A PHONETICALLY-DRIVEN ACCOUNT OF SYLLABLE WEIGHT

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It is proposed that syllable weight is driven by considerations of phonetic effectiveness and phonological simplicity. The phonetically best distinctions are claimed to be those which divide syllables into groups which are phonetically most distinct from each other. Phonologically complex distinctions are those which exceed an upper threshold in the number of phonological predicates to which they refer. It is claimed that languages adopt weight distinctions which are phonetically most effective without being overly complex phonologically. Syllable weight thus reflects a compromise between phonetic and phonological factors. The proposed model of weight further suggests that phonological weight distinctions are ultimately predictable from other basic phonological properties, such as syllable structure.*

1. SYLLABLE WEIGHT. Linguists have long observed that certain phonological processes in many languages distinguish between "heavy" and "light" syllables (e.g. Jakobson 1931, Trubetzkoy 1939, Allen 1973, Hyman 1977, 1985, 1992, McCarthy 1979, Zec 1988, Hayes 1989, etc.). Syllable weight has played an increasingly larger role in more recent phonological theory, as the number of prosodic phenomena argued to instantiate syllable weight has grown to encompass many diverse phenomena such as weight-sensitive stress, compensatory lengthening, reduplication, minimal word requirements, tone, among others. Drawing on data from these weight-sensitive phenomena, linguists have developed simple yet compelling theories of weight grounded in fundamental concepts such as phonemic length, segment count and sonority.

As our data base on weight-sensitive phenomena has expanded to include ever more explicit information on a larger cross-section of languages, theories of weight have been presented with new and interesting opportunities for empirical validation. While the expanded empirical base has corroborated many standard notions about syllable weight, it has also brought new challenges to the theory of weight: an increasingly diverse set of weight distinctions cross-linguistically, individual languages sensitive to multiple weight distinctions, weight distinctions based neither on the number of segments nor on phonemic length contrasts, and cases of conflicted weight criteria for different weight-sensitive processes in the same language. These new data continue to necessitate expansions of the formal apparatus in the theory of weight, suggesting the need for reexamination of the phenomenon of syllable weight.

This paper explores the extent to which syllable weight is linked to both structural and phonetic properties. As such, it may be viewed as part of two research programs: one relating the phonology of weight and phonetic properties (see, for example, Maddieson 1993, Archangeli and Pulleyblank 1994, Hubbard 1994, 1995, Broselow, Chen and Huffman 1997), and one linking phonological patterns to a combination of phonetic and structural considerations (see, for example, Hayes 1997).

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The focus of this paper is weight-sensitive stress, which is both the best documented weight-sensitive process and the one which also displays the broadest range of weight distinctions cross-linguistically. For these reasons, weight-sensitive stress provides a good testing ground for examining the theory of weight. Some data on metrics is also included as poetic metrics and stress bear a close relationship in many languages of the world (Hayes 1988, Gordon 1999a).

The paper consists of two main parts, one typological and one experimental. First, in sections 2 and 3, a typology of the weight distinctions involved in weight-sensitive stress systems is presented. In the remaining sections of the paper, it is argued on the basis of phonetic data from several languages that consideration of phonetic properties offers insight into a number of aspects of syllable weight: the basis for complex weight hierarchies involving three and four levels of weight, the language-specific choice of weight distinctions, and the relationship between syllable structure and weight. Consideration of phonetic data, however, shows that phonetics by itself is inadequate to account for the phonology of weight. Rather, phonological simplicity plays an important role in ruling out weight distinctions which are phonetically superior but overly complex.

2. A CROSS-LINGUISTIC OVERVIEW OF WEIGHT. In languages with weight-sensitive stress, syllables that are "heavier" tend to attract stress, while "lighter" syllables often resist being stressed (Hyman 1985, Levin 1985, Zec 1988, Hayes 1995). For example, in Yana (Sapir and Swadesh 1960), stress falls on the first syllable in a word which is either closed (1a) or contains a long vowel or diphthong (1b). If there are no closed syllables or syllables with a long vowel or diphthong, stress falls on the first syllable (1c). Thus, CVV and CVC are heavy in Yana.

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

Research has shown that languages differ as to which syllables count as heavy and which as light. For example, in Khalkha (Bosson 1964, Poppe 1970, Walker 1995), stress falls on the rightmost non-final syllable containing a long vowel or diphthong (2a,b). If the only long vowel or diphthong occurs in the final syllable, it is stressed (2c). If the word contains no long vowels or diphthongs, stress falls on the initial syllable (2d,e). Thus, in Khalkha, unlike in Yana, all syllables containing a short vowel are light even if they are closed.

(2) Khalkha stress (examples from Walker 1995)

a. áːruːl	'dry cheese curds'
b. uːrtáegaːr	'angrily'
c. galúː	'goose'
d. xáda	'mountain'
e. únʃisan	'having read'

Numerous other weight patterns are attested in languages of the world. A typology of weight distinctions is presented in section 3. Interestingly, one nearly universal fact about weight distinctions is that syllable onsets do not affect the weight of a syllable. For example, in Latin, the penultimate syllable in ***pu!bli.kus*** 'public' is light, even though it contains three segments under the most typical syllabification. Crucially, the penultimate rime contains only a short vowel, and thus is considered light. Following convention, however, a syllable initial consonant, though weightless, will often be used in transcribing syllable types in this paper, e.g. CVC, CVV.

While there are certain languages, e.g. Pirahã (Everett and Everett 1984, Everett 1988)[1], which are sensitive to syllable onsets in their calculation of weight, for purposes of the present paper, the discussion will largely be limited to rime-sensitive syllable weight, which itself displays striking cross-linguistic diversity in its weight distinctions, and hence presents serious challenges for any prospective theory of weight. Hopefully further research, perhaps along similar lines to the approach developed here for rime-sensitive syllable weight, will shed more light on the role of onsets in syllable weight.

3. A TYPOLOGY OF WEIGHT DISTINCTIONS. Based on an extensive survey of syllable weight in approximately 400 languages in Gordon (1999a),[2] the two most common weight distinctions are the Latin criterion which treats both CVV and CVC as heavy (a criterion henceforth abbreviated as CVX heavy) and the Khalkha criterion, according to which CVV but not CVC is heavy. The third most common type of weight distinction, considerably rarer than the first two distinctions, treats non-central vowels as heavier than central (i.e. schwa-like) vowels, as, for example, in Javanese (Herrfurth 1964, Prentice 1990), Chuvash (Krueger 1961), and Mari (Itkonen 1955). The crucial difference between central and non-central vowels in languages in which they differ in weight lies in the relatively great durational differences between the two vowel types and not merely on qualitative differences (cf. descriptions of Chuvash by Krueger 1961:71 and Ossetic by Abaev 1964:4). Given their short phonetic duration, central vowels which are phonologically light will henceforth be referred to as "short-central" vowels in order to differentiate them from central vowels which do not behave as light vowels. In some languages, only short-central vowels *in open syllables* are light, e.g. Malay (Winstedt 1927, Prentice 1990), Aljutor (Kodzasov and Muravyova 1978) and certain Mari dialects (Itkonen 1955; Kenstowicz 1994a). In Lamang (Wolff 1983), open syllables containing a short-central vowel and syllables closed by an obstruent which contain a short-central vowel are light. There are a few languages in which the only coda consonants which make a syllable heavy are sonorants (Zec 1988), e.g. Kwakwala (Boas 1947), closely related Nootka (Wilson 1986, Stonham 1990), and Inga Quechua (Levinsohn 1976).[3] Gordon's (1999a) survey includes two languages, Maori (Bauer 1993) and Kara (De Lacy 1997), which treat phonemic long vowels as heavier than diphthongs.

Another class of weight divisions is based on vowel height, where lower vowels are heavier than the higher vowels, as in, for example, the Jaz'va dialect of Komi (Lytkin 1961, Itkonen 1955), Kara (De Lacy 1997), Gujarati (Cardona 1965), Yimas (Foley 1991) and Kobon (Davies 1980, Kenstowicz 1994a). Interestingly, virtually all stress systems in Gordon (1999a) which are sensitive to vowel quality distinctions, including languages with weight distinctions between short-central vowels (abbreviated ShCen) and other vowels, do not possess phonemic vowel length distinctions. Of the 28 languages in his survey which make weight distinctions between vowels of different qualities, only three also have phonemic long vowels: Siraiki (Shackle 1976), Kara (De Lacy 1997) and Asheninca (Payne 1990). Interestingly, the three languages also make other weight distinctions in addition to the one based on vowel quality. Thus, in languages with phonemic vowel length, a distinction based on vowel quality implies the presence of at least one other weight distinction. An explanation for the virtual confinement of weight distinctions based on vowel quality to languages without phonemic long vowels will be offered in section 10.1.

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[1] Davis (1988) discusses a few further cases of weight sensitivity to onsets, one of which, Mathi-Mathi, has been subsequently reanalyzed by Gahl (1996)

[2] Note that the survey in this section does not include weight distinctions employed by other phenomena, e.g. compensatory lengthening, tone, minimal word requirements, etc.; for typological comparison of weight criteria for these phenomena and others, see Gordon (1999a).

[3] Lithuanian (Kenstowicz 1972, Zec 1988, Blevins 1993) also treats syllables closed by a sonorant differently from syllables closed by an obstruent, arguably a distinction based on weight. However, in Lithuanian, this distinction is clearly related to pitch; syllables which contain a long vowel or diphthong or which are closed by a sonorant are able to carry a particular pitch accent, whereas open syllables containing a short vowel or short-voweled syllables closed by an obstruent cannot. The ability of syllables closed by a sonorant to carry pitch accent is presumably directly related to the ability of pitch to be manifested on a sonorant, rather than a property directly related to stress.

There are also languages which treat weight in a scalar fashion, drawing more than a binary distinction between heavy and light. The most common three-way weight hierarchy is CVV > CVC > CV, e.g. Klamath (Barker 1964), Kashmiri (Kenstowicz 1994b), Chickasaw (Munro and Willmond 1994; section 8.1), and Yapese (Jensen 1977). A different complex weight distinction, CVVC > CVX > CV, is found in Pulaar Fula (Niang 1995).[4] Crucially, all complex weight hierarchies can be decomposed into a series of binary weight distinctions. For example, the CVV > CVC > CV hierarchy consists of two weight distinctions, each of which is widely attested. First, CVV is heavier than both CVC and CV. Second, both CVV and CVC (together CVX) are heavier than CV. If weight distinctions are viewed compositionally, then the set of core weight distinctions is reduced to the distinctions summarized in Table 1.

TABLE 1. SUMMARY OF WEIGHT DISTINCTIONS

Weight distinction	**Example language(s)**
CVV heavy	Khalkha
CVX heavy	Yana
CVV, CV[+son] heavy	Kwakwala
CVVC, (CVCC) heavy	Pulaar Fula, (Hindi)
Low V heavy	Yimas
Non-high V heavy	Komi Jaz'va
Diphthongs heavy	Maori
Short-central V light	Javanese
Short-central V in open σ light	Malay
Short-central V in open σ, Short-central V[-son] light	Lamang

These distinctions will be discussed further in the context of the discussion of phonological complexity in section 5. The phonetic basis for the three most common of these weight distinctions (CVV heavy, CVX heavy and Short-central V light), as well as the most common three-way weight distinction (CVV > CVC > CV) will be investigated in section 7.

4. WEIGHT AS A COMBINATION OF PHONETIC EFFECTIVENESS AND PHONOLOGICAL SIMPLICITY. The general hypothesis explored in this paper is that the phonology of weight is sensitive to two considerations: phonetic effectiveness and phonological simplicity. The first of these ingredients, phonetic effectiveness, requires that languages adopt weight distinctions which are best suited to the phonetic demands imposed by a given weight-sensitive phenomena. In the case of stress, the focus of this paper, the relevant phonetic dimension along which weight operates will be argued to be perceptual energy. It will be claimed that languages choose weight distinctions which divide syllable types into groups which are maximally distinct from each other.

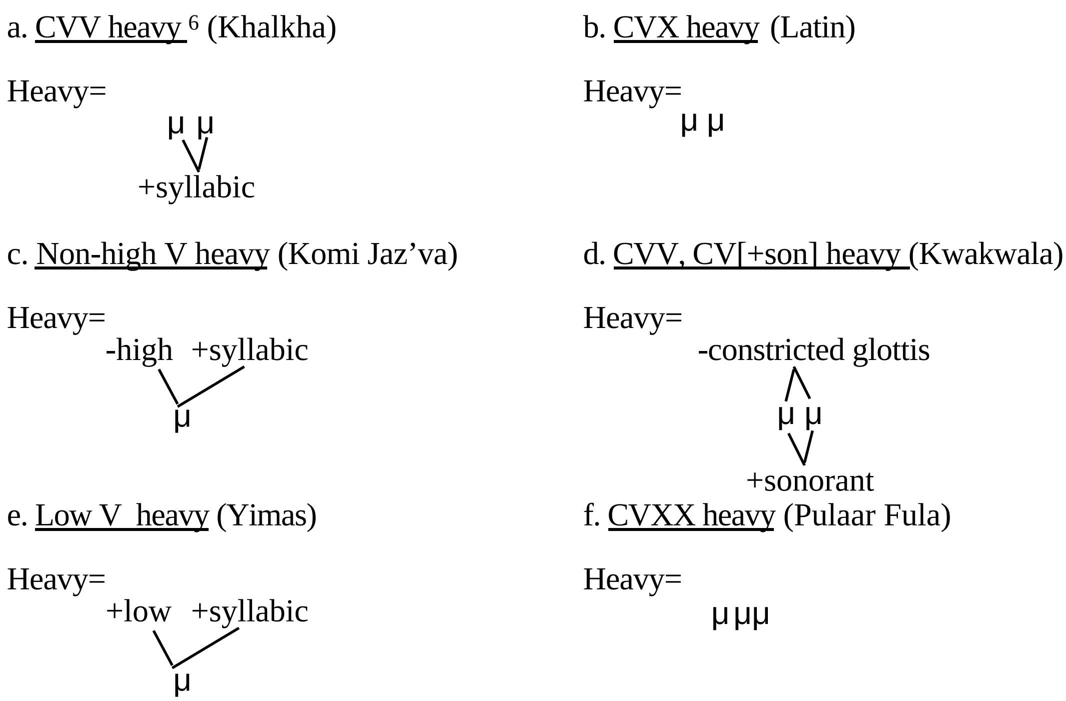
Another ingredient which will be shown to be essential to the discussion of weight-sensitive stress is phonological simplicity. The basic idea is that languages treat natural and symmetrical classes of sounds uniformly with respect to weight (cf. Hayes 1997 for similar claims about other phonological phenomena). For example, as shown already, many languages treat long vowels as uniformly heavy for purposes of stress. Other stress systems treat syllables with branching rimes, i.e. CVV and CVC, as heavy. Still other stress systems treat syllables with two sonorant timing positions in the rime, i.e. CVV and CV[+son], as heavy. What is not found are languages which make weight distinctions which are simultaneously sensitive to vowel height and length, e.g. languages in which long, non-high vowels are heavy, or which are sensitive to both place of articulation and sonority, e.g. languages in which syllables containing a low vowel plus a sonorant

[4] Kelkar (1968) describes a similar hierarchy for Hindi with the addition of CVCC (lacking in Fula) which is equivalent in weight to CVVC. The Hindi weight distinction, however, is the subject of controversy; see, for example, Ohala (1977).

are heavy. There thus seems to be pressure on weight systems to manipulate relatively simple classes of syllables which refer to a small set of phonological dimensions. Limiting the set of weight distinctions to simple ones has the obvious advantage of constraining the set of possible weight distinctions which a language learner must entertain when constructing or analyzing a weight system. The overall picture which thus emerges is that the phonology of weight is the result of a compromise between choosing weight distinctions which are ideal phonetically, but which are also structurally simple in terms of the phonological predicates which they manipulate.

5. THE ROLE OF STRUCTURAL COMPLEXITY IN SYLLABLE WEIGHT. As a starting point in the discussion of complexity, let us now consider some phonological representations which offer a means of characterizing weight distinctions. Because of its capacity to capture naturally the onset-rime weight asymmetry, a moraic model of the syllable (Hyman 1985, Zec 1988, Hayes 1989) is assumed here, though none of the claims made here crucially hinge on this decision. Following work by Steriade (1991), all segments in the rime are treated as moraic, reflecting their potential weight-bearing status. A consequence of this assumption is that differences in weight conditioned by sonority, such as between CVV and CVC or between CV[+son] and CV[-son], are represented not in terms of differences in the affiliation of timing positions, but rather in terms of differences in featural associations. The only exception to the generalization that all rimal segments carry a timing position is provided by phonologically light central vowels which are assumed, following Kager (1990), to not be associated with a unit of weight. This assumption finds phonetic support from the observation that centralized vowels are characteristically quite short in languages in which they behave as phonologically light (see discussion in section 3). Figure 1 contains representations uniquely characterizing the set of heavy syllables for the weight distinctions discussed in the typology in section 3 (see Table 1).[5]

FIGURE 1. SIMPLE AND ATTESTED WEIGHT DISTINCTIONS



[5] The feature [syllabic], as opposed to [+vocalic], is adopted here because it offers a unified treatment between vowels and syllabic nasals, which, like vowels, are well suited to carrying contour tones (see Gordon 1999).
[6] Recall that CVV stands for long vowels and diphthongs, while CV: stands for long vowels to the exclusion of diphthongs.

g. Diphthongs heavy (Maori)

Heavy=

μ
root root
+syllabic

h.. ShCen V light (Javanese)

Heavy=

μ
|
+syllabic

i. ShCen V in open σ light (Malay)

Heavy= μ

j. ShCen V in open σ,
ShCen V[-son] light (Lamang)

Heavy =

μ
|
+sonorant

The representations in Figure 1 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 two syllabic timing positions in the rime are heavy. Rimes which satisfy this structural description are all those which minimally contain two syllabic timing positions, e.g. all CVV syllables whether they contain long vowels or diphthongs, as well as CVVC(C) syllables with one or more coda consonants.

Most of the representations in Figure 1 are straightforward with a few exceptions. Under the assumption that short-central vowels lack a weight unit of their own, the weight distinction which treats short-central vowels as light (h) treats a syllable containing a syllabic weight unit as heavy. The Short-Central V in open σ, Short-Central V[-son] light distinction (j) considers heavy any syllables containing at least one sonorant weight unit. The Short-Central V in open σ light distinction (i) considers syllables containing at least one weight as heavy. The inclusion of the [-constricted glottis] feature in the CVV, CV[+son] heavy distinction (d) is necessary, since glottalized sonorants are treated as light for stress in Kwakwala and Nootka (Zec 1988). Finally, diphthongs are assumed to be associated with one timing position in languages in which they are lighter than long vowels (g), e.g. Maori. This hypothesis finds support from Maori, which contrasts short diphthongs which count as light and long diphthongs which count as heavy: fa.k**ai**.ri 'elevate' vs. k**a**:**i**.ŋ͡ga 'home' (Bauer 1993).

Weight systems which are sensitive to more than a binary distinction are composed of a combination of two or more simple weight distinctions. For example, the Chickasaw hierarchy, in which CVV > CVC > CV, is composed of two weight distinctions: a distinction of the Khalkha type (CVV heavy) and a distinction of the Yana type (CVX heavy). Combining these two distinctions produces the three-way hierarchy CVV > CVC > CV.

In order to provide a working definition of complexity it is instructive to recast the representations of weight in Figure 1 in terms of associations between features and individual timing positions, and, in the case of diphthongs, between features and individual root nodes. Thus, for example, the CVV heavy criterion requires that heavy syllables have two rimal timing positions which are [+syllabic]. This distinction thus refers to four predicates in total: two timing positions and two [+syllabic] features. Table 2 classifies the weight distinctions in Figure 1 according to their phonological predicates.

TABLE 2. WEIGHT DISTINCTIONS AND THEIR PHONOLOGICAL PREDICATES

CVV heavy	μ μ +syllabic +syllabic
CVX heavy	μ μ
CVV, CV[+son] heavy	$[\mu]_R$ $[\mu]_R$ +sonorant +sonorant
CVXX heavy	μ μ μ
Non-high V heavy	-high +syllabic μ
Low V heavy	+low +syllabic μ
Sh Cen V light	μ +syllabic
CV_iV_k(C) heavy	μ μ root root +syllabic
ShCen V in open σ light	μ
ShCen V in open σ, ShCen V[-son] light	μ +sonorant

Using the representations in table 2 as a guide, it is possible to speculate on the upper limit of complexity tolerated by weight distinctions. Most weight distinctions involve reference to only non-place predicates, i.e. root nodes, weight units, and non-place features. The two distinctions that refer to place refer only to a single place predicate. There are no distinctions which refer to more than one place predicate; thus, we do not find distinctions with a place feature linked to two weight units, as in a hypothetical distinction which treat long low vowels as heavy[7] or one which treats long non-high vowels as heavy. These unattested distinctions would thus be identical to the attested CVV, CV[+son] heavy distinction, except for involving a place feature. Given the set of distinctions in table 2, I thus offer the following measure 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.[8] 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

[7] Kara (De Lacy 1997), in fact, makes a weight distinction between long low vowels and other rimes. Because the only long vowel in Kara, however, is /aː/, this weight distinction can be expressed as a simple distinction like that in Khalkha between CVV and other syllables; it is thus phonologically simple in Kara.
[8] As Sharon Inkelas points out, this condition of simplicity plausibly reflects a more general meta-condition on representations characterizing phonological phenomena.

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].[9] The definition of complexity is formalized in (3).[10]

(3) 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.

As we will see in the phonetic case studies in section 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.

6. PHONETIC EFFECTIVENESS AND WEIGHT-SENSITIVE STRESS. The second ingredient in the phonology of weight is phonetic effectiveness, which is the focus of this section. For purposes of weight, 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. In contrast, the least effective division of syllables has heavy and light syllables which are least different from each other along a given phonetic dimension.

The motivation for this metric of phonetic effectiveness is perceptual in nature. It is claimed 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 also to learn than distinctions based on smaller differences. 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 which maximize the phonetic space (cf. Liljencrants and Lindblom 1972, Lindblom 1986), neutralization processes eliminating phonetic contrasts which are difficult to implement in a perceptually salient manner (Flemming 1995, Steriade 1999), and phonological processes which strive to preserve or create maximally distinct segments or combinations of segments (Flemming 1995).

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9 There is one attested weight distinction which is predicted to be complex by the complexity metric developed thus far: Asheninca, which observes the weight hierarchy CVV > Ca(C), Ce(C), Co(C), CiC > Ci > Cɨ in its stress system (see Payne 1990 for discussion). What is problematic is the uniform weight of CiC and all syllables containing a non-high vowel to the exclusion of Ci, a distinction which appears to require disjoint representations. Following Kager's (1990) analysis of non-moraic central vowels (see text), I assume that /i/ in open syllables in Asheninca lacks a weight unit. The weight distinction between heavy Ca(C), Ce(C), Co(C), CiN and light Ci is thus represented as in (i) in Figure 1, where all heavy syllables have at least one weight unit. There is evidence that /i/ is phonetically very short in open syllables in Asheninca and therefore plausibly does not carry its own weight unit. First, /i/ in open syllables is centralized after coronal stridents, suggesting that /i/ is very short and that this durational reduction prevents the tongue from reaching the peripheral high front target required for the canonical realization of [i]. The result is a hypoarticulated central vowel, which is so short that it is acoustically deleted between voiceless consonants, e.g. ʃit͡sa → ʃt͡sá 'intestinal worm' (Payne 1990:190). /i/ is not centralized in closed syllables, suggesting that, unlike /i/ in open syllables, it is long enough for the tongue to reach a more forward articulation. Furthermore, a fast speech process deleting secondary stressed /i/ (and not other vowels) in open syllables adjacent to a heavier syllable also suggests that Ci is extremely short (Payne 1990:201).

10 One might ask why weight distinctions referring to place features are discriminated against from a simplicity. 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 characteristically 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. THE PRESENT STUDY. This section tests the hypothesis that a phonetic property, either duration or energy, correlates with a variety of phonological weight distinctions. The languages and corpora from which measurements were made are discussed in sections 7.1 and 7.2, respectively. The choice of duration and energy as correlates of weight and the measurement procedure are discussed in section 7.3.

7.1. LANGUAGES. To examine the phonetic basis for weight-sensitive stress, six languages displaying various weight distinctions for stress and/or poetic metrics were investigated. Languages were chosen which represented a cross-section of attested weight distinctions, including the three most common weight distinctions cross-linguistically (see section 3): CVV heavy (Khalkha), CVX heavy (Japanese and Finnish), and Short-central vowels light (Javanese). The corpus also included two languages instantiating the most common three-way weight hierarchy (see section 3): CVV > CVC > CV (Chickasaw, Telugu). All of the weight distinctions tested are drawn from stress with the exception of two based on poetic metrics: the Japanese distinction and one of the distinctions (CVC > CV) comprising the three-way weight hierarchy in Telugu.[11] The six languages in the current study are listed in Table 7 with the relevant distinctions employed by each language, along with sources for the phonological data.

TABLE 7. SIX LANGUAGE STUDY OF THE PHONETIC BASIS FOR WEIGHT

Language	Weight distinction	Source(s)
Chickasaw	CVV > CVC > CV	Munro and Willmond (1994), Gordon (1999a, b)
Telugu	CVV > CVC > CV	Brown (1981), Petrunicheva (1960), Krishnamurti and Gwynn (1985), Sitapati (1936)
Khalkha	CVV > CVC, CV	Bosson (1964), Walker (1995)
Japanese	CVX > CV	Vance (1987)
Finnish	CVX > CV	Kiparsky (1968), Sadeniemi (1949), Hanson and Kiparsky (1996)
Javanese	ShCen V light	Herrfurth (1964), Horne (1974)

7.2. 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, (except in Javanese--see below) and keeping the vowel in the other syllable constant.[12] 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 had the opposite stress level of the first syllable, i.e. unstressed in languages other than Chickasaw, and stressed in Chickasaw. The Javanese short-central vowel in an open syllable had to be measured in the first syllable due to a restriction against absolute word-final central vowels in the native vocabulary. 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/. In Javanese, the short-central vowel was also examined. Rimes containing /i/ were not measured in Khalkha due

[11] Poetic metrics and stress typically stand in a close relationship (cf. Hayes 1988, Hanson and Kiparsky 1996). In fact, weight criteria for the two phenomena show a much greater tendency to agree cross-linguistically than any other pairs of phenomena commonly claimed to involve syllable weight (Gordon 1999a).

[12] Due to gaps in the lexicon, the vowel in the second syllable could not always be held constant in Chickasaw. Where a different vowel was used, the energy of the second vowel was adjusted by an appropriate factor as determined by controlled comparisons (see Appendix 1).

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; thus, the phonetic basis for weight distinctions between long vowels and diphthongs and between mid vowels and other vowel qualities was not examined experimentally. 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). Geminates were not included in the corpus, as they cannot be acoustically segmented into coda and onset phases. The set of coda consonants and the vowels examined for each language is listed in Table 8. The complete corpus recorded for each language appears in Appendix 1.[13]

TABLE 8. VOWELS AND CODAS MEASURED FOR SIX LANGUAGES

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

7.3. MEASUREMENTS**.** 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 energy (along with its perceptual correlate loudness) and duration are common phonetic correlates of stress. The correlation between stress and increased duration and/or loudness has been experimentally shown for many languages, including English (Fry 1955; Beckman 1986), French (Rigault 1962), Russian (Bondarko et al. 1973), Polish (Jassem et al. 1968), Mari (Baitschura 1976), Indonesian (Adisasmito-Smith and Cohn 1996), Tagalog (Gonzalez 1970), Dutch (Sluijter and van Heuven 1996), etc. and impressionistically noted for many other languages.

Furthermore, work by Maddieson (1993), Hubbard (1994, 1995) and Broselow, Chen and Huffman (1997) has suggested that duration is closely correlated with phonological weight distinctions. Of particular interest for the present study is Broselow et al.'s investigation of four languages with different weight systems (Malayalam, Hindi and two dialects of Arabic), which revealed duration differences corresponding to the different phonological weight criteria of these languages. Their work on the relationship between phonetic duration and phonological weight is reviewed in the context of the present results in section 9.

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 which is listed for each language in Appendix 1. Data were digitized at 16kHz using Kay Elemetrics Computerized Speech Lab. Two measurements were made for each rime: duration and a measure which I will term total perceptual energy (the integration of energy over time in the perceptual domain).

The duration was measured for each segment in the rime using a waveform in conjunction with a spectrogram and an energy display. Discontinuities in one or more of these displays were used for segmentation purposes. For vowels, the onset of the second formant was treated as the beginning point and the offset of the second formant was treated as the end.

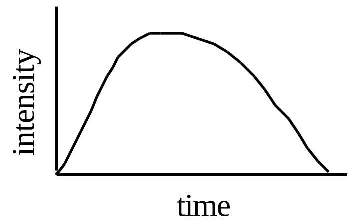
A measure of total energy rather than another measure of energy such as average energy is most relevant for testing the link between energy and weight-sensitive stress, since psychoacoustic

[13] Appendix 1 also includes corpora from five other languages discussed in the study of vowel duration in section 10.1.

experiments suggest 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). Total energy may be visually represented as the area under the curve in Figure 6, where the curve represents a continuous intensity display over a syllable rime.

FIGURE 6. MEASUREMENT OF TOTAL ENERGY

Total energy



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 across tokens. 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 from a graph in Warren (1970: 1399) based on 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.

An example of the method of calculating total energy is provided here. Let us assume that the first syllable of the word /p**an**ta̲/ is the target syllable for measurement. Let us suppose that the /**a**/ of the first syllable is 80 milliseconds and the /n/ is 60 milliseconds. First, the average energy of /a̲/ is subtracted from the average energy of /**a**/ and the average energy of /**n**/. Let us suppose the average energy of /**a**/ is 6dB greater than the average energy of /a̲/, and the average energy of /**n**/ is 3dB greater than the average energy of /a̲/. 6dB corresponds to a twofold increase in perceived loudness, while 3dB corresponds to a 1.55 increase in perceived loudness. The duration of /**a**/ (80 milliseconds) in /p**an**ta̲/ is thus multiplied by 2, and the duration of /**n**/ (60 milliseconds) in /p**an**ta̲/ is multiplied by 1.55 yielding total energy values for /**a**/ and /**n**/ of 160 and 93 (in arbitrary units), respectively. Finally, the product of these operations are summed together providing a total energy value for the rime as a whole, 253.

7.4. PHONETIC EVALUATION OF POTENTIAL WEIGHT CRITERIA**.** Along the two phonetic parameters of duration and total energy, the set of syllables measured in a given language were bisected a number of different ways, with each bisection representing a different weight distinction, just as syllables containing long vowels were grouped together to the exclusion of syllables containing short vowels in Figure 6 and high vowels were grouped together to the exclusion of low vowels in Figure 7. 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. 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] in the case of vowels, and [coronal] [dorsal] and [labial], [voice], [sonorant] and [continuant] in the case of consonants. Furthermore, the distinction between CVVC (superheavy) and other syllables was tested for Chickasaw, and the short-central vs. other vowel distinction was examined for Javanese. Additionally, the Malay type distinction, according to which only open syllables containing short-central vowels are light, was examined in Javanese.

7.5. 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 (4).

(4) 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 than higher values.[14]

8. THE CORRELATION BETWEEN ENERGY AND LANGUAGE-SPECIFIC WEIGHT DISTINCTIONS. Results of the phonetic study revealed a very close overall association between weight criteria and energy. Duration, on the other hand, was an effective predictor of certain weight criteria, but not others. For this reason, the results of the energy study are presented first in sections 8.1-8.7; discussion of duration is deferred until section 9.

8.1. CHICKASAW: CVV > CVC > CV. Chickasaw makes a ternary weight distinction in which long vowels are heaviest, followed by closed syllables containing a short vowel, followed by open syllables containing a short vowel. This weight hierarchy is evident both at the word level and at the phrase level (Munro and Willmond 1994, Gordon 1999a, b).

Because it possesses more than a binary weight distinction, Chickasaw provides a relatively tough testing ground for establishing a correlation between energy and syllable weight. 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 of rime type on energy values: $F(21,153) = 15.215$, $p<.0001$.

[14] The lower the Wilkes' lambda value, the greater the amount of variance is attributed to differences between the heavy and light syllables and the less the variance is attributed to differences among members of the heavy group or the light group.. Because the Wilkes' lambda values are affected by factors such as sample size which are not claimed to be relevant to the hypothesis examined here, they were not used as the definitive criterion for ranking weight distinctions in order of phonetic effectiveness; rather, as pointed out in the text, mean values were used to rank the relative phonetic effectiveness of distinctions.

In Table 9, the relative effectiveness of different weight distinctions in Chickasaw is compared. Distinctions are ordered from top to bottom with the phonetically more effective distinctions (according to differences in mean energy values between heavy and light syllables as described in section 7.3) 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 9 has a 50% smaller difference in energy between heavy and light syllables than the top ranked distinction. Table 9 also includes (in shaded cells) Wilkes' lambda values and significance levels according to the discriminant analyses.

Note that all of the ties in Table 9 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 9, 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 mean values. The interested reader is referred to Appendix 2 for the complete list of all weight distinctions, both simple and complex, and their relative rankings in terms of effectiveness in the energy domain. Note the following abbreviations in Table 9 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 9. 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
VX heavy	**71.5**	**.862489**	**.0000**				
VXX 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				

Strikingly, the two phonetically most effective weight distinctions among the simple distinctions are precisely 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 and CVC). The three way phonological hierarchy thus results from the combination of the top two weight phonetic distinctions. The Chickasaw data thus provides strong evidence for a match between syllable weight and the phonetic property of energy. The Chickasaw data also provides corroboration for the important role of phonological simplicity in syllable weight. Six of the top eight weight distinctions are ruled out only by virtue of their complexity. If phonological complexity did not play a role in the phonology of weight, then on the basis of phonetic effectiveness alone, one would incorrectly expect the phonology to observe the Caː heavy criterion. This distinction is complex because it refers to a place feature ([+low]) associated with two weight units. Furthermore, several phonetically effective but complex weight distinctions (/aː,iː/ heavy; VV, a[+son] heavy; VV, a[+nas] heavy; V, hiV[+dor] light) would also incorrectly be predicted to surface before the phonetically less effective CVX heavy criterion. The /aː,iː/ heavy distinction is complex because it refers to a place feature ([-back]) linked to two weight units, while the three complex weight distinctions ranked just below the /aː,iː/ heavy distinction in phonetic effectiveness are complex because they require disjoint representations of the heavy syllables.

8.2. TELUGU: CVV > CVC > CV. Like Chickasaw, Telugu, with its three-way weight hierarchy, CVV > CVC > CV, provides a particularly rigorous testing ground for examining the correlation between total energy and syllable weight. The Telugu weight hierarchy is evident when one collapses the weight system for stress with that employed for poetic metrics. The stress system treats CVV as heavier than both CVC and CV (Petrunicheva 1960, Brown 1981). In addition, Telugu has a system of quantitative poetic metrics which treats CVV and CVC uniformly as heavy syllables (Sitapati 1936, Brown 1981). The combination of the CVV heavy distinction for stress and the CVX heavy distinction for metrics thus yields the three-way weight hierarchy CVV > CVC > CV.

An analysis of variance indicates a highly significant effect of rime type on energy values: $F(23, 111) = 25.207$ $p<.0001$. The phonetically most effective weight distinctions are listed in Table 10.

TABLE 10. THE MOST EFFECTIVE WEIGHT DISTINCTIONS IN TELUGU

SIMPLE				COMPLEX			
Heavy	Diff	W-λ	p-val.	Heavy	Diff	W-λ	p-val.
				/aː,iː/ heavy	100	.677287	.0000
				/aː/ heavy	89.0	.866058	.0000
				hiV in open σ light	85.4	.764897	.0000
VX heavy	**79.5**	**.709650**	**.0000**				
VV heavy	**72.3**	**.760039**	**.0000**				
VV, V[+voi] heavy	66.1	.613276	.0000				
VV, V[-nas] heavy	47.7	.823348	.0000				
VV, V[+son] heavy	47.1	.780127	.0000				
VV, V[+cont] heavy	36.7	.866472	.0000				
-back V heavy	30.5	.916773	.0007				
+low V heavy	16.9	.974847	.0662				

The two phonetically most effective of the simple weight distinctions are also the two phonological distinctions as predicted. The Telugu data provide further confirmation of the important role of phonological simplicity in syllable weight: there are three complex weight distinctions which are phonetically superior to the actual phonological weight distinctions in Telugu. These are prohibited from playing a role in the phonology only by virtue of their exceeding the upper threshold of phonological simplicity.

8.3. KHALKHA: CVV HEAVY. Like Japanese, Khalkha Mongolian observes a simple binary weight distinction. However, the Khalkha stress system treats CVV, but not CVC, as 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 11.

TABLE 11. 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**				
VX 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 11 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. Thus, Khalkha provides evidence both for the correlation between syllable weight and total energy, and also the importance of phonological simplicity in the determination of syllable weight.

8.4. JAPANESE: CVX HEAVY. Japanese treats closed syllables and syllables containing a long vowel as heavy in both its system of recited poetry and in songs (Vance 1987). Japanese thus makes only a binary distinction between heavy and light syllables, unlike Chickasaw.

An analysis of variance conducted on the Japanese data demonstrated a highly significant effect of syllable type on energy: $F(11, 82) = 100.596$, $p<.0001$. Table 12 lists the most effective weight distinctions in Japanese following the protocol explained above in the discussion of Chickasaw.

TABLE 12. THE MOST EFFECTIVE WEIGHT DISTINCTIONS IN JAPANESE

SIMPLE Distinction	Diff	W-λ	p-val.	COMPLEX Distinction	Diff	W-λ	p-val.
VX heavy	**100**	**.435783**	**.0000**				
VV, V[+son] heavy	100	.435783	.0000				
VV, V[+voi] heavy	100	.435783	.0000				
VV, V[+nas] heavy	100	.435783	.0000				
				V, hiV[-nas] light	100	.435783	.0000
				V, hiV[+cont] light	100	.435783	.0000
				V, hiV[-son] light	100	.435783	.0000
				V, hiV[-voi] light	100	.435783	.0000
				V, hiV[+dor] light	100	.435783	.0000
				VV, V[-dor] heavy	100	.435783	.0000
				VV, V[-cont] heavy	100	.435783	.0000
VV heavy	17.5	.982682	.1767				
VV, V[+cont] heavy	17.5	.982682	.1767				
VV, V[-nas] heavy	17.5	.982682	.1767				
				VV, V[-voi] heavy	17.5	.982682	.1767
				VV, V[-son] heavy	17.5	.982682	.1767
+low V heavy	11.3	.991636	.3488				
-back V heavy	5.6	.997915	.6405				

The most effective weight distinction (CVX heavy) is also the one exploited by the phonology in Japanese. Thus, Japanese provides evidence for a correlation between the phonology of syllable weight and a phonetic measure of total energy. Note that other weight distinctions are equally as effective as the phonological distinction; however, they all involve the same division of rimes, since the only codas measured in Japanese were sonorants. Thus, Japanese is a less rigorous test of the correlation between energy and phonological weight, since many weight criteria are conflated. Nevertheless, the Japanese data is compatible with the hypothesis that phonological weight distinctions are the phonetically most effective in the energy domain.

8.5. FINNISH: CVX HEAVY. The Finnish stress system treats both CVV and CVC as heavy (Sadeniemi 1949) for purposes of determining the location of secondary stress. In addition to its stress system, Finnish employs a weight-sensitive tradition of poetic metrics which treats CVV and CVC equivalently for purposes of metrical scansion (Kiparsky 1968, Hanson and Kiparsky 1996).

An analysis of variance found a highly significant effect of syllable type on energy values: $F(21,149) = 34.300$, $p<.0001$. Table 13 lists the relative phonetic effectiveness of different weight distinctions in Finnish.

TABLE 13. THE MOST EFFECTIVE WEIGHT DISTINCTIONS IN FINNISH

SIMPLE				COMPLEX			
Heavy	Diff	W-λ	p-val.	Heavy	Diff	W-λ	p-val.
VX 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 13 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.

8.6. JAVANESE: SHORT-CENTRAL VOWELS LIGHT**.** [15] Beside the fact that it possesses a different weight distinction from the other languages examined experimentally in this paper, Javanese is also different in another respect: it lacks both phonemic long vowels and diphthongs.[16] There is thus no potential for making a weight distinction in Javanese between CVV and CVC. The absence of long vowels and diphthongs also may mean that certain distinctions which were unlikely to occur in languages with long vowels or diphthongs have a better chance of surfacing in Javanese. The reason for this is that certain distinctions which are complex in other languages are simple in Javanese. For example, the V[+nas] heavy distinction is simple in languages lacking long vowels and diphthongs, because it does not require disjunct representations for long vowels and syllables closed by a nasal.

An analysis of variance demonstrates a highly significant effect of rime type on energy values: $F(19, 92) = 15.080$, $p<.0001$. The most effective weight distinctions in Javanese appear in Table 14. Because none of the complex weight distinctions are superior to the phonological weight distinction, only the simple distinctions appear in Table 14.

[15] Note that because the only central vowel in Javanese is light, it is sufficient to simply use the term "central" rather than "short-central" in describing the Javanese data.

[16] Horne (1974) reports that all sequences of two adjacent vowels are heterosyllabic in Javanese.

TABLE 14. THE MOST EFFECTIVE WEIGHT DISTINCTIONS IN JAVANESE

SIMPLE Heavy	Diff.	W-λ	p-val.
ShCen V in open σ light	100	.828389	.0000
ShCen V light	**65.5**	**.721594**	**.0000**
V[+cont] heavy	55.9	.740907	.0000
VX heavy	53.3	.864457	.0001
V[-dor] heavy	53.3	.864457	.0001
V[-lab] heavy	53.3	.864457	.0001
V[+cor] heavy	53.3	.864457	.0001
Hi V in open σ light	46.7	.950932	..0189
V[-nas] heavy	44.8	.839328	.0000
-back V heavy	42.7	.884289	.0002
+low V	36.1	.890146	.0004
V[-cont] heavy	20.3	.978710	.1248
V[-voi] heavy	19.0	.970622	.0708
V[-son] heavy	19.0	.970622	.0708
V[+nas] heavy	18.3	.980861	.1458
CaC heavy	17.2	.983084	.1717
V[+son] heavy	12.0	.988028	.2508
V[+voi] heavy	12.0	.988028	.2508

Javanese presents the first mismatch between energy and phonological weight. The actual phonological distinction active for Javanese stress assignment is not the phonetically most optimal of the simple weight distinctions. Rather the Malay type distinction according to which only open syllables containing a short-central vowel are light is phonetically better than the actual Javanese distinction which treats *all* syllables containing a central vowel as light.

8.7. THE PHONETICS OF SYLLABLE WEIGHT: A SUMMARY. The experimental data in the preceding sections indicates a number of important facts. First, in all of the languages with weight-sensitive stress and/or metrical traditions, with the possible exception of Javanese, the phonological weight distinction(s) are also the phonetically most sensible of the simple distinctions. This is true not only of languages with binary weight distinctions like Japanese, Finnish, and Khalkha, but also those with three-way weight hierarchies like Chickasaw and Telugu. These data suggest a strong general correlation between the phonology of weight-sensitive stress/metrics and a measure of total energy.

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, Khalkha, and Telugu in filtering out weight distinctions which may be phonetically quite effective but nevertheless are too complex. Thus, the overall picture which emerges is that the phonology of syllable weight is the result of compromise between achieving the, often conflicting, goals of constructing a phonetically sensible grammar which also manipulates a relatively simple set of phonological predicates.

9. THE RELATIONSHIP BETWEEN DURATION AND SYLLABLE WEIGHT. Sections 8-8.7 demonstrated that a measure of integrated energy lines up quite closely with phonological weight in a number of languages with different weight distinctions. Duration was also examined in the six languages studied, but unlike energy, failed to match with phonological weight in many languages.

In Table 15, the effectiveness of the simple weight distinctions in the duration domain is considered. The difference (in milliseconds) between the means for heavy and light rimes according to each distinction appears along with a ranking indicating the effectiveness of a given weight distinction relative to others. Thus, the first ranked weight distinction is the most effective one, followed by the second ranked one, etc. The weight distinction(s) actually employed by the phonology of a given language is indicated by boldface. Simple weight distinctions which do not surface in the phonology appear in lightly shaded cells. If a weight distinction is complex in a given language, the corresponding cell is shaded darkly. Ties in ranking are indicated by a lowercase "t" in the rank column. The interested reader is referred to Appendix 3 for duration differences between heavy and light syllables for all the simple weight distinctions. Note the following abbreviations in Table 15: [+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 15. EFFECTIVENESS OF SIMPLE WEIGHT DISTINCTIONS IN TERMS OF DURATION

Weight distinction	Chickasaw		Telugu		Khalkha		Finnish		Japanese		Javanese	
Heavy	Diff.	Rank	Diff.	Rank	Diff.	Rank	Diff.	Rank	Diff.	Rank	Diff.	Rank
CVV heavy	**14.4**	**7**	**13.1**	**6**	**2.3**	**6**	22.3	6	9.1	5t		
CVX heavy	**101.2**	**1**	**66.5**	**1**	76.3	1	**95.5**	**1**	**81.5**	**1t**	68.1	2
CVV, V[+son] heavy	23.5	6	14.5	4	-6.1	5	39.7	4t	81.5	1t	5.4	11t
+low V heavy	8.6	8	7.9	8	-1.3	7	10.0	7	12.1	4	-16.7	7
-back V heavy			11.3	7			1.3	8	5.4	8	-8.5	10
ShCen V light											**29.4**	**4**
ShCen V in open σ light											109.8	1
CVXX heavy	30.3	4										
CVV, CV[+voi] heavy	28.8	5	30.3	3	-9.2	4	39.7	4t	81.5	1t	5.4	11t
CVV, CV[+cont] heavy	32.6	3	13.4	5	26.3	3	44.9	3	9.1	5t	29.3	5
CVV, CV[-nas] heavy	35.6	2	34.4	2	33.4	2	46.1	2	9.1	5t	37.4	3
CVV, CV[-cor] heavy												
CVV, CV[-cont] heavy											11.1	8t
CVV, CV[-son] heavy												
CVV, CV[-dor] heavy												
CVV, CV[-lab] heavy												
CVV, CV[-voi] heavy											11.1	8t
CVV, CV[+cor] heavy												
CVV, CV[+nas] heavy											4.3	13
CVV, CV[+dor] heavy												
CVV, CV[+lab] heavy												
CVV, CaC heavy											17.0	6

The CVX heavy distinction is among the two most effective distinctions in all languages examined. This includes languages in which this distinction is actually employed (Japanese, Telugu, Finnish, Chickasaw), as well as languages which employ weight distinctions other than this one (Khalkha, Javanese). The CVX heavy is thus phonetically quite an effective distinction from a durational standpoint.

However, other phonological weight distinctions do not provide as good a phonetic fit in terms of duration. For example, the distinction according to which CVV but not CVC is heavy is ranked far behind the CVV distinction in all languages, including one which exploits the CVV distinction but not the CVX heavy distinction: Khalkha. In Khalkha, the CVV vs. CVC, CV distinction divides syllables into two groups whose means differ from each other by only 2.3 milliseconds. Furthermore, in two other languages which exploit both the CVV heavy and the CVX heavy distinctions (Chickasaw and Telugu), the CVV heavy distinction is surpassed by several other weight distinctions which do not emerge in the phonology. The failure of duration to account for the observed weight facts is also apparent in Javanese, in which the non-central vs. central vowel distinction only provides the seventh best fit in duration even though it is the distinction actually exploited. In summary, the duration data fits well with the CVX heavy criterion, but does not provide a good fit to other weight distinctions such as the Khalkha one (CVV heavy, CVC, CV light), and the Javanese one (central vowels light).

Let us now consider, following work by Broselow et al. (1997), another way in which duration values could be argued to reflect differences in weight criteria. In their study of Malayalam, Hindi and various dialects of Arabic, Broselow et al. (1997) show that differences in phonological weight distinctions between these languages/dialects are reflected in durational differences as well. To take a striking example of the match between phonological structure and phonetic duration in Broselow et al.'s data, consider the difference between Malayalam and Hindi. Malayalam employs the Khalkha type weight distinction according to which long vowels but not closed syllables containing short vowels are heavy. Hindi, on the other hand, is like Yana: both long vowels and closed syllables are heavy. Broselow et al. make the interesting discovery that vowels are substantially shorter in closed than in open syllables in Malayalam but not Hindi. They argue that this is a result of different moraic structures in the two languages. They argue that the vowel and a coda consonant share a mora in Malayalam but not in Hindi and that the sharing of the mora in Malayalam is reflected phonetically in the shortening of vowels in closed syllables, as shown in Figure 7.

FIGURE 7. MORAIC REPRESENTATIONS FOR CVC IN TWO LANGUAGES
(AFTER BROSELOW ET AL. 1997)

Hindi (no mora sharing) Malayalam (mora sharing)

In the present experiment, there is no evidence for mora sharing in Khalkha, a language with the same weight distinction as Malayalam. Compare in Table 16 the duration of vowels in open and closed syllables (all syllable types) in Khalkha versus vowels in the same environments in two languages (Japanese and Finnish) with a Hindi like weight distinction of the form CVX heavy.

TABLE 16. DURATION (IN MILLISECONDS) OF SHORT VOWELS IN OPEN AND CLOSED SYLLABLES IN 3 LANGUAGES

Language	Weight distinction	open syll.	std.dev.	closed syll.	std.dev.
Khalkha	CVV > CV(C)	**70.3**	8.7	**67.5**	14.0
Japanese	CVX > CV	**49.9**	7.2	**88.2**	10.7
Finnish	CVX > CV	**75.8**	13.2	**95.9**	11.7

Although there are clearly differences in vowel duration between Khalkha, on the one hand, and Finnish[17] and Japanese, on the other hand, they do not tie into moraic structure in any obvious way. Vowels are only marginally longer in open than in closed syllables in Khalkha contra what one would expect if vowels and coda consonants shared a mora. This difference between open and closed syllables does not reach statistical significance for Khalkha according to an unpaired t-test: t = .773, p=.4411.

A controlled comparison was made for only syllables containing /a/ and /u/ followed by the coda consonant /m/ (the nuclei and coda which are common to the data set for all three languages). Measurements of vowel duration appear in Table 17.

TABLE 17. DURATION (IN MILLISECONDS) OF SHORT /A, U/ IN OPEN SYLLABLES AND SYLLABLES CLOSED BY /M/ IN 3 LANGUAGES

Language	Weight distinction	open syll.	std.dev.	closed syll.	std.dev.
Khalkha	CVV > CV(C)	**70.3**	8.9	**78.4**	13.7
Japanese	CVX > CV	**49.3**	7.4	**87.3**	11.2
Finnish	CVX > CV	**73.0**	15.2	**95.7**	10.6

As in the data in Table 16, vowels are not substantially longer in open than closed syllables in Khalkha. In fact, vowels are slightly longer in closed syllables in the data in Table 17, an unexpected phonetic result if the vowel and coda consonant were sharing a mora in Khalkha.

Finally, the duration of vowels in open and closed syllables was compared for Khalkha and Finnish, languages for which a larger set of coda consonants were examined than for Japanese. The duration of /a/ and /u/ (vowels measured for both languages) were measured in the environment before /m, r, l, s/ (coda consonants examined in both languages) in Finnish and Khalkha. Results appear in Table 18.

TABLE 18. DURATION (IN MILLISECONDS) OF SHORT /A, U/ IN OPEN SYLLABLES AND SYLLABLES CLOSED BY /M, R, L, S/ IN 2 LANGUAGES

Language	Weight distinction	open syll.	std.dev.	closed syll.	std.dev.
Khalkha	CVV > CV(C)	**70.3**	8.9	**70.2**	12.6
Finnish	CVX > CV	**73.0**	15.2	**99.3**	10.5

Parallel to results in Tables 16 and 17, there is no duration difference between vowels in open and vowels in closed syllables in Khalkha. The difference of .1 milliseconds is insignificant according to an unpaired t-test: t =.026, p=.9790.

In summary, seen from a variety of angles, duration does not appear to fit as closely with phonological syllable weight as a measure of total energy, at least in the languages examined in this paper. It thus appears that languages differ in the degree to which duration influences the energy values guiding language specific adoption of weight criteria. In certain languages, e.g. Khalkha, the low energy and hence light status of CVC is attributed primarily to the relatively large number of low energy coda consonants. In other languages, e.g. Malayalam, the short duration of the vowel in CVC also plays an important, possibly the principal, role in the less energetic and thus light profile of CVC.

[17] It is interesting to note that the differences in vowel duration between open and closed syllables in Finnish fall somewhere in between those reported in two other studies of Finnish duration. Lehtonen (1970) found slightly longer vowels in open than in closed syllables in his study of the variety of Finnish spoken around Helsinki. Leskinen and Lehtonen (1985), however, found substantial lengthening of vowels in closed syllables, greater than the differences found in the present study, in their study of southeastern varieties of Finnish. The speaker for the present study was from southwestern Finland.

10.1. THE INFLUENCE OF PHONOLOGICAL STRUCTURE ON PHONETIC VARIATION. In sections 8-8.7, evidence showing a close match between phonological weight for stress and a phonetic measure of energy was presented. What has not yet been 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 adapt certain phonetic patterns 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 in that both systems mutually influence each other.

Weight-sensitive stress provides arguments for an integrated model of the phonology/phonetics relationship whereby one aspect of phonological structure influences phonetic properties which in turn influence another phonological phenomenon. The first argument for this model comes from examination of the relationship between vowel duration and weight distinctions based on vowel quality. The second piece of evidence is gleaned from comparison of language-specific aspects of syllable structure with language-specific choice of weight criteria.

10.1. VOWEL INVENTORIES AND VOWEL QUALITY-BASED WEIGHT DISTINCTIONS. Recall from section 3 that virtually all languages which make weight distinctions based on vowel quality do not possess phonemic long vowels. Furthermore, those that have phonemic long vowels and make a weight distinction based on vowel quality exploit another phonetically more robust weight distinction in addition to the one based on vowel quality. For example, Asheninca (Payne 1990) makes a weight distinction between CVV and CV(C) in addition to the weight distinction between short high vowels in open syllables and other syllable types.

The virtual absence of vowel quality-based weight distinctions in languages without phonemic vowel length plausibly finds an explanation in terms of different phonetic patterns between languages with and languages without phonemic vowel length. In particular, the relevant phonetic property is claimed here to be duration, which is one phonetic component in the measure of total energy shown to be relevant for weight-sensitive stress. Assuming a phonetic basis for the distribution of weight distinctions based on vowel quality, a logical hypothesis is that languages without phonemic vowel length have greater durational differences between different vowel qualities than languages with phonemic vowel length. Greater duration differences between vowel qualities would be associated with greater energy differences and thus a greater likelihood of being exploited as a weight distinction.

To test this hypothesis, the duration difference between low and high vowels in languages with and languages without phonemic vowel length was investigated for the six weight-sensitive languages which have comprised the bulk of the phonetic data examined thus far. In addition, phonetic data from five other languages, one with phonemic length (Bole) and four without (French, Farsi, Italian, and Russian) were collected using the same procedures as the other six languages (see Appendix 1 for corpora). Results for the eleven languages appear in Figure 8. Statistical comparison (by unpaired t-tests) of the vowels appears in Table 19. Cells containing differences which are not statistically significant at the $p<.01$ level are shaded. Both phonemic short vowels and phonemic long vowels (in languages in which they occur) were measured. For Javanese, both the difference between non-central and central vowels and the difference between high and low vowels are shown.

FIGURE 8. DURATION DIFFERENCE BETWEEN VOWELS OF DIFFERENT QUALITIES (LOW V- HIGH V, EXCEPT WHERE NOTED)

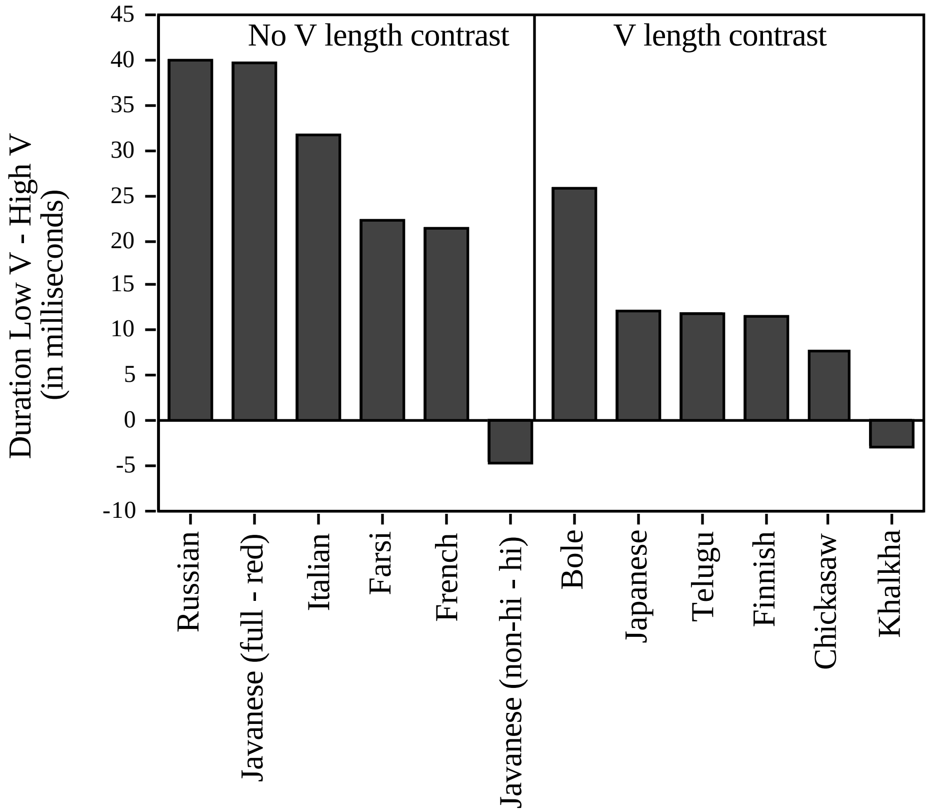


TABLE 19. DURATION DIFFERENCES BETWEEN VOWELS OF DIFFERENT QUALITIES IN 11 LANGUAGES

Language	Low V- High V	t-value	Significance Level
Russian	39.9	7.536	p<.0001
Javanese (NonShCen V - ShCen V)	39.6	12.395	p<.0001
Italian	31.6	9.805	p<.0001
Farsi	22.1	11.810	p<.0001
French	21.1	11.447	p<.0001
Javanese (+low V - hi V)	-4.8	1.126	p=.2635
Bole	25.9	5.900	p<.0001
Japanese	12.4	2.087	p=.0397
Telugu	11.8	2.417	p=.0170
Finnish	11.7	2.238	p=.0265
Chickasaw	7.6	1.747	p=.0824
Khalkha	-3.0	.733	p-.4644

In virtually all cases, languages without phonemic vowel length display greater durational differences between vowels of different qualities. The exceptional languages in this regard are Bole, in which vowel length is phonemic only in open syllables, and Javanese, which makes a large duration difference between non-central and central vowels but not between high and low vowels. The different duration patterns found in languages with and without phonemic vowel length contrasts impact total energy measurements, since the measurement of total energy factors in duration. Thus, the longer the vowel, the more energy it will have, all else being equal.

These data offer an explanation for the fact that virtually all languages with weight distinctions based on vowel quality do not possess phonemic contrasts in vowel length. Because the energy differences between low and high vowels are greater in languages without phonemic long vowels than in languages with phonemic long vowels, languages without phonemic long vowels are more likely to make a phonological weight distinction based on vowel height. Those languages with phonemic vowel length and a weight distinction based on vowel quality draw an additional weight distinction which is plausibly phonetically superior to the distinction based on vowel quality. Assuming this to be true, the general hypothesis advanced here that phonetically superior weight distinctions are adopted before distinctions which are phonetically less favorable is further supported.

The tendency for energy differences between vowels of different qualities to be more pronounced in languages without phonemic vowel length has a functional basis. There is a well-documented tendency for low vowels to be cross-linguistically longer than high vowels (Lehiste 1970), a fact which is typically attributed to the additional time needed for the jaw lowering needed to produce a low vowel (Westbury and Keating 1980). In languages with phonemic length contrasts there is less room for the intrinsically longer low vowels to enhance their inherent length by undergoing additional lengthening, because additional subphonemic lengthening would potentially lead to neutralization of phonemic length distinctions. In other words, contrasts based on vowel quality are limited in terms of the durational differences which may accompany them. In contrast, in languages without phonemic vowel length contrasts, contrasts based on vowel quality can safely be accompanied by large differences in duration without endangering any phonemic length contrasts.

In summary, comparison of duration and energy measurement in languages with phonemic vowel length contrasts and languages without phonemic vowel length demonstrates one way in which syllable weight is grounded in phonetic patterns which themselves are attributed to another aspect of the phonological system, the vowel inventory.

10.2. THE FUNCTION OF SYLLABLE STRUCTURE IN LANGUAGE SPECIFICITY OF WEIGHT CRITERIA. Results of the present study indicate another way in which cross-linguistic variation in a basic phonological property of a language, its syllable structure, triggers phonetic differences between languages which in turn lead to variation in weight criteria.

The relevant data demonstrating the effect of syllable structure on the phonetic dimension underlying weight-sensitive stress comes from comparison of languages observing the CVV heavy criterion for stress and those displaying the CVX heavy criterion for stress. The exemplar language discussed in this chapter which instantiates the CVV heavy criterion is Khalkha, while Japanese and Finnish both employ the CVX heavy criterion. As data has shown, for all three languages, the phonological weight criterion is also the phonetically most effective of the simple weight distinctions.

Interestingly, Khalkha differs from Finnish and Japanese not only in terms of weight criterion, but also in terms of their inventory of coda consonants. Let us consider the difference along two dimensions: the number of permissible voiced codas relative to the number of permissible voiceless codas, and the number of sonorant codas relative to the number of obstruents codas. 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 the energy of CVC syllables as a whole is considered, 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.

The prediction that the energy of CVC is dependent on coda inventory was tested by comparing the set of attested voiced codas and voiceless codas in Khalkha, Japanese, and Finnish. Using grammars, the set of permissible coda consonants for each language was compiled, including phonemes and allophones cited by the grammars.[18]

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, kʲ, k, s, ʃ, x, m, n, ŋ, l, r, b, g]. If this inventory is split along the voicing dimension, there are slightly more voiceless codas than voiced codas: nine voiceless codas, [p, t, ts, tʃ, kʲ, 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, kʲ, k, s, ʃ, x, b, g], and five sonorant codas, [m, n, ŋ, l, r].

Japanese (Vance 1987), on the other hand, has five voiced codas (including codas which are clearly phonemic and those which are allophonic), [m, ɲ, n, ŋ, ɴ] and five voiceless codas, [p, t, ts, tʃ, k]. Because all of the voiced codas are sonorants and all of the voiceless ones are obstruents, the division is the same along the sonorancy dimension. 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].[19]

Given that Khalkha has both a greater obstruent-to-sonorant ratio and a greater voiced-to-voiceless ratio of coda consonants than both Japanese and Finnish, CVC in Khalkha would thus be expected to have less energy than in either Japanese or Finnish, since. This hypothesis can, in fact, be tested by examining the energy of CVC relative to both CV and CVV in Khalkha and Finnish. Japanese is not a representative test case, since no obstruent codas were included in the corpus (see Table 8). 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. Results of testing this hypothesis appear in Figure 9, which contains energy values for CVV, CVC, and CV in Khalkha and Finnish.

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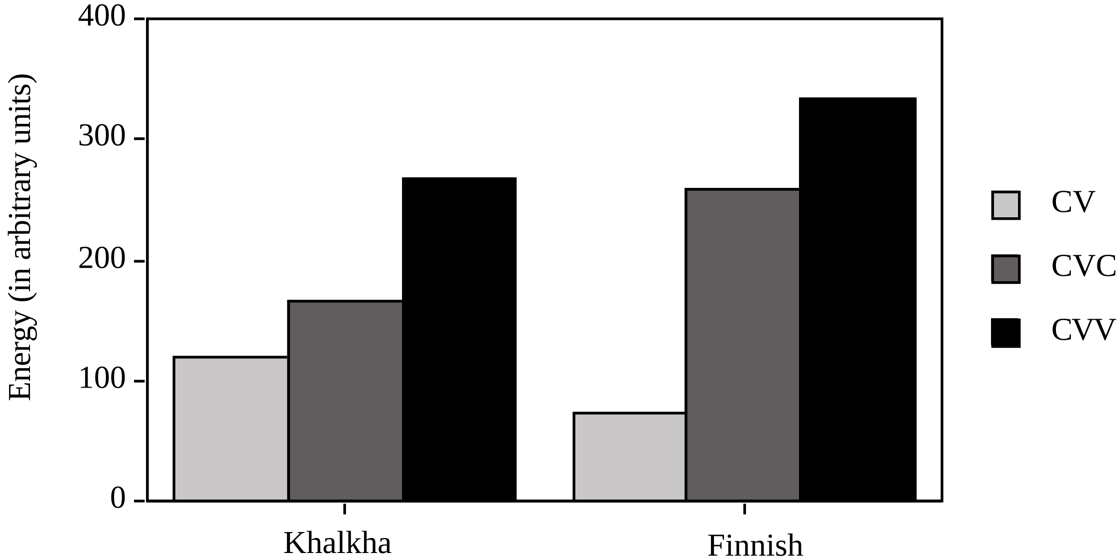
[18] All coda consonants were thus weighted equally regardless of their frequency of attestation, which would of course be impossible to assess accurately without tabulating large amounts of data from either dictionaries or text or spoken corpora.

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

FIGURE 9. ENERGY VALUES FOR CV, CVC, AND CVV 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 results 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, syllable structure, 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 quite interesting prediction borne out by Khalkha and Finnish, that weight distinctions are at least partially predictable if one considers the syllable structure 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 CVX 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 CVX 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 CVX 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 (1999a) 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, which has the CVX 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 CVX 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: χ^2=29.644, p<.0001.

It is clear that factoring in both sonority and voicing as predictors of the weight of CVC as a whole expands the predictive power of the hypothesis that syllable structure is ultimately responsible for language-specific choice of weight criteria. However, based on the data analyzed in this paper, languages vary in terms of whether weight distinctions sensitive to coda voicing or coda sonority are phonetically more effective. In Chickasaw and Khalkha, the CVV, CV[+son] heavy criterion is phonetically more effective than the CVV, CV[+voi] heavy criterion. In Telugu, on the other hand, the CVV, CV[+voi] heavy criterion is phonetically superior to the CVV, CV[+son] heavy criterion. This variation suggests that languages differ in terms of whether sonority or voicing is a better predictor of weight criteria. 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 syllable structure.

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.

11. CONCLUSIONS.

11. CONCLUSIONS. In this paper, I have shown that phonological weight distinctions for stress and poetic metrical systems match closely with the phonetic property of total energy. Languages choose weight distinctions which divide syllables into two groups of maximally differentiated syllables along the phonetic/perceptual parameter of total energy. Total energy, in turn, appears to be largely predictable on the basis of certain phonological properties of languages, such as the structure of the vowel inventory and the set of coda consonants.

Languages are not blindly faithful to phonetic properties, however, when evaluating potential weight distinctions. Languages eschew weight distinctions which are structurally too complex, even if they are phonetically more effective than other simple distinctions. Syllable weight thus represents a compromise between phonetic effectiveness and structural symmetry.

APPENDIX 1. Corpus of words for experiments on weight-sensitive stress (transcriptions in IPA)

Bole		**Chickasaw**	
pòrɗȉ__________ láːɟȉ Say __________ again please.		__________ tʃikːoʔsi aːtʃi. Say __________ quickly.	
pàtà	penis	pa'tʃiʔ	pigeon
pȉtà		tʃi'liʔ	chili
pùtà		shaː'tʃi	scrape
pàntà		tʃiː'li	lay eggs
pȉntà	fan	shan'tiʔ	rat
pùntà		sin'tiʔ	snake
pàːtà		im'pa	groceries
pȉːtà	fan	ʃambaʔ	blind person
pùːtà	rest	al'biʔ	paint
zàmbà		il'bak	hand, arm
zȉmbà	hit hard	al'ba[20]	weed
pùmbà		taʃ'ki	lie down
pàltà		iʃ'kiʔ	mother
pȉltà	hatch	pał'ki	go fast

[20] This word was compared to /albiʔ/ to calculate the difference in energy between /i/ and /a/ in the final syllable. This difference was then subtracted from /a/ in the second syllable of other words in the corpus, in order to allow for comparison of the first vowel in words containing /a/ in the second syllable with the first vowel in words containing /i/ in the second syllable.

pùltà	blow up (baloon)	piɫ'tʃi	sheep sorrel
tàrkà	get entangled	nak'siʔ	rib
tĩrkà		tik'baʔ	crotch
tùrkà		nib'li	dismember
		tab'li	cut
		yaːk'niʔ	cave
		naaf'ka	dress
		iːs'taʔ	easter
		tiːb'li	reinjure

Farsi		**Finnish**	
dobari ____________ begu.		sanon _________ kaksi kertaː.	
Say ____________ again.		I say _________ two times.	
pa̟'ʃe	mosquito	'lɑkɑt	varnish nom.acc.pl.
pi'ʃe	job	'likɑt	dirt nom.acc.pl. (dialect)
pu'ʃe	clothing	'nukɑt	nap nom.acc.pl.
pa̟m'be	cotton	'nɑːkɑt	jackdaw nom.acc.pl.
pim'be		'liːkɑt	surplus nom.acc.pl. (dialect)
pum'be		'nuːkɑt	
pa̟n'de		'lɑmpɑt	
pin'de		'limpɑt	
pun'de		'lumpɑt	
pa̟l'de		'mɑltɑt	be patient 2psg. pres.
pil'de		'milkɑt	
pul'de		'multɑt	
pa̟r'de	curtain	'mɑrkɑt	Finnish mark (money) nom.acc.pl.
pir'de		'mirkɑt	
pur'de		'murtɑt	break 2psg. pres. (dialect)
pa̟f'te		'lɑstɑt	splint nom.acc.pl.
pif'te		'niskɑt	nape of neck nom.acc.pl.
puf'te		'mustɑt	black nom.acc.pl.
pa̟s'be		'mɑtkɑt	journey nom.acc.pl.
pis'be		'mitkɑt	
pus'be		'mutkɑt	detour nom.acc.pl.
pa̟z'be			
piz'be			
puz'be			

pa̘ʃ'te	
piʃ'te	
puʃ'te	
pa̘ʒ'be	
piʒ'be	
puʒ'be	
ta̘x'te	wood
tix'te	
tux'te	
pa̘k'be	
pik'be	
puk'be	
pa̘g'be	
pig'be	
pug'be	

French		**Japanese**	
ʒə di ___________ dø fwɑ. I say ___________ two times.		mou itʃido ________ to itːe. Please say _________ again.	
pa'pe	father (dialect)	papa	papa
pi'pe	trick	pipa	
pu'pe	doll	pu̜pa	
pal'pe	touch	paːpa	
pil'pe		piːpa	
pul'pe		pu̜ːpa	
paʁ̥'ke	fold, enclose	pampa	
piʁ̥'ke		pimpa	
puʁ̥'ke		pu̜mpa	
pas'pe		panta	
pis'pe		pinta	
pus'pe		pu̜nta	

Khalkha		**Javanese**	
daxin xɛl ___________. Say again ___________.		kandane ____________ manɛh. As its said __________ again.	
'mɑnɑx	keep vigil	'd̪ami	dried rice stalk
'munɑx	become senile	'd̪amu	to blow (on, out)
'mɑːnɑx	stupid	'gadɑ̝	club
'muːrɑx	faint	d̪ə'lap	covetous
'namtɑx	become lower	'badan	body
'umbɑx	swim, ford	'basin	foul odor
'tsɑntɑx	be covered in frost	'lamun	when, if
'untɑx	sleep	'kaŋən	yearn for, miss
'mɑltɑx	dig, excavate	'babar	to proliferate
'mulgɑx	be confused	'd̪alir	stripes (on animal)

'mɑrtɑx	forget	'balur	type of fish
'ursɑx	flow, stream	'marmər	marble
'nɑslɑx	age, grow old	'babat	tripe
'nustɑx	get the flu	'babit	to swing at
'xɑʃgɑr	shouting	'manut	according to
'muʃrɑx		'padət	compact
'mɑxsɑx	crave meat	'bagas	healthy looking
'nuxlɑx	rub continuously	'garis	fate
'mɑktɑx	praise	'barus	chalk, udder
'uktɑx	welcome a visitor	'gaməs	eat all one can get
'mɑgnɑx	silk brocade		
'uglɑx	insert		

Russian

skaʒi _________.
Say ________.

'papa	papa
'pipa	kid's term for vagina
'pupa	

Italian

diko ___________.
I say ___________

'pampa	pampa
'pimpa	
'pumpa	
'panta	
'pinta	pint
'punta	point
'parta	
'pirta	
'purta	
'palta	
'pilta	
'pulta	
'pasta	pasta
'pista	track
'pusta	

Telugu

__________ kaːbolo.
__________ is said.

'para	foreign
'pira	
'pura	
'paːra	spade
'piːra	
'puːra	
'pampa	
'pimpa	
'pumpa	
'palta	
'pilta	
'pulta	
'parta	
'pirta	
'purta	
'pasta	
'pista	
'pusta	
'pakta	
'pikta	
'pukta	
'pagna	
'pigna	
'pugna	

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