*Syllable Weight**

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1 Introduction

The goal of this chapter is to explore the role which phonetics plays in shaping the phonology of syllable weight. Standard (moraic and skeletal slot) treatments of weight assume that weight criteria (i.e. what syllables count as "heavy") may vary from language to language; but that all phonological processes within a given language will employ a uniform weight criterion. An extensive survey of weight-sensitive phonological phenomena shows the very opposite, however: weight criteria are frequently non-uniform within a given language, but there is considerable consistency for each particular weight-sensitive phenomenon. In this chapter, I adopt a phonetic approach to explaining this finding, focusing on the particular cases of weight-sensitive stress and tone. I argue that stress and tone systems respect different criteria of weight because of the differences found in the phonetic implementation of stress and tone. In addition, I argue that phonetics can play a role in accounting for cross-linguistic variation in weight criteria for a given process: such variation can be attributed to independent phonetic properties of these languages, which are in turn grounded in other phonological properties such as the inventory of coda consonants.

I will argue in addition that the influence of phonetics in phonology is not direct, but rather is mediated by structural considerations. In particular, languages employ weight distinctions which operate over PHONOLOGICALLY SYMMETRICAL classes of syllables, even if this means not exploiting the phonetically most effective weight distinction(s).

Finally, I will argue that the ingredients of process-specificity of weight criteria, phonetic effectiveness, and phonological simplicity together play a crucial role in the ranking of a set of formal Optimality-theoretic constraints governing weight-sensitive phenomena. The divergent phonetic motivations behind different weight-sensitive processes are reflected in process-specific sets of constraints. Within individual phenomena, constraints referring to the phonetically most effective of the simple weight distinctions are ranked on a language-specific basis above constraints referring to phonetically less effective or more complex distinctions.

2 Background

2.1 Weight as a Phenomenon

Linguists have long observed that many languages display phonological phenomena which treat certain syllable types as heavier than others (e.g. Jakobson 1931, Allen 1973, etc.). For example, stress in Yana falls on the leftmost syllable which is closed or contains a long vowel (Sapir and Swadesh 1960). In words without closed syllables and long vowels, stress falls on the first syllable. Thus in Yana, closed syllables (CVC) and syllables containing long vowels (CVV) are "heavier" than open syllables containing a short vowel (CV).

Other phonological phenomena can also be weight-sensitive. For example, in many tone languages, syllables differ in terms of the range of tonal contrasts which they may support. Thus, while most languages allow level tones on all syllable types, many restrict contour tones to certain heavy syllables. For example, in Kiowa (Watkins 1984), contour tones are restricted to CVV and syllables closed by a sonorant coda (CV[+son]). Contour tones may not occur on CV or on short-voweled syllables closed by an obstruent (CV[-son]).

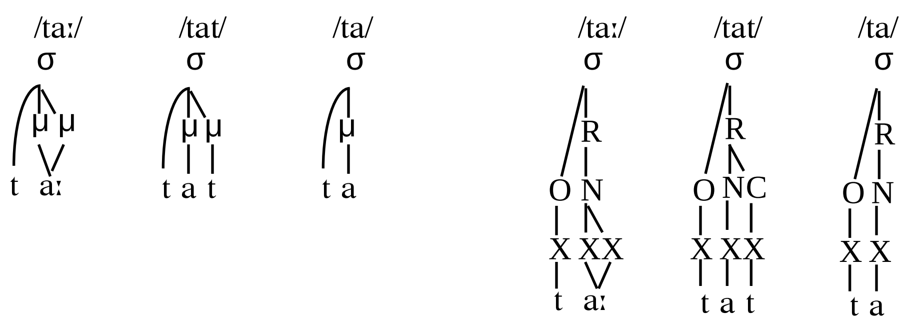
Other phenomena in addition to stress and tone have been linked to weight: minimal word requirements (McCarthy and Prince 1986,1995), metrical scansion (Hayes 1988), compensatory lengthening (Hayes 1989), reduplication (McCarthy and Prince), and syllable templatic restrictions such as prohibitions against long vowels in closed syllables (McCarthy and Prince). It is thus clear that syllable weight plays an important role in phonological theory.

2.2 Representations of weight

Two representations of weight which have gained wide acceptance in phonological theory are skeletal slot models, including CV and X slot models (McCarthy 1979, Clements and Keyser 1983, Levin 1985), and moraic models (Hyman 1985, Hayes 1989). The appeal of both of these models is that they assume representations which are projected from properties of the underlying representation such as segment count and phonemic length. Units of weight, either skeletal slots (in CV and X slot models) or moras, are assigned to segments. In the case of moraic theory, the only segments which are eligible to receive a mora are those in the syllable rime, the relevant domain of weight in most cases (Hyman 1985, Hayes 1989). Syllables with a greater number of segments logically receive a greater number of weight units. Similarly, contrasts in segmental length are represented by assuming that long segments are associated with two weight units, while short segments are associated with one unit of weight. Weight distinctions are thus reducible to differences in the number of units of weight in a syllable, and, in the case of skeletal slot theory, the affiliation of timing slots. Syllables with a greater number of weight units are “heavier” than syllables with fewer weight-bearing units. Additionally, in skeletal slot models, it is assumed that weight is calculated over only the nucleus in languages observing either the CVV heavy or the CVV, CV[+son] heavy distinctions (Levin 1985). Sample representations of weight in Yana in Hayes’ (1989) moraic and Levin’s (1985) skeletal slot models appear in Figure 1.

Figure 1. Moraic representations of three syllable types in Yana

a. Moraic　　　　b. Skeletal slot



Differences in tonal weight can also be captured by moraic and skeletal slot models. It is typically assumed that contour tones result from the combination of two level tones (e.g. Woo 1969, Hyman 1985, Duanmu 1994a,b). Thus, a rising tone reflects the combination of a low tone followed by a high tone, while a falling tone is represented as high tone followed by a low tone. Given the compositionality of contour tones, restrictions against contour tones are usually assumed to arise from a prohibition against associations between more than one tone and a single timing position (either a skeletal slot or mora). Because a contour tone consists of two tones, it requires two timing positions on which to be realized in languages with weight-sensitive tone. For example, the Kiowa restriction against contour tones on CV[-son] and CV follows if one assumes that only sonorants are associated with weight bearing timing positions in Kiowa.

2.3 Weight uniformity

An important claim of both theories of weight is that weight criteria may vary from language to language, but are uniform for different processes within the same language (Hyman 1985, McCarthy and Prince 1986, 1995, Zec 1988, Hayes 1989). Latin provides an example of uniformity of weight criteria within a single language: the metrical and stress systems, as well as other quantitative phenomena, treat CVV and CVC as heavy and CV as light (Mester 1994). Comparison of Latin stress with Khalkha stress illustrates the possibility of non-uniformity of weight across languages: the stress system in Khalkha treats only CVV as heavy (Bosson 1964, Walker 1995).

Most representations of weight have captured the assumption that weight is a property of languages by parametrizing weight representations as a function of language. For example, in Hayes' (1989) moraic theory, some languages (e.g. Yana) assign a mora to syllable-final (coda), while others (e.g. Khalkha) do not. Similarly, in skeletal slot models (e.g. Levin 1985), the syllabic affiliation of sonorant consonants is parameterized on a language specific basis: some languages (e.g. Kiowa) syllabify postvocalic sonorant consonants in the nucleus, while others (e.g. Yana and Khalkha) syllabify them as codas.

Several counterexamples to the moraic uniformity hypothesis have surfaced in recent literature, e.g. Steriade (1991), Crowhurst (1991), Hyman (1992), Hayes (1995). For example, Steriade (1991) shows that the stress system, the system of poetic metrics, and the minimal root requirement of Early and Classical Greek are sensitive to different weight criteria from the pitch accent system. At both historical stages of Greek, the stress and metrical systems as well as the minimal root requirement treat both CVV and CVC as heavy. Pitch accent weight criteria are more stringent, however, at both stages. In Early Greek CVV and CV[+son] are heavy, while in Classical Greek only CVV is heavy for purposes of pitch accent placement. Another example of conflicted weight criteria comes from Lhasa Tibetan (Dawson 1980). In Lhasa Tibetan, CVV is heavy for stress, while CVV and CV[+son] are heavy for tone; thus, if we conflate weight criteria for both phenomena, we get the three-way hierarchy: CVV > CV[+son] > CV. Crowhurst (1991), Hyman (1992), and Hayes (1995) present additional cases of non-uniformity of weight criteria within a single language.

Cases of conflicted weight criteria are problematic for two reasons. First, there is the issue of representing them, which necessarily require reference to at least three levels of weight in a single language. To see this, consider the case of Lhasa Tibetan. If one represents the three-way weight hierarchy in terms of mora count, CVV would need to be trimoraic to be heavier than CV[+son], which would be bimoraic, and CV, which would be monomoraic. CVV should only be bimoraic, however, in moraic theory, which assumes that representations are projected from segment count and phonemic length distinctions. Furthermore, the assumption that tones link to weight-bearing units in one-to-one fashion in languages with weight-sensitive tone would be violated if CVV were trimoraic. The representation of the Lhasa Tibetan facts is also problematic for skeletal slot theories, in which there is no straightforward way to represent the Lhasa distinction between CVV and CV[+son]. The difference between CVV and CV[+son] cannot be captured by assuming that weight for stress is calculated over the nucleus and weight for tone is determined over the rime, since CV[-son] also contains a branching rime but is nevertheless light for both tone and stress.

A second and more fundamental challenge presented by cases of conflicted weight criteria concerns the basic conception of weight as a language-driven rather than a process-driven phenomenon. Given the increasing number of cases of conflicted weight criteria reported in the literature, it seems worthwhile to explore systematically the alternative and equally plausible hypothesis that weight is more a function of process rather than language. Under this view, variation in weight criteria would be attributed principally to differences between weight-based *phenomena* in the weight distinctions they characteristically employ, rather than to differences between *languages.* For example, it could turn out that weight-sensitive tone tends to observe different weight criteria than weight-sensitive stress and that this process specificity accounts for many cases of conflicted weight criteria. If this scenario turned out to be true, the focus of the theory of weight should shift from explaining how and why languages differ in terms of their weight criteria to addressing how and why weight criteria differ between weight-sensitive phenomena.

Exploring weight as not only a language-driven but also a process-driven property also has the potential to provide insight into cases of weight uniformity. For example, suppose that codas were characteristically weightless for both tone and stress systems. Crucially, if this were true, even if one were to find a language in which coda consonants were weightless for both tone and stress, this convergence of weight criteria would not provide support for the view that weight is uniform as a function of language. The moral of this story is that, when considering the evidence for uniformity of weight, it is as important to pay attention to the cross-linguistic weight patterns displayed by a single process as to any convergences or divergences of weight criteria within the same language.

3 A cross-linguistic survey of weight

In order to gain a better understanding of the cross-linguistic distribution of weight, I conducted a survey of six weight-sensitive phenomena (stress, tone, poetic metrics, compensatory lengthening, minimal word requirements, and syllable template restrictions) in approximately 400 languages (Gordon 1999). In brief, the findings of the survey strongly suggest that weight is more process-driven than language driven: that is, there are as many, if not more, languages with conflicted weight criteria than there are languages with uniform weight criteria, while there is a relatively high degree of divergence between phenomena in their cross-linguistic cross-linguistic distribution of weight criteria.

The first result of the survey is that syllable weight observes a hierarchy, where CVV is heaviest, followed by CV[+son], followed by CV[-son], and finally by CV, as shown in (1) (see also Zec 1988).

(1) CVV > CV[+son] > CV[-son] > CV

For a given phenomenon, languages draw different cut-off points between heavy and light syllables along this hierarchy according to which syllables are heavy. For example, Kiowa's tonal system draws a division between CV[+son] and CV[-son] in the hierarchy. CV[+son] and syllable types to its left, i.e. CVV, are heavy, while CV[-son] and syllables to its right, i.e. CV, are light. The Yana stress system, on the other hand, makes its cut between CV[-son] and CV. CV[-son] and syllables to its left are heavy, while CV is light. Crucially, a syllable is not heavier than one to its left in the hierarchy.[1]

A second finding of the survey which bears directly on the issue of weight uniformity is that processes differ in their distribution of weight criteria. This is shown in Table 1, which depicts the number of languages displaying a given weight criterion for four of the six phenomena under discussion; compensatory lengthening and syllable template restrictions are excluded they are intrinsically deficient in the range of weight criteria they are capable of diagnosing (see Gordon 1999 for discussion of these phenomena). For reasons of space, Table 1 is limited to the three criteria accounting for virtually all variation in weight criteria cross-linguistically: CVV heavy; CVV, CVC heavy; CVV, CV[+son] heavy. The distribution of weight criteria for stress, which displays greater cross-linguistic diversity in weight criteria than other phenomena, is discussed in section 5.1.

Table 1. Weight criteria for different processes

		Process			
		Stress	Tone	Metrics	Minimal Word
Criterion	CVV heavy	**35**	**21**	0	**17**
	CVV, CVC heavy	**40**	**3**	**16**	**80**
	CVV, CV[+son] heavy	**3**	**25**	0	0

Minimal word requirements are heavily biased in favor of the CVV, CVC heavy criterion, though there are a substantial minority of languages observing the CVV heavy criterion, unlike in poetic metric systems. Stress systems are almost equally split between the CVV heavy and the CVV, CVC heavy criteria, with a very small number of CVV, CV[+son] heavy languages. Tone, on the other hand, rarely observes the CVV, CVC heavy criterion and is almost equally divided between languages with the CVV heavy criterion and those with the CVV, CV[+son] heavy criteria. Particularly instructive is the comparison of the CVV, CVC heavy and the CVV, CV[+son] heavy criteria for stress and tone: the CVV, CV[+son] criterion is quite common for tone but vanishingly rare for stress, whereas the converse is true for tone. On the other hand, the CVV, CVC heavy criterion is strikingly rare for tone, but is very common for stress. This distributional asymmetry between tone and stress will be attributed in sections 4 and 5, respectively, to differences in the phonetic factors underlying both phenomena.

Differences in the distribution of weight criteria between different processes can be examined statistically by means of a chi-squared test, which assesses differences between pairs of phenomena in the relative proportion of languages displaying a given weight criterion. A chi-squared test indicates that all pairs of phenomena with the exception of poetic metrics and minimal word requirements differ significantly from each other (at the $p<.01$ level) in their distribution of weight criteria. In summary, comparison of the distribution of weight criteria for different processes argues against the hypothesis that weight criteria are sensitive to individual languages and not to individual processes. If weight were primarily language-driven we would not expect processes to differ as much as they do in their cross-linguistic distribution of weight criteria.

It is also possible to test directly the standard assumption that weight criteria are uniform for different processes within the same language by examining languages in the survey with more than one weight-sensitive phenomenon. The most probative languages for testing the weight uniformity hypothesis are those containing multiple weight-sensitive phenomena with differing cross-linguistic distributions in weight criteria, since any convergences in weight criteria between processes with similar weight distributions would be more likely attributed to process-internal rather than language-internal consistency of criteria. Thus, in virtue of the processes involved, we would a priori expect a high degree of convergence in any pairwise comparison of criteria for metrics, syllable template restrictions, and minimal word requirements in a given language possessing at least two of these phenomena. This is in fact what we tend to find: eight of nine languages with both weight-sensitive poetic metrics and a minimal word requirement observe the same criterion, and all four languages with both a weight-sensitive metrical tradition and a syllable template restriction observe the same criterion. Rather striking is the high degree of conflictedness in criteria between syllable template restrictions and minimal word requirements: only seven of thirteen languages with both phenomena observe the same criterion, a finding which strongly contradicts the weight uniformity hypothesis. The weight uniformity hypothesis does not fare any better in other pairwise comparisons between phenomena in individual languages. For virtually all other comparisons (stress vs. tone, stress vs. syllable template restrictions, stress vs. minimal word requirements, tone vs. metrics, tone vs. minimal word requirements), agreement percentages hover at or below fifty percent (see Gordon 1999 for more in-depth discussion). If we compare stress and tone, the focus of this chapter, more closely, we see that, of the four languages in the survey which allow coda consonants and which have both weight-sensitive tone and stress, in two of them, Krongo (Reh 1985) and Cherokee (Wright 1996), weight criteria for tone and stress agree (CVV heavy in both languages), while in another two languages, Classical Greek (Steriade 1991) and Lhasa Tibetan (Dawson 1980), weight criteria disagree. The only pairwise comparison which yields a relatively high level of language internal consistency is the comparison of stress and metrics, for which 6 of 8 surveyed languages with both phenomena agree in criteria (see Gordon 1999 for analysis of the tendency for stress and metrical systems to observe similar weight criteria).

The upshot of the survey is that weight criteria do not tend to converge any more than one would expect by chance and by considering the cross-linguistic distribution of weight criteria for different phenomena. A greater success level in predicting weight criteria is thus achieved through consideration of the process-internal distribution of weight criteria rather than through language-internal comparison of weight criteria for different phenomena.

Given the divergence between different weight-sensitive phenomena in their cross-linguistic distributions of weight criteria, it is natural to seek explanations for weight in terms of factors unique to individual phenomena. Throughout the rest of this chapter, I focus on weight-sensitive stress and tone (see Gordon 1999 for discussion of other phenomena), arguing that differences in their phonetic conditioning factors lead to different distributions in phonological weight criteria for the two phenomena, i.e. the frequent observance of the CVV, CVC heavy criterion for stress and its corresponding rarity in tone systems contrasted with the frequent occurrence of the CVV, CV[+son] heavy criterion in tone systems and its rarity in stress systems. In the next section, focus is on the phonetic underpinnings of weight-sensitive tone.

4 The phonetic basis for weight-sensitive tone

The physical correlate of tone is fundamental frequency which is only present in voiced segments (see Maddieson 1978 for cross-linguistic observations about tone; see Beckman 1986, House 1990, and Moore 1995 for further discussion of its perceptual correlates). 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.

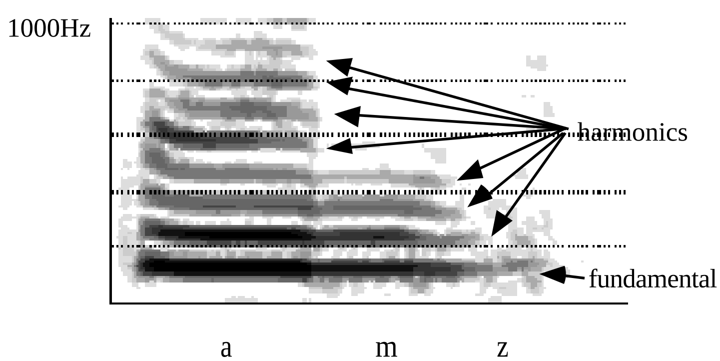
Crucially, the fundamental frequency profile of a segment or syllable (and hence its tonal profile) is cued not only by the fundamental itself but also by harmonics, which occur at frequencies which are multiples of the fundamental. Thus, a signal with a fundamental frequency of 200Hz will have harmonics 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 (House 1990, Moore 1995).

Segments differ in the intensity of these crucial harmonics. Because vowels typically have the most energy at higher frequencies, their higher harmonics have greater intensity than those of consonants. Voiced sonorant consonants also possess a fairly 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 sonorants. Thus, voiced obstruents are inherently impoverished relative to voiced sonorants in terms of their tonal salience. One 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.[2] A further factor contributing to the characteristic weightless status of obstruents in tonal weight is the relative rarity of languages with voiced coda obstruents.

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, 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 relatively weak.

The relative salience of tonal information realized on 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 CV[+son], followed by CV[-son], followed by CV. This hierarchy mirrors the phonetic hierarchy of tonal salience 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 CV[+son] and CV[-son] 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 discussed in section 3, CVV > CV[+son] > CV[-son] >CV, thus reduces to a hierarchy characterizing the relative ability of different segment types able to support phonetically the latter portion of the contour: V > R > O > Zero, where the difference between O and zero is not particularly robust (see earlier discussion). The interested reader is referred to Zhang (this volume) for further discussion of weight-sensitive tone.

5 Weight-sensitive stress

Throughout the rest of the paper, I will focus on weight-sensitive stress, which provides an instructive contrast to weight-sensitive tone, both in terms of its phonetic underpinnings and its resulting phonological distribution. I will argue that, unlike tone, weight-sensitive stress is sensitive to the total energy of the syllable rime, including both sonorant and non-sonorant energy. Examination of weight-sensitive stress also suggests that weight is guided not only by considerations of phonetic effectiveness but also by principles of phonological simplicity.

5.1 The role of structural simplicity in syllable weight

An interesting feature of syllable weight is the recurrence of relatively simple and symmetrical weight criteria in language after language. To take an example from stress (equivalent examples can be found for tone and other weight-sensitive phenomena), many languages treat all syllables containing long vowels as heavy (e.g. Khalkha Mongolian), whereas others treat all syllables with branching rimes, i.e. CVV and CVC, as heavy (e.g. Yana). Still others treat all syllables containing a certain vowel quality as heavy, e.g. full vowels in Javanese (Herrfurth 1964) and low vowels in Yimas (Foley 1991). We do not find, however, languages with very complex and asymmetrical criteria even if such criteria might be plausible on purely phonetic grounds, e.g. languages in which long voweled syllables and those containing low vowels followed by sonorants are heavy, or languages in which low vowels followed by a sonorant coda are heavy. An intuitive explanation for the absence of such hypothetical criteria is that they are too complex. A major part of the theory of weight proposed here is a limitation on the structural complexity of the available distinctions; the choice of the most phonetically effective distinctions is made only from among the simpler criteria (see Hayes 1999 for similar claims about postnasal voicing).

Despite its intuitive relevance, defining structural complexity is a very difficult issue. What follows is one proposal that is fully explicit and matches well with my survey data; other possibilities surely exist and remain to be explored.

As a starting point in the discussion of complexity, it is useful to consider in Table 2 representative weight distinctions (and the number of languages instantiating each distinction) found in the survey of weight-sensitive stress systems in Gordon (1999).

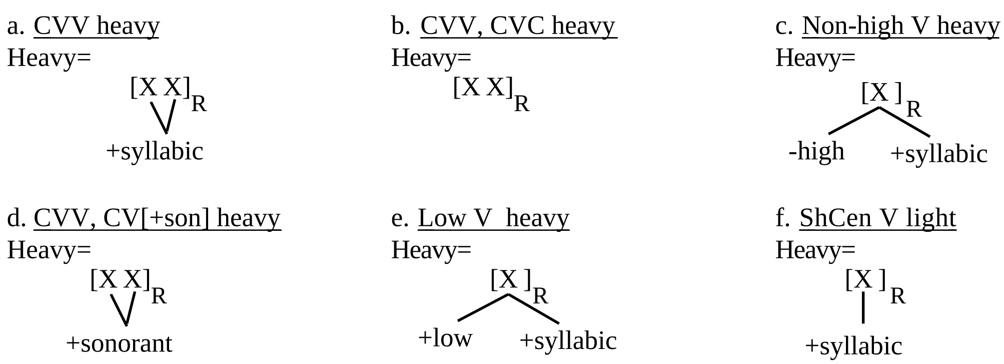
Table 2. Summary of representative weight distinctions

Weight distinction	No. of lgs.	Example language
CVV heavy	43	Khalkha
CVV, CVC heavy	43	Yana
CVV, CV[+son] heavy	4	Kwakw'ala
Low V heavy	5	Yimas
Non-high V heavy	3	Komi Jaz'va
Short-central V light	15	Javanese

Complex weight hierarchies can be decomposed into a series of binary weight distinctions. For example, the CVV > CVC > CV hierarchy, found in Klamath (Barker 1964) and Chickasaw (Munro and Willmond 1999, Gordon 1999) consists of two weight distinctions: CVV > {CVC, CV} and {CVV, CVC} > CV.[3]

Let us now consider some phonological predicates which define heavy and light syllables for the distinctions in Table 2. The overall goal will be to provide representations which offer a means of characterizing weight distinctions. A theory-neutral notion of weight unit is assumed here, with all segments in the rime receiving one weight unit, except for phonologically light central vowels, which are assumed, following Kager (1990), to lack their own weight unit in virtue of their extremely short phonetic duration.[4] Figure 3 depicts representations characterizing the set of heavy syllables for the weight distinctions in Table 2.

Figure 3. Representative weight distinctions



The representations in Figure 3 define the set of heavy syllables in a language and serve to differentiate them from the light syllables in that language. For example, according to the CVV heavy criterion, all syllables containing at least two [+syllabic] timing positions in the rime are heavy. Most of the other representations in Figure 3 are straightforward with the possible exception of the one in (f). Adopting the assumption that short-central vowels lack a weight unit of their own, this distinction treats a syllable containing a syllabic timing position as heavy.

Given the representations in Figure 3, we can hypothesize on the upper limit of complexity tolerated by weight distinctions. Most weight distinctions refer to only non-place predicates, i.e.

timing units and non-place features. The two distinctions which refer to place refer to a place feature linked to only a single timing unit. There are no distinctions which refer to a place feature linked to more than one timing unit, as in a hypothetical distinction which treat long low vowels as heavy or one which treats long non-high vowels as heavy. Given the set of distinctions in figure 3, I thus offer the following definition of complexity as a working hypothesis: A weight distinction is too complex if it refers to more than one place predicate. I also assume that weight distinctions which require disjoint representations of the heavy syllables are trivially complex, even if they only refer to a single dimension. Thus, for example, a weight distinction which treats long vowels and syllables closed by a lateral as heavy is complex, since there is no single representation of the syllable which encompasses both long vowels and syllables closed by lateral. The reason for this is that long vowels contain no [+lateral] timing positions; there is thus no way for the second timing position in the rime to be both simultaneously [+lateral] and [+syllabic].[5] The definition of complexity is formalized in (2).[6]

(2) Definition of complexity

A weight distinction is complex iff it refers to more than one place predicate.

OR

It makes reference to disjoint representations of the syllable.

This definition of complexity also allows for other sporadically attested weight distinctions not in Table 2 (see Gordon 1999, 2001a for discussion). As we will see in the phonetic case studies in section 5.8, the notion of phonological simplicity plays an important role in eliminating certain weight distinctions from the set of a priori logically possible weight distinctions, many of which are phonetically very effective.

5.2 Phonetic effectiveness and weight-sensitive stress

In this section, I examine the importance of phonetics in guiding the language-specific choice of weight criteria for a given phenomenon, in this case, weight-sensitive stress, though the same claims could be made for other processes. I will argue that languages choose their weight distinctions in order of phonetic effectiveness from among the phonologically simple weight distinctions. The relevance of phonetics in driving weight on a language-specific basis is thus shown to complement its role in predicting process-specific differences in weight of the type observed by comparing tone and stress systems.

Phonetic effectiveness may be defined as the degree to which a particular weight division separates syllables into two maximally distinct groups. In other words, the most effective division of syllables has heavy and light syllables which are most different from each other along a given phonetic dimension. The motivation for this metric of phonetic effectiveness is perceptual. It is hypothesized that languages prefer to rely on weight distinctions based on the largest phonetic differences, since distinctions based on larger phonetic differences are easier to perceive and thus to learn than distinctions based on smaller differences. Furthermore, distinctions relying on relatively large phonetic differences are plausibly easier to deploy, since they harmonize with inherent phonetic prominence. Phonetic and perceptual distinctness (or conversely, lack of distinctness) have been argued to play an important role in phonology in such diverse areas as the construction of segment inventories (cf. Liljencrants and Lindblom 1972, Lindblom 1986), neutralization processes eliminating phonetic contrasts which are difficult to implement in a perceptually salient manner (Steriade 1999, Flemming this volume), and phonological processes which strive to preserve or create maximally distinct segments or combinations of segments (Flemming 1995).

In the present study, phonetic effectiveness was examined along two phonetic dimensions: the duration of the syllable rime and the energy of the syllable rime. The procedures for measuring duration and energy, and the languages and corpora from which measurements were made are discussed in sections 5.3-5.7. Results are presented in section 5.8.

5.3 Languages

To examine the phonetic basis for weight-sensitive stress, six languages displaying various weight distinctions for stress were investigated. Languages were chosen which represented a cross-section of attested weight distinctions, including the most common distinctions (see Gordon 1999). This paper will consider results from three languages, one employing the CVV heavy criterion

(Khalkha), one with the CVV, CVC heavy criterion (Finnish), and one observing the three-way hierarchy CVV > CVC > CV (Chickasaw). The CVV heavy and the CVV, CVC heavy criteria are the two most common criteria for stress; the hierarchy CVV > CVC > CV is the most common three-way distinction. Results for Khalkha, Finnish, and Chickasaw are similar to those found in other languages, data for which is found in Gordon (1999, 2001a).

5.4 Corpora

A corpus of two syllable words of the form (C)V(:)C.CV(C) was constructed for each language, varying the rime of the first syllable, the target syllable, and keeping the vowel in the other syllable constant. Within each language, the first syllable was either phonologically stressed for all words in the corpus, or, in the case of Chickasaw, was phonologically unstressed for all words. The second syllable was unstressed in languages other than Chickasaw and stressed in Chickasaw. By keeping stress uniform for all target syllables, a difference in stress level between different syllable types is eliminated as a potential confounding factor. The rimes appearing in the first syllable were varied according to the vowel quality and length (if long vowels occurred in the language) of the syllable nucleus. Three vowel qualities were examined: /i, u/ and a low vowel, either /a/ or /ɑ/. Rimes containing /i/ were not measured in Khalkha due to confounds created by the vowel harmony system. Rimes containing /u/ were not measured for Chickasaw due to the absence of this vowel in the inventory. In order to create a more manageable data set for measurement, diphthongs and mid vowels were not examined in any of the languages. Short vowels were examined in both open syllables and syllables closed by a different member of a set of coda consonants; for example, by different sonorant codas and coda obstruents (if tolerated by the language). The set of coda consonants and the vowels examined for each language is listed in Table 3.

Table 3. Vowels and codas measured for Chickasaw, Khalkha, and Finnish

Language	Vowels and codas measured
Chickasaw	a, i, aː, iː, m, n, l, ʃ, ɬ, b, k
Khalkha	ɑ, u, ɑː, uː, m, n, l, r, s, ʃ, x, k, g
Finnish	ɑ, i, u, ɑː, iː, uː, m, l, r, s, t

5.5 Measurements

Recall from section 4, that weight-sensitive tone is claimed to be sensitive to the energy profile of the sonorant portion of the syllable rime. The phonetic underpinnings behind weight-sensitive stress are not as transparent as those underlying tone, however, as stress is often associated with multiple acoustic properties.

For the present study, duration and energy were targeted as phonetic dimensions for investigation because they are closely linked to the realization of stress in many languages. It is a well-known observation that both increased energy (along with its perceptual correlate loudness) and duration are common phonetic correlates of stress. In many languages, stressed syllables are either longer or louder than unstressed syllables or are *both* longer *and* louder than unstressed syllables. This has been shown for English (Fry 1955; Beckman 1986), Polish (Jassem et al. 1968), Mari (Baitschura 1976), Indonesian (Adisasmito-Smith and Cohn 1996), Dutch (Sluijter and van Heuven 1996), etc. and impressionistically noted for many other languages.

Six to eight tokens of each word were recorded from one speaker in each language. Words were read in random order and appeared in a carrier phrase. Data were digitized at 16kHz using Kay Computerized Speech Lab. Two measurements were made for each rime: duration and a measure which may be termed **total perceptual energy**: the integration of energy over time in the perceptual domain). A measure of total energy rather than average intensity is most relevant for testing the link between energy and weight-sensitive stress, since psychoacoustic experiments suggest that the ear integrates intensity and time over durations of the magnitude common for syllables in natural speech (see Moore 1995 for a review of the relevant literature).

The procedure for measuring total perceptual energy was as follows. First, in order to control for token to token variation in speaking level, average amplitude (RMS) in decibels for each target vowel and the following coda consonant (if any) was calculated relative to a reference vowel. This reference vowel, which was the vowel in the other (non-target) syllable, was kept constant for each set of comparisons. Second, the average amplitude of each segment in the target rime was converted to a value representing perceived loudness relative to the vowel in the second syllable. Perceived loudness was computed on the basis of Warren's (1970: 1399) results in experiments designed to measure relative perceived loudness of tones. While Warren's results are based on a different type of stimulus than real speech, they serve as a reasonable and also tractable estimate of the relationship between acoustic energy and perceived loudness. Third, the relative loudness value for each segment was multiplied by the duration of the segment to yield a total energy value for the segment. Finally, if the rime contained a coda, total energy values for the vowel nucleus and the coda were added together yielding a total energy value for the rime.

5.6 Phonetic evaluation of potential weight criteria

Along the two phonetic parameters of duration and total energy, the syllables measured in a given language were bisected a number of different ways, with each bisection representing a different weight distinction. In determining the phonetic effectiveness of different weight distinctions, the goal was to test all reasonable distinctions against the phonetic data. A total of 55 weight distinctions were tested, though not all weight distinctions were tested in every language due to gaps in the inventory of syllable types in certain languages. Furthermore, in some cases, two different distinctions provided the same division of the data. Thus, for example, distinctions based on the voicing of the coda and those based on the sonorancy of the coda divide the data in the same way for Finnish, as the only sonorants in Finnish are voiced and the only coda obstruents in Finnish are voiceless.

The tested weight distinctions were based on several phonological parameters, including duration (i.e. one vs. greater than one timing position) and the features ([high]/[low] for vowels, and [coronal], [dorsal], [labial], [voice], [sonorant] and [continuant] in the case of consonants). In addition, the distinction between CVVC (superheavy) and other syllables was tested for Chickasaw.

5.7 A quantitative metric of phonetic effectiveness

For the parameters of duration and total energy, distinctions were compared in a three step process. First, a one factor analysis of variance was performed treating rime type (e.g. /an/, /am/, /is/, /uk/, etc.) as the independent variable and duration and energy as the dependent variables. The purpose of this initial analysis was merely to determine whether syllable type had an effect on duration and energy values.

The second step was to compare the mean values for heavy and light syllables for each weight distinction. Weight distinctions for which the means for heavy and light syllables were most divergent were deemed to be the most effective weight distinctions. Because they are not dependent on number of tokens, differences in means were used to determine the relative effectiveness among the weight distinctions. The metric of phonetic effectiveness adopted as a differentiator of weight criteria is summarized in (3).

(3) Definition of phonetic effectiveness

> A weight distinction *x* is more effective than a weight distinction *y*, if the difference between the mean energy of heavy syllables and the mean energy of light syllables for distinction *x* is greater than the difference between the mean energy of heavy syllables and the mean energy of light syllables for distinction *y*.

The final step involved in examining the phonetic effectiveness of different weight distinctions was to perform a discriminant analysis for each distinction to determine how well each one sorted syllables into heavy and light groups. Each weight distinction was treated as a categorical variable with two values, one for light syllables and another for heavy syllables. Significance levels and Wilkes' lambda values for each weight distinction were examined to determine how reliable various weight distinctions were in differentiating heavy and light syllables. Lower Wilkes' lambda values generally indicate greater robustness in the statistical difference between heavy and light syllables.

5.8 The link between energy and language-specific weight distinctions

This section presents the results of the phonetic study of the link between duration and energy and phonological weight. Strikingly, there was a very close overall association between weight criteria and total energy. Phonological weight distinctions chosen by languages were the ones which were phonetically most effective along the energy dimension. Duration, on the other hand, was a less effective predictor of certain weight criteria than energy. In particular, duration did not predict the CVV heavy distinction in languages with this weight criterion (see Gordon 1999, 2001a for discussion of duration, and also Broselow et al. 1997, who find a correlation between duration and weight in three languages).

5.8.1 Chickasaw: CVV > CVC > CV

Let us begin with Chickasaw, a language which makes a ternary weight distinction of the CVV > CVC > CV type, the most common three-way weight hierarchy (Munro and Willmond 1999, Gordon 1999). As a first step, an analysis of variance was conducting to determine whether rime type had a significant effect on energy values. This ANOVA indicated a highly significant effect: $F (21,153) = 15.215$, $p<.0001$. In Table 4, the relative effectiveness of different weight distinctions in Chickasaw is compared. Distinctions are ordered from top to bottom with the phonetically more effective distinctions (as described in section 5.7) on top. Mean values are normalized as a ratio relative to the top ranked distinction which is assigned an arbitrary value of 100. For example, a weight distinction with a value of 50 in Table 4 has a 50% smaller difference in energy between heavy and light syllables than the top ranked distinction. Table 4 also includes Wilkes' lambda values and significance levels according to the discriminant analyses.

Note that all of the ties in Table 4 between two weight distinctions are the result of two weight divisions completely overlapping. For example, the first two distinctions in the column of complex distinctions, the distinction between long low vowels and other rimes (i.e. /aː/ heavy) and the distinction between long back and long low vowels and other rimes (i.e. /aː/ and /uː/ heavy), are equivalent for the data set examined, since Chickasaw does not have a long /uː/. Equivalent weight distinctions of this sort are surrounded by brackets. The bold-faced distinctions are the ones actually employed by the language being examined, in this case, Chickasaw. Due to space constraints, only the complex distinctions which are superior to at least one of the actual phonological distinctions are listed in Table 4, and in subsequent tables for other languages. All of the simple distinctions after the phonological ones are listed in order of relative phonetic effectiveness according to differences between means. Note the following abbreviations in Table 4 and subsequent tables: [+voi] represents a voiced consonant, [-voi] a voiceless consonant, [+cont] a continuant, [-cont] a non-continuant, [+nas] a nasal, [-nas] a non-nasal, [+lab] a labial, [-lab] a non-labial, [+cor] a coronal, [-cor] a non-coronal, [+dor] a velar and [-dor] a non-velar.

Table 4. The most effective weight distinctions in Chickasaw

SIMPLE				COMPLEX			
Distinction	Diff	W-λ	p-val.	Distinction	Diff	W-λ	p-val.
				/aː/ heavy	100	.657425	.0000
				/aː,uː/ heavy	100	.657425	.0000
VV heavy	**80.6**	**.603375**	**.0000**	/aː,iː/ heavy	80.6	.603375	.0000
				VV, a[+son] heavy	73.3	.581391	.0000
				VV, a[+nas] heavy	72.5	.612845	.0000
				V, hiV[+dor] light	71.6	.796293	.0000
VV, VC heavy	**71.5**	**.862489**	**.0000**				
VVC heavy	67.8	.799441	.0000				
VV, V[+son] heavy	64.8	.661233	.0000				
VV, V[+voi] heavy	56.3	.760122	.0000				
VV, V[+cont] heavy	55.9	.747150	.0000				
VV, V[-nas] heavy	31.7	.934154	.0006				
+low V heavy	17.7	.974586	.0351				

As can be seen, the two phonetically most effective weight distinctions among the simple distinctions are the ones exploited by the phonology of Chickasaw. The optimal simple distinction is the one referring to the heaviest member of the weight hierarchy, CVV, while the second best simple distinction refers to the two heaviest syllable types in Chickasaw (CVV, CVC). The three way phonological hierarchy thus results from the combination of the top two phonetic distinctions. The Chickasaw data thus supports a match between syllable weight and the phonetic property of energy.

The Chickasaw data also provides corroboration for the importance of phonological simplicity in syllable weight. Six of the top eight weight distinctions are ruled out only by virtue of their complexity. If simplicity did not play a role in the phonology of weight, one would incorrectly expect the phonology to observe the Caː heavy criterion. One would also incorrectly predict several other complex weight distinctions to surface before the CVV, CVC heavy criterion.

5.8.2 Khalkha: CVV heavy

Khalkha Mongolian observes a simple binary weight distinction for stress, according to which CVV is heavy (Bosson 1964, Walker 1995). An analysis of variance indicated a highly significant effect of syllable type on energy: $F(21, 132) = 5.857$, $p<.0001$. Individual distinctions are compared in Table 5.

Table 5. The most effective weight distinctions in Khalkha

SIMPLE				COMPLEX			
Distinction	Diff.	W-λ	p-val.	Distinction	Diff.	W-λ	p-val.
				VV, a[+nas] heavy	100	.634865	.0000
				VV, a[+lab] heavy	99.1	.707726	.0000
VV heavy	**89.7**	**.832069**	**.0000**				
VV, VC heavy	48.1	.948532	.0047				
VV, V[+son] heavy	43.9	.878960	.0000				
VV, V[+voi] heavy	38.8	.905707	.0001				
VV, V[+cont] heavy	13.9	.988034	.1769				
VV, V[-nas] heavy	13.5	.990921	.2398				
+low V heavy	11.9	.991083	.2441				
VV, V[-son] heavy	2.9	.999471	.7770				

Table 5 shows that the phonological weight distinction between CVV and other rimes is the phonetically most effective distinction among the structurally simple weight distinctions. There are only two distinctions which are superior phonetically to the actual phonological distinction: CVV, a[+nas] heavy and CVV, a[+lab] heavy; however, both of these distinctions are structurally complex, since the heavy syllables in both distinctions cannot be united in a single representation Thus, Khalkha provides evidence both for a link between syllable weight and total energy, and also the importance of phonological simplicity in the determination of syllable weight.

5.8.3 Finnish: CVV, CVC heavy

The Finnish stress system treats both CVV and CVC as heavy (Sadeniemi 1949) for purposes of determining the location of secondary stress. An analysis of variance found a highly significant effect of syllable type on energy values: F (21,149) = 34.300, p<.0001. Table 6 lists the relative phonetic effectiveness of different weight distinctions in Finnish.

Table 6. The most effective weight distinctions in Finnish

SIMPLE				COMPLEX			
Heavy	Diff	W-λ	p-val.	Heavy	Diff	W-λ	p-val.
VV, VC heavy	**100**	**.431361**	**.0000**	V, hiV[+dor] light V, V[+dor] light VV, V[-dor] heavy	100 100 100	.431361 .431361 .431361	.0000 .0000 .0000
				hiV in open σ light	99.5	.603583	.0000
VV, V[+son] heavy VV, V[+voi] heavy	62.6 62.6	.554805 .554805	.0000 .0000				
VV, V[+cont] heavy	57.2	.628306	.0000				
VV heavy	53.8	.835684	.0000				
VV, V[-nas] heavy	52.8	.735541	.0000				
-back V heavy	12.0	.985190	.1161				
+low V heavy	1.1	.999879	.8872				

As Table 6 shows, the link between energy and phonology is quite strong, as in other languages: the phonological weight distinction is also the most effective distinction phonetically. It is ranked ahead of all other weight distinctions, both simple and complex.

5.8.4 The phonetics of syllable weight: a summary

The experimental data in the preceding sections indicate a number of important facts. First, in all of the languages with weight-sensitive stress, the phonological weight distinction(s) are also the phonetically most sensible (as determined by total energy) of the simple distinctions. Although space constraints do not permit showing all the data here, a similarly good fit between phonetic effectiveness and phonological weight obtained for other languages examined in the phonetic study of weight-sensitive stress (see Gordon 1999, 2001a for details). In addition, differences in the language-specific choices in weight criteria for phenomena other than stress turn out to be correlated with language-specific phonetic properties, albeit along different phonetic dimensions than the energy dimension. For examples, language-specific differences in weight criteria for tone are associated with differences in sonorous duration, while differences in weight criteria for syllable template restrictions appear to be correlated with differences in rime duration, i.e. syllable template restrictions reflect an upper limit on the total duration of the rime. The interested reader is referred to Gordon 1999 for discussion of the phonetic motivations behind these and other weight-sensitive phenomena.

An equally important fact emerging from the data is that syllable weight is not sensitive only to phonetic properties. Rather, phonological simplicity plays an important role in Chickasaw and Khalkha in filtering out weight distinctions which may be phonetically quite effective but nevertheless are too complex. Thus, the overall picture which emerges is that syllable weight is the result of compromise between achieving a phonologically simple grammar and a phonetically effective one.

5.9 The influence of phonological structure on phonetic variation

In section 5.8, evidence for a close match between phonological weight for stress and a phonetic measure of energy was presented. What has not yet explored in the context of weight-sensitive stress is the directionality of the relationship between phonetics and phonology. Thus, one may ask whether languages tailor their stress systems to fit their phonetic characteristics or whether languages ad0pt certain phonetic patterns so as to maximize the phonetic effectiveness of their weight systems. A third and intermediate possibility is that the relationship between phonetics and phonology is bi-directional.

Weight-sensitive stress provides arguments for an integrated model of the phonology/phonetics relationship whereby one aspect of phonological structure (specifically, the inventory of coda consonants) influences phonetic properties, which in turn influence the choice of weight criterion. One argument will be considered in detail in section 5.10.1. Further evidence for this phonology/phonetics relationship is considered in Gordon (1999, 2001a).

5.9.1 The function of coda inventories in language specificity of weight criteria

Results of the present study suggest that a basic phonological property of a language, its inventory of coda consonants, can trigger phonetic differences between languages which in turn lead to variation in weight criteria. Some of the relevant data demonstrating the effect of coda inventories on the phonetic dimension underlying weight-sensitive stress comes from comparison of languages observing the CVV heavy criterion for stress and those displaying the CVV, CVC heavy criterion for stress. The exemplar language discussed in this paper which instantiates the CVV heavy criterion is Khalkha, while Finnish employs the CVV, CVC heavy criterion. As has been shown, for both languages, the phonological weight criterion is also the phonetically most effective of the simple weight distinctions.

Interestingly, Khalkha differs from Finnish not only in terms of weight criterion, but also in terms of its inventory of coda consonants. Let us consider the difference along two dimensions: the number of permissible voiceless codas relative to the number of permissible voiced codas, and the number of obstruent codas relative to the number of sonorant codas. The reasons for examining voicing and sonorancy will become apparent shortly.

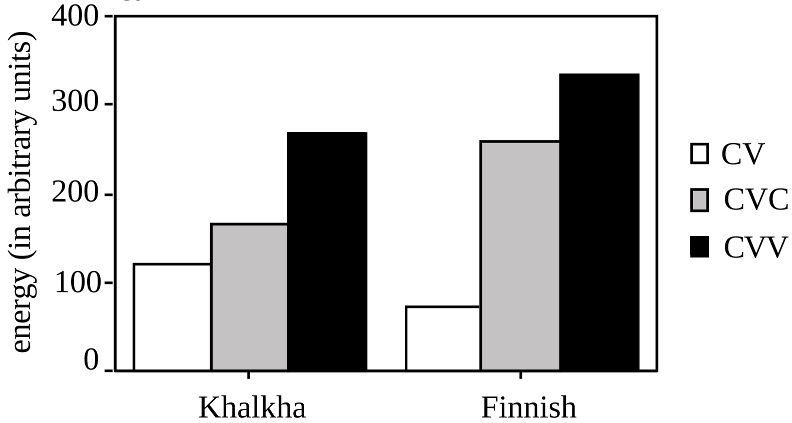
Both the voiceless-to-voiced ratio and the obstruent-to-sonorant ratio for codas is much larger in Khalkha than in Finnish. This structural difference can be seen just by comparing the set of attested voiced codas and voiceless codas in the target languages, without weighing their relative lexical frequencies; for example, if one assumes that all codas (excluding recent loans) are weighted equivalently whether they occur in 10 words or 100 words. Thus, what is claimed to be relevant here is the type frequency, and not necessarily the token frequency. According to Poppe (1951), Khalkha has the following inventory of coda consonants, including codas which are clearly phonemic and those which are allophonic: [p, t, ts, tʃ, k^j, k, s, ʃ, x, m, n, ŋ, l, r, b, g]. If one splits this inventory along the voicing dimension, there are slightly more voiceless codas than voiced codas: nine voiceless codas, [p, t, ts, tʃ, k^j, k, s, ʃ, x], as compared to seven voiced codas, [m, n, ŋ, l, r, b, g]. Divided along the sonorancy dimension, there are eleven obstruent codas, [p, t, ts, tʃ, k^j, k, s, ʃ, x, b, g], and five sonorant codas, [m, n, ŋ, l, r]. Finnish has five sonorant codas, all of them voiced [m, n, ŋ, r, l], and four obstruent codas, all of them voiceless [s, p, t, k].[7]

The reason sonorancy and voicing are relevant to the present discussion is that differences between segments along these dimensions are reliably associated with differences in energy. Sonorants characteristically have greater energy than obstruents and voiced sounds typically have greater energy than voiceless sounds, all else being equal. Although these generalizations are not without exception, sonorancy and voicing are two of the best, if not the best, features for predicting energy values. If one considers the energy of CVC syllables as a whole, CVC will, all else being equal, have greater energy if a larger set of the coda consonants are voiced rather than voiceless. Similarly, CVC will have greater energy if a larger set of the coda consonants are sonorants rather than obstruents. This argument of course adopts the assumption made above that all coda consonants are weighted equally in the calculation of energy for CVC as a whole.

Following this line of reasoning, CVC in Khalkha would thus be expected to have less energy than in Finnish, since Khalkha has both a greater obstruent-to-sonorant ratio and a greater voiceless-to-voiced ratio of coda consonants than Finnish. This hypothesis can, in fact, be tested by examining the energy of CVC relative to both CV and CVV in Khalkha and Finnish. The Khalkha data includes three sonorant codas (m, r, l) and five obstruent codas (s, ʃ, x, k, g). Considered along the voicing dimension, four voiced consonants (m, r, l, g) and four voiceless consonants (s, ʃ, x, k) were included. The Finnish data includes three sonorant codas, all of them voiced, (m, r, l) and two obstruent codas, both of them voiceless (s, t). The corpus for the two languages thus roughly reflect differences between the two languages in the type frequency of voiced relative to voiceless consonants and in the type frequency of sonorants relative to obstruents.

Given the differences in the set of codas examined for Finnish and Khalkha, one would also expect differences in the energy of CVC relative to CVV and CV between the two languages. In particular, CVC should be closer to CVV in energy in Finnish than in Khalkha. Conversely, CVC should be closer to CV in Khalkha than in Finnish. This hypothesis is tested in Figure 5 which contains energy values for CVV, CVC, and CV in Khalkha and Finnish.

Figure 5. Energy values for CV, CVC, and CVC in Khalkha and Finnish



As predicted, CVC is closer in energy to CV than CVV in Khalkha, whereas CVC is closer to CVV than to CV in Finnish. This result corresponds to the difference in the weight of CVC in the two languages. In Khalkha, CVC is light, whereas, in Finnish, CVC is heavy. The overall picture which thus emerges is that one language-specific aspect of the phonological system, the coda inventory, leads to phonetic differences between languages, which in turn are responsible for differences in weight criteria. Positing this link between structural properties and syllable weight via the intermediary of phonetics makes the interesting prediction that weight distinctions are at least partially predictable if one considers the coda inventory of a language. This prediction can be tested by examining the inventory of coda consonants in other languages employing either the CVV heavy or the CVV, CVC heavy distinctions for stress. The account given here would predict that languages with the CVV heavy criterion should have a greater obstruent-to-sonorant coda ratio and/or a greater voiceless-to-voiced coda ratio than languages employing the CVV, CVC heavy criterion.

This hypothesis was tested by examining the set of coda consonants for languages in Gordon's (1999) survey which observe either the CVV heavy or the CVV, CVC heavy criteria for stress and which possess both closed syllables and either long vowels or diphthongs. The inventory of codas was examined for a total of 62 languages. Results, which are presented in greater detail in Gordon

(1999) are summarized here. Of these 62 languages, in 23, both the sonorant-to-obstruent ratio and the voiced-to-voiceless ratio are less than one, and in 24, both the sonorant-to-obstruent ratio and the voiced-to-voiceless ratio are at least one.

Strikingly, of the 23 languages in which both the sonorant-to-obstruent ratio and the voiced-to-voiceless ratio are less than one, 22 employ the CVV heavy criterion, just as predicted by the hypothesis that weight is ultimately determined in large part by coda inventory. The only exceptional language is Yana (Sapir and Swadesh 1960), which has the CVV, CVC heavy criterion yet has sonorant-to-obstruent and voiced-to-voiceless ratios of less than one. Conversely, of the 24 languages in which both the sonorant-to-obstruent ratio and the voiced-to-voiceless ratio are at least one, all but all four observe the CVV, CVC heavy criterion, again as predicted. A chi-squared test in which languages were coded categorically as either containing sonorant-to-obstruent and voiced-to-voiceless ratios of less than one or containing sonorant-to-obstruent and voiced-to-voiceless ratios of at least one confirmed that the close link between coda inventory and weight is not due to mere chance: $\chi^2=29.644$, $p<.0001$.

Future research should investigate the extent to which the phonological weight criteria are the phonetically most effective criteria in languages which are exceptional in either their voiced-to-voiceless coda ratio or their sonorant-to-obstruent coda ratio, or, even more importantly, languages which are exceptional along both dimensions (e.g. Yana). As far as the present research is concerned, though, it is quite striking that coda inventories serve as an excellent predictor of weight criteria, as predicted by the proposed account in which syllable weight is ultimately dependent on coda inventory.

In summary, data presented in this section suggest that certain aspects of the phonology, such as vowel and coda inventory, play an important role in establishing phonetic patterns which in turn are responsible for language-specific choices in weight criteria for stress.

6 A constraint set for weight-sensitive stress

Thus far, we have seen that the phonological weight distinctions in languages are those which are simultaneously phonetically effective and also structurally simple in terms of the phonological dimensions to which they are sensitive. Discussion of the formal representation of weight-based stress has been kept to a minimum thus far, used only in the discussion of structural complexity in section 5.1. In this section, I explore the way in which phonetic conditioning factors can be incorporated into a formal theory of weight. The discussion here will focus on stress (see Gordon 1999 for analyses of other weight-sensitive processes), though a similar relationship between phonetic effectiveness and the formal analysis of weight obtains for other weight-sensitive phenomena, with the dimensions along which phonetic effectiveness is calculated differing between phenomena. Before proceeding in this endeavor, a caveat is necessary. The present proposal is not intended to be a comprehensive metrical theory, which although an integral part of a complete account of syllable weight, goes well beyond the scope of this chapter.

The model which I briefly sketch here as a formalism of syllable weight is couched within an Optimality-theoretic framework (Prince and Smolensky 1993) and follows work by Prince and Smolensky (1993), Kenstowicz (1994) and others in which much of the burden of phonology is shifted from representations to constraints. In their accounts of weight-sensitive stress, Prince and Smolensky (1993) and Kenstowicz (1994) posit constraints referring to different syllable types involved in a hierarchy of prominence. These constraints capture what Prince and Smolensky (1993:38) term "prominential enhancement that calls directly on contrasts in the intrinsic prominence of syllables."

Following the work of these authors, I assume that structurally simple weight distinctions mentioned are reflected in constraints referring to weight-sensitive stress. I further hypothesize that the language learner first tests simple weight criteria against the phonetic map and only proceeds to more complex criteria after the simple ones have proven themselves to be phonetically poor suited to the language. Thus, what is innate is not the set of constraints but the learning algorithm which tests simple weight distinctions before complex ones.[8]

The constraints discussed here refer to stress. All of the representations in section 5.1 which refer to heavy syllables appear as positively stated constraints requiring that the given syllable be stressed. For example, the CVV, CVC heavy distinction is reflected in the high ranking of the constraint in (4).

(4) STRESS $[XX]_R$: CVV and CVC syllables are stressed.

One violation of the constraint is incurred for each instance of an unstressed syllable containing a long vowel.

The structurally simple constraints are ranked on a language specific basis according to how well different weight distinctions fit the phonetic map. More effective weight distinctions in a given language are ranked ahead of less effective distinctions in the family of weight-sensitive constraints. For example, if the CVV, CVC heavy distinction is the optimal phonetic distinction in a language, that language will rank the STRESS $[XX]_R$ constraint above all the other stress constraints. Under this view, the default ranking of constraints in a given language is determined on the basis of phonetic effectiveness. The constraints on stress are interleaved with other constraints; for example, constraints against more than one stress per word, constraints requiring stress in a word, constraints against stress clashes, etc.

In complex weight hierarchies, more than one constraint is ranked highly enough in the grammar to impact the language; for example, in Chickasaw both STRESS $[XX]_R$ and the constraint requiring that syllables containing long vowels be stress are highly ranked.

In the next section, a sample analysis illustrating the interaction between the STRESS constraints and other constraints is presented in the form of a simple example from Yana.

6.1 Yana stress and the STRESS constraints

Recall from the introduction in section 2.1, that in Yana (Sapir and Swadesh 1960), stress falls on the first syllable in a word which is either closed (5a) or contains a long vowel or diphthong (5b). If there are no closed syllables or syllables with a long vowel or diphthong, stress falls on the first syllable (5c). Thus, CVV and CVC are heavy in Yana.

(5) Yana stress
a. sibúmk’ai ‘sandstone’
b. suk’óːniyaː, ‘name of Indian tribe’, ʒáuxauyaː ‘Hat Creek Indians’,
tsiniyáː ‘no’
c. p’údiwi ‘women’

Only a few constraints are necessary to account for Yana. First, the STRESS constraint in (4) requiring that all CVV and CVC syllables be stressed is highly ranked in Yana. A second constraint, universally inviolable in Yana and perhaps in all languages, requires that there be a single syllable in every stress domain which has greater stress than others, following Prince’s (1983) Culminativity condition on metrical representations. This constraint is formulated in (6).

(6) ONE STRESS: A word has one and only one stressed syllable.

The final constraint needed is one which requires that stress fall on the *first* heavy syllable, and if there are no heavy syllables, then on the first syllable. The relevant constraint for Yana is a member of the ALIGN family of constraints, ALIGN (σ́, L, PrWd) (McCarthy and Prince 1993), which requires that stress fall on the first syllable of the word (7).

(7) ALIGN (σ́, L, PrWd): Stresses are aligned with the left edge of a prosodic word; i.e. stresses must fall on the first syllable; one violation is incurred for every syllable separating a stress from the left edge of word.

ALIGN (σ́, L, PrWd): competes with its antithesis, ALIGN (σ́, R, PrWd), which requires that stresses be aligned with the right edge of a prosodic word. The crucial ranking of our three constraints is as in (8).

(8) ONE STRESS >> STRESS $[XX]_R$ >> ALIGN (σ́, L, PrWd)

With these rankings, we are in a position to consider a few sample tableaux for Yana. First, we consider in (9) a four syllable form with a long vowel in the second and final syllables. This form demonstrates that the relevant STRESS constraint is ranked above ALIGN (σ́, L, PrWd).

(9)

Input suk'oːniyaː	ONE STRESS	STRESS [XX]$_R$	ALIGN (σ́, L, PrWd)
☞ a) suk'óːniyaː		*	*
b) suk'oːníyaː		**!	**
c) suk'oːniyaː	*!	**	
d) suk'óːniyáː	*!		****
e) suk'oːniyáː		*	***!
f) súk'oːniyaː		**!	

Candidates (b) and (f) each incur two violations of the STRESS constraint and are destined not to surface. Candidate (f) is crucial, since it indicates that the STRESS constraint is ranked above ALIGN (σ́, L, PrWd). If the opposite ranking obtained, candidate (f) with stress on the initial syllable rather than the first long vowel, would incorrectly emerge as the victor. Candidate (c) is also eliminated from consideration, since it has no stresses, thereby incurring a fatal violation of ONE STRESS. The demise of candidate (d) is also attributed to its violation of ONE STRESS, in this case due to its second stress. Candidate (e) stresses a syllable with a branching rime, but it does not have stress on the branching rime closest to the left edge of the word; hence it commits two more violations of the ALIGN constraint than the winning candidate (a).

In tableau (10), a form containing a closed syllable and a diphthong is considered. The surface form contains stress on the first syllable which is closed or contains a long vowel or diphthong.

(10)

Input: sibumk'ai	ONE STRESS	STRESS [XX]$_R$	ALIGN (σ́, L, PrWd)
☞ a) sibúmk'ai		*	*
b) sibumk'ái		*	**!
c) síbumk'ai		**!	

Finally, we consider in (11) a form with only light syllables. Notice that the leftmost syllable attracts stress in the absence of any heavy syllables. This reflects the ranking of ALIGN (σ́, L, PrWd) over its lower ranked sister ALIGN (σ́, R, PrWd).

(11)

Input: p'udiwi	ONE STRESS	STRESS $[XX]_R$	ALIGN (σ́, L, PrWd)
☞ a) p'údiwi			
b) p'udíwi			*!

ALIGN (σ́, L, PrWd) must crucially be ranked above ALIGN (σ́, R, PrWd); otherwise we would incorrectly get final stress in the form /p'údiwi/.

(12)

Input: p'udiwi	ALIGN (σ́, L, PrWd)	ALIGN (σ́, R, PrWd)
☞ a) p'údiwi		**
b) p'udiwí	*!	

Other weight-sensitive stress patterns are captured by permuting the rankings of the stress constraints referring to different weight distinctions both relative to each other and relative to other constraints bearing on the location and number of stresses. For example, if the constraint requiring stress on syllables with branching rimes is substituted with the constraint requiring stress on syllables containing full vowels, the stress pattern of Au (Scorza 1985) results: Stress the leftmost full vowel, otherwise the leftmost syllable. If ONE STRESS is ranked below the constraint requiring stress on syllables with branching rimes, stress is predicted to fall on all CVV and CVC syllables, as in Koya (Tyler 1969). For further discussion of the factorial typology of weight-sensitive stress, see Gordon (in preparation).

7 Conclusions

In summary, this chapter has presented evidence from tone and stress systems showing that syllable weight has an important process-specific component which is not modeled in standard theories of weight. The basis for the process-specificity of weight is phonetic: weight-sensitive tone and stress differ in terms of the phonetic dimensions along which they operate. The portion of the rime characterized by sonorant energy is the relevant domain for determining weight for tone, whereas weight-sensitive stress is sensitive to the energy profile of the entire rime. Because weight-sensitive tone and weight-sensitive stress differ in their phonetic underpinnings, they display different phonological distributions in their weight criteria.

On the level of specific languages, phonetic considerations were also shown to account for cross-linguistic variation in weight criteria for a single process. The language specific choice in weight criteria for a given phenomenon is linked to language specific phonetic properties. Many, but not all, of these language specific phonetic differences can in turn be attributed to differences between languages in other aspects of the phonological system. The model which thus emerges is one in which phonetics and phonology are interleaved. Certain language specific aspects of the phonology, such as segment inventories and syllable structure (perhaps along with other phonetic properties which cannot reliably be attributed to basic phonological features), shape the phonetic map against which the phonetic goodness of potential phonological weight criteria is evaluated.

The selection of weight criteria is not completely driven by considerations of phonetic goodness, however. Rather, the set of weight criteria being evaluated is constrained by a notion of phonological simplicity, which filters out more complex weight criteria. This reliance on a combination of phonetic effectiveness and phonological simplicity results in adoption of weight criteria which are simultaneously both phonetically and phonologically sensible. Finally, the combination of phonetic effectiveness and phonological simplicity shapes the language-specific ranking of a series of constraint sets, each referring to different weight-sensitive phenomena.

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NOTES

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[1] Cantonese tone presents an apparent exception to this hierarchy of weight. In Cantonese, contour tones may occur on CV[+son], CVV[+son], and CV, but not on CV[-son] and CVV[-son]. As it turns out, however, the vowel in phonemic CV is actually phonetically long, while the phonemic long vowel in CVV[-son] is quite short phonetically (Kao 1971, Gordon 1999). These phonetic observations account for the heavy status of CV and the light status of CVV[-son], the two apparent counterexamples to the hierarchy in the text.

[2] In fact, there is evidence that, in the three languages in the survey (Hausa, Musey, and Luganda) which superficially appear to treat CV[-son] as heavier than CV, the coda obstruent in CV[-son] does not actually support tonal contrasts on the surface (see Gordon 2001b and Zhang this volume, 2001).

[3] Note that, for languages with greater than a binary weight distinction for stress, all distinctions are included in table 2; for example, the Tamil stress system, which observes the hierarchy CVV > CVC > CV, contributes one token to the CVV heavy row and one to the CVV, CVC heavy row.

[4] The representation of short-central vowels is a difficult issue, and one which is logically tied into the matter of how central vowels should be represented. In languages in which centralized vowels are light, they are characteristically quite short (see discussion in Gordon 1999), and thus can plausibly be assumed to lack a timing position. Given this approach, the only cross-linguistic variation in the number of timing positions assigned to segments is between languages in which central vowels are very short in duration and those in which they are not. In languages in which central vowels are very short, they do not carry a timing position. In languages in which central vowels are not particularly short, they are associated with a timing position. In this way, the representation of central vowels is predictable based on duration.

[5] See Gordon (1999, 2001a) for analysis of a weight distinction in Asheninca (Payne 1990), which is predicted to be complex by the complexity metric proposed here.

[6] One might ask why weight distinctions referring to place features are discriminated against from a simplicity standpoint. It is plausible that the reason why place features are penalized more than other types of predicates stems from considerations related to the size of the hypothesis space being tested by learners of a weight system. Place features are distinctive for all segments in a syllable rime, including both vowels and consonants. Non-place features (e.g. manner and voicing features), on the other hand, are typically redundant for at least the vowel in a syllable. Thus, the set of possible contrasts in place of articulation for the entire rime is larger than the set of possible contrasts in manner or voicing. For this reason, it is plausible that the discrimination against place features by the complexity metric merely reflects an attempt to reduce the hypothesis space of the learner.

[7] /h/ also appears in coda position in Finnish; it is unclear whether it should be treated as a sonorant or an obstruent.

[8] An alternative view, not inconsistent with the data presented in this chapter, is that evaluation of complexity is innate and that constraints referring to complex distinctions do not even exist in the grammar.