Weight-by-Position Adjunction and Syllable Structure[1]

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Most cross-linguistic variation in weight criteria is attributed to the parameterized application of Weight-by-Position adjunction to codas on a language-specific basis (Hayes 1989). This paper explores the hypothesis that coda weight is ultimately predictable from syllable structure. An extensive survey of quantity-sensitive stress systems shows that languages that allow a proportionately large set of high sonority codas are far more likely to treat CVC as heavy than languages possessing a proportionately smaller inventory of high sonority codas. This link between coda inventory and coda weight is shown to follow from a model of weight in which syllable structure influences the phonetic map against which potential weight criteria are evaluated on a language-specific basis.

Keywords: codas, stress, syllable weight, weight, Weight-by-Position

1. Introduction

One of the more prominent diagnostics for syllable weight is stress assignment (Allen 1973, Hyman 1977, Zec 1988, etc.). For example, stress in Yana (Sapir and Swadesh 1960) preferentially falls on closed syllables and on syllables with long vowels. Thus, Yana places stress on the leftmost syllable that is either closed or contains a long vowel or diphthong; otherwise stress falls on the initial syllable. Examples of Yana stress appear in (1).

(1) Yana stress

Leftmost heavy: siˈbumk’ai ‘sandstone’, suˈk’oːnijaː ‘name of Indian tribe’, tsiniˈjaː ‘no’

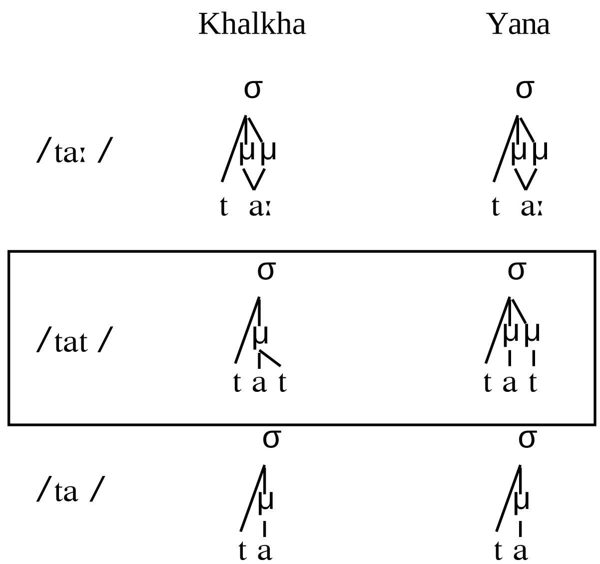
Otherwise initial: ˈp’udiwi ‘women’

Stress systems differ in terms of which syllables are treated as heavy and which count as light. Thus, in Yana, both syllables containing a long vowel or diphthong (CVV(C)) as well as closed syllables (CVC) are heavy for stress; open syllables containing a short vowel (CV) are light. In Khalkha Mongolian, on the other hand, only CVV(C) is heavy for stress; both CVC and CV are light (Bosson 1964, Walker 1996).[2]

It is standardly assumed (e.g. Hyman 1985, Zec 1988, Hayes 1989) that the weight of coda consonants is parameterized on a language-specific basis: some languages assign weight to coda consonants, in others, coda consonants are weightless. Differences in coda weight between languages are captured in moraic theory by assuming that codas are associated with a mora in languages in which they bear weight, but not in languages in which they are weightless. This is shown schematically in (2), where the difference between heavy and light syllables is reflected in differences in mora count: heavy syllables have two moras and light syllables have one. In all languages, CVV is bimoraic and CV is monomoraic, as vocalic moras are projected from phonemic contrasts in length. Languages differ in the weight of CVC, however, according to whether codas are weight-bearing or not. Hayes (1989) attributes this source of cross-linguistic variation to the Weight-by-

Position parameter. In languages with Weight-by-Position adjunction, codas are moraic and thus make their syllables heavy; in languages without Weight-by-Position adjunction, codas are non-moraic and thus do not lend weight to the syllable in which they occur. Onset consonants are non-moraic, as they are characteristically ignored in the calculation of weight.[3]

(2) Moraic representations of CV, CVC, and CVV



Up to now, investigations of syllable weight have focused on the nature of cross-linguistic variation in weight criteria and the phonological representations capturing this variation without examining possible motivations behind the language-specific adoption of a particular weight criterion. It thus remains unknown whether the language specific setting of the coda weight parameter is at all predictable from independent properties of the languages concerned.

Investigation of the predictability of language-specific weight criterion is the focus of this paper, which belongs to the research program investigating the relationship between the phonetics and phonology of syllable weight (see, for example, Maddieson 1993, Hubbard 1994, 1995, Broselow, Chen, and Huffman 1997, Goedemans 1993, 1998). It will be claimed that the presence or absence of Weight-by-Position adjunction is not an arbitrary parameter setting determined on a language-specific basis, but rather can be reliably predicted on the basis of syllable structure. Languages in which codas contribute weight differ from those in which codas are weightless not only in moraic structure and thus weight of CVC, but also in syllable structure. In particular, languages with heavy CVC will be shown to have a preponderance of codas that are relatively prominent from a phonetic standpoint, whereas languages with light CVC tend to have less prominent codas. It will be argued that these differences between languages in coda prominence lead to differences in the overall phonetic prominence of CVC and ultimately to differences in the phonological weight of CVC.

2. Coda inventory as a predictor of coda weight

As the preceding discussion suggests, one of the more obvious places to look for potential predictors of weight criteria is in the inventory of coda consonants, since differences in coda weight appear to account for most of the cross-linguistic variation in weight criteria (cf. Hayes 1989). In many stress systems, as in Latin and Yana, codas contribute weight; in many others, such as Khalkha, codas do not.[4]

The hypothesis explored here is that the overall prominence of the set of coda consonants acts as a predictor of weight criteria for stress. In particular, it is hypothesized that the greater the net prominence of the coda inventory in a language, the more likely it is that CVC syllables will be heavy. A crucial foundation in this proposal is an explicit mapping between prominence and phonological weight; it is this mapping that I will now lay out.

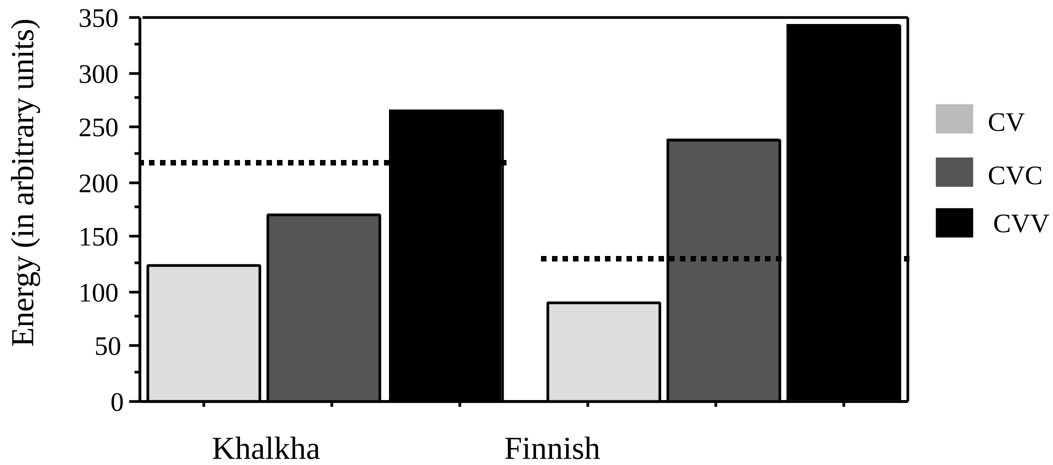
The posited link between coda prominence and weight of CVC is based on the assumption that phonetic prominence motivates the phenomenon of weight-sensitive stress. Recent work by Gordon (1999, to appear) suggests that the language specific choice of weight criterion for stress is predictable on phonetic grounds. Heavy syllables are those that are phonetically more prominent than light syllables in a given language, where prominence is evaluated along the phonetic dimension of total rimal energy, the integration of intensity over the duration of the syllable rime (see below for further discussion of this measure). A syllable rime thus benefits in prominence if it is relatively long and/or contains relatively intense segments. As we will see in section 2.2, the phonetic properties of duration and intensity relevant for establishing phonetic prominence for weight correspond closely to the phonological notions of timing and sonority, respectively. CVV is universally heavy, as long vowels are characterized by a long period of high acoustic intensity. CV, on the other hand, is light, since, although intense, it is short. CVC as a whole varies widely in energy between languages depending on which consonants occur as codas: the more energetic the set of codas, the greater the overall energy profile of CVC. For example, CVC in a language with a large proportion of sonorant codas will have more energy than CVC in a language with a large proportion of obstruent codas. It is claimed that these differences in energy of CVC dependent on coda inventory have implications for the phonological weight of CVC. If CVC is more energetic it is more likely to be treated as heavy than if it possesses less energy.

2.1. The phonetic link between coda inventory and weight

The link between phonetic energy and weight of CVC can be made more explicit by considering energy data from two representative languages collected as part of a larger experiment on phonetic correlates of syllable weight (Gordon 1999, to appear). The first of these languages, Khalkha treats CVC as light for stress (Bosson 1964, Walker 1996), whereas the second language, Finnish (Sadeniemi 1949), treats CVC as heavy for stress. The basic methodology of the experiment is summarized here (see Gordon 1999 for further discussion). A speaker of each language was recorded reading a list of disyllabic words in which the rime of the first syllable was systematically varied such that a range of rime types was represented. The stress pattern of each word was the same (stressed syllable followed by unstressed syllable), and the vowel in the second syllable was held constant. The duration of each segment in the rime of the first syllable was measured from a waveform using Kay CSL. In addition, the intensity of each segment in the rime of the first syllable was calculated relative to the intensity of the vowel in the second syllable and then converted to a measure of perceptual intensity reflecting the auditory system's response to the rime (see footnote and Gordon 1999 for discussion).[5] Finally, the overall energy of each measured rime was calculated as the integration of perceptual intensity over time.

The target syllables, all of which occurred as the first syllable of disyllabic words, were varied according to vowel quality and type of coda consonant. Three vowel qualities were represented in Finnish, /ɑ, ɪ, u/, whereas vowel harmony constraints in Khalkha limited the data to /ɑ, u/. Both long and short vowels were recorded in both languages, while codas were systematically varied such that they occurred with the different vowel qualities. Codas examined in Finnish were /m, l, r, s, t/, while those measured in Khalkha were /m, n, l, r, s, ʃ, x, k, g/. The set of codas for each language was chosen such that sonorants and obstruents and also voiced and voiceless codas were represented in roughly approximate proportion to their occurrence in the coda inventory as a whole. (The reason for focusing on the dimensions of voicing and sonorancy[6] will become clear later.) Thus, the proportion of the measured codas that were sonorants and voiced was higher in Finnish than in Khalkha, reflecting differences in the set of codas occurring in each of the languages. Finnish has five sonorant codas, all of them voiced [m, n, ŋ, r, l], and four obstruent codas, all of them voiceless [s, p, t, k].[7] Khalkha has the following inventory of coda consonants: [p, t, ts, tʃ, k^j, k, s, ʃ, x, m, n, ŋ, l, r, b, g]. Energy values for CV, CVC, and CVV for Khalkha and Finnish appear in (3). The dotted line indicates the phonetically optimal cut-off point between heavy and light syllables (see discussion below).

(3) Average energy values for CV, CVC, and CVV in Finnish and Khalkha



As one considers results of the energy study, it should be borne in mind that the goal of the phonetic study was not to provide exact measurements of the energy of CVC in Finnish and Khalkha, but merely to corroborate the intuition that differences in coda inventory between languages are associated with differences in overall energy profile of CVC. In fact, as expected, CVC has greater energy relative to CV and CVV in Finnish than in Khalkha. Thus, CVC in Finnish is closer to CVV in energy than to CV, whereas the energy of CVC in Khalkha more closely approximates that of CV than CVV. Thus, if we were to draw a line splitting syllable types into heavy and light groups, as in (3), the optimal cut-off point in Finnish in terms of creating maximal separation of heavy and light syllables would fall between CV and CVC. The motivation for this metric of phonetic optimality involving maximization of phonetic distinctness between heavy and light syllables is perceptual in nature. It is hypothesized that languages prefer to rely on weight distinctions based on the largest phonetic differences, since distinctions based on larger phonetic differences are easier to perceive than distinctions based on smaller differences (see Gordon 1999 for discussion; see also Liljencrants and Lindblom 1972, Lindblom 1986, Goedemans 1993, 1998, Flemming 1995, Steriade 1999, Kirchner 2000 for arguments that perceptual factors play an important role in phonology).

In terms of weight, the phonetically most sensible distinction in Finnish would thus treat CVC and CVV as heavy and CV as light. In Khalkha, on the other hand, the phonetically most effective cut-off falls between CVC and CVV, corresponding to a weight distinction that treats CVV but not CVC as heavy. It is interesting to observe that the distinctions that are most sensible from a phonetic standpoint are exactly the phonological distinctions employed by the two languages: Khalkha treats CVV but not CVC as heavy, whereas Finnish has both heavy CVV and heavy CVC. As hypothesized, the difference in energy and corresponding phonological weight between Khalkha and Finnish can be linked in large part to differences in coda inventories between the two languages. CVC possesses relatively greater energy in Finnish due to the high proportion of energetic codas. These results are not particularly surprising given that differences in CVC energy between Khalkha and Finnish are reducible in large part to differences in phonological sonority, where it is understood that sonority scales are ultimately projected from phonetic prominence scales.

2.2. Extending the predictions to other languages

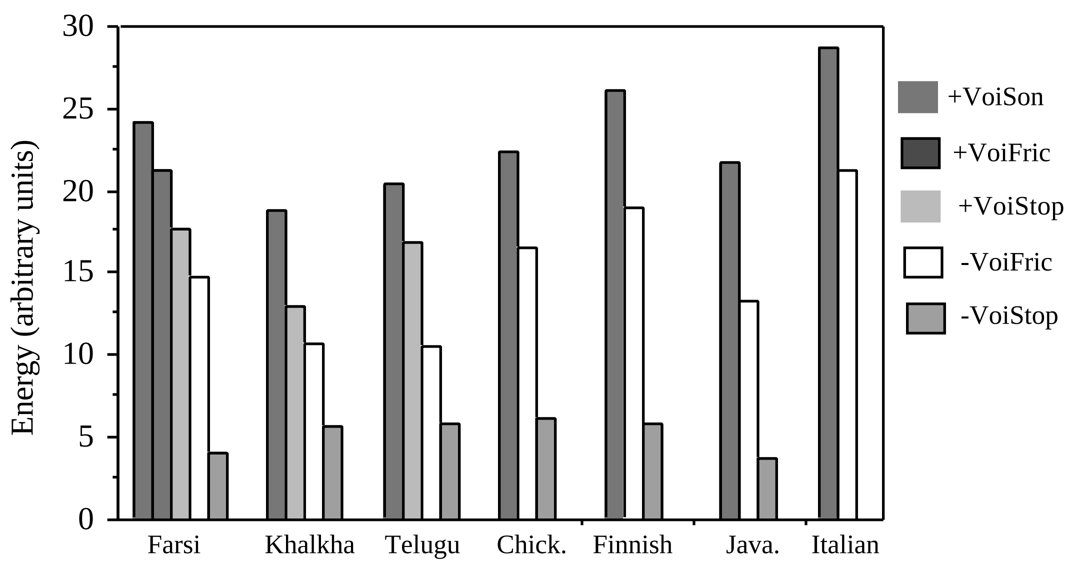
Given the link between phonological weight and phonetic energy of CVC in Khalkha and Finnish, it is reasonable to attempt to extend predictions to other languages differing in weight of CVC. In an ideal world, one would collect phonetic data from all languages treating CVC as heavy and all languages with light CVC to determine whether differences in coda inventory resulted in variation in CVC energy in a way that corresponded to differences in phonological weight, following the procedure adopted for Finnish and Khalkha. Although such a study is unreasonable on practical grounds, we are fortunate in dealing with a phonetic property, energy, that is sensitive to universal (or nearly universal) phonetic scales predictable in large part, as we have already seen in Khalkha and Finnish, from phonological properties, such as voicing and sonorancy. Thus, given a suitable phonological sonority scale corresponding closely to a phonetic continuum of energy, one can examine phonological coda inventories in primary sources and infer with reasonable reliability, subject to certain limitations, the phonetic energy profile of CVC as a whole. A crucial first step in this endeavor is the establishment of a phonological sonority scale for consonants that corresponds closely to a phonetic energy scale. Establishing a correspondence between phonetic energy and phonological sonority is not a trivial task, as the relation between standard sonority scales, e.g. Steriade (1982), Selkirk (1984), Clements (1990), and quantifiable phonetic properties has not been experimentally established. Nevertheless, standard sonority scales serve as a good starting point as they are sensitive to differences in manner of articulation that are likely to correspond to differences in phonetic energy as well. Experimental evidence for this position will be presented below.

Three phonological distinctions that correspond closely to differences in energy are the following: sonorant vs. obstruent, stop vs. fricative, voiced vs. voiceless (see Stevens and Keyser 1989 for discussion of the phonetic basis for phonological features). Although these are not the only distinctions relevant in sonority scales, they are the ones that correspond (based on examination of data from languages considered below) to the largest differences in phonetic energy; for this reason, they are most likely to play a decisive role in the language-specific weight of CVC. Furthermore, they allow for stronger predictions on a cross-linguistic basis than other distinctions relevant in standard sonority scales (e.g. liquids vs. nasals), since more of the cross-linguistic variation in coda inventories is attributed to differences in number of sonorant vs. obstruent codas, voiced vs. voiceless codas, and stop vs. fricative codas, than is attributed to other sonority-based differences, such as liquids vs. nasals.[8]

We are now in a position to set up a sonority scale for coda consonants, where the ordering of consonants is a function of phonetic energy. The relevant consonant types are the following: sonorants (which are almost always voiced), voiced stops, voiced fricatives, voiceless stops, and voiced fricatives. In order to enhance the likelihood of the scale being universal (or close to universal), it is important to consider data from several languages.

Average energy values (calculated as described in section 2.1) for a representative coda belonging to each occurring member of our sonority scale (sonorants, voiced stops, voiced fricatives, voiceless stops, and voiced fricatives) were thus collected from a total of seven languages. The seven languages consisted of Khalkha and Finnish plus three other weight-sensitive languages examined as part of the phonetic study of weight-sensitive stress in Gordon (1999, to appear): Telugu, Chickasaw, and Javanese. In addition, data from two other languages with weight-insensitive stress were collected: Farsi and Italian. One speaker of each language was recorded and all measured codas within a single language occurred in syllables carrying the same level of stress. An attempt was made to measure the same codas for each language, though the nature of the data set did not always allow for this. The sonorant measured in each language was a nasal (/m/ or /n/), the voiced fricative (only found in Farsi among the recorded languages) was /z/, the voiced stop was /g/, the voiceless fricative was /s/ and the voiceless stop was /k/ or /t/. Results appear in the graph in (4).

(4) Energy values for various codas in seven languages



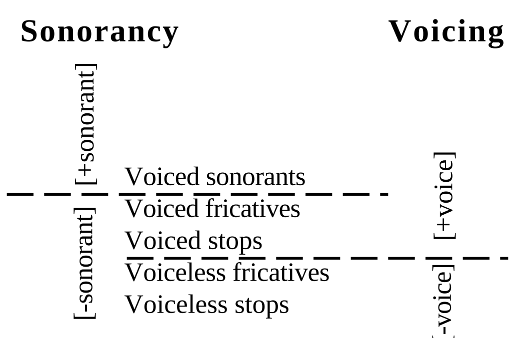
As is clear from (4), all of the languages (to the extent that the relevant codas are present) display the same ranking of elements in terms of energy. Sonorants have the greatest energy, followed by voiced fricatives, followed by voiced stops, followed by voiceless fricatives, followed by voiceless stops. Although most languages contain only a subset of coda types relevant for the sonority scale, the fact that all examined languages, both weight-sensitive (Khalkha, Telugu, Chickasaw, Finnish, Javanese) and weight-insensitive (Farsi and arguably Italian), display the same hierarchy of energy for consonant types that are present, strongly suggests a universal character to the hierarchy of energy. We may thus posit the phonological hierarchy in (5) projected from the phonetic property of coda energy.

(5) Hierarchy of phonetic energy

High Energy ↑	Voiced sonorants
	Voiced fricatives
	Voiced stops
	Voiceless fricatives
Low Energy ↓	Voiceless stops

The phonological dimensions that allow for a bifurcation of the scale in (5) into two continuous halves are voicing, expressed by the feature [+/- voice] and sonorancy, reflected in the feature [+/- sonorant]. Thus, if one draws a line separating codas that are positively specified for each feature from those that are negatively specified for the same feature we would have the divisions in (6).

(6) The energy hierarchy divided according to [sonorant] and [voice]



The division between [+sonorant] and [-sonorant] falls between sonorants and voiced fricatives and the cut-off between [+voice] and [-voice] codas falls between voiced stops and fricatives. Manner features other than [sonorant] and [voice] do not split the hierarchy in half. For example, the feature [continuant] creates multiple divisions in the hierarchy, since nasals and stops are [-continuant] while fricatives are [+continuant]. Continuancy thus does not predict the scale in (5) as well as voicing and sonorancy.

Much of the cross-linguistic variation in coda inventories is attributed to differences between the languages in the number of sonorant codas relative to the number of obstruent codas and to differences between languages in the ratio of voiced to voiceless codas. As we saw earlier, for example, Khalkha has five sonorant codas versus eleven obstruent codas and nine voiceless codas versus seven voiced codas. Finnish, on the other hand, has both more sonorant codas than obstruent codas and more voiced codas than voiceless ones: all five sonorant codas are voiced in Finnish and all four obstruent codas are voiceless. Thus, the sonorant to obstruent ratios and voiced to voiceless ratios are above one in Finnish but below one in Khalkha.

Other a priori possible divisions in the scale in (5) that are sensitive to combinations of continuancy and voicing or sonorancy do not differentiate Finnish and Khalkha nearly as well. For example, if we were to classify the two languages according to their number of stops relative to other codas, Khalkha would have 5 stops (including affricates) and 11 codas that are not stops, whereas Finnish would have 3 stops compared to 6 codas that are not stops. Thus, the ratio of stops to non-stops is roughly similar in the two languages. Furthermore, drawing a division between voiced fricatives and voiced stops would not lead to any further differentiation beyond that attained by considering the features [voice] and [sonorant], as neither language has voiced coda fricatives. The upshot of this discussion is that the predictive power achieved by looking at codas according to their voicing and sonorancy is greater than that achieved by considering additional dimensions.

At this point, one might ask whether it is necessary to consider codas along both dimensions of sonorancy and voicing to predict coda weight or whether one of these two dimensions alone might be sufficient. In fact, the phonetic data in (4) suggests that languages differ in whether sonorancy or voicing allows for a better bifurcation of syllable types into light and heavy groups. Thus, in some languages, the biggest drop off in energy occurs immediately following sonorants (Khalkha), whereas in others, the biggest drop off in energy occurs between voiced and voiceless codas (Telugu). In still others (Farsi), both divisions are approximately equally good. Finally, in some languages (Finnish, Chickasaw, Italian, Javanese), the bifurcation based on sonorancy is the same as the one based on voicing, since the only voiced codas are sonorants and the only voiceless codas are obstruents. From these differences, we can conclude that although the hierarchy of energy in (5) appears to be universal in terms of ranking of elements, energy differences between syllable types along the hierarchy vary in magnitude on a language-specific basis. In the absence of phonetic data from every language with either heavy or light CVC, we thus cannot be sure a priori whether voicing or sonorancy is expected to be a better predictor of weight criterion. Nevertheless, despite this limitation, we can still formulate powerful predictions linking coda inventory to syllable weight for a large subset of languages by looking at codas according to both their voicing and their sonorancy. In particular, we can hypothesize that the greater the number of [+voice] and [+sonorant] coda consonants relative to [-voice] and [-sonorant] codas, respectively, in a language, the greater the overall energy of the set of codas and thus the greater the mean energy of CVC in that language. Conversely, the greater the number of [-voice] and [-sonorant] codas in a language, the less the overall energy of the coda inventory and hence the less the energy of CVC in that language. Assuming that the weight of CVC is determined on the basis of its energy, we can hypothesize that CVC will be heavy in languages with a relatively large number of [+voice] and [+sonorant] codas while CVC will be light in languages with a relatively large number of

[-voice] and [-sonorant] codas. Languages are thus claimed to examine the overall sonority of their coda inventories and determine the weight of CVC as a whole category based on the net degree of coda sonority along both the [voice] and [sonorant] dimensions. The finding that is crucial in confirming the hypothesis linking coda weight to coda sonority is that languages with light CVC have lower [+voice] to [-voice] and [+sonorant] to [-sonorant] coda ratios than languages with heavy CVC. This result is sufficient to demonstrate a link between coda sonority and weight of CVC, regardless of the actual location of the best fitting cut-off point for separating languages with light CVC from those with heavy CVC.

As we will see below, the optimal cut-off point between languages differing in weight of CVC turns out to be one. Thus, languages in which both the ratio of [+sonorant] to [-sonorant] codas and the ratio of [+voice] to [-voice] codas are at least one overwhelmingly treat CVC as heavy, whereas languages with both [+sonorant] to [-sonorant] and [+voice] to [-voice] coda ratios of less than one almost universally have light CVC.

Languages with mismatched [+sonorant] to [-sonorant] and [+voice] to [-voice] ratios may either treat CVC as heavy or light on a language-specific basis; this is the point at which the absence of phonetic data demonstrating language specific energy values imposes its aforementioned limitations.[9] For example, no reliable prediction is possible for languages in which the ratio of [+sonorant] to [-sonorant] codas is at least one but the ratio of [+voice] to [-voice] codas is less than one: some will treat CVC as heavy, while others will treat CVC as light. Similarly, some languages in which the ratio of [+sonorant] to [-sonorant] codas is less than one but the ratio of [+voice] to [-voice] codas is at least one will treat CVC as heavy, while others will treat CVC as light. The predictions of the coda sonority-to-weight hypothesis are summarized in Table 1.

Table 1. Predicted weight criteria based on coda sonority

[+voice]/[-voice] Ratio	[+sonorant]/[-sonorant] Ratio	Prediction
≥ 1	≥ 1	CVC is heavy
< 1	< 1	CVC is light
≥ 1	< 1	CVC either heavy or light
< 1	≥ 1	CVC either heavy or light

3. A survey of weight criteria and coda inventories

3.1. Methodology

The hypothesis linking weight of CVC to coda inventory was tested against the entire set of languages in Gordon's (1999) survey of 381 languages that satisfied two criteria. First, languages had to make a binary weight distinction either treating CVC as heavy or CVC as light. Second, they had to possess closed syllables and long vowels and/or diphthongs. A total of 62 languages satisfied both of these criteria. Of these 62, 33 treated CVC as heavy and 29 treated CVC as light.

The inventory of coda consonants, including phonemes and allophones cited by sources, was evaluated for each of the 62 languages along the voicing and sonorancy dimensions. The number of voiced codas was compared to the number of voiceless codas, and the number of sonorant codas was compared to the number of obstruent codas for each language. As has been implicit throughout discussion up to this point, number in this context refers to the type frequency of each coda and not necessarily the token frequency; thus a coda consonant was weighted equally whether it occurred in 10 words or 100 words (see section 3.4.3. for discussion of frequency). All coda consonants were counted, excluding /h/ and glottal stop, since their phonetic realization, which is relevant for assessing their sonority, typically could not be inferred from published descriptions. Glottal stops, particularly in coda position, are often realized as a creaky continuation of the preceding vowel, while /h/ varies between languages in how fricative-like as opposed to approximantlike it is. All voiceless consonants, including those whose voiced counterparts are sonorant, were treated as [-sonorant], under the phonetic criterion that [+sonorant] sounds have continuous energy at low frequencies (Stevens and Keyser 1989).

3.2. Results of the survey

Results appear in Tables 2 (languages with light CVC) and Table 3 (languages with heavy CVC). In both tables, languages in which the voiced to voiceless and sonorant to obstruent ratios fall on different sides of one are shaded and appear after the unshaded languages, since no prediction about the weight of CVC is possible for them (but see section 3.6 for an extended hypothesis allowing for predictions for the shaded languages). The shaded languages are those with at least some voiced obstruent codas in addition to voiceless obstruents and voiced sonorants. This scenario yields a relatively high voiced to voiceless ratio but a relatively low sonorant to obstruent ratio.[10] Languages are organized alphabetically by name within the shaded and unshaded subcategories. Sources are indicated in footnotes.

The unshaded languages are most probative in testing our hypothesis, since their [+voice] to [-voice] ratio and [+sonorant] to [-sonorant] ratios are either both less than one or both at least one. The former scenario (both ratios less than one) characteristically arises in languages that tolerate a large number of voiceless obstruent codas, but have relatively few voiced obstruent codas. In some languages (e.g. Buriat), this may be attributed to neutralization of voicing in coda obstruents (see section 3.3 for discussion of coda neutralization and weight), but in most, it reflects a more general absence or paucity of voiced obstruents in any position. For example, the [+voice] to [-voice] and the [+sonorant] to [-sonorant] ratio are low in languages with voiceless but not voiced fricatives (e.g. Iraqw) and in languages with voiceless glottalized stops but not voiced glottalized stops (e.g. Hupa, Aguacatec).[11] The latter scenario (both ratios at least one) occurs in languages that either lack obstruent codas (e.g. Carib, Boiken, Manam, Sentani) or that permit more sonorant codas than obstruent codas and have very few or no voiced obstruents (e.g. Estonian, Cebuano).

Table 2. Languages with light CVC for stress[12]

Language	Vcd: Vcls	Vcd/Vcls	Son: Obst	Son/Obst
Aguacatec	7:16	**.44**	7:16	**.44**
Aleut	8:10	**.8**	6:12	**.5**
Cayuga	2:4	**.5**	2:4	**.5**
Cherokee	5:9	**.56**	5:9	**.56**
Comanche	2:5	**.4**	2:5	**.4**
Huasteco	7:14	**.5**	7:14	**.5**
Hupa	8:15	**.53**	8:15	**.53**
Iraqw	12:15	**.8**	7:20	**.35**
Karok	4:9	**.44**	3:10	**.3**
Khalkha	7:9	**.78**	5:11	**.45**
Koasati	6:8	**.75**	5:9	**.56**
Luiseño	8:10	**.8**	7:11	**.64**
Malecite-Passamaquoddy	3:6	**.5**	3:6	**.5**
Menomini	2:6	**.33**	2:6	**.33**
Mojave	7:8	**.78**	6:9	**.6**
*Nyawaygi	8:0	**no voiceless**	8:0	**no obstruent**
Ojibwa	4:6	**.67**	4:6	**.67**
Quechua (Huallaga)	6:7	**.86**	5:8	**.86**
Selkup	6:8	**.75**	6:8	**.75**
*Tidore	6:3	**2**	5:4	**1.25**
Tübatulabal	6:7	**.86**	6:7	**.86**
Winnebago	0:7	**no voiced**	0:7	**no sonorant**
Wintu	5:7	**.71**	5:7	**.71**
Wolof	7:9	**.78**	6:10	**.6**
Yupik (Central)	11:15	**.73**	4:22	**.18**
Buriat	8:6	**1.33**	5:9	**.56**
Krongo	10:7	**1.43**	8:9	**.89**
Malto	16:8	**2**	10:14	**.71**
Murik	9:4	**2.25**	5:8	**.625**

Looking first at Table 2, of the languages in which CVC is light, there are four shaded languages for which no reliable correlation between coda sonority and weight criterion is predicted. Setting aside these four languages, it is striking to observe that 23 of the 25 (92%) remaining languages have both fewer voiced than voiceless codas and fewer sonorant than obstruent codas, as predicted, the two exceptional languages (indicated by an asterisk) being Nyawaygi and Tidore (see section 3.4.1 and 3.4.2, respectively, for discussion of these languages). Evaluation of coda sonority in languages with light CVC thus offer strong support for the hypothesis linking weight of CVC to coda energy.

To corroborate the hypothesis, however, it is necessary to show that the link between coda sonority and weight is not attributed to an independent dispreference for voiced and sonorant codas in *all* languages regardless of weight of CVC. Thus, it must be documented that languages with heavy CVC characteristically do *not* have fewer voiced than voiceless codas and do *not* have fewer sonorant than obstruent codas.

Table 3. Languages with heavy CVC for stress[13]

Language	Vcd: Vcls	Vcd/Vcls	Son: Obst	Son/Obst
Ainu (Sakhalin)	5:1	**5**	5:1	**5**
Amele	5:5	**1**	5:5	**1**
Apalai	1:1	**1**	1:1	**1**
Boiken	3:0	**no voiceless**	3:0	**no obstruent**
Carib	4:1	**4**	4:1	**4**
Cayapa	2:2	**1**	2:2	**1**
Cebuano	10:4	**2.5**	7:7	**1**
Cuna	4:4	**1**	4:4	**1**
Estonian	10:6	**1.67**	9:7	**1.29**
Finnish	5:4	**1.25**	5:4	**1.25**
Khmer	7:5	**1.4**	7:5	**1.4**
Kiriwina	1:0	**no voiceless**	1:0	**no obstruent**
Latin	5:4	**1.25**	5:4	**1.25**
Macushi	6:4	**1.5**	6:4	**1.5**
Maidu	7:5	**1.4**	7:5	**1.4**
Manam	3:0	**no voiceless**	3:0	**no obstruent**
Miwok (Northern)	6:6	**1**	6:6	**1**
Munsee	7:7	**1**	7:7	**1**
Sentani	6:0	**no voiceless**	6:0	**no obstruent**
Nez Perce	11:6	**1.43**	11:6	**1.43**
Songai	10:3	**3.33**	7:6	**1.17**
Tepehuan (SEast)	8:5	**1.6**	8:5	**1.6**
West Tarangan	7:3	**2.33**	7:3	**2.33**
*Yana	6:10	**.6**	6:10	**.6**
Arabic (Egyptian)	14:9	**1.56**	7:16	**.44**
English	15:8	**1.88**	7:16	**.44**
Evenki	8:5	**1.6**	6:7	**.86**
Greek (Ancient)	9:4	**2.25**	5:8	**.63**
Hopi	8:7	**1.14**	6:9	**.67**
Koya	14:7	**2**	8:13	**.62**
Turkish	8:7	**1.14**	6:9	**.67**
Veps	15:10	**1.5**	8:17	**.47**
Votic	15:10	**1.5**	8:17	**.47**

In fact, Table 3 indicates that languages with heavy CVC typically have very different coda inventories than those with light CVC. As predicted, virtually all languages with heavy CVC have at least as many voiced as voiceless codas and have at least as many sonorant as obstruent codas. Setting aside the 9 shaded languages that are not probative in testing the hypothesis, 23 of 24 (96%) of the remaining languages (Yana being exceptional; see discussion in section 3.4.2) have at least as many voiced as voiceless codas and at least as many sonorant as obstruent codas.

In summary, considering coda inventories makes correct predictions about weight of CVC for 46 of the 49 (94%) languages in which both the voiced to voiceless and sonorant and obstruent ratios are at least one and those in which both ratios are less than one. Thus, coda sonority is a reliable predictor of the weight of CVC, supporting the hypothesis that coda weight is predictable from syllable structure (see section 3.8 for further discussion of the relationship between coda inventory and phonological weight).

Before concluding discussion of the findings, let us briefly consider voicing and sonorancy as independent predictors of the weight of CVC. To speak to this question, it is necessary to consider both the shaded and the unshaded languages in Tables 2 and 3. In fact, as it turns out, there is no single feature that acts as a reliable predictor of the weight of CVC in both languages with heavy CVC and those with light CVC. Voicing is an excellent predictor of weight in languages in which CVC is heavy (32 of 33 languages), but does not perform nearly as well in languages with light CVC (22 of 29 languages), whereas sonorancy is an excellent predictor of weight in languages in which CVC is light (27 of 29 languages), but not in languages with heavy CVC (24 of 33 languages).

3.3. Coda neutralization and CVC weight

Given the correlation between coda inventory and weight of CVC, one would expect languages in which the set of codas is a subset of the set of consonants in the language as a whole to tend toward certain weight criteria, where the effect on the weight system would depend on the particular subset relation observed in a language. Thus, it would be expected that languages in which codas are limited to those consonants characterized by relatively great energy should treat CVC as heavy. Conversely, languages in which consonants allowed in coda position have relatively little energy would be expected to treat CVC as light. In fact, these predictions can be tested for a number of languages in the survey that asymmetrically ban certain consonants from coda position.

One of the most cross-linguistically common types of coda restrictions, found in several languages in the survey, entails a ban against all obstruent codas. In such languages, the set of coda consonants is restricted to include only sonorants, which occupy the top position in the energy hierarchy in (5). We would expect such languages to treat CVC as heavy, since their sonorant to obstruent and voiced to voiceless ratios are greater than one. There were five languages in the survey that restrict their codas to sonorants, Boiken, Kiriwina, Manam, Sentani, and Nyawaygi. In fact, four of these five languages, all except Nyawaygi, treat CVC as heavy, as predicted based on our hypothesized link between coda inventory and weight of CVC (see section 3.4.1 for discussion of Nyawaygi).[14]

Interestingly, there is a small minority of languages with a coda restriction that is exactly the opposite of the ban against non-sonorant codas discussed in the preceding paragraph. In these languages, including one in the survey, Winnebago, only voiceless obstruents are allowed in coda position. This type of restriction would be expected to decrease the likelihood of CVC being heavy, as voiceless obstruents are the lowest energy codas. As predicted by our hypothesis, Winnebago treats CVC as light.

Another type of coda restriction that is likely to impact weight of CVC is a restriction against coda stops. Thus, certain languages allow sonorants and voiceless fricatives in coda position, but not any stops, voiced or voiceless. Assuming that such languages do not have a proliferation of voiceless fricatives, which would lower both the sonorant to obstruent and voiced to voiceless ratios, their restrictions against stops would be expected to raise the overall energy profile of CVC. In fact, all four of the languages in the survey that allow voiceless fricatives but not stops in coda positions, Sakhalin Ainu, Apalai, Cayapa, and Carib, treat CVC as heavy, as predicted.[15]

The types of coda restrictions discussed thus far are not an exhaustive set of those occurring in languages of the world. Just focusing on the surveyed data, certain languages, e.g. Latin and Cuna, do not tolerate voiced obstruents in coda position. Others, e.g. Turkish, neutralize laryngeal contrasts among stops but not fricatives in coda position, allowing only plain voiceless unaspirated stops but both voiced and voiceless fricatives.

For these types of coda restrictions, the predictions are less clear, as their overall effect on the coda inventory is dependent on the set of codas that are allowed to surface. Restrictions against all voiced obstruent codas, as in Latin and Cuna, will have the effect of raising the sonorant to obstruent ratio. If the set of sonorants is at least as numerous as the set of voiceless obstruents in coda position, a restriction against voiced obstruents will push the language in question into the class of languages expected to treat CVC as heavy. Latin and Cuna fall into this category, as the absence of voiced coda obstruents increases the sonorant to obstruent ratio to the threshold level of one at which languages are predicted to treat CVC as heavy. Although the lack of voiced coda obstruents lowers the voiced to voiceless ratio in Latin and Cuna, it still remains above the threshold value of one at or above which languages are predicted to treat CVC as heavy.

It is, however, possible to imagine a language with the same coda restriction against voiced obstruents as in Latin and Cuna but in which the absence of voiced coda obstruents would not result in CVC being heavy, unlike in Latin and Cuna. Such a language would have a large number of voiceless obstruent codas, such that they outnumbered the set of voiced sonorants. Wintu is a language falling into this category. Thus, although Wintu neutralizes all laryngeal contrasts in final position, a sufficiently large number of voiceless obstruents, including stops and fricatives, nevertheless remain as codas to preserve the light status of CVC.

Turkish is another language with voicing neutralization in coda position, which could potentially impact the treatment of CVC by the stress system. In Turkish, voiced stops do not occur as codas, though voiced fricatives can. The loss of voiced stops in Turkish is not sufficient to allow for reliable predictions about the weight of CVC given our conservative formulation of the coda weight hypothesis, as the ratio of coda sonorants to coda obstruents remains low due to the presence of voiced fricatives as well as voiceless stops in coda position. As it turns out, however, a finer scale of coda energy, such as the one to be introduced in section 3.6, does make the correct predictions about the weight of CVC in Turkish and other languages with voicing neutralization in stops but not fricatives (see section 3.6 for discussion).

3.4. Counterexamples to the hypothesis

In section 3.2, we saw that coda inventory serves as an extremely reliable predictor of CVC weight. Nevertheless, there were three exceptional languages that did not display the expected correlations. One of these languages, Yana, displayed low sonorant to obstruent and voiced to voiceless ratios but nevertheless treated CVC as heavy. On the flip side, Tidore and Nyawaygi had high sonorant to obstruent and voiced to voiceless ratios but treated CVC as light. In this section, we will briefly consider these languages and possible reasons for their exceptional behavior, starting with Nyawaygi.

3.4.1. Vowel lowering in Nyawaygi

Nyawaygi[16] (Dixon 1983) has a binary stress count going from right to left starting with the penult: σσ́σ, σ́σσ́σ. However, even if the binary count does not predict initial stress, as in words with an odd number of syllables, an initial CVV syllable nevertheless attracts stress from the second syllable, i.e. σ́σσ rather than *σσ́σ if the initial syllable is CVV. Thus, an initial CVV syllable has special stress attracting abilities in Nyawaygi. (Long vowels are confined to initial syllables.) Crucially, initial CVC does not attract stress in odd parity words, contra expectations given the absence of obstruent codas and the resulting high-energy profile of CVC in Nyawaygi.

Dixon's phonetic description of long vowels suggests an explanation for the unexpected light behavior of CVC in Nyawaygi. According to Dixon, the three long vowels have a tendency to be realized with a more open, i.e. lower, articulation than their corresponding short vowels. Thus, the long counterpart to short /i/ and /u/ are often realized as /ɛː/ and /ɔː/, respectively. Similarly, the long low vowel has a more open and backer articulation than its short counterpart. This difference in vowel quality between the long and short vowels likely has implications for the relative energy of CVV and CVC, given the cross-linguistic observation that lower vowels have greater energy than higher vowels (Lehiste 1970). Because the vowel in CVV is produced with a lower tongue position than the vowel in CVC, the difference in energy between CVV and CVC is most likely greater than the difference would be if CVV and CVC were produced with the same vowel quality. It is thus perhaps not surprising that Nyawaygi draws its weight distinction between CVV and CVC rather than between CVC and CV, as would be expected based on inspection of coda inventory alone.

3.4.2. Tonal crowding avoidance in Tidore

The second exceptional language with respect to the correlation between coda inventory and weight of CVC is Tidore (Pikkert and Pikkert 1995), in which the final syllable is stressed if CVV, otherwise the penult carries stress, even if the final syllable is CVC. Insight into the unexpected light status of CVC in Tidore is provided by considering the intonational factors present at the right edge of a domain, following work by Hyman (1977) and more recently Gordon (2000). The right edge of intonational units is in virtually all languages characterized by a fall in fundamental frequency in unmarked declarative statements. Stress, on the other hand, is typically marked by heightened fundamental frequency. Placing stress on a final syllable thus potentially entails crowding the low pitch at the right edge of the domain and the high pitch associated with stress onto the same syllable, under the plausible assumption that stress patterns reported in grammars are typically those of words uttered in isolation, where the word is equivalent to a large intonational constituent. Tonal crowding at the right edge is shown schematically in (7) where the high tone associated with stress is indicated with an asterisk and the boundary tone with a percent sign, following Pierrehumbert (1980).

(7) Stress repulsion at the right edge as tonal crowding

σ σ σ σ]

T* T%

Tonal crowding is a cross-linguistically undesirable property, as evidenced by the existence of a number of tone languages with do not allow contour tones on a single syllable, e.g. Capanahua (Loos 1969), Slavey (Rice 1989). In the case of stress, tonal crowding can be avoided without sacrificing either of the tones by pushing stress one syllable in from the edge. Consideration of tone languages provides insight into the asymmetry between peripheral CVV and other syllables with respect to stress placement in Tidore. Tonal crowding is not as problematic on CVV as on other syllables, since CVV is well-suited to carry a tonal contour due to its rich harmonic structure, which provides an ideal backdrop for realizing tonal information (see Zhang to appear for discussion). In many tone languages, e.g. Tubu (Lukas 1953), Navajo (Sapir and Hoijer 1967), Somali (Berchem 1993), contour tones are restricted to syllables containing long vowels and may not occur on syllables with short vowels. Just as many tone languages restrict contour tones to CVV, the stress system of Tidore also plausibly allows tonal crowding on CVV but not other syllables for the same phonetic reasons as tone languages. The intonationally-driven analysis of stress repulsion from edges also offers an explanation for other sonority-sensitive stress phenomena at domain edges, including certain types of extrametricality as well as stress-intonation interactions (see Gordon 2000 for discussion).[17]

3.4.3. Yana and closed syllable vowel lengthening

The remaining exceptional language with respect to coda inventory and weight is Yana (Sapir and Swadesh 1960), an extinct North American Indian language that treats CVC as heavy despite a relatively small proportion of voiced and sonorant codas. Stress in Yana falls on the leftmost heavy syllable (CVV or CVC), otherwise on the initial syllable. An interesting observation that perhaps provides insight into the unexpected heavy behavior of CVC is provided in a footnote on page 19 of Sapir and Swadesh's work. Referring to Sapir's transcription of vowels in closed syllables, they state that the "added syllabic weight generally inherent in closed syllables easily made the vowel sound long." Based on this description it is possible that vowels are allophonically lengthened in closed syllables in Yana.[18] Because Yana lacks a vowel length contrast in closed syllables, such phonetic lengthening would not jeopardize a phonemic contrast in length, unlike in open syllables where vowel length is contrastive. If vowels were lengthened in closed syllables, this would enhance the overall energy of CVC, making it less like CV and more like CVV, thereby explaining the heavy status of CVC in Yana.

As a final point, it may be noted that Karok and Mojave, both of which are Hokan languages genetically related to Yana, have similar sonorant to obstruent and voiced to voiceless coda ratios as Yana but treat CVC as light, unlike Yana. Karok and Mojave thus display the predicted correlation between coda inventory and weight of CVC. Interestingly, Karok and Mojave contrast vowel length in both open and closed syllables and would thus have less room for sub-phonemic vowel lengthening in closed syllables than Yana. It is thus plausible that a difference in the distribution of vowel length contrasts explains the different weight status of CVC within the Hokan language family.

There is another interesting fact about Yana which might further contribute to the a priori unexpected heavy status of CVC. Sapir and Swadesh's description of Yana suggests that low energy obstruent codas are relatively rare compared to high energy sonorants. They report that the only frequent word-final codas are the sonorants /l, m, n/ and that the ejectives /p', t', tʃ', k'/ rarely occur in coda position as the first member of a cluster. Furthermore, coda stops in general, including non-ejectives, are rare in all varieties of Yana except for Northern Yana. All of these statements suggest an overall paucity of low energy obstruent codas relative to high energy ones. It is thus possible that a method for evaluating coda energy which was sensitive to token frequency might boost the overall energy profile of CVC in Yana, thereby contributing, perhaps in conjunction with the hypothesized greater length of vowels in closed syllables, to the heavy overall status of CVC. Unfortunately, practical considerations involved in quantifying token frequency, e.g. from dictionaries, transcripts or texts, would make evaluation of frequency effects on a broad cross-linguistic basis difficult. Given the huge scope of such a task, it will be left as a potentially promising area for future research.

3.5. Intra-family variation in weight criterion

Hokan is among the several surveyed families consisting of multiple languages at least some of which differ in their treatment of CVC. Given the link between coda weight and coda inventory, we would expect such intra-family differences in weight criterion to be accompanied by differences in coda inventory. This prediction is confirmed for the surveyed languages for which evaluation of the hypothesis is possible.

Of the four surveyed Algic languages, the three that treat CVC as light (Menomini, Malecite Passamaquoddy, Ojibwa), have lower sonorant to obstruent and voiced to voiceless ratios than the one language, Munsee, which treats CVC as heavy. A similar situation obtains in the Penutian family, where three languages have heavy CVC and high sonorant to obstruent and voiced to voiceless coda ratios (Miwok, Maidu, and Nez Perce), and one has light CVC and correspondingly low sonorant to obstruent and voiced to voiceless ratios (Wintu).

Of the five surveyed Uralic languages, the four with heavy CVC (Estonian, Finnish, Veps and Votic) have higher voiced to voiceless ratios than the one with light CVC (Selkup). In this case, however, three of the four with heavy CVC, all except Finnish, have relatively low sonorant to obstruent ratios; a reliable prediction about the weight of CVC was impossible for this reason. We thus have a continuum in Uralic. At one end is Selkup with light CVC and low sonorant to obstruent and voiced to voiceless coda ratios. At the other end is Finnish with heavy CVC and high sonorant to obstruent and voiced to voiceless ratios. Intermediate are Estonian, Votic and Veps, all of which treat CVC as heavy and have high voiced to voiceless but low sonorant to obstruent ratios.

Altaic and Dravidian are the two families displaying the greatest indeterminacy. Two Altaic languages have light CVC (Khalkha and Buriat) while two have heavy CVC (Turkish and Evenki). Of these four languages, only Buriat has the necessary coda inventory, high voiced to voiceless and high sonorant to obstruent ratios, to allow for predictions about the weight of CVC. Khalkha, Turkish, and Evenki all have mixed ratios: high voiced to voiceless ratios but low sonorant to obstruent ratios. A similar situation obtains in Dravidian. One language, Koya, treats CVC as heavy, whereas the other, Malto, treats CVC as light. Both languages have high voiced to voiceless ratios but low sonorant to obstruent ratios, thereby preventing reliable predictions about CVC weight.

A recurring theme throughout virtually all of these intra-family comparisons of weight criteria and coda inventories is that, wherever the necessary coda ratios for making predictions are found, the correct predictions are made: languages with high sonorant to obstruent and voiced to voiceless coda ratios treat CVC as heavy, whereas those with low sonorant to obstruent and voiced to voiceless ratios treat CVC as light.

3.6. Expanding the predictions: a more finely grained energy hierarchy

Although predictions about the weight of CVC could be made for most languages in Tables 2 and 3, it may be recalled that were 13 languages with split ratios for which no prediction was made: high voiced to voiceless ratios but low sonorant to obstruent ratios. Of these 13 languages, nine treated CVC as heavy, whereas 4 treated CVC as light. We will now explore a slightly less conservative hypothesis linking weight of CVC to coda inventory that will allow for a prediction to be made for these 13 languages. As discussed earlier, languages with high voiced to voiceless but low sonorant to obstruent coda ratios share a fairly rich coda obstruent inventory including both voiced and voiceless obstruents. These languages differ, however, in their ratio of voiced to voiceless obstruents and also their ratios of fricatives to stops. It is thus conceivable that a more finely grained method for assessing coda energy among obstruents might differentiate between the 9 languages for which no prediction has yet been made but which treat CVC as heavy and the 4 languages with light CVC for which no predictions have been made. Clearly, attempts to make predictions based on fine distinctions in energy between obstruents should be regarded as tentative in the absence of supporting phonetic evidence. It is nevertheless worth exploring whether such an approach is likely to be fruitful.

A preliminary and coarse method for making predictions about possible links between differences in obstruent inventories and differences in weight is to assign integer values to the four types of obstruents in our energy scale presented earlier: voiced fricatives, voiced stops, voiceless fricatives, and voiceless stops. Since voiced fricatives have the greatest energy among the obstruents they may be assigned the highest integer value, which may be set at 4 given the existence of four types of obstruents in the hierarchy. Voiceless stops, which are at the opposite end of the energy hierarchy, may be given a value of one, with voiceless fricatives receiving a two and voiced stops a three. Since affricates are intermediate between stops and fricatives, they are assigned intermediate values: 1.5 for voiceless affricates and 3.5 for voiced affricates. It should be pointed out, of course, that it is unclear how closely the tentative integer values correspond to differences in phonetic energy; an answer to this question must await further phonetic research; the integers are merely employed here as a preliminary attempt to expand the predictive power of the theory to encompass more languages.

For each language, the integer values can be multiplied by the number of codas belonging to the class of obstruents with that integer value. For example, if a language has five voiced fricative codas, the total value for voiced fricatives would be 20. A language with four voiceless fricative codas would receive a value of 8. Total values for each type of obstruent may then be summed together and divided by the number of obstruent codas to yield an average value for the entire class of obstruents. For example, a language with five voiced fricatives and four voiceless fricatives in coda position would have an average value of 3.11 for the set of obstruent codas: 28 divided by nine obstruents. The higher the average value, the greater the hypothesized energy profile of the set of obstruent codas.

This procedure was applied to the 13 languages for which no prediction was made in section 3.2. Results appear in Table 4 in order from highest to lowest average obstruent energy values; languages with heavy CVC are italicized.

Table 4. Languages and their coda obstruent inventories

Language	**+VoiFric**	**+VoiStop**	**-VoiFric**	**-VoiStop**	**Average**
English	*4.5*	*3.5*	*4.5*	*3.5*	*2.56*
Arabic (Egyptian)	*3.5*	*3.5*	*5.5*	*3.5*	*2.44*
Veps	*4*	*3*	*5*	*5*	*2.35*
Turkish	*3*		*3.5*	*3.5*	*2.25*
Greek (Ancient)	*1*	*3*	*1*	*3*	*2.25*
Votic	*2*	*5*	*5*	*5*	*2.24*
Koya	*1.5*	*4.5*	*2*	*5*	*2.19*
Evenki	*2*		*2*	*3*	*2.14*
Murik	.5	2.5	1	3	2.07
Buriat		3	3	3	2
Malto		6	2	6	2
Krongo		2	2	5	1.67
Hopi		*1*	*1.5*	*5.5*	*1.44*

Interestingly, languages with heavy CVC, with the exception of Hopi, cluster together to the exclusion of languages with light CVC in their average obstruent energy values. It is thus possible to draw a dividing line separating languages according to their treatment of CVC, as in Table 4: languages with heavy CVC have higher obstruent energy values than those with light CVC. This is exactly what one would expect given the hypothesized link between energy and coda weight. The only exceptional language is Hopi, which has heavy CVC but a low average obstruent energy value. In general, though, subdividing obstruents according to their energy profiles increases the predictive power of the theory and provides further confirmation of the correlation between coda inventory and weight of CVC.

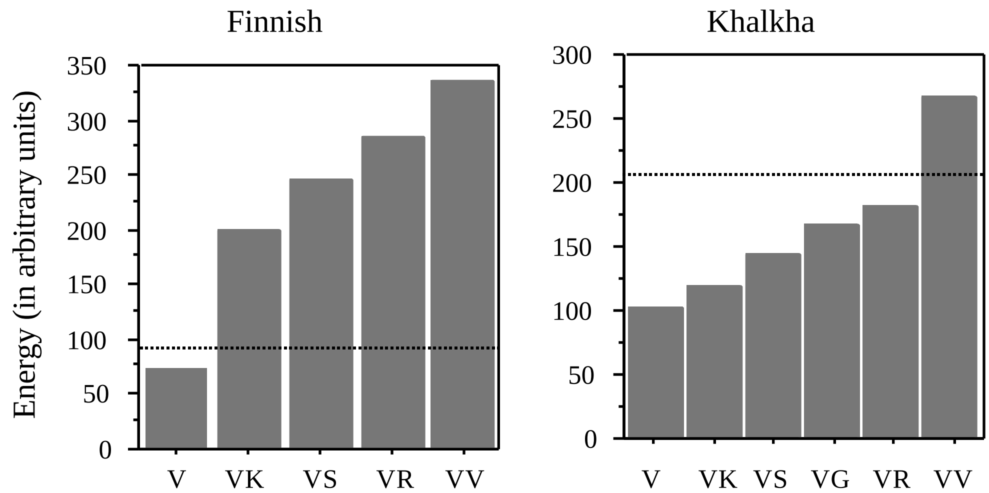
We are now in a position to return to the case of Turkish that was deferred in the earlier discussion of coda neutralization in section 3.3. It may be recalled that Turkish displays a subtype of obstruent voicing neutralization such that voiced fricatives but not voiced stops occur in coda position. Our more conservative formulation of the hypothesis linking coda inventory to weight of CVC in section 3.1 did not allow for predictions for Turkish, since the voiced to voiceless coda ratio is high but the sonorant to obstruent coda ratio is low in Turkish. However, given our finer scale of coda obstruent energy, a prediction can be made for Turkish: preservation of voiced coda fricatives would be expected to increase the likelihood of CVC being heavy, as voiced fricatives have the greatest energy of the obstruents. This prediction is confirmed, as Turkish treats CVC as heavy. If, on the other hand, we assumed hypothetically that Turkish had a different neutralization pattern and banned all voiced obstruents, including fricatives, the average coda energy values in Table 4 would be drastically lowered to 1.5 and would place Turkish in the group of languages predicted (erroneously) to treat CVC as light.

3.7. Weight distinctions based on coda sonority

There is one issue that remains to be addressed. One might reasonably ask why languages do not simply make weight distinctions that treat syllables closed by more energetic codas, such as sonorants or voiced consonants, as heavy and syllables closed by less energetic codas, such as obstruents or voiceless consonants as light. This would be a practical strategy for achieving a close match between phonetic energy and phonological weight. In fact, there are a few documented cases of stress systems that make such a distinction, the best examples coming from the Wakashan languages, e.g. Kwakwala (Boas 1947, Wilson 1986, Zec 1988) and Nuuchahnulth (Wilson 1986).[19] These languages are reported to treat syllables closed by a sonorant as heavy and those closed by an obstruent as light. The question then is: why do more languages not make sonority-based, i.e. energy-based, distinctions in coda weight?

A straightforward solution to this issue appeals to the evaluation of phonetic goodness of different potential weight distinctions. In a phonetic study of ten languages with different weight distinctions, including two with heavy CVC, one with light CVC, two with three way weight hierarchies of the type CVV > CVC > CV, one in which full (non-schwa) vowels are heavy, and four with weight-insensitive stress systems, Gordon (1999) shows that weight distinctions that treat CVC either as uniformly heavy or as uniformly light are phonetically superior to those that divide CVC according to the sonority of the coda. In languages with a high percentage of low energy codas, e.g. Khalkha, the difference in energy between different types of CVC is smaller than the difference in energy between any subtype of CVC and CVV. Conversely, in languages with a high percentage of energetic codas, e.g. Finnish, the difference in energy between various types of CVC is smaller than the difference in energy between any subtype of CVC and CV. This can be seen in (8), which graphs energy values for different types of CVC alongside both CV and CVV for Finnish and Khalkha. (Note that K = a voiceless stop, S = voiceless fricative, G = voiced stop, R =sonorant)

(8) Energy of different syllable types in Finnish and Khalkha



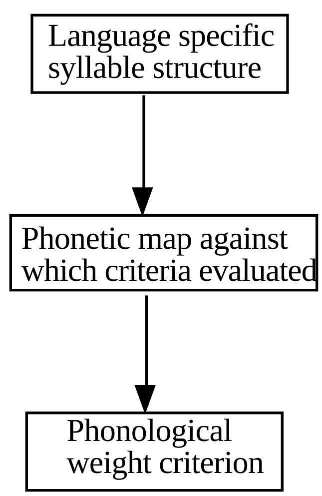
In Finnish, the biggest increase in energy (indicated by a dotted line) occurs between CV and the least energetic CVC, namely CVK, whereas in Khalkha, the biggest rise in energy falls between the highest energy CVC, namely CVR, and CVV. In both languages, energy differences between different subtypes of CVC are relatively small compared to the cutoff point coinciding with the phonological weight criterion observed by each language.

Other languages, including some with weight-insensitive stress, display similar relatively small differences in energy between different types of CVC, suggesting that uniform treatment of CVC is phonetically more sensible than distinctions that differentiate between different types of CVC (see Gordon 1999 for further discussion). The relevance of coda energy for weight-sensitive stress thus appears to manifest itself principally through its effects on the overall profile of CVC rather than directly giving rise to weight distinctions sensitive to type of CVC. Following this line of reasoning, the rare language like Kwakwala that does make weight distinctions based on coda sonority would be expected to show larger differences in energy between syllables closed by a sonorant and other types of CVC than between any CVC subtype and either CV or CVV. Unfortunately, this prediction must await testing, as the relevant phonetic data is lacking.

3.8. The relationship between coda inventory and weight of CVC

In closing, we may address the relationship between the present findings and the theory of weight. Drawing on a survey of coda inventories and weight criteria in 62 languages, we have seen evidence that the moraic status of coda consonants is not an arbitrary language-specific parameter but is ultimately predictable from syllable structure via the medium of phonetic prominence. If a relatively high percentage of codas are high energy ones, then codas are treated as moraic at much greater than chance levels, whereas codas overwhelmingly tend to be non-moraic in languages with a relatively low percentage of high-energy codas. Crucially, the scale of phonetic prominence to which coda weight is sensitive is universal, as demonstrated in the phonetic investigation of energy in section 2.2, and thus largely independent of syllable weight. It is thus unlikely that differences in phonetic prominence are solely attributed to differences in weight criterion, i.e. it is not the case that phonological weight is responsible for the observed phonetic patterns. The model of weight developed here is depicted schematically in (9).

(9) The proposed model of syllable weight



As the diagram in (9) depicts, in the proposed model of weight, language specific aspects of syllable structure contribute to interlanguage variation in phonetic prominence of CVC, which in turn, drives the language-specific choice of phonological weight criterion. I would claim that evaluation of the phonetic map driving choice of weight criterion is carried out by every generation of speakers, though, of course, purely inductive learning of phonological patterns would, in most cases, lead to adoption of the same weight criterion as phonetic evaluation by language learners. Phonetic evaluation becomes decisive whenever historical processes driven by other non-weight related considerations conspire to change the inventory of coda consonants and thereby the relative phonetic effectiveness of different weight distinctions. For example, loss of final vowels could potentially introduce new coda obstruents in a language with heavy CVC. Similarly, the introduction of a process of coda obstruent devoicing would eliminate voiced codas. Both apocope and obstruent devoicing would have the effect of reducing the prominence of CVC, thereby leading to a mismatch between the phonological treatment of CVC as heavy and its phonetic prominence.

In such cases involving a mismatch between phonetic prominence and the weight patterns evidenced through inductive learning, speakers must either be content with a phonetically sub-optimal weight distinction or takes steps to align the weight system and the phonetic map. These steps might entail adopting a new weight criterion, or alternatively, altering the coda inventory (see below). The existence of genetically related languages displaying different weight criteria and concomitant differences in coda inventories (see section 3.5) suggests that learners are indeed sensitive to mismatches between phonetic sensibility and phonological weight and actively correct them by altering their weight criteria, though this correction may not necessarily be enacted by the first generation of speakers.

In summary, under the model in (9), Weight-by-Position adjunction is a predictable language-specific parameter sensitive to a basic linguistic property, syllable structure, rather than an arbitrary language-specific setting. In being ultimately predictable from other independently documented language-specific properties, Weight-by-Position thus parallels associations between moras and segments projected from phonemic length. In the case of moras assigned on the basis of length contrasts, however, moras may be regarded as an underlying aspect of phonological representations. Coda weight, on the other hand, is determined as a function of phonetic prominence.

In a more speculative vein, there is another component that might be added to the model in (9). It is quite possible, perhaps likely, that not only does phonetic prominence influence choice of weight criterion, as suggested in (9), but that choice of weight criterion may also affect phonetic prominence. Thus, although the universal nature of the prominence scale claimed to be relevant for weight-sensitive stress strongly argues that weight is projected to a large extent from coda inventory via phonetic prominence, phonetic prominence may also be adjusted such that it maximizes the salience of phonological weight criterion. There exist many different strategies for a language to alter its phonetic properties to achieve a closer match between phonological weight criterion and phonetic energy. To cite just a few of the large number of possibilities, a language with light CVC could devoice coda obstruents or shorten coda sonorants, two strategies that would lower the overall energy profile of CVC. A language with heavy CVC, conversely, could lengthen coda sonorants or lengthen vowels before either some or all codas, as in Yana. These hypothetical strategies for optimizing the phonetic expression of phonological weight involve duration adjustments. It would also be possible for languages to alter the intensity profile of certain syllable types. For example, a language with heavy CVC could increase the intensity of some or all closed syllables, while a language with light CVC could conversely reduce the intensity of CVC. Yet another, more dramatic, strategy for enhancing the match between phonetics and weight would be to employ phonological processes to alter the coda inventory and thereby the prominence profile of CVC. Thus, a language with light CVC and only sonorant codas might syncopate final vowels, thereby introducing obstruents into coda position. Conversely, a language with heavy CVC might drop final obstruents in order to increase the net energy profile of CVC.

The upshot of this discussion is that, although this paper has focused on providing evidence for syllable weight being motivated by coda inventory via phonetic prominence, the possibility of syllable weight driving phonetic prominence and even coda inventory must also be acknowledged (see Broselow et al. 1997 for an analysis in which weight criterion guides phonetic duration patterns).

It may also be noted that coda energy is not necessarily the only phonetic factor involved in shaping the phonology of weight. There are certain weight effects which are plausibly sensitive to other phonetic considerations. For example, intonational factors such as those described in section 3.4.2 appear to play a role in sonority-driven weight distinctions at the right edge of domains. Thus, in Inga Quechua (Levinsohn 1976), the final syllable is stressed if closed by a sonorant (long vowels do not occur), otherwise the penult is stressed. Sonority-based weight distinctions operative at the right edge of a domain, such as the Inga Quechua one, plausibly are sensitive to intonational factors related to tonal crowding (see section 3.4.2 and Gordon 2000 for discussion of repulsion of stress from edges). Intonation and energy may even intersect as factors to create right-edge weight-asymmetries, some of which fall under the rubric of extrametricality (Hayes 1979). It is conceivable that phonetic considerations play a role in other positionally-based weight asymmetries of the type discussed by Rosenthall and van der Hulst (1999), as well as the vanishing rarity of onset-sensitive weight (see Goedemans 1993, 1998 on phonetic motivations for the characteristic irrelevance of onsets in weight-sensitive stress systems).

4. Summary

The results presented here provide support for the hypothesis that the language-specific parameterization of coda weight is, with few exceptions, ultimately predictable from the inventory of coda consonants via the medium of acoustic energy. Languages with a preponderance of relatively high-energy codas overwhelmingly tend to treat CVC as heavy, since high-energy codas increase the overall energy profile of CVC. Conversely, languages with predominantly low energy codas almost exclusively treat CVC as light, as low energy codas diminish the overall energy of CVC as a class. The energy of different codas can be inferred from published descriptions given a universal hierarchy of acoustic energy substantiated by phonetic examination of several languages. Adopting a conservative hypothesis considering voicing and sonorancy as the crucial dimensions for evaluating coda weight allows for predictions about coda weight for the majority of weight-sensitive languages. A survey of 62 languages with differing treatments of CVC in their stress systems indicates that these predictions are corroborated at overwhelmingly greater than chance levels. The predictive power of the approach is further broadened, with additional confirmation of the proposed link between coda inventory and phonological weight, by adopting hypotheses that impose finer, but necessarily more tentative, divisions in energy between different types of obstruents.

The model of weight for which the present study argues is one in which a basic phonological property of a language, its syllable structure, guides a higher level phonological phenomenon, syllable weight, indirectly through its effects on the phonetic property of acoustic energy underlying weight-sensitive stress. More generally, the present study demonstrates how certain phonological properties may ultimately be predictable from other superficially unrelated aspects of the phonology.

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Notes

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[2] Interestingly, work by Steriade (1991), Crowhurst (1991), and Hyman (1992) suggests that weight criteria are often inconsistent within languages. For example, although CVC in Khalkha is light for stress, it counts as heavy for the Khalkha minimal word requirement. The pervasiveness of conflicted weight criteria has recently been systematically demonstrated by a survey of weight in 381 languages in Gordon (1999). This work indicates that weight criteria tend to be more consistent within phenomena than within languages, and that the process-dependent nature of weight offers an explanation for many language internal consistencies and inconsistencies in weight criteria. For example, the conflict in weight criteria between the minimal word requirement and stress in Khalkha is less surprising than at first glance, when one considers that the majority of minimal word requirements (80 of 101 languages in Gordon's survey) treat CVC as heavy, while CVC is heavy in fewer than half of the weight-sensitive stress systems (35 of 88 in Gordon's survey). The upshot of these results is that both the process-dependent nature of weight as well as the parameterization of weight criteria between languages for a given phenomenon must be explained by any theory of weight. Focus here is on the latter issue (see Gordon 1999, Zhang to appear for discussion of the former) with weight-sensitive stress serving as the relevant phenomenon.

[3] The weightless status of onset consonants is an interesting issue explored recently from a phonetic standpoint by Goedemans (1993, 1998).

[4] A recent survey of 88 weight-sensitive stress systems conducted by Gordon (1999) indicates that variation in coda weight accounts for 71 of the 88 languages: 35 languages treat CVC as heavy, while 36 treat CVC as light. Of the 17 remaining languages, 15 make weight distinctions based on vowel quality, e.g. non-schwa vowels heavier than schwa, low vowels heavier than non-low vowels, etc. (see Kenstowicz 1997 for discussion of vowel quality-based weight distinctions). The other two are Wakashan languages (Kwakw'ala and Nuuchahnulth) that treat long vowels and syllables closed by a sonorant as heavy (see section 3.7 for further discussion). Weight distinctions based on coda sonority, though quite rare in stress systems, are very common in tone systems, where the phonetic conditioning factors governing weight are very different from those relevant in stress systems (see Gordon 1999 for survey results and discussion).

[5] Perceptual intensity, i.e. 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 intensity and loudness.

[6] Note that "sonorancy" refers here to the specification of a segment for the feature [sonorant] and not to sonority.

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

[8] Of course, there are also differences in phonetic energy among members of the same class of consonants defined according to sonority. For example, differences in place of articulation may also be associated with differences in energy. However, it appears on the basis of phonetic data from several languages (see discussion in text), that place dependent differences between codas tend to be associated with much smaller differences in energy than

manner (including voicing) dependent differences. For this reason, they are unlikely to exert as much of an effect as manner differences on the overall energy profile of CVC.

[9] In section 3.6, the hypothesis will ultimately be broadened to allow predictions to be made about all languages.

[10] Note that there are no languages in which the sonorant to obstruent coda ratio is larger than the voiced to voiceless coda ratio. This is a function of the nature of consonant inventories given a definition of [+sonorant] that does not include voiceless sonorants.

[11] Voiceless glottalized stops are treated as [-voice] for purposes of assessing coda sonority along the voicing dimension.

[12] Sources for languages are as follows: Aguacatec, McArthur and McArthur (1956); Aleut, Bergsland (1994); Cayuga, Michelson (1988), Doherty (1993); Cherokee, Scancarelli (1987); Comanche, Charney (1993); Huasteco, Larsen and Pike (1949); Hupa, Golla (1970); Iraqw, Mous (1993); Karok, Bright (1957); Khalkha, Poppe (1951), Bosson (1964); Koasati, Kimball (1991, 1994); Luiseño, Kroeber and Grace (1960); Malecite-Passamaquoddy, Teeter (1971); Menomini, Bloomfield (1962); Mojave, Munro (1976), Munro et al. (1991); Nyawaygi, Dixon (1983); Ojibwa, Bloomfield (1956); Quechua (Huallaga), Weber (1989); Selkup, Erdélyi (1970); Tidore, Pikkert and Pikkert (1995); Tübatulabal, Voegelin (1935); Wintu, Pitkin (1984); Wolof, Ka (1987); Yupik (Central), Reed et al. (1977); Buriat, Poppe (1960); Krongo, Reh (1985); Malto, Das (1973); Murik, Abbott (1985); Winnebago, Susman (1943).

[13] Sources for languages are as follows: Ainu, Refsing (1986); Amele, Roberts (1987); Apalai, Koehn and Koehn (1986); Boiken, Freudenberg and Freudenberg (1974); Carib, Hoff (1968); Cayapa, Lindskoog and Brend (1962); Cebuano, Bunye and Yap (1971); Cuna, Holmer (1947); Estonian, Hint (1973), Saagpakk (1982); Finnish, Sulkala and Karjalainen (1992); Khmer, Gorgonijev (1966); Kiriwina, Senft (1986); Latin, Allen (1973,

1975); Macushi, Abbott (1991); Maidu, Shipley (1963, 1964); Manam, Lichtenberk (1983); Miwok (Northern), Callaghan (1987); Munsee, Goddard (1979); Sentani, Cowan 1965), Songai, Prost (1956); Tepehuan, Willett (1991); West Tarangan, Nivens (1992); Yana, Sapir and Swadesh (1960); Arabic (Egyptian), Khalafallah (1969); English, Finegan (1990); Evenki, Konstantinova (1964); Greek (Ancient), Joseph (1990); Hopi, Jeanne (1982), Seaman (1985); Koya, Tyler (1968); Nez Perce, Aoki (1970); Turkish, Kornfilt (1990); Veps, Zaitseva (1981); Votic, Ariste (1968).

[14] Another language not included in the survey with only sonorant codas, Apurucayalí Asheninca (Payne et al. 1982), also conforms to expectations in treating CVC as heavy, though it should be noted that another dialect of Asheninca, the Pichis one described by Payne (1990), treats CVC as light contra expectations. Since the only codas that occur in Asheninca are nasals homorganic to a following onset stop, it is conceivable that Pichis Asheninca speakers have analyzed nasal plus stop sequences as pre-nasalized stops for purposes of weight, in which case there would not be any codas at all.

[15] Languages that display the opposite of this pattern and allow voiceless stops but not voiceless fricatives (e.g. Cantonese), would likewise be expected, all else being equal, to treat CVC as heavy. Since none of the languages in the present survey fit this profile, the testing of this hypothesis must await further research.

[16] Wargamay (Dixon 1981) has essentially an identical stress system to that of Nyawaygi.

[17] It should be noted that two other languages with light CVC in the survey have a stress system identical to that of Tidore: Huallaga Quechua (Weber 1989) and Aleut (Bergsland 1994). It is possible that these stress systems are also intonationally-driven, as hypothesized for Tidore, in which case the correlation between syllable structure and weight criteria posited earlier might be coincidental in the case of these two languages.

[18] Although cross-linguistically rare, lengthening of vowels in closed syllables is attested in certain languages, e.g. southeastern varieties of Finnish (Leskinen and Lehtonen 1985).

[19] Inga Quechua (Levinsohn 1976) also makes a weight distinction between syllables closed by a sonorant (heavy) and syllables closed by an obstruent (light). Inga Quechua differs from the Wakashan cases, in that the distinction is localized to the right edge and thus amenable to an intonationally-driven analysis (see sections 3.4.2 and 3.8).