Syllable Weight and the Phonetics/Phonology Interface
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SYLLABLE WEIGHT AND THE PHONETICS/PHONOLOGY INTERFACE

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This paper examines the hypothesis that syllable weight is determined on the basis of two phonetic properties: duration and total energy. It is argued that syllables which are inherently prominent in terms of either duration or energy are treated as heavy syllables for purposes of weight (quantity) sensitive stress. It is argued on the basis of experimental data from ten languages that duration and energy for different rimes are similar across languages regardless of the phonological weight system employed by a particular language. These phonetic hierarchies correspond closely to the phonological weight hierarchies observed by languages of the world. Syllables which are heavy cross-linguistically are also phonetically longer and/or possess more energy. Phonological differences in weight result principally from a difference in the phonetic property upon which weight distinctions are based: duration or energy. This parametrization creates weight reversals, cases in which the same syllable is heavy in one language but light in another. Within a single phonetic dimension, however, languages choose the weight distinction(s) which rely on the largest phonetic and perceptual differences.*

1. INTRODUCTION. This paper explores the relationship between syllable weight and two phonetic properties which are independently known to lend prominence to a syllable: duration and energy. As such, it may be viewed as part of a general research program (albeit with slightly different results and conclusions) on the relationship between syllable weight and phonetics (see, for example, Hubbard 1994, 1995, Broselow, Huffman and Chen 1996).

Before proceeding further, a couple of caveats are in order regarding the limitations of this paper. First, I deal primarily with syllable weight as diagnosed by stress assignment, which is both the best documented weight-sensitive process and the one which displays the broadest range of weight distinctions cross-linguistically. Other processes which are commonly taken as indicators of syllable weight, such as minimal word requirements, reduplication, compensatory lengthening, etc. are not treated in this paper for reasons of space. For more data on these processes and their relationship to syllable weight and stress, the reader is referred to Gordon (1997a). I also do not offer an explicit formal account of the mapping between phonetic properties and phonological weight patterns which behave more symmetrically than consideration of phonetic patterns alone might suggest. The reader is referrred to Hayes 1996 for an algorithm linking phonetic properties to phonological patterns and Gordon 1997b for discussion of this algorithm as it relates to syllable weight.

The structure of the paper is as follows. Section 2 provides a typological overview of the types of weight criteria displayed by stress systems. In section 3, an inventory of *unattested* weight hierarchies of weight certain rimes is presented. In section 4, I discuss the phonetic basis for weight, arguing on the basis of phonetic data from ten languages with diverse weight patterns that syllables which are either inherently long or possess inherently great energy are selected as heavy. It is shown that cross-linguistic differences in syllable weight arise from two sources. First, languages may differ in the phonetic property on which they base weight distinctions, duration or energy. Second, languages differ as to where they draw weight distinctions. This difference has a phonetic basis: languages choose weight distinction based on the most robust phonetic and perceptual differences.

2. SYLLABLE WEIGHT: AN OVERVIEW. It has long been known that stress placement in many languages is a function of syllable weight (e.g. Allen 1973, Hyman 1977, McCarthy 1979, Prince 1990, etc.). In these weight-sensitive languages, "heavier" syllables attract stress. For example, in Latin (Allen 1973), stress falls on the penultimate syllable if it contains either a long vowel or diphthong or ends in a consonant. In words with more than two syllables, if the vowel in the penultimate syllable is short and not followed by a tautosyllabic consonant, stress falls on the antepenultimate syllable. Examples of Latin stress appear in (1).

(1) Latin stress
amí:kus 'friend', *karpéntum* 'carriage', *símulo:* 'I pretend'

Research has also revealed that languages may differ as to which syllables count as heavy and which as light. For example, in Khalkha (Bosson 1964, Poppe 1970, Walker 1995), CVV but not CVC is heavy for purposes of stress.

Numerous other weight patterns are attested in languages of the world. Some of these distinctions are presented in section 2.1. Interestingly, one nearly universal fact about weight distinctions is that syllable onsets do not affect the weight of a syllable[1]. For example, in Latin, the penultimate syllable in *pú.bli.kus* 'public' is light, even though it contains three segments under one possible syllabification. Crucially, the penultimate rime contains only a short vowel, and thus is considered light. Henceforth, onset consonants will not be considered in the discussion of weight. Following convention, however, a syllable initial consonant, though weightless, will be used in this paper in transcribing syllable types, e.g. CVC, CVV. Furthermore, note that CVV refers to both long vowels and diphthongs unless otherwise noted.

2.1. A TYPOLOGY OF WEIGHT DISTINCTIONS. In this section, a typology of weight distinctions is presented focusing on simpler binary weight distinctions and beginning with the two cross-linguistically most common weight distinctions, the Latin type one in which both CVV and CVC is heavy and the Khalka one in which CVV but not CVC is heavy. The reader is referred to Gordon (1997b) for discussion of the typology of weight distinctions including more complex weight hierarchy.

2.1.1. CVV, CVC HEAVY VS. CV LIGHT. Languages like Latin which treat long vowels and diphthongs as well as syllables closed by a consonant as heavy are cross-linguistically quite common, attested, for example, in diverse languages such as Estonian (Hint 1973), Arabic (McCarthy 1979), Cebuano (Shryock 1993), among many others.

2.1.2. CVV HEAVY VS. CVC, CV LIGHT. The Khalkha weight system in which CVV but not CVC is heavy is also quite common in languages of the world, attested in languages like Malayalam (Mohanan 1986), Menomini (Bloomfield 1962), and Yukulta (Keen 1983).

2.1.3. CVV, CV + SONORANT HEAVY VS. CV + OBSTRUENT, CV LIGHT. In addition to the Latin and Khalkha types of weight distinctions, there are a few languages which make a weight distinction between syllables closed by an obstruent and those closed by a sonorant, e.g. Kwakw'ala (Boas 1947). In these languages, only syllables containing a long vowel or syllables containing a short vowel and a sonorant coda are heavy. Syllables containing a short vowel and an obstruent coda or no coda at all are light.

2.1.4. WEIGHT DISTINCTIONS BASED ON VOWEL QUALITY. Certain languages draw weight distinctions based on vowel quality. The most common subgroup of this type are languages which treat full (i.e. non-reduced vowels) as heavier than reduced (i.e. schwa-like or centralized vowels). Crucially, in languages which make a weight distinction between full and reduced vowels, the reduced vowels are phonetically very short relative to the non-reduced vowels. This can be seen in measurements from Mari (Gruzov 1960) and Javanese (see below in section 4) and also in descriptions found in grammars. In Chuvash, the reduced vowels are "fleetingly pronounced, and sometimes so reduced as to sound almost coalesced with the following consonant..." (Krueger 1961: 71). Among languages which distinguish between full and reduced vowels, there exist two subgroups. One group ignores coda consonants, e.g. Javanese (Herrfurth 1964) and Chuvash (Krueger 1961), while the other group treats *all* closed syllables as heavy whether they contain a reduced vowel or not, e.g. Malay (Winstedt 1927).

Some other languages make weight distinctions between vowels of different qualities which do not involve a full vs. reduced vowel distinction. In languages which draw weight distinctions based on vowel height, it is the lower vowels which are universally heavier than the higher vowels. For example, in the Jaz'va dialect of Komi (Lytkin 1961), non-high vowels are heavy, whereas high vowels are light.

3. IMPLICATIONAL WEIGHT HIERARCHIES. If one considers the type of weight distinctions discussed in section 2, certain universal patterns emerge. Most notably, there are certain syllable types which are never heavier than certain other syllable types. For example, there appear to be no languages in which VC is heavier than VV[2]. Furthermore, there are no languages, to the best of my knowledge, in which syllables closed by an obstruent coda are heavier than syllables closed by a sonorant coda. There are other unattested weight patterns. High and mid vowels are never heavier than low vowels, mid vowels are never heavier than low vowels, and reduced vowels are never heavier than full vowels (where reduced entails a schwa or centralized quality and short duration). It is possible, however, for the same syllable type to be heavy in one language but light in another language. For example, in many languages, including Latin, closed syllables and syllables containing a long vowel are heavier than open syllables containing a short vowel, regardless of vowel quality. In other languages, including Komi Jaz'va and Javanese, syllables containing a heavy (=full or relatively low) vowel are heavier than all syllables containing a light vowel, even those closed by a coda consonant. To take an illustrative example compare the syllables /tip/ and /ta/ in Latin and Komi Jaz'va (11). In Latin, /tip/ is heavy, whereas /ta/ is light. In Komi Jaz'va, the opposite pattern obtains: /tip/ is light, whereas /ta/ is heavy. In section 5, the difference between languages like Latin and languages like Komi Jaz'va will be argued to arise from a difference in sensitivity to the two phonetic properties of duration and energy.

4. A PHONETIC BASIS FOR WEIGHT. This section presents phonetic data from ten languages which demonstrate that phonologically heavy syllables intrinsically possess either greater energy or duration than light syllables, or are *both* longer and louder than light syllables. It is a well-known observation that both energy (and its perceptual correlate, loudness) and duration are common phonetic correlates of stress. In many languages, stressed syllables are either longer or louder than unstressed syllables or are *both* longer *and* louder than unstressed syllables. The correlation between stress and an increase in duration and/or loudness has been experimentally shown for many languages including English (Fry 1955; Beckman 1986), Italian (Bertinetto 1980), Mari (Baitschura 1976),

Tagalog (Gonzalez 1970), etc. and impressionistically noted for many other languages. It thus is not surprising that quantity-sensitive languages would use these same phonetic properties not only to signal stress, but also to determine the position of stress in a word[3].

4.1. EXPERIMENTAL EVIDENCE. An experiment was designed to test the general hypothesis that languages treat syllables which are either longer or possess more energy as heavy. Ten languages with diverse weight patterns and different prominence systems were examined. Two languages in which CVV but not CVC or CV are heavy were considered: Telugu and Khalkha. Three languages in which both CVV and CVC are heavy were included: Italian, Finnish and Japanese. The Japanese evidence for this weight distinction comes from primarily from poetry (Vance 1987). Note that Italian does not possess phonemic long vowels. It does, however, have diphthongs which pattern as heavy. One language with a weight distinction between full and reduced vowels was also analyzed: Javanese. In addition to the languages displaying quantity sensitive stress, three languages with quantity insensitive stress (French, Farsi, and Russian) as well as a tone language (Bole) served as experimental controls. The languages investigated for the phonetic study appear in table 1.

Language	Weight distinction	Reference(s)
Telugu	CVV > CVC, CV	Brown 1981
Khalkha	CVV > CVC, CV	Poppe 1970, Bosson 1964
Italian	CVV, CVC > CV	Bertinetto 1981
Finnish	CVV, CVC > CV	Sadeniemi 1949
Japanese	CVV, CVC > CV	Vance 1987
Javanese	Full V > Reduced V	Herrfurth 1964
French	quantity insensitive (phrase)	Delattre 1966
Farsi	quantity insensitive (final)	Windfuhr 1990
Russian	quantity insensitive (phonemic/morphological)	Comrie 1990
Bole	tone	Lukas 1969

TABLE 1. Languages examined

Languages without quantity-sensitive stress serve as experimental controls, in the sense that, if they display similar duration and energy patterns to those found in quantity-sensitive languages, we avoid a potential circular relationship between phonetics and syllable weight whereby phonetic patterns could be argued to be purely the result of phonological criteria.

4.2. METHODOLOGY. A corpus of two syllable words of the form (C)VC(C)V(C) was constructed for each language, varying the rime of the first syllable and keeping the vowel in the second syllable constant. The first syllable was chosen as a target in order to avoid potential final lengthening effects (Wightman et al. 1992). 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, a/. Short vowels were examined in both open syllables and syllables closed by a member of a set of coda consonants; for example, by different sonorant codas, usually /m, n, r, l/, and coda obstruents (if tolerated in non-final position by the language). The set of coda consonants and the vowels examined for each language is listed in Table 2. Attempts were made whenever possible to control for keep surrounding consonants uniform. The first syllable had the same stress level for all words in the corpus, as did the second syllable. The first syllable was stressed in all languages except for Farsi, French, Chickasaw, and also Javanese in cases where the first syllable was a reduced vowel. In Javanese, the reduced vowel was measured in the second (=stressed) syllable of a word containing a reduced vowel in the first syllable[4]. By keeping stress uniform for all target syllables, a difference in stress level between different syllable types is eliminated as a potential confounding factor. Due to the lack of a consensus regarding syllable affiliations in Russian, only open syllables were examined. Rimes containing /u/ were not measured in Chickasaw due to an absence of this vowel in the inventory. Rimes containing /i/ were not measured in Khalkha due to confounds created by the vowel harmony system.

Language	Vowels and codas examined
Telugu	a, i, u, aː, iː, uː, m, l, r, s, k, g
Khalkha	a, u, aː, uː, m, n, l, r, s, ʃ, x, k, g
Italian	a, i, u, m, n, l, r, s
Finnish	a, i, u, aː, iː, uː, m, n, l, r, s, t
Javanese	a, i, u, ə, m
French	a, i, u, l, ʀ, s
Farsi	a, i, u, m, n, l, r, f, s, z, ʃ, ʒ, x, k, g
Russian	a, i, u
Japanese	a, i, u, aː, iː, uː, m, n
Bole	a, i, u, aː, iː, uː, m, n, l, r

TABLE 2. Vowels and codas measured

Six to eight tokens of each word were recorded from one speaker in each language. Words appeared in a carrier phrase. Two measurements were made for each rime using Kay CSL: duration and total perceptual energy, the integration of energy and duration in the perceptual domain. Total energy was measured rather than another measure of energy such as average energy, because psychoacoustic experiments suggest that the ear integrates energy and time up to durations under which most syllable durations fall (see Moore 1989 and Scharf (1978) for a review of the literature).

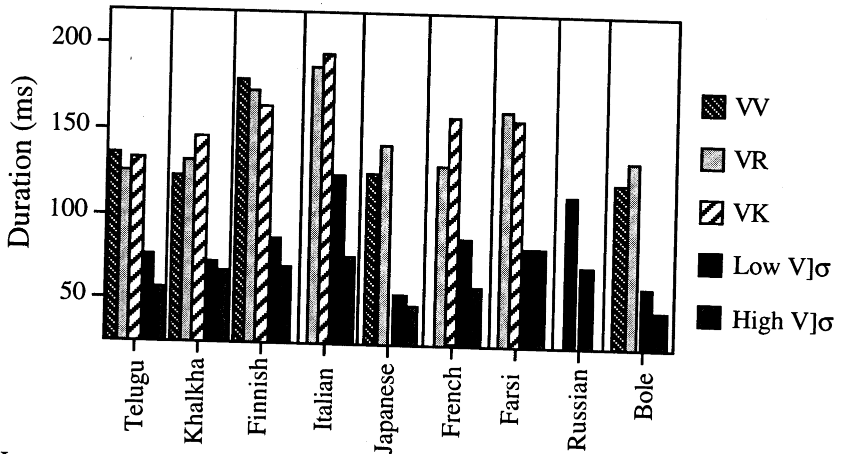
The procedure for measuring total perceptual energy was as follows. First, in order to control for token to token variation in speaking level, average amplitude (RMS) in decibels for each target vowel and the following coda consonant (if any) was calculated relative to a reference vowel in the 2nd syllable which, as mentioned earlier, was kept constant. 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) 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, it may 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 (see endnote for an example of the procedure)[5].

4.3. RESULTS. Average duration and energy values for the various rime types examined in each language are presented in sections 4.3.1. and 4.3.2. Values are grouped by each rime type which plays a role in weight distinctions in languages of the world: i.e. long vowels, sonorant closed syllables containing a short vowel, obstruent closed syllables containing a short vowel, and low and high vowels in open syllables. The values for each class of rimes were calculated by grouping rimes by natural classes into progressively larger groupings. For example, the average values for obstruent closed syllables were determined by first averaging values for rimes closed by fricatives and combining this average value with the average of rimes closed by a stop. Similarly, averages for long vowels were computed by first averaging values for *high* long vowels and averaging this number together with the average for *low* long vowels. Likewise, if only one type of syllable closed by a nasal was examined but two liquids were measured (e.g. Telugu), the two liquids were averaged together and then this average was averaged with the value for the nasal closed syllables. By adopting this method of averaging, imbalances in the number of segments belonging to each class were controlled for.

4.3.1. DURATION. Duration values for the five rime types VV, VR, VO, and phonemically short low and high vowels in open syllables appear in figure 1. Values for the reduced vowel in Javanese were also calculated. Due to graphical limitations related to the introduction of a category of reduced vowels, which would have made the figure less readable, values for Javanese appear immediately below figure 1.

The general pattern which emerges from figure 1 is for long vowels and closed syllables (both obstruent and sonorant closed) to be substantially longer than open syllables containing a short vowel, either a low or a high vowel. This is reflected in the large values for VV, VR, and VK relative to the high vowel and also relative to the low vowel. By comparison, the difference in duration between high vowels and low vowels is relatively small. Also, the difference between any two members of the set of rimes including VV, VR and VK is typically fairly small compared to the difference between any of these rimes and both low and high vowels in open syllables. These general patterns emerge in all languages regardless of language specific weight patterns, though there are differences between languages in the magnitude of the difference between these three longest rime types and the two shortest ones, as well as different rankings of VV, VR and VK relative to each other.

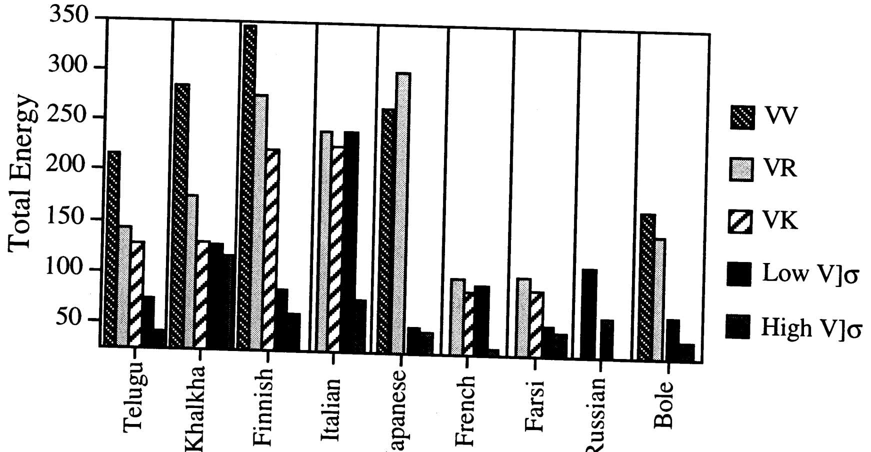
It appears on the basis of figure 1, that the Latin type weight pattern in which CVV and CVC (including CVK and CVR) accords well with the phonetic data where VV and VC are also phonetically long. However, it is also important to note that in Khalkha nor Telugu, VV is not significantly longer than VC even though CVV is phonologically heavier than CVC in both of these languages. In Khalkha, VV is actually shorter than both VR and VK. Nor is the weight distinction between full and reduced vowels in Javanese reflected in duration patterns not shown in figure 1. A full vowel in an open syllable is insignificantly longer than a reduced vowel in a closed syllable: reduced V in a closed syllable = 73.7ms vs. full V in an open syllable = 72.3. On the basis of these facts, it appears that duration does not offer an explanation either for weight distinctions of the Khalkha or Telugu type or for full vs. reduced vowel distinctions of the Javanese type.



Javanese: VR=128.9ms, Low V= 86.5ms, High V=60.8ms, Reduced V=26.1ms

FIGURE 1. Duration of five rime types in ten languages

4.3.2. ENERGY. Results of the energy measurements appear in figure 2. Values for low and high vowels are for phonemically short low and high vowels in open syllables.



Javanese: VR= 88.45, Low V= 85.05, High V= 56.00, Reduced V= 26.10

FIGURE 2. Energy values for five different rimes in eleven languages

As is apparent from figure 2, long vowels typically are characterized by the greatest amount of total energy in all languages containing long vowels. Lowest in energy are the high vowels. The ordering of VR and VK rimes relative to one another is also fixed across languages, with VR always having greater energy than VK. The ordering of VR and VK relative to low vowels displays the greatest variability from language to language. In Italian and French, low vowels have approximatley the same amount of energy as VR and VK, whereas in Telugu, Khalkha, Chickasaw, Finnish, Farsi, Japanese and Bole, low vowels have less energy than VR and VK (where VK occurs).

Energy offers an explanation for weight distinctions which cannot be accounted for by consideration of duration alone. Long vowels in Telugu and Khalka have much more energy than all other rimes, patterning with the heavy behavior of long vowels in Telugu and Khalkha. The difference in energy between long vowels and the next highest ranked rime in terms of energy is greater than the difference in energy between any of the four lowest ranked rimes. In Telugu, the energy value for VV is 73.24 higher than for VR, whereas the largest difference between any of the four lowest ranked rimes is only 53.88 (between VK and LowV). In Khalkha, the energy value for VV is 109.77 greater than that of VR, while the next largest difference (between VR and VK) is only 35.15. Thus, just as languages like Italian, Japanese, and Finnish employ weight distinctions between rimes which are maximally different in terms of *duration*, Telugu and Khalkha exploit the weight distinction between rimes which are maximally differentiated in terms of *energy*. Similarly, in Javanese, reduced vowels have much less energy than other rimes patterning with their light behavior phonologically. The difference between reduced vowels and other rimes is greater than the difference between any other rimes. This difference between reduced vowels and high vowels, the next lowest ranked rime in terms of energy, is not much greater than the difference between high vowels and the next highest rime, low vowels (29.9 vs. 29.05). However, bear in mind that the proximity of reduced vowels and high vowels to one another in terms of energy is probably an artifact of the experimental corpus. Recall from section 4.2. that the reduced vowel was measured relative to another reduced vowel, which has less energy than full vowels to which other targeted vowels were compared.

It is also interesting to note, that VR has greater energy than VK in all languages considered, though none of the languages examined makes a phonological weight distinction between obstruent and sonorant closed syllables. Also, in all languages, low vowels have greater energy than high vowels, even though none of the languages examined makes this weight distinction. These low level phonetic patterns in the examined languages correspond to phonological weight distinctions found in other languages. A reasonable and empirically testable hypothesis is that low vowels have much more energy than high vowels in languages which make this weight distinction, and that syllables closed by a sonorant have much more energy than syllables closed by an obstruent in languages which phonologically distinguish between the two for weight. Thus, one might hypothesize that in Kwakw'ala, there is a marked distinction in energy between long vowels and sonorant closed syllables on the one hand, and all other rimes on the other hand.

There is another interesting phonetic pattern seen in figure 2. Languages in which low and high vowels differ most markedly in terms of energy (Italian, French, Javanese, Russian) tend to be the languages without phonemic long vowels. In contrast, differences in energy between low and high vowels tend to be much smaller in languages without phonemic length distinctions (Telugu, Khalkha, Finnish, Japanese, Bole). Farsi is somewhat anomalous in this respect, since its energy difference between low and high vowels is relatively small compared to the other languages without phonemic vowel length contrasts. However, it is unclear whether distinctions in the Farsi vowel system are based entirely on qualitative rather than durational differences. Length contrasts are preserved in certain dialects of Farsi as well as in certain poetic traditions (Windfuhr 1990).

The different energy patterns between languages with and languages without phonemic long vowels is largely due to different duration patterns found in the two sets of languages (see figure 1). Duration differences between low and high vowels are greater in languages in which there are no phonemic length contrasts for the vowels. This difference presumably has a functional explanation. In languages without phonemic length contrasts, vowel qualities which are inherently long, the low vowels, may be made even longer relative to inherently shorter vowel qualities without potentially jeopardizing a phonemic vowel length contrast. This phonetic asymmetry between languages with and languages without phonemic vowel length contrasts corresponds to a phonological asymmetry in syllable weight. Languages with weight distinctions based on vowel quality including full vs. reduced vowel distinctions occur almost exclusively (21 of 23 cases) in languages without phonemic vowel length. In the exceptional cases in which they do occur, there is also a weight distinction between phonemically long and short vowels. On the basis of the data seen in this paper, we may hypothesize that the presence of a weight distinction based on smaller phonetic differences (e.g. weight distinctions based on vowel quality) necessarily implies that there will also be a weight distinction based on larger phonetic differences (e.g. weight distinctions between phonemically long and short vowels).

5. SUMMARY: DURATION AND ENERGY -- PUTTING THE TWO TOGETHER. The data examined in this paper strongly suggests that weight distinctions have a phonetic basis. Certain weight distinctions are grounded in energy, while others are grounded in duration. Examples of energy based weight distinctions are the Khalkha type distinction where CVV but not CVC is heavy, and the Javanese type of distinction, according to which full vowels are heavier than reduced vowels. Presumably other vowel quality based weight distinctions are also energy based, though data from the relevant languages were not examined here. Duration based weight distinctions include the Latin type pattern, according to which CVV and CVC are heavy, as well as possibly the pattern seen in languages like Malay according to which both full voweled syllables and closed syllables are heavy, though the data at this stage is inclusive as to whether this is an energy or duration based weight distinction.

The parametrization of weight along the two phonetic dimensions of duration and energy results in weight reversals, cases in which the same rime may be heavy in one language but light in another language: e.g. Latin vs. Komi Jaz'va. In Latin /tip/ is heavy and /ta/ is light, whereas in Komi Jaz'va, /tip/ is light and /ta/ is heavy. On the basis of the data examined in this paper, it is presumably the case that in Latin, duration is the relevant property for weight, whereas in Komi Jaz'va, energy is the crucial property. It does not at this stage seem possible to determine the phonetic dimension upon which a language will base its weight distinctions merely by looking at phonetic properties. For example, there are quite large energy differences between high vowels and other rimes in Italian. This difference, however, is not exploited phonologically: Italian weight distinctions are based on duration. Crucially, however, within either of the two phonetic dimensions of duration and energy, languages exploit the weight distinction which relies on the most robust phonetic differences.

The unattested phonological weight distinctions are correctly predicted to be unlikely to occur on the basis of phonetics. For example, although in Italian, French, Khalkha, VK is the longest rime, in none of these languages is the duration difference between VK and the shorter rimes larger than the difference between any of the rimes other than VK. Thus, the difference between VK and other rimes is unlikely to be exploited into a weight contrast, at least without first making another more salient weight distinction. Similar small phonetic reversals like that seen between VR and VV in Japanese are likewise unlikely to exploited into a weight distinction, since other weight cutoffs are phonetically and perceptually more desirable.

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[1] The familiar counterexample to the claim that onsets are universally weightless is provided by Pirahã (Everett and Everett 1984). Davis (1988) discusses a few additional cases of languages which apparently are sensitive to onsets in determining stress.

[2] Two exceptions to this generalization have been argued for in the literature. Biblical Hebrew (McCarthy 1979) and Salcha (Tuttle 1991). In both of these languages stress falls on a heavy final syllable where heavy is equivalent to closed syllables but not open syllables containing a long vowel, otherwise on the penult. While I am unable to comment on the Hebrew facts, Tuttle states that long vowels are shortened in word-final position, a phonetic fact which could explain their failure to attract stress.

[3] It is conceivable that other factors play a role in the assignment of stress, notably the ability of certain syllables to carry certain intonation contours which could enhance the prominence of a syllable. For example, pitch, which is linked to stress in many languages, is better realized on vowels than many consonants due to the sonorant nature of vowels. Thus, if a language wanted stressed syllables to possess a particular pitch contour more suited to vowels than consonants, it might be more likely to stress long vowels than VC syllables. However, energy seems more closely related to "stress" as typically conceived than pitch, since most languages have distinct (though often intersecting) intonational (including pitch accent) and stress systems.

[4] Because energy for the reduced vowels in Javanese was measured relative to another reduced vowel rather than to a full vowel, energy values for the target reduced vowel could potentially be inflated. This does not influence the conclusion reached in section 5.

[5] The procedure may be illustrated by means of a concrete example. Let us take the first syllable of the word /pant<u>a</u>/. First, the average energy of /<u>a</u>/ was 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 /<u>a</u>/, and the average energy of /**n**/ is 3dB greater than the average energy of /<u>a</u>/. 6dB corrpesonds to a twofold increase in perceived loudness, while 3dB corresponds to a 1.55 increase in perceived loudness. The duration of **/a/** in /p**ant**<u>a</u>/ is thus multiplied by 2, and the duration of /**n**/ in /p**an**t<u>a</u>/ is multiplied by 1.55 yielding total energy values for /**a**/ and /**n**/. Finally, the product of these operations are summed together providing a total energy value for the rime as a whole.

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