A TYPOLOGY OF CONTOUR TONE RESTRICTIONS

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ABSTRACT

This paper presents results of a survey of contour tones in 105 languages with lexical tone. Results indicate an implicational hierarchy of tone bearing ability, whereby long vowels are most likely to carry contour tones, followed by syllables containing a short vowel plus a sonorant coda, followed by syllables containing a short vowel plus an obstruent coda, followed by open syllables containing a short vowel. It is claimed that this tonal hierarchy is phonetically motivated: syllable types which are phonetically better suited to carrying tonal information are more likely to support contour tones. Languages whose tone distributions superficially appear to fall outside the range of variation predicted on phonetic grounds are demonstrated, upon closer examination, to be unexceptional in their behavior.

1 Introduction

In many languages, syllables differ in terms of the number of tonal contrasts which they may support (Clark 1983, Hyman 1988). For example, while most languages allow level tones on all syllable types, many restrict contour tones to certain syllable types. Thus, in Kiowa (Kiowa-Tanoan; Watkins 1984), contour tones may only occur on syllables containing long vowels (CVV(C)) and syllables closed by a sonorant coda (CVR) (1a). Contour tones may not occur on open syllables containing a short vowel (CV) or on short-voweled syllables closed by an obstruent (CVO) (1b).

(1) *Kiowa contour tones (from Watkins 1984)*

a. k^{h}ûːl ‘pull off’, hâː ‘arise’ refl., **k^{h}ûl**tɔː ‘pull off’ future

b. k^{h}út ‘pull off’ perfective (=k^{h}ûː-t), *k^{h}ût, *k^{h}û

Thus, in Kiowa, CVV(C) and CVR carry a fuller range of tonal contrasts than CVO and CV. We may thus say that CVV(C) and CVR are heavier than CVO and CV with respect to tone-bearing ability in Kiowa (Hyman 1985).

In other languages, although certain types of contour tones may occur on all syllable types, there are others which are restricted to certain syllable types, such as CVV(C) and CVR. For example, in Shan (Daic; Morev 1983), the set of contour tones found on CV and CVO is a subset of those allowed in CVR and CVV(C). Tonal distributions of this sort may also be treated as weight-related, in the sense that the number of permissible tonal contrasts is a function of the prosodic shape of the syllable. Crucially, these weight-sensitive tone restrictions concern the presence vs. absence or number of contour tones permissible on different syllable types. They thus differ from segmentally conditioned ones which restrict certain tone levels in certain segmental environments, such as prohibitions against low tone in the vicinity of voiceless stops or high tone on vowels adjacent to glottal stop (cf. Hombert 1978 for an overview on segmentally conditioned tonal restrictions).

Parallel to Kiowa and Shan, there are also languages in which pitch accents are restricted as a function of syllable type. For example, in Lithuanian (Indo-European; Senn 1966, Kenstowicz 1972), a word carries one pitch accent which may fall on either a vowel or on a sonorant coda, but not on an obstruent coda. The location of the pitch accent is contrastive for both CVR, where it may fall on either the vowel or the sonorant coda, and for CVV(C), where it may fall on either half of the long vowel. (Note that CVV(C) stands for both long vowels and diphthongs unless indicated otherwise). Thus, CV and CVO contrast only in terms of whether they carry a pitch accent or not, whereas CVV(C) and CVR potentially contrast not only in terms of whether they have a pitch accent or not, but also in the location of the pitch accent, if present. Because pitch accent and tone are cued by the same physical property, fundamental frequency, we may say that CVV(C) and CVR have a greater capacity for supporting tonal contrasts and are hence heavier than CVO and CV in Lithuanian, just as in Kiowa and Shan.

This paper will explore the phonology of weight-sensitive tone restrictions, such as those found in Kiowa, Shan, and Lithuanian (i.e. non-segmentally triggered restrictions), from a typological and a phonetic standpoint. It will be shown that the cross-linguistic distribution of weight-sensitive tone is not arbitrary but follows an implicational hierarchy which is phonetically grounded. The present work thus belongs to the research program investigating the distribution of tonal contrasts on a cross-linguistic basis (cf. Maddieson 1970, Clark 1983, Hyman 1988, etc.).

The structure of this paper is as follows. Section 2 presents results of a genetically balanced survey of contour tone restrictions in 105 languages. This survey indicates the existence of an implicational hierarchy of syllables ranked in order of ability to support contour tones, whereby CVV(C) is heaviest, followed by CVR, followed by CVO and CV. Section 3 presents evidence that this implicational hierarchy of tonal weight has a phonetic basis in terms of the relative ability of different syllables to carry tonal information. Section 4 explores two types of weight distinctions which superficially contradict the phonetically-driven model of tonal weight proposed in section 3; these exceptional cases are shown, upon closer phonetic examination, to not to be so exceptional after all. Finally, section 5 summarizes the principal results.

2. A typology of tone

2.1. The languages

As a starting point in the investigation, a survey of 105 with weight-sensitive tone/ pitch accent was conducted. The goal of the survey was twofold. First, the survey sought to explore potential cross-linguistic implicational hierarchies in the ability of different syllable types to support contour tones. A second goal of the survey was to discover potential asymmetries in the relative frequency with which different types of tonal restrictions are attested. It is this second goal, in particular, which necessitates a reasonably balanced survey of languages across different genetic groupings. The survey consisted of the tonal/pitch accentual subset of languages forming part of a genetically balanced larger survey of several prosodic properties in 388 languages (Gordon 1999). In order to create a reasonably representative and genetically balanced survey, this larger survey included a maximum of two languages per language family, the lowest level of genetic grouping in the 12th Edition of the Ethnologue, a relatively conservative classification of languages. (Grimes and Grimes 1993). A maximum of two languages per family was targeted in order to have a survey which was relatively large, but which did not unfairly skew the data in favor of better documented language phyla. Within each phylum, an attempt was made, as far as resources allowed, to choose diverse languages.

In section 2.2, some further methodological preliminaries relevant for the analysis of individual languages are addressed, before the results of the tonal typology are presented in section 2.3.

2.2. Methodological preliminaries

There are certain complicating issues that arise in the discussion of tonal restrictions of the type discussed in this paper. First, many languages have independent restrictions on syllable structure that preclude evaluation of the weight status of certain syllable types. For example, there are several languages in the survey, in which only long vowels may bear contour tones, but in which coda consonants are not permitted. Though such languages fall under the rubric of languages with weight-sensitive tone, they of course do not shed light on the tone-bearing weight of coda consonants. Furthermore and along similar lines, there are many languages in the survey that tolerate only sonorant codas and not obstruent codas. While these languages provide insight into the overall ability of coda consonants to carry weight, they offer no evidence of course for evaluating the relative ability of syllables closed by a sonorant to support tonal contrasts as compared to syllables closed by an obstruent. Languages in the survey lacking either coda consonants or coda sonorants will be indicated as such in the text and in Appendix 1.

There is another more subtle confounding issue that is relevant to the study of weight. Many published descriptions of languages assume a one-to-one mapping between tones and syllables, such that every syllable carries exactly one tone. Given this analysis, it is necessary to assume that long vowels or vowel sequences which phonetically carry a contour tone are split by a syllable boundary.

In many cases, this is in fact the correct diachronic analysis: long vowels or sequences of vowels have arisen from disyllabic sequences through loss of an intervocalic consonant. However, adopting this analysis as a synchronic one rests on the crucial assumption that a phonetically long vowel on the surface is interrupted by a syllable boundary. In many cases, the most compelling synchronic evidence for this interpretation comes from tonal assignment itself; this is, however, a circular argument unless there is independent evidence for the proposed syllable boundary. In the absence of such evidence, it is assumed for purposes of the survey that long vowels and diphthongs constitute a single syllable synchronically and thus that any contour tones with which they are associated belong to a single syllable as well.

2.3. Results

A total of 105 languages in the survey were found to use tone or pitch accents contrastively. These 105 languages, which serve as the focus of this paper, are listed in Appendix 1 along with sources consulted and the genetic affiliation of each language at the level of the phylum, the largest grouping. Languages are grouped according to the syllable types which are heavy for tone, i.e. syllables which possess a fuller range of tonal contrasts. Languages which do not allow tautosyllabic contour tones on any syllable types are designated with the word "no contours", while languages which allow contour tones on a full range of syllable types (CV, CVO, CVR, CVV) are indicated with the designation "none", indicating that they do not possess any of the relevant tonal restrictions. Languages are alphabetized within each of the groups organized according to their tonal distributions.

Of the tonal/pitch accent set of languages, 12 of 105 were found not to have contour tones on single syllables, regardless of syllable type. Note that this classification only holds for single syllables and does not preclude the existence of contour tones across syllable boundaries, as might arise for instance, in hiatus contexts involving adjacent unlike vowels which fail to constitute a diphthong.

A total of 25 languages (23.8%) allow contour tones, either rising or falling, only on CVV(C). Of these 25, 4 lack closed syllables, so they are not probative in diagnosing the weight of CVO and CVR relative to CVV.

A further 29 languages of 105 (27.6%) allow contour tones on CVV(C) and CVR, but not on CVO and CV.[1] Of these 29 languages with the CVV(C), CVR heavy criterion, the weight distinction is based on the number of contour tones permitted on various syllable types rather than on an absolute prohibition against contour tones on certain syllables, as in Shan (see section 1). Furthermore, of the 29 languages, 5 lack CVO.

Only 3 languages (Hausa, Luganda[2], and Musey) were described as allowing contour tones on CVV(C), CVR, and CVO, but not on CV.[3]

Finally, a total of 36 languages were found to allow contour tones, either falling or rising or both, on CV, CVO, CVR, and CVV(C) (provided they occur of course).[4] For 5 of these languages, however, tonal restrictions could not be established with confidence based on available sources. This uncertainty is indicated by a question mark in the tonal restrictions column of Appendix 1. Of the remaining 31 languages for which tonal properties could be determined with greater

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[1] In 3 of the 29 languages (Cantonese, Vietnamese and Maru), phonemic short vowels may carry a contour tone in open syllables. In fact, it will be proposed in section 4.2.1 on the basis of phonetic data from one of these languages (Cantonese) that short vowels are phonetically long in open syllables in these three languages, which it will claimed not coincidentally all lack phonemic long vowels in open syllables. Thus, properly understood, these languages behave parallel to the other languages in the survey which allow contour tones on CVV(C) and CVR, but not on CVO and CV.

[2] As a reviewer points out, Luganda also tolerates contour tones on CV in pre-pausal position (see section 4.1.1 for further discussion of Luganda).

[3] It will be claimed in section 4.1.1 that coda obstruents themselves do not support tonal information on the surface in these languages; rather the contrast between level and contour tones is manifested on adjacent vowels. These languages thus, properly understood, will be shown to belong to the set of languages in which only CVV(C) and CVR may carry contour tones. For the time being, however, these languages will conservatively be treated as belonging to a separate category.

[4] This does not necessarily mean that there are no segmental conditioning effects which may create gaps in the inventory of tonal contrasts associated with certain syllable types. For example, certain segments (e.g. glottal stop) may trigger a local tone raising or lowering effect which may influence the distribution of tones in its vicinity. Since the present paper is concerned with

certainty, 11 lack coda consonants, 3 do not have obstruent codas, and 11 lack syllables containing phonemic long vowels. Of the 11 lacking long vowels, 5 also either lack coda consonants or only have sonorant codas. This leaves only 19 languages of the original 105 (18.1%) with a full range of syllable types all of which may support contour tones.

Interestingly, there are no clear cases of languages in which the syllable onset plays a role in determining the ability of the syllable to carry a contour tone or not. Thus, the domain of tone is the syllable rime, parallel to many other prosodic phenomena such as weight-sensitive stress and weight-sensitive poetic metrics (cf. Jakobson 1931, Trubetzkoy 1939, Hyman 1985, Hayes 1989, etc.)

The range of variation in tonal distribution is summarized in Table 1 according to the types of syllables which can support contour tones for a given language type. The number of languages instantiating each linguistic type appear in parentheses.[5] "Yes" indicates that the given syllable type may carry contour tones (or a fuller range of contour tones) in the given language type, "No" indicates that the given syllable may not carry contour tones (or carries a reduced number of contours).

Table 1. Patterns of contour tone restrictions

	Language				
Syllable	Type 1 (12)	Type 2 (25)	Type 3 (29)	Type 4 (3)	Type 5 (36)
CVV	No	Yes	Yes	Yes	Yes
CVR	No	No	Yes	Yes	Yes
CVO	No	No	No	Yes	Yes
CV	No	No	No	No	Yes

prosodic tone restrictions and not segmentally conditioned ones, these segmental effects are not discussed in the text (see Hombert 1978 for discussion of segmental influence on tone).

5 It should of course be borne in mind that certain of the languages included in the figures do not possess the full range of syllable structures as discussed in the earlier text.

Looking at Table 1, an implicational hierarchy is apparent. If a language allows contour tones on CV, it also tolerates them on CVO, CVR, and CVV. If a language permits contour tones on CV and CVO, it also permits them on CVR and CVV. Finally, if a language tolerates contour tones on CV, CVO and CVR, it also allows them on CVV. If we conflate these implicational statements, we are left with the hierarchy in Figure 1 in which tolerance of contours on a given syllable type implies tolerance of contours on syllable types to its left.

Figure 1. Hierarchy of weight for tone

Heavy Light

CVV CVR CVO CV

The hierarchy of tone bearing ability in Figure 1 will be explained in section 3 in terms of the relative ability of different syllable types to support tonal information phonetically. More generally, the hierarchy in Figure 1 is not unique to tone among weight-sensitive phenomena. Other phonological phenomena such as stress assignment and minimal word requirements are sensitive to this hierarchy or portions of it (see, for example, Hyman 1985, Zec 1988, Hayes 1989, etc.)

Table 2 considers contour tone restrictions as a function of genetic affiliation. A total of 24 phyla (of 86 total in the Ethnologue) contained at least one surveyed language in which tone or pitch accents are used contrastively. In addition, there were 2 creoles and 1 language isolate in the survey which employ tone or pitch accents in a contrastive role.

Looking at Table 2 first by columns according to tonal distributions, we see that each of the five distribution patterns (no contour tones, contours on CVV, contours on CVV, CVR, contours on CVV, CVR, CVO, and no restrictions) is attested in multiple phyla. Most phyla with more than two or three surveyed tonal languages contained languages instantiating more than one of the distribution patterns. In fact, it is possible to find closely related languages/dialects displaying different tonal distribution restrictions and even individual languages which change their tonal restrictions from one historical stage to another. For example, whereas Early Greek, the predecessor to Classical Greek, allowed contour tones on CVV and CVR, Classical Greek observed a more stringent restriction, only permitting contour tones on CVV (Steriade 1991). Setting aside the extremely small set of languages which allow contour tones on CVV, CVR, and CVO, the densest genetically defined concentrations of a single pattern are the occurrence of 8 Daic languages which treat CVV and CVR as tonally heavy and the existence of 9 Niger-Congo languages which limit contour tones to CVV syllables. The 8 Daic languages account for 27.6% of the 29 surveyed languages employing the CVV, CVR heavy criterion for tone, while the 9 Niger-Congo languages account for 36% of the 25 surveyed languages with the CVV heavy criterion.

Table 2. Contour tone distributions by phylum

	Contour tone distribution				
Phylum	**no contours**	**contours on CVV**	**contours on CVV, CVR**	**contours on CVV, CVR, CVO**	**no restrictions**
Afro-Asiatic	2	1		2	2
Austro-Asiatic			3		1
Austronesian					1
Caddoan			2		
Daic			8		
Indo-European	2	1	1		
Iroquoian		1			
Khoisan		1	3		2
Kiowa-Tanoan			2		2
Mayan					1
Miao-Yao					1
Mura		1			
Na Dene	2	3			
Niger-Congo		9	3	1	7
Nilo-Saharan		3	2		6
Oto-Manguean					5
Panoan	3				
Sepik-Ramu		1			
Sino-Tibetan	1		5		5
Siouan		1			
Trans New Guinea		1			
Tucanoan					2
Uto-Aztecan	1				
Witotoan		1			
Others (creoles, isolates)	1	1			1
Total	**12**	**25**	**29**	**3**	**36**

Of the 25 languages with contours on CVV, a further 3 each belong to the Na Dene and Nilo-Saharan phyla. No other phylum contains more than 2 languages which allow contours on CVV but not on other syllables.

Of the 29 with heavy CVV, CVR, 5 are Sino-Tibetan languages and 3 each are members of the Austro-Asiatic, Khoisan, and Niger-Congo phyla. No other phylum contains more than 2 languages with heavy CVV and CVR.

Of the 12 languages which do not have tautosyllabic contour tones, 3 (25%) are members of the Panoan family. The other 9 languages lacking contour tones are spread out over several phyla, none of which contains more than 2 languages lacking contours.

Of the 36 languages with no restrictions on contour tones, 7 (19.4%) are Niger-Congo languages, 6 (16.7%) are Nilo-Saharan, and 5 (13.9%) each are Oto-Manguean and Sino-Tibetan. No other phylum contains more than 2 surveyed languages lacking weight-sensitive contour tone restrictions. Of course it should be recalled that many of these languages have an impoverished inventory of syllable types. After these genetically delimited concentrations of linguistic types, no pattern of contour tone distributions is found in any more than 3 languages within a single phyla.

Considering Table 2 now by rows according to genetic affiliation, there are a few patterns which stand out. First, all 8 of the Daic languages in the survey preferentially treat CVV(C) and CVR as heavy for tone. Furthermore, all 5 of the Oto-Manguean languages allow contour tones on a full range of syllable types, though it should be noted that 3 of the 5 languages do not have coda consonants and a fourth lacks phonemic long vowels. Of the phyla with more than one language surveyed, all 3 Panoan languages prohibit contour tones and both Tucanoan languages do not restrict contour tones. With respect to the last observation, it should be noted that both Tucanoan languages lack both coda consonants and phonemic long vowels.

3. A phonetic basis for contour tone restrictions

In this section, we will see that the distribution of weight criteria for tone finds an explanation in terms of the phonetic requirements of tone. The physical correlate of tone is fundamental frequency which is only present in voiced segments. In fact, the property which defines a voicing contrast is the fundamental frequency: voiceless segments lack a fundamental, voiced segments have one. Thus, the only type of segment on which tone may be *directly* realized is a voiced one.[6]

Crucially, the fundamental frequency profile of a segment or syllable (and hence its tonal profile) is cued not only by the fundamental frequency itself but also by other acoustic information. In particular, the presence of low frequency harmonics in the signal assists the recovery of the fundamental frequency. The reason for this is that harmonics occur at frequencies which are multiples of the fundamental frequency. Thus, a fundamental frequency of 200Hz will have harmonics at 400Hz, 600Hz, 800Hz, 1000Hz, and at 200Hz increments thereafter. The presence of harmonics greatly enhances the salience of the fundamental frequency, and can even allow for recovery of the tone when the fundamental itself has been extracted from the signal (see House (1990) and Moore (1995) for review of the relevant psychoacoustic literature).

While the relationship of harmonics to the fundamental in the frequency domain is the same for all segments (harmonics occur at multiples of the fundamental), voiced segments differ in terms of the intensity of their harmonics. Because vowels typically have the most energy at higher frequencies, their higher harmonics have

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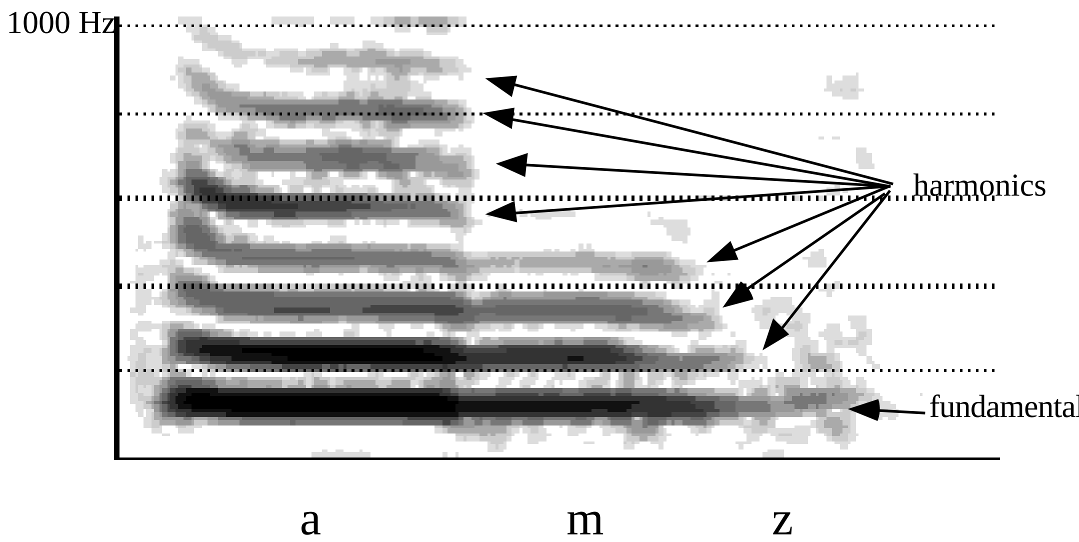
[6]A voiceless segment does not inherently possess a fundamental frequency itself, although its laryngeal settings may influence the fundamental frequency of neighboring voiced segments. Influences of this sort are not strictly weight-sensitive and are thus not discussed here.

greater intensity than those of consonants. Voiced sonorant consonants also possess a fairly rich and energetic harmonic structure relative to voiced obstruents, but typically do not possess as intense harmonics as vowels. Nevertheless, the more crucial harmonics for the perception of the fundamental, the low frequency harmonics (House 1990), are typically present in sonorants.

In contrast to sonorants, obstruents provide either minimal or no cues to fundamental frequency. Voiceless consonants, including obstruents, do not have a fundamental or harmonics. In voiced obstruents, harmonics above the fundamental typically have very little energy; furthermore, the fundamental itself is typically substantially less intense than in obstruents in sonorants. The absence of a salient harmonic structure in obstruents and the low intensity of the fundamental frequency are due to the narrow constrictions associated with obstruents. Thus, voiced obstruents are inherently impoverished relative to voiced sonorants in terms of the salience of their fundamental frequency and their ability to carry tonal contrasts. We would thus expect voiced obstruents to contribute extremely little to the ability of a syllable to carry a contour tone or not. This fact, taken together with the inability of voiceless obstruents to carry tone, means that the class of obstruents considered as a whole is quite poorly suited to supporting tonal information.

The relative ability of different segment types to carry tone can be made more vivid by considering a narrowband spectrogram of different types of voiced segments in Figure 2. Voiceless segments are not included since they lack a fundamental and harmonic structure.

Figure 2. Narrowband spectrogram of voiced segments



In Figure 2, we see that the vowel has the greatest number of visible harmonics (i.e. those with sufficient intensity to show up in the narrowband spectrogram) above the fundamental and also the most intense ones (as reflected in the darkness of the harmonics). The sonorant consonant also has a relatively rich harmonic structure and relatively intense harmonics, though the sonorant consonant's harmonics are visibly fewer in number (again due to decreased intensity at higher frequencies) and less intense than the vowel's. Compared to both the vowel and sonorant, the voiced obstruent provides very little tonal information: there are no continuous harmonics visible above the fundamental and the fundamental itself is quite weak in terms of intensity. [7]

[7]The close link between sonority and contour tone licensing also offers an account for the observation that contour tones in many languages are limited to the right edge of a word. Vowels in word-final position are typically (though not universally; see discussion of Luganda in section 4.1.2) longer than their word-medial counterparts due to a strong cross-linguistic tendency to lengthen segments at the right edge of prosodic domains (Wightman et al. 1992). By virtue of its

The difference between vowels, sonorant consonants, and obstruents in their tone bearing ability can be quantified by summing together the intensity values of the low frequency harmonics most crucial for carrying tonal information. This was done for representative segment types in three languages: Hausa, Cantonese, and Navajo One speaker of each language was recorded reading a list of words varying in their syllable rimes. In the case of Hausa and Cantonese, the data for the most part were part of larger experiments on weight-sensitive tone whose methodology is discussed further in individual sections on each language: Hausa in section 4.1.1 and Cantonese in section 4.2. The only word recorded which was not part of the larger experiments discussed later was a Hausa word containing a voiced obstruent: /màbːà/. The crucial aspect of the data for present purposes is the quantification of the differences in harmonic structure between different segments apparent in figure 2. To quantify this difference, an average FFT spectrum was calculated over the duration of each target segment type using a 512 point window and a 10 millisecond step size between frames. Given the sampling rate of 10 kHz and the 512 point window, the frequency resolution was 19.5 Hz, more than sufficient for resolving individual harmonics. The intensity of the first five harmonics, those most crucial for recovering the fundamental, were summed together yielding a value representing the overall low frequency intensity. In the case of Cantonese, which lacks voiced obstruent codas (the only obstruent codas with any energy), the short vowel /a/ and the sonorant coda /m/ were measured for their low frequency intensity. For Navajo which also lacks voiced obstruent codas, the short vowel /a/

additional phonetic duration, a word-final vowel is thus, in many languages, better able to support a contour tone than a word-medial one (cf. Clark 1983 for discussion of this tonal asymmetry).

and the sonorant coda /n/ were measured. Finally, for Hausa, which does have voiced obstruent codas, the low frequency intensity of the short vowel /a/, the sonorant coda /n/ and the voiced obstruent coda /b/ were calculated. Net intensity values of the first five harmonics for each targeted segment type were averaged together over all occurrences of the segment in low toned syllables. The words in which the measured segments were found are listed in the appendix. Measured segments occurred in all three languages. Results appear in Table 3.

Table 3. Intensity values for different segment types (sum of the first five harmonics in dB; standard deviations in parentheses)

Language	Vowel	Sonorant	Obstruent
Cantonese	255.8 (23.7)	146.0 (28.5)	
Hausa	246.5 (24.2)	219.0 (13.0)	162.3 (11.3)
Navajo	149.2 (27.2)	107.6 (21.9)	

In all languages, intensity values are highest for the vowel than for the sonorant coda. (Note that differences between languages in absolute intensity values reflect differences in overall recording levels and thus are not linguistically significant.) This result quantifies the visual finding in Figure 2 that vowels have a richer and more intense harmonic structure than sonorant consonants. Furthermore, in Hausa, obstruent codas have much less intensity than either vowels or sonorant codas. In fact, the drop off in intensity going from sonorants to obstruents is considerably more precipitous (57dB) than the fall in intensity going from vowels to sonorants (27.5dB). This fits with both the visual impression from Figure 2 and with the phonological observation made in section 2.3 that obstruents are virtually always weightless with respect to tone bearing ability.

Similar duration-based asymmetries which impact tonal weight hold of stressed vs. unstressed

Under the assumption that greater low frequency intensity enhances tonal salience, the intensity of low frequency harmonics associated with different segment types offers an explanation for the distribution of weight-sensitive contour tone restrictions discussed earlier. Recall the implicational hierarchy of syllable types which may bear contour tones: CVV is heaviest, followed by CVR, followed by CVO, followed by CV. This hierarchy mirrors the phonetic hierarchy of tonal salience illustrated in Figure 2 under the assumption that contour tones require a longer duration to be realized than level tones. It is thus crucial that not only the initial portion of the rime but also the *latter* portion of the rime possess properties which will allow for recovery of the tonal information. Thus, it is the second half of the long vowel in CVV and the coda consonant in CVR and CVO which serve to differentiate them from each other and from CV in terms of relative ability to carry a contour tone. The hierarchy of syllable types in Figure 1 thus reduces to a hierarchy characterizing the relative ability of different segment types able to carry the latter portion of the contour: V > R > O > Zero, where the difference between obstruents and zeros is much smaller than the difference between vowels and sonorants (see the Hausa intensity measures in Table 3 and the discussion in section 4.1.1).[8] This hierarchy corresponds to the phonetic hierarchy of segments in Figure 2 and also to the phonological hierarchy of syllable types in Figure 1.

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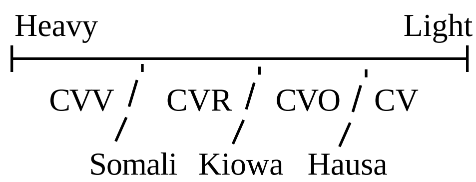
syllables (see Zhang 1999 for further discussion of these factors in tonal weight).

[8] Note, however, that there is some evidence that CVO could be subdivided into syllables closed by a voiced obstruent and those closed by a voiceless obstruent, given the (slightly) better tone bearing ability of voiced obstruents which has ramifications for the realization of contour tones in at least one language, Luganda (see section 4.1.2). However, because no languages, to the best of my knowledge, appear to draw a phonological distinction in contour tone-bearing ability between CVO with a voiced obstruent and CVO with a voiceless obstruent, they are collapsed as CVO in figure 3.

Languages with weight-sensitive restrictions on contour tones draw different “cut-off” points along this hierarchy, as in Figure 3.

Figure 3. Different cut-off points for weight-sensitive tone



In any given language, contour tones are permitted on syllable types to the left of the line, but not on syllable types to the right of the line, reflecting the fact that syllable types further left on the continuum are phonetically better suited to carry a contour tone. Thus, the licensing of contour tones on syllables which are less well suited to supporting a contour tone implies the licensing of contour tones on syllables which are phonetically better suited to supporting a contour.

4. Apparent exceptions to the tonal weight hierarchy

4.1 Languages with contours on CVO but not CV

Positing a phonetic explanation for contour tone restrictions raises an interesting question about the three languages in the survey, Hausa, Musey, and Luganda, which draw their cut-off point in Figure 3 between CVO and CV. Assuming that obstruents are particularly ill-equipped to carry tonal information, there is then little reason to think that a CVO syllable would be much, if any, better suited to carry a contour tone than CV. The Hausa, Musey, and Luganda pattern is especially surprising when one considers the fact that many of the coda obstruents in these languages are voiceless and thus cannot carry tone at all.

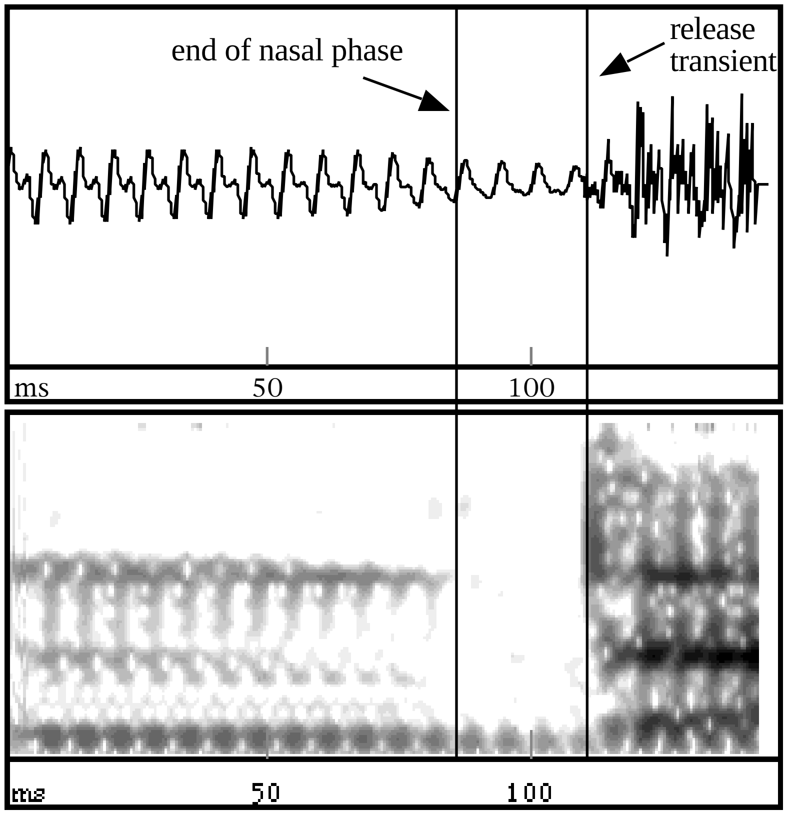
4.1.1. Phonetic experiment: Hausa

In order to examine whether this a priori unexpected distribution of contour tones finds a phonetic explanation, a small experiment was conducted using data from Hausa (Afro-Asiatic). Hausa possesses the following syllable types: CV, CVC, and CVV (Newman 1990, Wolff 1993). CVVC is not a permissible syllable type in Hausa, a restriction which triggers shortening of underlying long vowels which, through morpheme concatenation, come to fall in a closed syllable. Closed syllables include those containing vowels followed by a geminate, a consonant cluster, or a word-final consonant. Contour tones, which can be falling but not rising, occur on CVV, CVR, and CVO syllables in Hausa.

One native speaker of Hausa (male in his twenties) was recorded reading a list of words in isolation eight times into a high quality microphone in a sound proof booth. The list of words consisted of disyllabic words in which the rime of the first syllable was systematically varied such that various syllable types were represented in the list, in particular, CVV, CVR, CVO, and CV. In the list, which consisted almost entirely of actual Hausa words (all except for one), the target syllables contained the long vowel /aː/ in an open syllable (=CVV type) and the short low vowel /a/ in an open syllable (=CV type), in a syllable closed by the coda sonorant /n/ (=CVR type), and in a syllable closed by the coda obstruent /s/ (=CVO type). An effort was made to record words which differed as minimally as possible with respect to properties other than the systematically varied target syllable.

The list of recorded words appears in Appendix 2. Data were digitized at a 10kHz sampling rate using the Kay CSL speech analysis system and two measurements were taken. First, the duration of segments in the rime of the first syllable, the target syllable, was measured from a waveform in conjunction with a spectrogram and an intensity display. In most cases, segment boundaries could readily be determined from acoustic properties present in the waveform, spectrogram, and intensity display. The most challenging segment transitions to discern were the nasal stop-voiced oral stop clusters in the pair of word **ràn**dáː 'large water pot' and **mán**dáː 'dark Bornu medicinal salt' in the first list. The nasal-oral stop boundaries in these words were marked, however, by a simplification of the waveform and a diminution in intensity, reflected in a reduction in high frequency energy in the spectrogram and a reduction in intensity in the waveform (see Figure 4).

Figure 4. Segmentation at nasal-voiced stop boundaries



The second measurement taken for each segment was a measure of total low frequency energy, the phonetic property claimed in section xx to be relevant for predicting tone-bearing ability. The procedure for obtaining this measure was as follows. First, An FFT spectrum averaged over the entire duration of each target segment was computed using a series of 512 point windows calculated at 10 millisecond intervals. The resulting frequency resolution (19.6Hz) allowed for recovery of the individual harmonics. The intensity of each of the first five harmonics was taken from the FFT spectrum and these values were then summed together. This procedure yielded a value reflecting the total low frequency intensity for each segment. This value for each segment was subsequently multiplied by the duration of the segment representing the total low frequency energy associated with the segment. Finally, the energy values for each segment in the rime (assuming a rime with more than one segment) were summed together, yielding a total energy value for the rime. Thus, assuming equal average low frequency intensity values for its component segments, a longer rime will have greater total low frequency energy than a shorter rime. Integrating intensity over time finds independent support from psychoacoustic experiments indicating that the ear integrates energy and time over durations of the magnitude common for syllables in natural speech (see Moore 1995 for a review of the relevant literature).

To provide a concrete example of the measurement procedure, let us consider a rime consisting of a vowel plus a sonorant, e.g. /an/. Let us assume that the vowel is 100 milliseconds and coda consonant is 80 milliseconds. Let us further assume that the total intensity of the first five harmonics averaged over the duration of the vowel is 150dB and that the total intensity averaged over the coda is 100dB. The total low frequency energy of the vowel would be 15,000 dBmilliseconds (100 x 150) while the total low frequency energy of the vowel would be 8,000 dBmilliseconds. Finally, summing the energy values for the individual segments yields a total low frequency energy value of 23,000 dBmilliseconds.

Let us now consider actual energy results for the Hausa data. Average measurements of the energy of the vowel and the energy of the portion of the rime characterized by sonorant energy (henceforth, termed the sonorous phase) appear in Table 4, which separates the four syllable types (CV, CVO, CVR, and CVV) and the three tone types (high, low, and falling) found in Hausa. Values are in dB milliseconds divided by 100 due to space limitations. Standard deviations appear in parentheses following each measure. A boldface line separates syllable types which can carry contour tones (CVO, CVR, CVV) from those which cannot (CV).

Table 4. Energy measurements(in dB milliseconds/100) for Hausa rimes

	Syllable Type										
	CV		**CVO**			**CVR**			**CVV**		
	H	L	H	L	HL	H	L	HL	H	L	HL
Vowel	24.7 (3.6)	23.6 (2.3)	27.3 (3.3)	24.4 (3.2)	31.6 (2.3)	30.8 (3.9)	33.2 (5.1)	33.3 (5.5)	65.9 (6.6)	57.9 (4.6)	59.5 (5.6)
Sonorous phase	24.7 (3.6)	23.6 (2.3)	27.3 (3.3)	24.4 (3.2)	31.6 (2.3)	65.4 (2.2)	65.4 (6.3)	57.6 (7.1)	65.9 (6.6)	57.9 (4.6)	59.5 (5.6)

Interestingly, measurements suggest that it is not the coda obstruent in CVO which makes CVO a better licenser of contours than CV, but rather it is the *vowel* in CVO which bears the burden of carrying the contour tone. The crucial evidence for this position is that vowels carrying contour tones in CVO syllables have greater energy than vowels carrying level tones in CVO syllables. The vowel carrying a falling tone in CVO averages 31.6 x 10^2 dB milliseconds, as compared to 27.3 x 10^2 dB milliseconds and 24.4 x 10^2 dB milliseconds for vowels carrying level high and level low tones, respectively. The energy difference between vowels carrying a falling tone and vowels carrying either type of level tone in CVO was found to be statistically significant by an unpaired t-test: p=.0217 for falling vs. high tone in CVO, p=.0009 for falling vs. low tone in CVO. In contrast, the difference in vowel energy between high and low toned CVO did not reach statistical significance: p=.1320. Examination of results for CVR and CVV indicate that the greater energy associated with vowels carrying contour tones is localized to CVO. Vowels carrying contour tones in CVR and CVV are not longer than their level toned counterparts. Furthermore, the total low frequency energy for CVR and CVV rimes do not differ according to whether they carry contour tones or level tones. This suggests that there is a threshold level of energy which a rime must have in order to be able to support a contour tone. Because CVR and CVV already possess sufficient energy to carry a contour tone, they do not need greater energy when carrying a contour tone. CVO carrying a contour tone, on the other hand, must have greater energy than its level toned counterparts, because CVO syllables do not inherently possess enough energy to effectively realize contour tones.

These results raise an important question about the source of the energy boost apparent in CVO carrying a contour tone relative to its level toned counterparts. Because the total energy values factor in both intensity and duration, an increase in total energy could either be attributed to an increase in intensity or to an increase in duration or possibly to a combination of both.

As it turns out, average intensity values did not differ reliably between CVO syllables varying in their tone. CVO carrying a high tone had an average intensity value of 243 dB, CVO carrying a low tone had an intensity of 236 dB, and CVO carrying a falling tone had an intensity of 289 dB. All three pairwise comparisons of intensity between these three tone types associated with CVO were insignificant according to unpaired t-tests.

Examination of duration as a potential source for energy differences between CVO differing in tone proved more fruitful. CVO carrying a contour tone was found to be significantly longer on average than either CVO carrying a level high tone or CVO carrying a level low tone. CVO with a contour tone averaged 133 milliseconds, CVO with a level high tone 112 milliseconds, and CVO with a level low tone 103 milliseconds. The difference between CVO realized with a contour tone and the two level toned CVO syllables was highly significant according to an unpaired t-test: for falling vs. high tone, p=.004; for falling vs. low tone, p=.0005. In contrast, the difference between high and low toned CVO did not reach statistical significance: p=.089. Furthermore, if we expand our examination of duration to encompass other rimes in Table 5 (measurements in milliseconds; standard deviations in parentheses), we see that the lengthening effect seen in syllables carrying a contour tone is localized to CVO. Thus, vowels carrying contour tones in CVR and CVV are not lengthened relative to their level toned counterparts. Nor does the total duration of the sonorous portion of the rime differ between CVR or CVV syllables carrying a contour tone versus their level toned counterparts.

Table 5. Duration measurements (in milliseconds) for Hausa rimes

	Syllable Type										
	CV		**CVO**			**CVR**			**CVV**		
	H	L	H	L	HL	H	L	HL	H	L	HL
Vowel	103 (9.3)	98 (7.7)	112 (7.5)	105 (9.7)	133 (10.6)	115 (7.8)	132 (15.4)	126 (7.9)	272 (17.2)	262 (17.5)	263 (8.7)
Sonorous phase	103 (9.3)	98 (7.7)	112 (7.5)	105 (9.7)	133 (10.6)	271 (15.2)	279 (16.3)	238 (9.9)	272 (17.2)	262 (17.5)	263 (8.7)

These data suggest that the vowel in CVO syllables carrying a contour tone is lengthening in order to aid in the realization of the contour, because the coda obstruent itself provides little assistance. As a result of this lengthening, CVO carrying a contour tone will have greater total low frequency energy and will thus better suited to supporting a contour tone. Lengthening is not necessary in CVR and CVV, because the rime in these syllables consists entirely of sonorants which, due to their greater harmonic energy relative to obstruents, are well suited to supporting tonal information.

At this point, one might reasonably ask whether there are any independent factors unique to Hausa which contribute to or facilitate the substantial amount of subphonemic lengthening seen in CVO syllables carrying a contour tone. A related question concerns the asymmetrical ability of CVO but not CV to carry a contour tone in Hausa. One might ask why Hausa does not also allow contour tones on CV syllables and just lengthen a vowel in CV which carries a contour tone.

There is a related fact about Hausa syllable structure which offers a functionally-driven answer to this question. As pointed out earlier, Hausa has a vowel length contrast in open but not closed syllables. It is conceivable that the subphonemic lengthening in CVO carrying a contour tone is allowed precisely because there is no phonemic contrast in vowel length which could be jeopardized through subphonemic vowel lengthening. In open syllables, on the other hand, subphonemic lengthening of short vowels could potentially jeopardize the salience of the phonemic length contrast. This account assumes that certain phonological conditions are a prerequisite for the Hausa weight distinction, but that the adoption of that phonological distinction is actually triggering the phonetic lengthening.

In summary, despite initial appearances to the contrary, Hausa actually provides further evidence that it is really the low frequency energy associated with the sonorant portion of the rime which serves as the basis for determining syllable weight for tone. Thus, the presence of an obstruent does not itself contribute to the ability of a syllable to carry a contour tone. It is only when the presence of the obstruent allows for lengthening of the preceding vowel and thus a concomitant increase in energy, as in Hausa, that CVO is better able to support a contour tone than CV. The Hausa pattern also suggests that the ability of a syllable to carry a contour tone is a property of the entire syllable. It is the presence of the coda which licenses vowel lengthening in CVO syllables bearing a contour tone, but it is the vowel which actually carries the burden of realizing the latter part of the tonal contour.

Before concluding the discussion of Hausa, it is worth discussing the contrast between the ability of CVO to carry a contour tone underlyingly and the obstruent's inability to realize the latter portion of the contour tone on the surface. Thus, in Hausa (and, it will be claimed, in this section, in other languages with a similar weight criterion for tone), there is a mismatch between underlying tone bearing status and the phonetic capacity to realize tones on the surface. One might reasonably ask why a language would employ an inherently sub-optimal tone assignment strategy underlyingly, only to remedy the deficiency on the surface. In answer to this query, it is possible that tone bearing ability in certain languages, such as Hausa, is sensitive to structural length lexically and that phonetic considerations remedy any deficiencies in the ability of a syllable carrying a lexical contour tone to realize the contour on the surface. Pursuing this approach, contour tones could thus be assigned to CVO lexically in Hausa because the rime in CVO contains two segments and is thus "phonologically" as long as CVR and CVV. However, because CVO is ill-suited to support a contour tone phonetically, steps must be taken to ensure that the latter half of the contour tone is properly realized on the surface. In Hausa, the remedy takes the form of lengthening of the vowel in a CV bearing a contour tone, where this lengthening is made possible by the absence of a vowel length contrast in closed syllables. Other a priori ways to deal with the inability of CVO to support a contour would be to eliminate (or shorten) the contour or realize it on the following vowel; in fact, this latter solution appears to be adopted in some cases by Luganda (see discussion below).

Whatever the reason for the existence of languages with phonetically sub-optimal associations between tones and syllables on the lexical level, it is striking that such languages appear to be quite rare compared to the number of languages in which lexical tone assignment is in sync with phonetic tone bearing ability. The extreme rarity of Hausa-type languages suggests that languages overwhelmingly prefer to assign lexical contour tones to syllables which will be best able to realize them phonetically.

4.1.2. Other languages with contour tones on CVO but not CV

Let us now briefly consider the two other languages in the survey which superficially appear to allow contours on CVO but not on CV: Luganda and Musey. Luganda (Niger-Congo), as it turns out, also lacks CVVC syllables. It is thus plausible that CVO carrying a contour tone could undergo vowel lengthening without potentially diminishing the salience of a phonemic contrast in length, just as in Hausa.

Interestingly, Tucker, in his introduction to Snoxall's (1967) dictionary, reports an asymmetry between syllables closed by a voiceless obstruent and ones closed by a voiced obstruent which is in keeping with the phonetic basis for tone restrictions. Although CVO ending in a voiced obstruent and carrying a contour tone regularly realizes its contour tone, CVO ending in a voiceless obstruent and carrying a phonological falling tone, the only type of contour in Luganda, are reported to often carry only a “psychological low tone”. Phonetically, the high part of the contour is realized on the CVO syllable while the low tone is characteristically phonetically realized through its lowering effect on the tone of the following syllable, though it should be pointed out that the vowel in CVO ending in a voiceless obstruent can realize the contour tone itself.

The general asymmetry in Luganda between syllables closed by voiced obstruents, which consistently can be realized with contour tones, and those closed by voiceless obstruents, which typically do not support entire contour tones, is not surprising given the phonetic motivations behind contour tone restrictions: a voiceless obstruent offers a worse backdrop for tone than a voiced obstruent, since a voiceless obstruent lacks a fundamental frequency.

There is another interesting fact about Luganda which ties into the present discussion.[9] Although CV in most contexts does not carry a contour, CV in pre-pausal position can bear a contour tone. Although I do not have phonetic data bearing on this issue, a plausible hypothesis to account for this asymmetry between phrase-medial and phrase-final CV in tone-bearing ability is that phrase-final CV carrying a contour tone is phonetically longer than phrase-final CV with a level tone. This hypothesis would appear to be particularly tenable given the absence of a vowel length contrast in this environment; thus, just as a vowel carrying a contour

[9] Thanks to a reviewer for bringing these facts to my attention.

tone in a closed syllable can safely lengthen due to the lack of a phonemic vowel length contrast in closed syllables, a phrase-final vowel carrying a contour tone could also lengthen without jeopardizing a phonemic length contrast.

Like Hausa and Luganda, Musey (Afro-Asiatic), the third language in the survey which appears to allow contour tones on CVO but not CV, also does not possess a vowel length contrast in closed syllables. Although I do not have phonetic data to bear on the issue, it is thus plausible that vowels carrying contour tones in Musey are phonetically lengthened in CVO syllables relative to vowels carrying level tones. Aaron Shryock's impressionistic observation of Musey data (p.c.) suggest that this is indeed the case.

In summary, closer examination of the three languages which allow contour tones on CVO but not on CV suggests that the obstruent coda itself, particularly when voiceless, provides little assistance in realizing contour tones. Rather it is an adjacent vowel which bears the burden of carrying the surface tonal contour in CVO syllables. In Hausa and plausibly Musey and Luganda, the vowel preceding a coda obstruent allophonically lengthens to support the contour tone. Furthermore, in Luganda, it is the vowel following a syllable ending in a voiceless obstruent which often acoustically manifests the latter portion of the contour tone.[10]

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[10] Given the Hausa results, there is another hypothesis worthy of investigation. In languages which allow contour tones on all syllable types, not only would vowels in CVO syllables with contour tones be longer than vowels in CVO syllables with level tones, just as in Hausa, but also vowels in CV syllables with contour tones would be longer than vowels in CV syllables with level tones. The most probative languages for testing this hypothesis are those with a phonemic vowel length contrast, since such languages are limited in the amount of subphonemic lengthening they may employ in realizing a contour tone compared to languages like Cantonese which can freely lengthen vowels in open syllables where length is non-contrastive. A recent phonetic study which bears on this issue is Russell's (to appear) study of short vowels carrying contour tones (rising tones) in syllables beginning with tone depressing consonants in Zulu. As one might predict, her study found that short vowels carrying contour tones are longer than short vowels with

4.2 Cantonese

Cantonese is one of the few languages in the survey which does not observe the implicational weight hierarchy in Figures 1 and 3. The Cantonese tone facts are as follows, following Kao (1971) and Bauer and Benedict (1997). Contour tones (which include a high rising, a low rising, and a falling tone) are permitted on phonemic short vowels in open syllables (CV) and on syllables closed by a sonorant, whether they contain a short vowel (CVR) or a long vowel (CVVR). Contour tones in morphologically simple forms do not occur on syllables closed by an obstruent (all of which are voiceless) regardless of whether the vowel is short (CVO) or long (CVVO).[11] Syllables closed by an obstruent carry either level low, level mid, or level high tones. Crucially, Cantonese lacks a vowel length distinction in open syllables.

Given these facts, Cantonese appears to be an exception in more than one way to the implicational hierarchy in Figure 1. First, phonemic CV may bear a contour tone, but CVO may not, a pattern which is the opposite of the Hausa type distribution. Second, both CV and CVR may bear a contour but CVVO may not, an apparent exception to the general pattern of CVV being heavier than both CV and CVR.

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level tones, but that this length asymmetry is not found for long vowels. It should be noted, however, that Russell's study focused on vowels carrying rising tones, which tend to be inherently longer than vowels realized with falling tones (Gandour 1977).

[11] Contour tones can occur on syllables closed by an obstruent in certain morphologically derived forms and, more rarely, in certain reduplicated forms. These contour tones which are members of

4.2.1 Cantonese: A phonetic experiment

In order to test whether the exceptional distribution of Cantonese tones finds a phonetic explanation, measurements of various Cantonese rimes were collected from a native speaker of Cantonese (female, in her early twenties) under conditions similar to those used to record Hausa. The subject read a list of disyllabic words in isolation eight times. The data consisted of monosyllabic words in which the rime of the first syllable was varied so that different rime types were instantiated in the corpus. The target rimes were /a/, /am/, /ap/, /aːm/, and /aːp/ which represent the range of prosodic shapes of rimes in Cantonese: V, VO, VR, VVO, VVR. All words were low-toned, since it was possible to find the closest minimal set of words for this tone. The Cantonese corpus appears in Appendix 3. Words were digitized and measured according to the same criteria described for Hausa above.[12]

In Table 6, we see mean low frequency energy values (in dB milliseconds divided by 100) for the vowel and the entire sonorous phase of the rime, the relevant portions of the syllable for assessing the ability of a syllable to carry a contour tone or not. Standard deviations appear in parentheses following each mean value. Syllables which cannot carry contour tones appear to the right of the boldface line; those to the left of the line can carry contours.

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the set of ***piːn jam***, or ‘changed tones’, are discussed at length in Bauer and Benedict (1997).

12 Although confining the data set to low toned syllables does not allow for examination of the effect of tone type on duration and interactions between syllable type and tone, it does allow for controlled comparison of the duration of different syllable types. Any duration differences found in the low-toned rime types thus cannot be attributed to the presence of a contour tone.

Table 6. Energy measurements (in dB milliseconds/100) for different rimes in Cantonese

	Syllable Type				
	CVO	**CVVO**	**CV**	**CVR**	**CVVR**
Vowel	20.5 (3.9)	41.2 (3.5)	69.6 (10.7)	25.7 (4.9)	51.2 (4.4)
Sonorous phase	20.5 (3.9)	41.2 (3.5)	69.6 (10.7)	51.5 (5.6)	66.0 (4.5)

Interestingly, the three syllable types which can carry contours in Cantonese (CV, CVR, CVVR) are precisely those with the greatest low frequency harmonic energy for the entire rime. The energy of CV averages 69.6 x 10^2 dB milliseconds, that of CVR averages 51.5 x 10^2 dB milliseconds, and that of CVVR averages 66.0 x 10^2 dB milliseconds. In contrast, the average energy is only 20.5 x 10^2 dB milliseconds for CVO and 41.2 x 10^2 dB milliseconds for CVVO. Thus, although the energy associated with the vowel itself in CVVO is greater than the energy of the vowel in CVR, the presence of the coda sonorant in CVR gives the total energy for the rime a sufficient boost to allow for realization of a contour tone. In CVVO, on the other hand, the energy of the vowel is insufficient to compensate for the absence of a sonorant coda.

Parallel to Hausa, we can seek out the source of the energy differences observed in Table 6. One question we might ask is whether the ability of certain syllables to carry contour tones is at least partially attributed to the fact that they have more intense vowels than their counterparts not able to bear contour tones. This question is particularly relevant in the comparison of CV, which can carry a contour tone even though it contains a phonemic short vowel in an open syllable, with CVVO, which does not support contour tones even though it contains a phonemic long vowel. One a priori explanation for this curious distribution is that the vowel in CV is sufficiently more intense than the vowel in CVVO such that any deficiencies in the duration of CV would be compensated for.

In fact, examination of average intensity values (in dB) for vowels in the five measured syllable types in Table 7 disconfirms this hypothesis. Vowels in syllables able to support contour tones are not more intense than vowels in syllables unable to carry contour tones. In fact, vowels in CV, CVR, and CVVR are actually slightly less intense than vowels in CVO and CVVO, though these differences are fairly small in general.

Table 7. Average intensity values for sum of first five harmonics (in dB) for different rimes in Cantonese

	Syllable Type				
	CVO	**CVVO**	**CV**	**CVR**	**CVVR**
Vowel intensity	265 (22.6)	275 (18.3)	245 (23.6)	260 (23.1)	247 (15.3)

As we saw for Hausa, another possible source for differences in total low frequency energy are duration differences. This possibility is explored in Table 8, which presents average duration values (in milliseconds) of the sonorous portion of the five measured rimes and their vowels.

Table 8. Duration measurements (in milliseconds) for different rimes in Cantonese

	Syllable Type				
	CVO	**CVVO**	**CV**	**CVR**	**CVVR**
Vowel	77 (11.1)	150 (8.9)	283 (21.1)	99 (14.4)	208 (12.7)
Sonorous phase	77 (11.1)	150 (8.9)	283 (21.1)	275 (24.1)	301 (22.9)

As Table 8 indicates, duration provides an explanation for the energy results seen in Table 6. The three syllable types which can carry contour tones have longer sonorous portions than the two syllable types which do not carry contour tones. This fits the energy measurements in Table 6 which indicated that rimes which are able to support contour tones have greater low frequency harmonic energy than rimes which are unable to realize contour tones. Particularly striking about the duration measurements is the observation that the vowel in CV is quite long phonetically, much longer than V in either CVR or CVO, or, for that matter, than the phonemic long vowels in CVVR and CVVO. Thus, it is the longer status of the vowel in CV relative to CVO and CVVO, and not its greater intensity which makes CV have greater energy than CVO and CVVO and allows CV to carry a contour tone where CVO and CVVO cannot. The duration results found in the present experiment corroborate those of earlier researchers. Kao (1971), for example, reports similar phonetic results in her study of Cantonese which, unlike the present study, did not control for vowel quality or the type of coda consonant. The vowel in CV is also qualitatively quite similar to the long vowels in CVVR and CVVO which are more peripheral than the short vowels in CVO and CVR. Thus, although there is no phonemic contrast in length in open syllables, the vowel in CV is more accurately treated as a long vowel than as a short vowel, both in terms of quality and in terms of duration. The assignment of the vowel in CV to the long category is also corroborated by the judgments of my consultant and also those of other investigators (e.g. Kao (1971), also cf. Duanmu (1994b) on Mandarin).

It is plausible that the length of the vowel in open syllables is a function of a minimal word requirement. Many languages require that content words have a minimum prosodic shape, such that certain words which are too "light" are avoided. Minimal word requirements are, in fact, common in Chinese languages (cf. Duanmu 1994a), which, Cantonese included, have overwhelmingly monosyllabic words. In response to this minimal word requirement, Cantonese, like other Chinese languages, requires that the vowel in CV be phonetically long. This lengthening of the vowel allows for the phonetic realization of contour tones in CV, by indirectly increasing its low frequency harmonic energy. In contrast, both CVO and CVVO, which have phonetically shorter vowels and thus less energy than CV, are unable to support contour tones.

Duration also ultimately accounts for the greater tone bearing capacity of CVR relative to CVVO in Cantonese. The relatively long duration of phonemic long vowels before sonorants relative to before obstruents may be viewed as an exaggerated manifestation of the cross-linguistic tendency for vowels to be longer before voiced or sonorant sounds (the sonorants are all voiced and the obstruents are all voiceless in Cantonese) (see Lehiste 1970 for a cross-linguistic overview of this phenomenon).

In summary, examined from a phonetic standpoint, Cantonese fails to constitute a true exception to the phonetic basis for the implicational hierarchy of weight found in the survey in section 3.1. Before concluding this section, it is worth noting that there are two other languages in the survey (Vietnamese and Maru) which superficially appear to restrict the inventory of tones on CVO but not on CV, a distribution which parallels that found in Cantonese. Like Cantonese, both of these languages lack phonemic long vowels in open syllables and employ a high percentage of monosyllabic words. It is thus plausible that, parallel to Cantonese, a vowel in an open syllable is actually a long vowel in these languages. These languages would thus also be unexceptional in their distribution of contour tones.

5. Conclusions

In this paper, we have seen that many languages have prosodically determined tonal restrictions. An extensive survey of such restrictions indicates that they are not arbitrary but follow an implicational hierarchy grounded in phonetic factors. Syllables which have greater overall sonorous energy are better equipped to support contour tones than syllables with lesser sonorous energy. The phonetic factors underlying contour tone restrictions conspire to yield an implicational hierarchy of tone bearing ability, whereby tolerance of contour tones on syllables which are inherently less well suited to carrying tonal information implies tolerance of contour tones on syllables which are better suited to manifesting tone. Exceptions to the phonetically motivated hierarchy of tone bearing ability may arise when language-specific durational properties, many of which are ultimately motivated by other phonological properties, such as syllable structure and minimal word requirements, influence the energy values crucial for determining the ability of a syllable to support contour tones. Properly understood, these exceptional languages provide further evidence for the phonetic basis for contour tone restrictions.

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Appendix 1. Survey of weight-sensitive tone

A superscripted [a] indicates that the language lacks coda consonants; [b] indicates an absence of obstruent codas; [c] indicates an absence of phonemic long vowels; [n] indicates that heavy syllables carry a fuller range of tones than light syllables, though light syllables may carry certain phonetic contour tones. R stands for a sonorant coda. CVV(C) stands for both long vowels and diphthongs, unless languages lacks either phonemic long vowels or diphthongs.

Languages which allow contour tones on CVV(C) only

Language	**Macro-Phylum**	**Source(s)**
Abau	Sepik-Ramu	Bailey (1975)
Andoke[13]	isolate	Landaburu (1979)
Anufo[b] [14]	Niger-Congo	Stanford and Stanford (1970)
Apache, Chiracahua	Na Dene	Hoijer (1946)
Bete[a]	Niger-Congo	Werle (1976)
Bushong	Niger-Congo	Vansina (1959)
Cherokee	Iroquoian	Munro (1996a), Scancarelli (1987), Wright (1996)
Crow	Siouan	Kaschube (1967)
Didinga	Nilo-Saharan	Rosato (1980), Odden (1983)
Duala	Niger-Congo	Ittmann (1978)
Greek (Classical)	Indo-European	Steriade (1991)
Ijo[a]	Niger-Congo	Williamson (1965)
Jukun[a]	Niger-Congo	Shimizu (1980)
Krongo	Niger-Congo	Reh (1985)
Kru[15]	Niger-Congo	Rickard (1970)
Kung (Zu|'Hõasĩ)[b]	Khoisan	Snyman (1975)
Mumuye	Niger-Congo	Shimizu (1983)
Mura-Pirahã[a]	Mura	Everett and Everett (1984), Everett (1986, 1988)
Navajo	Na Dene	Sapir and Hoijer (1967)
Ocaina[16]	Witotoan	Agnew and Pike (1957)
Sarsi	Na Dene	Cook (1984)
Shilluk[17]	Nilo-Saharan	Heasty (1974), Gilley (1992)
Somali	Afro-Asiatic	Berchem (1993), Saeed (1993)
Telefol	Trans New Guinea	Healey (1964)
Tubu	Nilo-Saharan	Lukas (1953)

[13] The only coda is glottal stop.
[14] Contours occur only on utterance final syllables.
[15] The only coda is /m/ resulting from /mV/.
[16] The only coda is glottal stop.
[17] Tonal distribution operates as a lexical restriction, which can be violated on the surface.

Languages which allow contour tones on CVV(C) and CVR

Language	Macro-Phylum	Source(s)
Ai-Cham[n]	Daic	Lin and Jianxin (1988)
Caddo	Caddoan	Chafe (1976)
Cantonese [18]	Sino-Tibetan	Kao (1971), Bauer and Benedict (1997)
Ching[n]	Daic	Dabai (1988)
Dzongkha	Sino-Tibetan	Mazaudon and Michailovsky (1988)
Gana-Khwe (≤Ani)[b]	Khoisan	Vossen (1986)
Kabiye[b]	Niger-Congo	Delord (1976)
Khamti	Daic	Weidert (1977)
Kiowa	Kiowa-Tanoan	Watkins (1984)
Kissi[19]	Niger-Congo	Childs (1995)
Khmu[20]	Austro-Asiatic	Svantesson (1983)
Kitsai	Caddoan	Bucca and Lesser (1969)
Lao	Daic	Morev et al. (1979)
Lithuanian	Indo-European	Senn (1966), Kenstowicz (1972), Young (1991)
Maru [c]	Sino-Tibetan	Burling (1967)
Mbai [b]	Nilo-Saharan	Fortier (1971)
Muong [c n]	Austro-Asiatic	Solntsev et al. (1987)
Nama	Khoisan	Hagman (1977)
Naro[b]	Khoisan	Vossen (1997)
Nung[n]	Sino-Tibetan	Saul (1980)
Saek[n]	Daic	Morev (1988)
Shan[n]	Daic	Morev (1983), Young (1985)
Tai, Lung Ming[n]	Daic	Gedney (1991)
Tewa[21]	Kiowa-Tanoan	Harrington (1910), Speirs (1966)
Thai	Daic	Noss (1964), Hudak (1990)
Tibetan (Lhasa)	Sino-Tibetan	Dawson (1980), Meredith (1991)
Tura[b22]	Niger-Congo	Bearth (1971)
Turkana[23]	Nilo-Saharan	Dimmendaal (1983)
Vietnamese [c24]	Austro-Asiatic	Nguyen (1969), Van-Chinh (1970), Nguyen (1990)

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[18]There is no vowel length contrast in open syllables in Cantonese; vowels in open syllables are phonetically long (see section 4.2); neither CVO nor CVVO may carry a contour tone.

[19]The only sonorant codas are derived from loss of V2 in CVCV.

[20]The weight distinction is found in the “minor” (unstressed, pre-root) syllables, which may themselves carry a tone only if they contain a sonorant.

[21]The only sonorant coda is /n/; other codas include /h/ and glottal stop.

[22]The only permissible coda in Tura is /ŋ/ which can also be syllabic.

[23]Tones on sonorant codas result from tones left over from intervocalic high vowel deletion. Tone does not reassociate with obstruent codas.

Languages which allow contour tones on CVV(C) and CVC

Language	Macro-Phylum	Source(s)
Hausa	Afro-Asiatic	Newman (1990), Wolff (1993)
Luganda	Niger-Congo	Tucker (1962), Snoxall (1967)
Musey	Afro-Asiatic	Shryock (forthcoming)

Languages which allow contour tones on full range of syllables

Language	Macro-Phylum	Source(s)
!Xoo [b]	Khoisan	Traill (1985), Miller-Ockhuizen (1998)
Barasano[a] [c]	Tucanoan	Smith and Smith (1971), Stolte and Stolte (1971)
Bobo[a]	Niger-Congo	Le Bris (1981)
Chinantec, Comaltepec[25]	Oto-Manguean	Anderson (1989), Anderson et al. (1990)
Coreguaje[a] [c]	Tucanoan	Gralow (1985)
Fong[a] [26]	Niger-Congo	Guédou (1985)
Fur	Nilo-Saharan	Beaton (1968)
Hmong, Green[b] [c]	Miao-Yao	Lyman (1979)
Jemez[27]	Kiowa-Tanoan	Bell (1993)
Kpelle	Niger-Congo	Westermann (1930), Welmers (1962), Leidenfrost (1973)
Kunama	Nilo-Saharan	Thompson (1983), Böhm (1984)
Lahu [c] [28]	Sino-Tibetan	Matisoff (1973, 1988)
Lango [c]	Nilo-Saharan	Noonan (1992)
Mandarin [b]	Sino-Tibetan	Chao (1968)
Mangbetu	Nilo-Saharan	Larochette (1958)
Mazatec [a]	Oto-Manguean	Pike and Pike (1947), Jamieson (1977a, b)
Mende [a]	Niger-Congo	Crosby (1944), Innes (1962, 1969)
Mixtec [a]	Oto-Manguean	Bradley (1970)
Mocha	Afro-Asiatic	Leslau (1959)

[24]Syllables closed by an obstruent only contrast two tones compared to six tones in other syllable types. The two tones occurring in CVO syllables may be analyzed as high and low phonologically, though they are actually phonetically rising and falling. As in Cantonese, open syllables can carry all six tones in Vietnamese; there are two short centralized vowels which only occur in closed syllables, suggesting that vowels in open syllables may perhaps be longer than in closed syllables, as in Cantonese.

[25]The only codas are /r/ and /b/ which occur only as the reduced forms of certain morphemes.

[26]Contour tones, of which only falling tones are attested, occur only on final syllables.

[27]The only coda which occurs is the noun-suffix /ʃ/.

[28]The only coda is glottal stop; only high and low tones may occur in syllables closed by a glottal stop; however, glottal stop is subject to reanalysis as a tonal feature of the preceding vowel (see Matisoff 1973).

Mulwi	Afro-Asiatic	Tourneux (1978)
Nandi	Nilo-Saharan	Creider and Creider (1989)
Ndumbea [a]	Austronesian	Rivierre (1973), Paita and Shintani (1983)
Nocte [c]	Sino-Tibetan	Das Gupta (1971)
Otomi [a] [c]	Oto-Manguean	Manuel (1955)
Pacoh [c]	Austro-Asiatic	Watson (1966)
Senoufo [a]	Niger-Congo	Chéron (1925), Mills (1984)
Taos (N.Tiwa) [c]	Kiowa-Tanoan	Trager (1946), Trager (1971)
Tunen	Niger-Congo	Dugast (1967, 1971)
Vai [a]	Niger-Congo	Welmers (1976)
Yucatecto	Mayan	Straight (1976)
Zapotec, Mitla [c]	Oto-Manguean	Briggs (1961)
Bagirmi	Nilo-Saharan	Stevenson (1969)
Hatsa[a] [c]	Khoisan	Dempwolff (1916-7)
Sango[a]	Creole	Samarin (1967)
Tangkhul [c]	Sino-Tibetan	Arokainathan (1980, 1987)
Tangsa [c] [29]	Sino-Tibetan	Das Gupta (1980)

Languages which do not have contour tones

Language	**Macro-Phylum**	**Source(s)**
Capanahua	Panoan	Loos (1969)
Cashinahua	Panoan	Kensinger (1963)
Chacobo	Panoan	Prost (1960)
Cora	Uto-Aztecan	Casad (1984), McMahon (1967)
Dizi	Afro-Asiatic	Breeze (1988)
Iraqw Karen [c] [30]	Afro-Asiatic Sino-Tibetan	Mous (1993) Jones (1961)
Nubi	Creole	Heine (1983)
Runga	Nilo-Saharan	Nougayrol (1990)
Slavey	Na Dene	Rice (1989)
Tlingit	Na Dene	Boas (1917), Naish and Story (1963), Story and Naish (1973)
Yulu	Nilo-Saharan	Santandrea (1970), Boyeldieu (1987)

[29] Some dialects have long vowels instead of diphthongs.

[30] The only coda is glottal stop.

Appendix 2. Hausa corpus

List 1

Syllable Type	Word	Gloss
CV	**fà**sá: **sá**fú:	 row, line (also pronounced sáhú:)
CVO	f**às**kí: **más**kó: **râs**:á:	being very broad large blacksmith’s hammer branches
CVR	**ràn**dá: **mán**dá: **mân**tá:	large water pot dark Bornu medicinal salt forgot
CVV	**mà:**má: **rá:**ná: **lâ:**lá:	breast sun indolence

Appendix 3. Cantonese corpus

Syllable Type	Word	Gloss
CV	mà	to curse
CVO	làp	to stand
CVR	sàm	very
CVVO	là:p	to cure meat
CVVR	là:m	to (use) indiscriminately

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