing segment than a sonorant consonant when they are of comparable duration (see section 2.1.1 and the definition of C_{CONTOUR}), we arrive at the following hypothesis: the sonorous rhyme duration of syllables with a long nucleus should be longer than or comparable to that of syllables with a short nucleus. In particular, $\{\text{CVV, CVVO}\} \geq \text{CVR}$.

The prediction, unfortunately, is not fully testable with the available data. The problem is that we do not know in advance the value of the parameter *a* in the formula (1), which weights the contribution of R vs V in determining the value of C_{CONTOUR}. We will see, however, that the data do lend themselves to a plausible interpretation.

Navajo data were collected from one male native speaker. The target syllable is always the second syllable of a disyllabic word. For each syllable type, two words with /i/ and two words with /a/ were used, and all target syllables have a low tone. Eight repetitions were recorded.

The sonorous rhyme duration for each syllable type is plotted in figure 6.4. The grey portion again indicates sonorous duration contributed by the coda consonant.

A one-way ANOVA shows that the syllable type has a significant effect on the sonorous rhyme duration: $F(5, 162) = 596.7$, $p < 0.0001$. CVR has a comparable sonorous duration in the rhyme to CVV and CVVO: it is not significantly different from either CVVO (Fisher's PLSD post-hoc tests, $p > 0.01$) or CVV ($p > 0.01$).

The data here are less conclusive than in the Thai and Cantonese cases. In particular, CVR, which cannot bear contours, has a sonorous duration comparable to the CVVX syllables, which can. However, the data are compatible with the direct hypothesis provided *a* is sufficiently high to give CVV and CVVO substantially higher $C_{CONTOUR}$ values than CVR. There is in fact a crucial comparison that supports this conjecture: in Thai and Cantonese, the sonorous rhyme duration in CVR is considerably longer than that in CVVO; but in Navajo, the two durations are comparable. This difference suggests that a considerable amount of sonorant consonant duration may be needed to balance a given amount of vocalic duration. This suggests that *a* is indeed rather high, and thus that Thai and Cantonese CVR would qualify for contour bearing while Navajo CVR would not. The experimental data thus appear to be compatible with the direct approach.

4.3 Conclusion to the instrumental studies

The fact that all the phonetic case studied here reveal data patterns consistent with the more restrictive direct approach constitutes significant support for this approach, as this implies that there is no empirical reason for us to adopt the less restrictive structure-only approach. The direct approach is more restrictive because it does not predict situations in which contours are restricted to phonemic long vowels in Thai and Cantonese, or to sonorant-closed syllables in Navajo.

Xhosa and Beijing Chinese illustrate a similar point from the interaction of two different durational factors: stress and final position in a prosodic domain. It turns out that in both languages, stress plays the decisive role in determining the sonorous duration of the rhyme and correspondingly the distribution of contour tones.

5 The basics of a formal analysis

In the previous two sections, I have argued that the distribution of contour tones is best captured by a direct approach, which encodes the phonetic index $C_{CONTOUR}$ of a rhyme. In this section, I sketch out a formalisation of this approach.

5.1 Overview of the theoretical apparatus

The patterns of contour tone distribution that an analysis must capture are the following. First, the distribution of contour tones depends on a phonetic index of the rhyme – $C_{CONTOUR}$; the lower the $C_{CONTOUR}$ value, the more limited distribution the contour tones will have on the rhyme. Second, when a contour tone encounters a syllable with insufficient tone-bearing ability, there are three possible resolutions: increasing the $C_{CONTOUR}$ value of the syllable, flattening out the pitch excursion, or both.[7] For both lengthening and flattening, the change can be either neutralising (merging with some other phonological category) or allophonic.

I posit three families of constraints. Markedness constraints of the family *CONTOUR(T)-C$_{\text{CONTOUR}}$(R) are violated when contour tones occur on rhymes with certain C$_{\text{CONTOUR}}$ values. Markedness constraints of the family *DUR penalise extra duration on the syllable. Faithfulness constraints of the family PRES(Tone) enforce similarity between tonal input and output. Each of these constraint families has a set of intrinsic rankings, described below.

The interaction of these three constraint families gives rise to the attested patterns of contour tone restriction. In the following sections of this chapter, I formally define these constraint families and discuss their interactions in detail.

5.2 Constraints and their intrinsic rankings

*5.2.1 *CONTOUR(x)-C$_{CONTOUR}$(y)* The Markedness constraints *CONTOUR(x)-C$_{\text{CONTOUR}}$(y) ban contours when their C$_{\text{CONTOUR}}$ values are too low. Formally, they are defined as follows:

(16) *CONTOUR(x_i)-C$_{\text{CONTOUR}}$(y_j):
no contour tone x_i is allowed on a syllable with the C$_{\text{CONTOUR}}$ value of syllable y_j or smaller.

The *CONTOUR(x_i)-C$_{\text{CONTOUR}}$(y_j) constraints observe two sets of intrinsic rankings, given in (17), which are projected from the phonetics.

(17) a. If C$_{\text{CONTOUR}}$ (y_a) > C$_{\text{CONTOUR}}$(y_b), then *CONTOUR(x_i)-C$_{\text{CONTOUR}}$(y_b) $\gg$ *CONTOUR(x_i)-C$_{\text{CONTOUR}}$(y_a).
b. If contour tone x_m is higher on the *Tonal Complexity Scale* (see (2) and (3)) than contour tone x_n, then *CONTOUR(x_m)-C$_{\text{CONTOUR}}$(y_j) $\gg$ *CONTOUR(x_n)-C$_{\text{CONTOUR}}$(y_j).

These rankings reflect the speaker's knowledge that a structure that is phonetically more demanding should be banned before a structure that is less so; and that a syllable should be able to host a tone with a lower complexity before it can host a tone with a higher complexity.

5.2.2 *DURATION Assuming that each segment in a certain prosodic environment has a minimum duration (Klatt 1973; Allen et al. 1987), I define the *DURATION (abbr. *DUR) constraint family as follows:

(18) *DUR(τ_i): for all segments in the rhyme, their cumulative duration in excess of the minimum duration in the prosodic environment in question cannot be τ_i or more.

These constraints also have an intrinsic ranking, as in (19).

(19) If $\tau_i > \tau_j$, then $*\textsc{Dur}(\tau_i) \gg *\textsc{Dur}(\tau_j)$

For more detailed discussion on this constraint family and how it interacts with the minimal duration requirement for each segment, see Zhang 2002a.

5.2.3 PRESERVE*(Tone)* PRESERVE(Tone) constraints penalise candidates according to their deviation – defined in perceptual terms – from the input. Assume that we can define a function $S(T_I, t)$, which returns the value of perceptual similarity between any pair of tones T_I and *t*. $S(T_I, t)$ can be defined in such a way that if t_1 is perceptually more similar to T_I than t_2, then $S(T_I, t_1) < S(T_I, t_2)$.[8] We can then define the constraint family PRESERVE(Tone) (abbr. PRES(T)) as in (20).

(20) $\forall i$, $1 \leq i \leq n$, $\exists$ constraint PRES(T, *i*), defined as:
an input tone T_I must have an output correspondent T_O which satisfies the condition $S(T_I, T_O) < i$.

This constraint family is internally ranked by the principle that the candidate that deviates the most from the input will be penalised by the highest ranked constraint (cf. the 'P-map' approach of Steriade 2001b). More formally, we have:

(21) PRES(T, *n*) $\gg$ PRES(T, *n-1*) $\gg$ ... $\gg$ PRES(T, *2*) $\gg$ PRES(T, *1*).

5.3 Assumptions made in the model

My model relies on the following general assumptions.

Canonicality. I assume that the canonical speaking rate and style are the basis on which the grammar is constructed. Thus, $C_{CONTOUR}$ is calculated from the canonical duration of the sonorous portion of the rhyme. This assumption is necessary because syllable durations and pitch range vary under different speaking rates and styles, and the 'tolerance level' for tone slope varies too. Since the standard mode of speech is what language users are most frequently exposed to and most frequently utilise, it is reasonable to assume that it is this mode that defines the quantitative values that appear in the constraints.

Normalisation. Upon identifying the canonical speaking rate and style, I further assume that speakers are able to normalise duration and pitch across speaking rates and styles (Kirchner 1998; Steriade 1999). Only under this assumption can we discuss the grammatical behaviour of different rates and styles and account for the stability of the phonological system across these rates and styles. For example, if the speaker was not able to normalise, but took the phonetic values in the inputs, outputs, and constraints at face value, then a HL contour on CVO would violate a higher ranked *Contour (x_i)-C$_{\text{CONTOUR}}$(y_j) constraint in the fast speech grammar in the slow speech grammar, so that the phonological system for the two rates would be different.

This assumption does not preclude the possibility of different phonological behaviour in different speaking rates and styles. It is still possible for particular speech styles to be associated with constraints that are specific to them, for example constraints that refer to the realisation of affective signalling or constraints that refer to absolute duration instead of normalised duration to express physiological limitations, and soon. For discussion, see Kirchner's chapter, as well as Harris 1969 and Ao 1993. But given the overall stability of the phonological system despite the fluctuating speaking rates and styles, I believe that normalisation is a necessary assumption here.

The assumption of normalisation is justified by experimental evidence that speakers can attend to and compensate for fluctuations in speaking rate and style. For example, many perceptual studies show that the speaking rate of the stimuli influences listeners' perceptual boundary between two segments if this boundary is dependent on duration (Port 1979; Miller and Grosjean 1981; Pols 1986). For studies on tone normalisation, see Leather 1983, Moore 1995, and Moore and Jongman 1997.

Contrast constraints. We know that given a phonetic dimension, only a small number of contrasts will emerge in any given language. But if phonetic details such as a minute change of duration or pitch excursion can be included in phonological representations, how can contrasts emerge? Flemming (1995; this volume) and Kirchner (1997) have addressed this problem with proposals to incorporate constraints on the perceptual distance of contrasts (MinDist constraints by Flemming, Polar constraints by Kirchner). Here I simply acknowledge that the system in which I operate also needs constraints that achieve such effects, without committing myself to either approach.

5.4 *Sample analyses*

Consider now the predictions made by this formal apparatus. Suppose that in language *L*, there exists an underlying contour tone *T* whose pitch excursion under the standard speaking rate and style is of Δf. Suppose further that that input form *T* is lodged on a rhyme *R* whose C$_{\text{CONTOUR}}$ value is *c* and whose minimum sonorous rhyme duration is *d*. Let us see what predictions (in terms of phonological alternation or allophonic distribution) the apparatus makes.

5.4.1 *No change necessary*

The first possibility is that all members of the Pres(T) and *Dur families outrank *Contour(*T*)-C$_{\text{CONTOUR}}$(*R*). Under this ranking, the contour faithfully surfaces on the given rhyme without lengthening. This is because any flattening of the contour or lengthening of the sonorous rhyme duration in order to satisfy *CONTOUR(T)-$\mathrm{C_{CONTOUR}}$(R) will incur violations of higher ranking PRES(T) or *DUR constraints:

(22) $T_{\Delta f}, R_d \rightarrow \Delta f, d$

	$T_{\Delta f}, R_d$	PRES(T)	*DUR	*CONTOUR(T)-$\mathrm{C_{CONTOUR}}$(R)
☞	faithful: $\Delta f, d$			*
	contour reduction: $\Delta f - f_0, d$	*!		
	rhyme lengthening: $\Delta f, d + d_0$		*!	

Languages of this sort are attested. For example, !Xũ (Snyman 1970), ǂKhomani (Doke 1937), and a number of Chinantec languages allow all tones on all syllable types, be they open or checked, long-vowelled or short-vowelled. Although most of the sources I consulted on these languages do not give phonetic details of tone and duration, thus it is possible that the contour tones on shorter syllable types are somewhat flattened, or these syllables are somewhat lengthened, there is some phonetic documentation on Lalana Chinantec (Mugele 1982) which shows that the same contour tone exhibits relative stability of onset and endpoint on different syllable types, and the same syllable type exhibits relatively stable duration when carrying different tones.

The analysis further predicts that on a rhyme R' with a $\mathrm{C_{CONTOUR}}$ value greater than c, Δf will also be faithfully realised, since the constraint *CONTOUR(T)-$\mathrm{C_{CONTOUR}}$(R') will be even lower ranked than *CONTOUR(T)-$\mathrm{C_{CONTOUR}}$(R). This prediction is consistent with the implicational hierarchies established in the survey.

5.4.2 Partial contour reduction Now consider cases in which a particular contour type must appear in partially reduced form (less pitch range) on certain short rhymes. In such cases, *CONTOUR(T)-$\mathrm{C_{CONTOUR}}$(R) outranks some but not all PRES(T) constraints, but the *DUR constraint family is still undominated. Under this ranking, the contour is flattened to satisfy the *CONTOUR(T)-$\mathrm{C_{CONTOUR}}$(R) constraint, but no extra duration can be added to the sonorous portion of the rhyme, as illustrated in (23).

(23) $T_{\Delta f}, R_d \rightarrow \Delta f\text{-}f_0, d$

$T_{\Delta f}, R_d$	*DUR	*CONTOUR(T)-CCONTOUR(R)	PRES(T)
faithful: $\Delta f, d$		*!	
☞ contour reduction: $\Delta f\text{-}f_0, d$			*
rhyme lengthening: $\Delta f, d + d_0$	*!		

Such flattening occurs in Pingyao Chinese (Hou 1980), where the contour tones 53 and 13, which are fully realised on CV (with a phonetically long vowel) and CVR, have partial realisations 54 and 23 on CVO.

This ranking type also predicts that on a rhyme *R'* with a C_{CONTOUR} value greater than *c*, Δf will be more faithfully realised, i.e. realised with less or no reduction of the pitch excursion. This is because the relevant *CONTOUR(x)-C_{CONTOUR}(y) constraint *CONTOUR(T)-C_{CONTOUR}(R') will be lower ranked than *CONTOUR(T)-C_{CONTOUR}(R), and this will allow more PRES(T) constraints to exert influence on the output form. This, again, is consistent with the implicational hierarchy established in the survey.

5.4.3 Complete contour reduction The third possibility is to have all *CONTOUR(x)-C_{CONTOUR}(R) and *DUR constraints outrank all the relevant PRES(T) constraints. That is, *CONTOUR(δ)-C_{CONTOUR}(R), where δ represents the smallest perceptible pitch excursion, outranks the PRES(T, *i*) constraint that penalises changing the tone *T* to a level tone. This ranking predicts that the tone *T* will be flattened all the way to a level tone, as illustrated in (24).

(24) $T_{\Delta f}, R_d \rightarrow \Delta f\text{-}f_0, d$

$T_{\Delta f}, R_d$	*DUR	*CONTOUR(δ)-C_{CONTOUR}(R)	PRES(T, *i*)
faithful: $\Delta f, d$		*!	
partial contour reduction: $\Delta f\text{-}f_0, d$		*!	
☞ complete contour reduction: *0, d*			*
rhyme lengthening: $\Delta f, d + d_0$	*!		

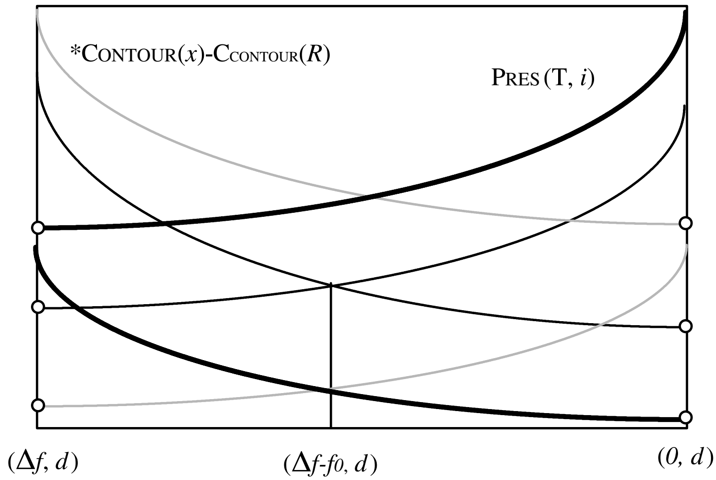

Figure 6.5 Interaction of *CONTOUR(x)-C$_{\text{CONTOUR}}$(R) and PRES(T, i) yielding different degrees of contour reduction

This is the most commonly attested pattern of contour tone restrictions in languages, that is certain contour tones cannot occur on syllables with low C$_{\text{CONTOUR}}$ values. We have seen many examples of this sort, for example Xhosa's restriction of contour tones to stressed syllables, Navajo's restriction of contour tones to long vowels, Cantonese's restriction of contour tones to non-checked syllables, and so on.

The ranking in figure 6.5 further predicts that on a rhyme R' with a C$_{\text{CONTOUR}}$ value greater than c, Δf will be more faithfully realised, that is, realised with less or no reduction of the pitch excursion: *CONTOUR(δ)-C$_{\text{CONTOUR}}$(R') will be lower ranked than *CONTOUR(δ)-C$_{\text{CONTOUR}}$(R), and this will allow more PRES(T) constraints to exert influence on the output form. This is yet again consistent with the implicational hierarchy established in the survey.

5.4.4 Summary The scenarios described in sections 5.4.1–5.4.3 are summarised in the schematic graph in figure 6.5. In the graph, the x-axis represents tonal candidates, arranged from left to right according to the degree of reduction of their pitch range. Thus, the leftmost candidate on the x-axis is the most faithful to the input, with no flattening at all (Δf). The rightmost candidate is the one with complete flattening (to zero). Since all *DUR constraints are always ranked on top in the scenarios described so far, I only consider candidates that respect these constraints, that is, candidates with no lengthening. Thus, in all candidates, d appears as the sonorous rhyme duration.

The *y*-axis represents constraint ranking: the higher the *y* value, the higher the ranking. The curves in the graph represent the highest ranked constraints in the *CONTOUR(x)-C$_{\text{CONTOUR}}$(R) and PRES(T, i) families that the candidates on the *x*-axis violate.

The thick black lines in the graph indicate the ranking of the two constraint families that ensures the faithful realisation (as described in section 5.4.1) of the pitch excursion Δf, which appears as the leftmost candidate on the *x*-axis. The highest ranked constraint it violates is *CONTOUR(T)-C$_{\text{CONTOUR}}$(R). Any other candidate to the right, which deviates from the input, will induce violation of a higher ranked PRES(T, i) constraint.

The thin black lines indicate the ranking that produces partial reduction of the contour to Δf-f_0 (cf. section 5.4.2). This is the candidate on the *x*-axis that corresponds to the point of intersection of the two curves. Any candidate further to the left violates a higher ranked *CONTOUR(x)-C$_{\text{CONTOUR}}$(R) constraint, and any candidate further to the right violates a higher ranked PRES(T, i) constraint.

The grey lines indicate the ranking that forces complete reduction of the contour tone to a level tone, as described in section 5.4.3. Level tone is represented here as the rightmost candidate on the *x*-axis. The highest ranked constraint it violates is the highest ranked PRES(T, i) constraint. Any other candidate further to the left which would deviate less from the input will induce the violation of a higher ranked *CONTOUR(x)-C$_{\text{CONTOUR}}$(R) constraint.

From these three examples, then, it should be clear that any degree of pitch-range reduction is derivable in this system. Moreover, the same analytic strategy can be straightforwardly extended to cover cases in which duration is altered, either alone or in addition to a pitch range adjustment. The three basic cases are summarised below; for full exemplification of these cases, see Zhang 2002a.

Nonneutralising lengthening. This occurs when *CONTOUR(T)-C$_{\text{CONTOUR}}$(R), along with some members of the PRES(T) family, outrank some *DUR constraints. It is found in Mitla Zapotec (Briggs 1961) and Wuyi Chinese (Fu 1984).

Neutralising lengthening. Where the *CONTOUR(T)-C$_{\text{CONTOUR}}$(V_d) constraint associated with a long vowel outranks *DUR(d), and some PRES(T) constraints are ranked on top, the ranking predicts neutralising lengthening when the tone T occurs on a short vowel. This is found in Gã (Paster 1999).

Both contour reduction + rhyme lengthening. This outcome, found in Hausa (Newman 1990; Gordon 1998), results when *CONTOUR(T)-C$_{\text{CONTOUR}}$(R) outranks some *DUR constraints and some PRES(T) constraints.

5.5 Summary

In this section, I have proposed an explicit formalisation for the direct approach to contour tone distribution and discussed the patterns that are predicted by the model. The model directly encodes phonetic details such as $C_{CONTOUR}$ and the durational properties of the rhyme. I have argued that such a move is necessary (sections 3–4), and makes restrictive predictions.

6 Alternative approaches

In this section, I discuss two alternative approaches to contour tone distribution.

6.1 Moras

Traditionally, the mora is used in phonology to capture the heavy vs light distinction in weight-related phenomena such as stress assignment, compensatory lengthening, metrics, and word minimality (Newman 1972; Hyman 1985; McCarthy and Prince 1986; Hayes 1989; among others). It has also been proposed by Duanmu (1990, 1993, 1994a, 1994b) to be the tone-bearing unit. Observing that Chinese languages with fewer distributional restrictions on contour tones (e.g. Mandarin) have generally longer syllable rhymes than those with more restrictions (e.g. Shanghai), Duanmu argues that a contour tone must be represented as a concatenation of level tones, each of which needs a mora to be licensed. The difference in contour tone restrictions between Mandarin and Shanghai stems from the fact that syllables are bimoraic in Mandarin but monomoraic in Shanghai. I will give three arguments here that the bimoraic status is neither sufficient nor necessary for contour tone licensing.

First, given that the main purpose of the mora is to capture the heavy vs light distinction, the maximum mora count is usually assumed to be two (or at most three, for cases like Estonian where a three-way weight distinction has to be made; Hayes 1989). But the contour tone licensing behaviour sometimes requires more than three levels of distinction. For example, in Mende (Leben 1973; Dwyer 1978; Zhang 2000), long vowels can carry LHL, LH, or HL in monosyllabic words, but only LH or HL in other positions. Short vowels can carry LH or HL in monosyllabic words, HL in the final position of disyllabic or polysyllabic words, but no contour in other positions. This is a four-way distinction, and goes beyond the maximum mora count that any version of moraic theory is willing to accommodate.

Second, sometimes contour tones with the same number of pitch targets have different distributional restrictions. Thus, in many languages, rising tone has a more limited distribution than falling (Mende, Gã, Kɔnni, Kukuya, Tiv). In many Chinese dialects (Pingyao, Shanghai, Fuzhou), contour tones with more pronounced pitch excursion are restricted to non-checked syllables, while contour tones with less pronounced pitch excursions can occur on checked syllables. These asymmetries cannot be captured in a moraic approach, as the same number of pitch targets ought to require the same number of moras to be licensed.

Third, languages do not always favour syllables with clearly higher mora count (such as those with long vowels or sonorant codas) for contour tone bearing. We have seen that many languages allow contour tones more freely in phrase-final syllables and syllables in shorter words. Although the effect of final lengthening may be neutralising in some languages (e.g. Luganda), it is not in many others; and the effect of syllable lengthening in shorter words is not neutralising in any language of which I am aware. Since these effects are purely quantitative, it is implausible to attribute them to the structural property of mora count.

To summarise, the moraic approach attempts to capture the correlation of tonal contour complexity and duration representationally, but the patterns of correlation are too complicated to be accounted for by the limited mechanism of mora counting.

6.2 *Gordon's approach*

Gordon (1998, 1999, this volume) also recognises that a syllable's contour tone carrying ability is crucially dependent on the duration and sonority of the rhyme. He maintains, however, that the effects of phonetics in phonology are indirect, mediated by phonological structures projected from phonetics. In his system, the constraint that bans contour tones on CV and CVO, for example, takes the form of (25). The constraint does not directly refer to the phonetic measurement of contour tone bearing ability $C_{CONTOUR}$, but to the number of timing slots and the feature [+sonorant].

(25)	*T T \\ / R	unless	[XX]$_R$ \\ / [+sonorant]	:	A contour tone is licensed by a rhyme containing two timing slots that are [+sonorant].

Consequently, unlike the direct approach (in which partial contour reduction, partial rhyme lengthening, and the combination of both are all treated in a uniform fashion as governed by same constraint hierarchy), Gordon must assume that these are phonetic effects, as his analysis of Hausa indicates (26) (Gordon 1998: 247). With the tonal faithfulness constraint flanked between the constraint requiring two timing slots for contour tones and the constraint requiring two [+sonorant] timing slots for contour tones, Gordon's analysis predicts that the falling tone can surface on CVO, but does not predict that the falling tone is partially flattened and the fall-carrying CVO has a lengthened rhyme. Gordon actually does not explicitly specify where the partial flattening and lengthening take place, whether in the phonology proper or in the phonetics.

(26)

Faithfulness(Tone)
↓

*T T			*T T		[XX]$_R$		*T T		[XX]$_R$
\\ /	unless [XX]$_R$	»	\\ /	unless	\\ /	»	\\ /	unless	\\ /
R			R		[+sonorant]		R		[+syllabic]

With constraint formulation as in (25), Gordon's approach is in fact subject to the same criticisms to the moraic approach. First, representing the contour tone as [T T] concatenation misses any generalisations regarding tonal complexity, particularly those involving tones with the same number of pitch targets. Second, the concept of timing slots in the rhyme is formally identical to moras; then we have the same problems (cf. section 6.1) with the number of distinctions that must be made and whether it is appropriate to add timing slots for phrase-final syllables and syllables in shorter words.

7 Conclusion

I have argued for two points. First, the phonological behaviour of contour tone licensing is determined by the duration and sonority of the syllable rhyme, and the root of this correlation lies in the fact that the production and perception of tonal contours require sufficient sonorous rhyme duration. Second, a formal analysis of contour tone licensing must encode the language-specific phonetic facts of duration and sonority in the constraints; a structure-only approach that only refers to the privileged phonological positions makes erroneous predictions.

In a broader context, the facts of contour tone licensing illustrate the two ways in which phonetics influences the phonological patterning of positional licensing. First, positional licensing is contrast-specific; that is, different phonological contrasts preferentially occur in different positions. This is due to the fact that different contrasts require the support of different phonetic properties. Second, for a particular contrast, its positional licensing behaviour is tuned to language-specific phonetics; that is the richness of the relevant phonetic property in a given phonological context can differ from language to language, and the positional licensing behaviour of the contrast in question is sensitive to these differences. A valid analysis of positional licensing needs to reflect the relevance of contrast-specific and language-specific phonetics, and the direct approach sketched out above is an example of how such analyses should proceed.

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Notes

1. Here and elsewhere, L = low pitch, M = mid, H = high, LH = a contour rising from L to H, and similarly for other contours.
2. Tones here are denoted with the Chao letters (Chao 1948, 1968); '5' and '1' indicate the highest and lowest pitches in a speaker's regular pitch range.
3. This kind of additive lengthening effect has been documented for English in Klatt 1973 and for Mandarin Chinese in Zhang 2002a. Both works show that a stressed syllable in prosodic-final position is longer than a stressless final syllable or a stressed non-final syllable.
4. In brief, Lealao Chinantec, Margi, and Zengcheng Chinese only have rising tones. This is unexpected given what we know about the differences between rising and falling tones. But they also have contour restrictions that are related to the duration and sonority of the rhyme in the expected direction: Lealao Chinantec limits contours to stressed syllables (Rupp 1990); Margi limits contours to monosyllabic words (Hoffman 1963); and Zengcheng Chinese limits contours to CVV and CVR (He 1986). In Lao (Morev et al. 1979), a rising tone and a high-falling tone can occur on CVO, but not on CVVO; and in Saek (Hudak 1993), complex tone 454 occurs on CVO, but not on CVVO. Without detailed phonetic description and historical knowledge of these languages, I take them as exceptions to the implicational laws and tendencies established in this section.

5. For discussion on other factors that could potentially increase the C_{CONTOUR} value of the rhyme, but do not behave as privileged contour tone licensers in any language in the survey, such as low vowels (as opposed to high vowels), voiced obstruent coda (as opposed to voiceless ones), see Zhang 2002a.
6. The fact that CVVO primarily carries HL and L and CVO primarily carries H and L can be understood from the following historical perspective. In Early Thai (pre-fifteenth century), there was no tonal contrast on checked syllables. Between the fifteenth and seventeenth centuries, a tonal split occurred: on CVVO, the split resulted in HL after a voiced onset and a L after a voiceless onset; on CVO, it resulted in a H after a voiced onset and a L after a voiceless onset. Possibly, the reason why a HL did not result on CVO was that there was not enough duration for the contour to surface.
7. Theoretically, there are various ways to increase the C_{CONTOUR} value of the syllable: increasing the sonorous rhyme duration, changing its sonorant coda into a vowel, making the syllable in question stressed, and so on. The factorial typology with the *CONTOUR(x)-C_{CONTOUR}(y) constraints and IDENT[length], IDENT[vocalic], IDENT[stress] should predict all these patterns. But in reality, I have not seen cases in which the sonorant coda is changed to a vowel or the stress is shifted in order to accommodate a contour tone. This is part of the 'too many solutions' problem, a general issue in Optimality Theory. For proposed solutions, see Steriade 2001b and Wilson 2000.
8. For more discussion on the similarity function and the consequence of using similarity function of this sort in the evaluation of faithfulness constraints, see Zhang 2002a.