# Why Syllable Weight Seems to Work Differently at the Right Edge, and Why It Really Works the Same*

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1 CVC weight asymmetry

Syllables of the shape CVC present a weight asymmetry in many languages, including Arabic (McCarthy 1979), English (Chomsky & Halle 1968), Estonian (Prince 1980), Greek (Steriade 1980), a dialect of Hindi (Hayes 1981, citing Mohanan 1979), Icelandic (Kiparsky 1984), Menomini (Hayes 1995), Norwegian (Kristoffersen 1991), Ponapean (McCarthy & Prince 1986), Romanian (Steriade 1984), Swedish (Riad 1992), and Swiss German (Spaelti 1994). These languages are among those that treat coda consonants as heavy. In standard moraic theory (Hyman 1985, McCarthy & Prince 1986, Hayes 1989), these languages employ WEIGHT-BY-POSITION, the requirement that a consonant in coda position is associated with a mora.

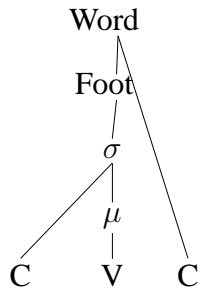(1)   Moraic structure for WEIGHT-BY-POSITION (Hayes 1989)
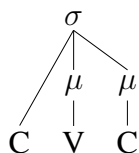
As shown in (1), CVC syllables are heavy (bimoraic), as expected, in non-final positions. But we find that these languages treat CVC syllables in word-final position as light (monomoraic). The traditional explanation for this is that word-final consonants are extrametrical; that is, word-final consonants are exempt from the lower levels of metrical structure.

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(2)   Word-final consonant extrametricality

```
        Word
       /   \
     Foot   \
       \     \
        σ     \
       / \     \
      |   μ     \
      |   |      \
      C   V       C
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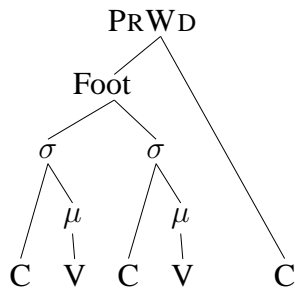
As shown in (2), final consonants are taken to be exempt from lower prosodic structure in languages which normally apply WEIGHT-BY-POSITION but treat a word-final CVC as though it were light. In the framework of optimality theory (OT), where the grammar is viewed as a set of ranked constraints (Prince & Smolensky 1993), extrametricality has been recast as a prohibition against final stress, encoded through the constraint NONFINALITY. Its definition, as originally formulated by Prince and Smolensky (1993: 52), is given in (3).

(3)   NONFINALITY: No head of PrWd is final in PrWd

Final consonant extrametricality is also captured by NONFINALITY, as a language may violate strict prosodic succession and have a final consonant directly dominated by the prosodic word.

(4)

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           PRWD
          /    \
       Foot     \
       /  \      \
      σ    σ      \
     / \  / \      \
    |   μ |   μ     \
    |   | |   |      \
    C   V C   V       C
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By associating the final consonant directly with the prosodic word, stress on either of the two syllables will not violate NONFINALITY as neither the stressed syllable nor the head foot will be word-final, due to the final consonant that is set off from the lower prosodic structure. However, the final consonant in (4) is an appendix (Rubach & Booij 1990, Rosenthall & van der Hulst 1999) and therefore violates strict prosodic succession (Selkirk 1984, Nespor & Vogel 1986, Ito & Mester 2003/1992, Hyde 2003). The prosodic hierarchy is given in (5).

(5)   Prosodic hierarchy (Selkirk 1984)

ϕ phonological phrase
|
Wd   prosodic word
|
Ft   foot
|
σ syllable
|
μ mora
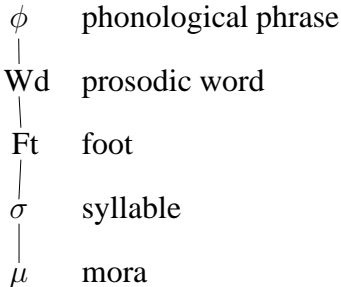
As the prosodic parsing of the final consonant in the templatic word in (4) skips intermediate prosodic levels it violates *APPEND-TO-PRWD (Rosenthall & van der Hulst 1999), the constraint prohibiting attachment of a segment directly to the prosodic word.

It is not clear what motivates extrametricality/NONFINALITY, apart from the fact that something special needs to be said about the right edge of the word for the analysis of stress in many languages. A possible explanation for NONFINALITY is that it avoids stress clash (discussed in Gordon 2000, Karvonen 2004). Stress clash would occur if NONFINALITY were violated and the initial syllable of the following word were stressed. While this is a possible explanation for final syllable extrametricality, it still potentially puts two stressed syllables next to each other in languages with final consonant extrametricality. This situation is shown in (6).

(6)   Clash even when NONFINALITY is obeyed
        [CV.CV́C.C]$_{\text{PrWd}}$ [CV́:C]$_{\text{PrWd}}$

Since final superheavy syllables are pronounced as monosyllabic, despite their representation, clash will still occur. In fact, even final syllable extrametricality will only cause stress clashes to be avoided if adjacent words are both greater than two syllables.[1] Given that shorter words are generally common, clash avoidance is a suspect motivation for extrametricality/NONFINALITY.

Gordon (2000) notes further problems with extrametricality that extend to NONFINALITY. He points out that it cannot account for languages like Chickasaw and Klamath which allow CVVC to be stressed word finally but not CVCC, despite the fact that syllables closed with a consonant are treated as heavy in non-final position. This is a finer distinction than final consonant extrametricality or NONFINALITY is able to make. Further, he notes that if the goal is avoidance of clash, we should see more languages with peninitial stress, parallel to the large number of languages found with penultimate stress.

The OT analysis of final consonant extrametricality is troubling because it links the property of allowing an appendix with whether a final consonant is discounted for stress. These things should be independently variable. We must presume that all languages traditionally analyzed with final consonant extrametricality in fact allow a final appendix. This is suspicious if the only evidence for an appendix is whether the language appears to metrically discount the final consonant. I propose

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[1] I want to thank Jaye Padgett for drawing this to my attention.

a reanalysis of how weight is determined that makes final consonant extrametricality unnecessary.

I suggest that word-final CVC syllables count as light because syllables in word-final position are subject to final lengthening, causing the duration of a final CVC to be not as perceptually distinct from a final CV as a non-final CVC is from a non-final CV.

The fact that segment duration varies at prosodic boundaries has been noted at least since Oller (1973) for English and Lindblom and Rapp (1973) for Swedish. Phonetic final segment lengthening is found at the right edge of words, phrases and utterances. It has been demonstrated that final lengthening affects the rime of the syllable preceding the prosodic boundary (Crystal & House 1990, Wrightman et al. 1992), where the final segment is lengthened more than other segments in the final rime.

The increased duration at the right edge of the word means that a final CV syllable is significantly longer than a non-final CV syllable. It is a known fact of perception that if a shorter and a longer duration are increased by the same amount the increase to the shorter duration will be perceptually greater. This aspect of human perception is credited to Ernst Heinrich Weber (1795–1878) who performed experiments with the perception of weight and, later, of sight and hearing.[2] He found that the smallest noticeable difference was essentially proportional to the starting unit. For example, the difference between a 100 gram weight and a 110 gram weight was paralleled at a higher level by a 1000 gram weight and a 1100 gram weight. The decibel scale encodes this same perceptual discrepancy for loudness: each raw increase on the decibel scale is greater than the one before it but all increases are perceptually equivalent. In the following section I tie this fact of perception to the categorization of syllable weight.

2 Proposal for the proportional increase theory of weight

Standard moraic theory encodes a segment's weight (or lack of weight), not its length. However, there is a connection between syllable weight and syllable length. Heavy syllables are (unsurprisingly) longer than light syllables (Broselow, Chen, & Huffman 1997).[3] I show, using data from Norwegian speakers, that heavy syllables are significantly longer than light syllables. I assume that in order to be perceived as heavy, a syllable must be sufficiently longer than a light syllable in the same position. In non-final position, a coda consonant causes a length increase that sufficiently differentiates the duration of a closed syllable from that of a CV syllable. In final position, however, the increase in duration due to a coda consonant is not sufficient to differentiate a CVC from a CV syllable to the same degree. This is shown schematically in (7).

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[2]I am indebted to a participant of the LSA annual 2006 conference who drew my attention to Weber's work.

[3]Duanmu (1994) demonstrated this for Mandarin and Shanghai, although weight in these languages is only relevant for tone assignment. Zhang (2002) argues that tone association is not dependent on the mora count of a syllable and so while Duanmu demonstrates what seems to be a durational correlate of weight, his findings are open to reanalysis. Hubbard (1994) shows that vowel quantity is the most important factor in determining medial vowel duration in Bantu languages (specifically Luganda and Runyambo). Gordon (2002) shows that a language may group syllable shapes into weight categories based on duration, where shapes with longer durations count as heavy.

(7)   The same increase does not have the same perceptual effect (Weber's law)

a. i. ▮▮▮▮▮▮▮ + x
    ii. ▮▮▮▮▮▮▮▮▮▮

b. i. ▮▮▮▮▮▮▮▮▮▮▮▮▮ + x
    ii. ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮

The first and second bars in the pairs in (a) and (b) in (7) are separated by the same raw increase in length (x). However, the two bars in (a) are more perceptually distinct than the two in (b). This is true both looking at the lengths visually and if they were audible. The perceived distinction between the two bars in (a) and (b) is different from the actual distinction between them because humans are more sensitive to increases to smaller amounts (Weber's law). Thus, the increase x to the relatively short bar in (a-i) seems greater than the increase x to the relatively long bar in (b-i). If we want to achieve the same perceived increase to the bar in (b-i) we need a greater raw increase.

(8)   A greater raw increase is needed for the same perceivable difference

a. i. ▮▮▮▮▮▮ + x
    ii. ▮▮▮▮▮▮▮▮   60% increase

b. i. ▮▮▮▮▮▮▮▮▮▮▮▮ + x
    ii. ▮▮▮▮▮▮▮▮▮▮▮▮▮   30% increase

c. i. ▮▮▮▮▮▮▮▮▮▮▮▮
    ii. ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮   60 % increase

The first bar in (c) is as long as the first bar in (b). The set of bars in (c) are separated by more than x but the perceptual difference between them is the same as the perceptual distance between the set of bars in (a). Although a greater raw increase is needed in (c) to equal the perceptual distance in (a), the proportional increase remains constant.

The schema in (8) models the proportional increase of a heavy syllable of a same-position CV non-finally versus finally, as will be supported by data from Norwegian. I assume that a non-final CVC is heavy because the extra duration due to the final consonant perceptually distinguishes the duration of a CVC from that of non-final CV, as illustrated in (8-a). I propose that a final CVC is light because a final CV is so long due to final lengthening that the added duration due to a coda is not sufficient to set the two syllables apart perceptually, as illustrated in (8-b). In order to achieve the same perceptual difference between light and heavy syllables present in non-final positions, a heavy syllable in word-final position must be extra-long, that is, have three segments in the rime, resulting in a contrast as in (8-c). The contrast in duration between such a final CVXC syllable and a final CV is claimed to be perceptually the same as is found between a non-final CV and CVC.

Given this insight, I propose the proportional increase theory of weight: in order for a syllable shape in a given position to be categorized as heavy it must be consistently realized as sufficiently longer than an unstressed CV syllable in the same position. The increase necessary to be sufficiently longer is an empirical question, taken to be related to the level at which the duration of a syllable is clearly perceptually distinct from a CV syllable in the same position. It follows that additional length is needed for word-final syllables to be categorized as heavy. The same raw increase (adding a coda consonant) does not sufficiently distinguish a CVC syllable from a CV syllable in word-final position because of the additional length due to final lengthening. Therefore the same raw difference in duration does not correctly model syllable weight distinctions, since the raw increase needed non-finally will be insufficient in final position. The proportional increase of a heavy syllable over a CV syllable in the same position, however, is consistent across positions.[4]

This proposal differs radically from the solution offered by final consonant extrametricality. Rather than discounting the final consonant, the length provided by the final consonant in a CVXC syllable is crucially needed in order to set the duration of a heavy syllable in final position apart from a final CV syllable. In the following section I show that this theory of weight categorization is supported by measurement of rime durations in Norwegian.

3   Evidence from Norwegian

Norwegian (like Swedish, but unlike Danish) requires that stressed syllables be heavy. Final stressed syllables require three segments in the rime. An inventory of syllable types is shown in (9). The grayed syllable shapes are heavy.[5] Medial geminates are represented here and elsewhere with the notation "CVC.:", where a syllable boundary is shown before the length mark (as the second half of the geminate occurs in the following syllable). Note that long vowels and geminates only occur under stress.

(9)

	unstressed		stressed
non finally	CV	CVC	CVC, CVː, CVC.ː
finally	CV,	CVC	CVːC, CVCː, CVCC

I undertook an experiment to investigate the relationship between stress and rime duration in Norwegian. The data consisted of nonsense words of three syllables. The nonsense words had a voiceless stop in the three onset positions ([k], [t], [p], respectively) and the vowel [a] in all of the nucleus positions. The onset consonants in each position were not varied as a pilot experiment showed no effect of place of articulation of the onset on the duration of the following rime. Only

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[4]The theory proposed here is presumably compatible with the case of Chickasaw and Klamath (where final CVVC is heavy but final CVCC is light) since a long vowel will likely be found to have more inherent length than two consonants. Given this, it is also noteworthy that the proposed categorization of weight predicts that we would never find the reverse: a language in which final CVCC counted as heavy while final CVVC was light.

[5]Norwegian also has diphthongs (which are heavy in all positions) and, exceptionally, some loan words from French and Greek with stressed final long vowels. I leave these two syllable shapes aside, although I discuss them in Lunden (2006): chapter 3, section 2.2.

one vowel quality was used in order to control for known variances in the inherent length of differ-
ent vowels (Lindblom 1968). The voiceless stops were chosen since they are maximally distinct
from vowels and therefore most easily distinguished in a spectrogram. The test stimuli are given
in (10). Capital letters indicate the syllable to be stressed. The stimuli follow regular Norwegian
orthographical conventions in which geminates are represented by a double consonant and a long
vowel is represented by the absence of a coda in a stressed syllable.

(10)   Production experiment stimuli

CV and CV: in each position	KAtapan	KAtapa	
	kaTApan	kaTApa	
	kataPAN		
non-final geminates	KATtapat	KATtapa	
	kaTAPpat	kaTAPpa	
CV́C and CV̆C in each position	KANtapat	KANtapa	KAPtapa
	kanTApat[6]	kantaPAT	
	kaTAMpat	kaTAMpa	kaTAKpa
	KAtanpat	katanPAT	
final CVCC	kataPATT	kataPAKK	kataPANN
	kataPANK		

The words in (10) were made up in order to get samples of all syllable shapes under all possible
stress conditions in all possible syllable positions. Note that all combinations are not possible
because, for example, CV (with a short vowel) never occurs under stress. Syllable shape CVC
cannot occur stressed in final position. (When a final, stressed CVC occurs orthographically it is
pronounced CV:C.) And the syllable shapes CV:C and CVCC (a final cluster or geminate) can
only occur in word-final position, under stress.

These 23 forms were duplicated (so that two copies of every word were in the data set) and
randomized for each speaker. There were six additional test words that were in the stimuli set twice
each as well. These were four-syllable words based on the basic shape *pakatapa* but these were
not analyzed (in part because speakers had a difficult time pronouncing them fluidly). This means
the stimuli consisted of 58 tokens (29 types, 23 of consequence). These stimuli were placed in the
carrier phrase *Æ lige ____ og smør* ('I like ____ and butter', written in Vest-Agder dialect).[7]

The speakers were four native Norwegian speakers from the Vest-Agder area of southern Nor-
way. The speakers were 25 to 35 years of age and all grew up in the area and had always lived in
Norway. (The subjects were a 28 year-old woman, a 29 year-old man, a 24 year-old woman, and a
30 year-old woman; none were related.) As part of their instruction before the experiment was run
they were given sample stimuli paired with real Norwegian words with corresponding stress. They

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[6]The stress on this token runs counter to a pattern in the stress system of Norwegian as it has a stressed CV penult
when the antepenult is heavy, which would usually result in antepenultimate stress.

[7]One speaker, the first one recorded, instead said *Æ lige ____ med smør* ('I like ____ with butter'). I changed
the sentence after the first speaker to use *og* ('and') rather than *med* ('with') because the following vowel is easier to
visually distinguish from the end of the test word than the nasal is. There is no reason to think the change of this word
altered pronunciation of the test words.

were also instructed to say the sentence as *Æ lige [____ og smør]*, rather than *Æ lige ____. . . [og smør]*. This was to make sure that the stimuli were not final in a prosodic phrase as this might affect the degree of final lengthening. They were instructed to say each sentence as naturally and fluidly as possible, and to pronounce the stimuli as though they were real Norwegian words. Each speaker was recorded using Praat on a PowerBook G4 saying each sentence into a head-mounted microphone (a Sennheiser PC130) connected to the PowerBook via an iMic. They were encouraged to redo a sentence they felt did not come out right or which they stressed differently from the indicated stress. However, they were not corrected if they said a word with a different stress than was indicated. Although rare, this resulted in having to throw out a few words from the analysis because they were not spoken with the indicated stress, or, in one case, because a coda consonant had been omitted. There were 184 three-syllable tokens recorded (23*2*4). A native Norwegian speaker (not one of the subjects) with a good ear for stress listened to all the readings and marked those that were not consistent with the indicated stress. These judgments were later verified by the author in the course of examining the spectrograms of the tokens in Praat. Eleven were not measured due to errors and another was thrown out as pronounced abnormally (its syllables surfaced as clear outliers in boxplots of relative duration). As each token contains three syllables the final data set contained 516 cases ((184-12)*3).

I measured the rime duration as the percentage of the overall word (rime/word) to control for rate of speech. A syllable's weight is almost predictable from considering a combination of rime size and position. Therefore I group syllable shapes by rime size, as shown in (11). The average rime/word percentages by rime size are given in (12).

(11)   Syllable shapes by rime size

shape	rime size	shape	rime size
CV	1	CVːC	3
CVː	2	CVCː	3
CVC	2	CVCC	3
CVCː	2		

(12)   Avg. rime/word percentages by size

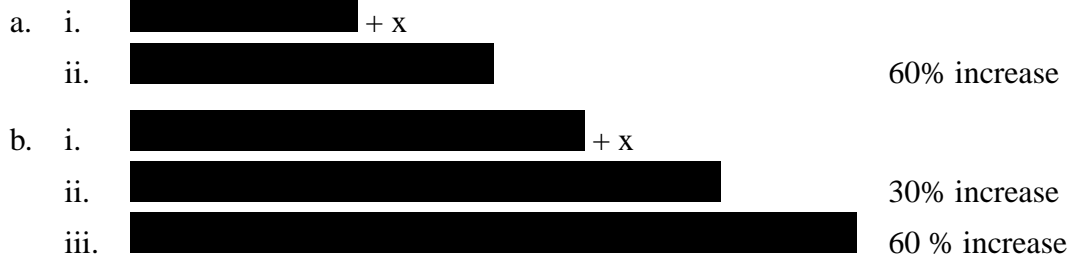|		non-final	final
size	1	8.1%	18.7%
	2	15%/19%	22.8%
	3	–	32.5%

Rimes of size two have two difference measurements in non-final position because they may occur unstressed (CVC only) or stressed. While a non-final unstressed CVC is categorized as heavy, it receives additional lengthening under stress (a phonetic effect of stress). If a theory correctly categorizes a non-final syllable with a rime/word percentage of 15% as heavy it will clearly categorize one with a rime/word percentage of 19% as heavy as well. Therefore I will consider the unstressed CVC syllables in the following comparisons and leave aside their duration under stress.[8]

If we visually compare the rime/word percentages in non-final and final position, we see that, proportionally, the difference between rimes of one versus two segments non-finally is paralleled

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[8]I assume speakers categorize weight according to the information available to them. Because rimes containing three segments only surface under stress it cannot be known how much of their duration is due to phonetic effects of stress, beyond their phonological weight. I therefore consider the syllables as speakers must, based on the forms that actually occur. Note that the categorization of weight here is independent of stress (as much as possible). Stress is assigned independently, referencing syllable weight.

word-finally by rimes of one versus three segments. This can be seen by comparing the bar graph in (14) to the preceding (modified) general bar graph from §1.

(13)

a. i. ▮▮▮▮▮▮ + x

   ii. ▮▮▮▮▮▮▮▮   60% increase

b. i. ▮▮▮▮▮▮▮▮▮▮ + x

   ii. ▮▮▮▮▮▮▮▮▮▮▮▮   30% increase

   iii. ▮▮▮▮▮▮▮▮▮▮▮▮▮▮   60 % increase

(14)   Rime/word percentage by syllable position and size

As was discussed in §1, the same raw increase does not always correspond to the same perceived increase. This is represented generically in (13), where the bars in (a) and the first two bars in (b) are separated by the same raw increase. However, the bars in (a) are more perceptually distinct, both visually, as shown here, and audibly, if heard as sound durations. The same pattern is repeated in (14) with the results from the production experiment with Norwegian speakers. We see that there is close to the same raw difference between syllables with one rime segment and those with two regardless of position. However, the two do not have the same perceptual difference across positions. Because single-segment rimes are longer in final position than they are non-finally, two-segment rimes are not perceived to be as distinct in final position as they are non-finally (audibly, although represented here visually). Rimes with three segments, however, clearly contrast with final single-segment rimes, in a way that parallels the two-segment rime contrast with single-segment rimes non-finally.

The basic observation in both (13) and (14) is that a given increase results in a greater perceptual difference at lower/shorter levels and a lesser perceptual difference at higher/longer levels. I suggest that it is this principle of perception that motivates the split between CV and CVX syllables non-finally but between CV/CVC and CVXC syllables word-finally. I do not claim that the light/heavy split is made on the basis of a just-noticeable increase, but, rather, is at a proportional increase that makes a particularly good perceptual split. In (15) I schematically show the difference in the average rime/word percentages by syllable size with the raw increase over a CV in the same position noted to the right of the bars.

(15)   Average rime/word percentages

	non finally		finally	
CV	8.1% ▮▮		18.7% ▮▮▮	
CVC	14.6% ▮▮▮▮	+6.5%	23.8% ▮▮▮▮	+5.1%
CVXC			32.5% ▮▮▮▮▮▮	+13.8%
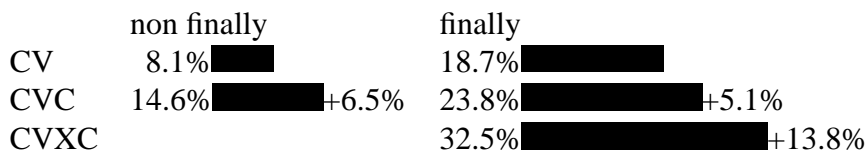
A CVC syllable is approximately six percent more of the word than a CV syllable, regardless of the position of a syllable. However, because a final CV syllable is so much longer than a non-final CV syllable, the proportional increase of a CVC syllable over a CV syllable in the same position

is much greater in a non-final position. While the raw increase of a heavy syllable over a light one varies by position, the (minimal) proportional increase remains constant. The proportional increase of one rime over another is measured as shown in (16).

(16)   proportional increase $= (\frac{rime/word}{same-position\ CV\ rime/word} - 1) * 100$

The same bars (representing the average rime/word percentages) are given again in (17) but instead of the raw increase, the proportional increase over a CV in the same position is given. An unstressed CV syllable is taken to be the baseline because this is the syllable shape that occurs in every position and is uniformly light.

(17)   Avg. rime/word percentages proportional increase over same-position CV

	non finally	finally
CV	▓▓▓	▓▓▓▓▓
CVC	▓▓▓▓ 80%>	▓▓▓▓▓ 27%>
CVXC		▓▓▓▓▓▓ 74%>

Non-finally, we see that a heavy (unstressed) syllable is, on average, 80% greater than a non-final CV syllable. We know that non-final CVC syllables are heavy, so clearly an 80% increase is sufficient to be perceived as substantially greater than a non-final light syllable. Word-finally, syllable sizes fall into a pattern we can now interpret. A word-final CVC is only 27% greater than a final CV on average. This falls far short of the 80% increase we see for a CVC in non-final position. Therefore, while a non-final CVC is substantially greater than a CV in the same position, a final CVC is not. I assume that in order for a syllable to be categorized as heavy it must be substantially greater than a CV syllable in the same position. Thus, CVC naturally patterns as heavy non-finally but as light word-finally, based on the syllable shape's average increase over a CV in the same position. A final CVXC, on the other hand, is 74% greater than a final CV on average. This looks much more like the 80% average increase for a heavy syllable we see non-finally.

The boxplots in (18) show the distribution of proportional increases by syllable shape and position. The grayed boxplots belong to syllable shapes that are categorized as heavy (darker gray marks syllable shapes that seem to be subject to additional, phonetic lengthening under stress).

(18)   Distribution of increases over average rime/word of a same-position CV
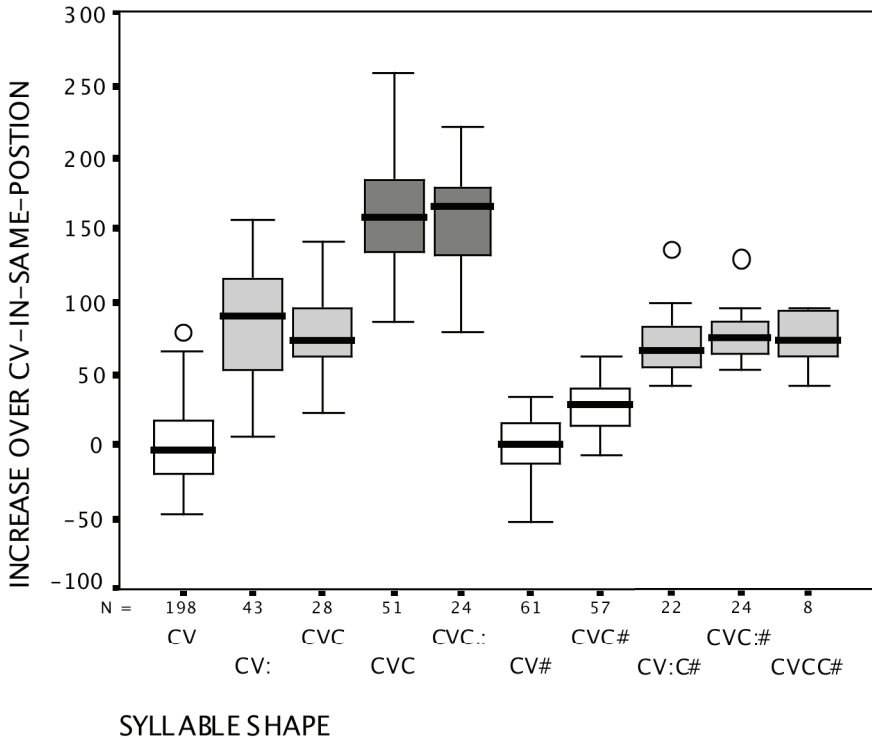
SYLLABLE SHAPE

The question of the proportional increase threshold may be considered in light of the boxplots in (18). We see that the uppermost 75% of heavy syllables falls above approximately 60%, while the top of the tails of light syllable shapes barely reach 60%. I will therefore take 60% to be the proportional increase threshold in Norwegian. Given the proportional increase theory of weight, a speaker of Norwegian is thought to categorize a syllable as light or heavy based on whether the syllable shape is one that is consistently substantially perceptually greater than a CV syllable in the same position. We can now characterize "perceptually greater" as having a proportional increase of at least 60%.

This proposal raises the question of how weight classification occurs. One possibility is that a syllable's weight is calculated online for each utterance. In this scenario it is necessary that the proportional increase threshold is reached for every utterance of a heavy syllable, which must be assumed to be compared to a previously-calculated and stored average of a CV syllable in the same position. I instead assume that speakers assign weight to a syllable based on their knowledge of whether such a syllable is usually pronounced with a duration that surpasses the proportional increase threshold. The weight of a syllable thus depends on whether the duration of such a syllable regularly sufficiently contrasts with a CV syllable in the same position, not on the duration of a particular utterance of such a syllable. Since the categorization of weight is not done online for each utterance it is impossible for the same syllable shape in the same position to be categorized as light in one utterance and heavy in another, a desirable result. A speaker of Norwegian knows from experience whether a given syllable shape in a given position is light or heavy. The calculated categorization of syllable shapes in non-final and final positions is given in (19). The calculation of syllable weight based on the proportional increase threshold is thought to reflect whether or not

the duration of a syllable sufficiently contrasts perceptually with an unstressed CV in the same position.

(19)   Proportional increase and associated phonological weight

		increase over same-position CV̌	at least 60% increase?	phonological weight
non final	CV	0%	no	μ
	CV:	88%	yes	$\mu\mu$
	CVC	80% (162%)[9]	yes	$\mu\mu$
	CVC:	157%	yes	$\mu\mu$
word final	CV	0%	no	μ
	CVC	27%	no	μ
	CV:C	68%	yes	$\mu\mu$
	CVC:	74%	yes	$\mu\mu$
	CVCC	74%	yes	$\mu\mu$

This proportional increase of theory of weight determines the weight of a particular syllable shape for the rime as a whole. A particular syllable shape is categorized as heavy if its rime is, on average, at least 60% longer than a CV syllable in the same position and is categorized as light otherwise. Standard moraic theory, on the other hand, takes moras to be associated with individual segments in the rime. In the following section I discuss the consequences of the proportional increase theory of weight for moraic theory.

4   Consequences for moraic theory

Moraic theory, at its core, makes several claims.

(20)   Classical moraic theory

1. **Binarity:** There is a binary distinction between light and heavy syllables.

2. **Quantity sensitivity**: Prosodic processes are sensitive to syllable weight, not to segments.

3. **Moraic equivalence**: Syllables of different shapes but belonging to the same weight class pattern together.

These basic tenets of moraic theory originate in classical Latin and Greek metrics. They are part of standard moraic theory (Hyman 1985, McCarthy & Prince 1986, Hayes 1989) and are not disputed here.

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[9]Proportional increase when stressed.

Anya Lunden

Standard moraic theory makes several additional claims.

(21)   Standard moraic theory

1. **Moraic status:** Weight-bearing segments are associated with a mora.

2. **Moraic distinction:** Segment length is encoded by moraic association.

The first claim, that moras have the status of prosodic constituents and are associated directly to segments, leads to the necessity of assuming final-consonant extrametricality or NONFINALITY for languages with CVC weight asymmetry. I have argued that the proportional increase theory of weight is preferable to both of these approaches. However, a theoretical consequence of determining syllable weight as proposed is that moras cannot be taken to be associated to individual segments. This affects both the claims in (27), as if the first claim does not hold then there can be no distinction made between segments on the basis of whether or not they are associated with a mora. I consider these claims in turn.

Taking moras to be associated with individual segments does not always lead to the correct prediction of syllable weight. The CVC weight asymmetry is a case in point. While segmentally-associated moras have been taken to be a unit of tone association (e.g. Hyman 1985), Zhang (2002) has demonstrated that tone association does not match up to the mora count of a syllable, even in languages in which tones had been thought to associate with individual moras. He shows, for example, that contour tones are allowed on word final syllables that are not allowed non-finally. The additional length in final position due to final lengthening enables more tones to occur on the syllable. This cannot be due to additional moras since the syllables in final position behave differently than syllables of the same shape in non-final positions. Zhang therefore argues that tones are sensitive to the phonetic duration of a syllable and that the mora is not an appropriate unit for tone association. Thus we are not able to assume that moras are associated directly to segments without significant repairs and exceptions to the system.

In the absence of segmentally-associated moras we need to be able to identify weight-contributing segments. I assume syllabic structure of an onset and rime node, where the weight-contributing segments are parsed into the rime node.[10]

(22)   Assumed syllable structure (e.g. Fudge 1987)
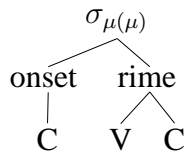
$$\sigma_{\mu(\mu)}$$
onset   rime
C   V   C

The segments that contribute to syllable weight may be identified by locating the sonorant peak of the syllable as this will be the syllable nucleus.[11] Note that, given richness of the base,

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[10]The split of onset and rime is sufficient for my purpose here, but in a language that treats CVC as light lower levels of the rime (nucleus, coda) will be relevant as only the nucleus contains weight-contributing segments.

[11]I do not detail the process of parsing syllabic structure but see, for example, Zec (1988), Clements (1990), and the notion of harmonic alignment in Prince and Smolensky (1993).

the grammar must also be able to identify the weight-contributing segments under standard moraic theory assumptions. Standard moraic theory relies on the grammar to correctly assign moras to segments that are in mora-bearing positions but are underlyingly mora-less.[12] Here, such segments identified by the grammar are taken to be dominated by a rime node, uniting those segments that contribute to the weight-determining algorithm.

Assuming a rime node also gives us an option for capturing compensatory lengthening other than the moraic theory analysis put forth by Hayes (1989). Under the analysis presented by Hayes, when a coda consonant associated with a mora deletes, the preceding vowel will associate to the mora that was left behind. The lengthening is motivated by mora preservation and explains why we do not find lengthening in response to onset deletion. Given the proposed weight criterion in which weight is a property of syllables, not segments, we could see compensatory lengthening as weight preservation of the syllable.(Also see Kavitskaya (2002) for phonetic accounts of compensatory lengthening that cast doubt on an auto-segmental analysis of weight.)

The assumption under standard moraic theory that geminates are consonants with an underlying mora, as shown in (29), is also problematic.

(23)   A geminate in moraic theory (the geminate-weight hypothesis)

$$\mu$$
$$|$$
$$C$$

Under this assumption, which I will refer to as the geminate-weight hypothesis, length is a consequence of weight.[13] A moraic consonant is not necessarily long, however; it will only be realized as a geminate if the structure of the word requires consonantal length.

(24)   Moraic consonants

a. singleton coda
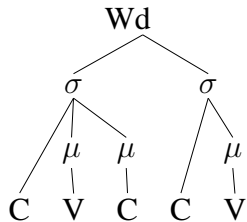
b. geminate coda

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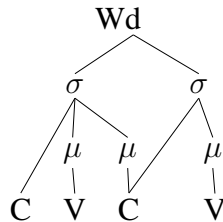
[12]Bermúdez-Otero (2001) and Campos-Astorkiza (2004) argue that DEP_μ should not penalize epenthesized moras for underlying segments that are in a weight-bearing position, showing that it is problematic if the constraint does. Under the theory of weight proposed here there are no faithfulness constraints relativized to moras, avoiding such issues.

[13]Ham (2001) finds that coda geminates are longer than onset geminates. This has been taken as phonetic evidence for the mora as a segmental unit of weight (Cohn 2003). However, it may also be attributed to a difference between the phonetic realization of segments in the onset and those in the rime.

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The moraic consonant in (a) is realized as a singleton whereas the moraic consonant in (b) is realized as a geminate. This is due to whether or not there is a following consonant. If there is not, the moraic consonant will lengthen to fill the onset of the following syllable, as well as serving as the coda of the syllable that contains its mora. However, this is not sufficient to predict gemination as we also find geminates in words like *febbre* ('fever') in Italian where the consonant is geminated although there is a following consonant. Rather, the geminate-weight hypothesis predicts that we should find syllabification contrasts like hypothetical *feb.re* and *fe.bre*, based on whether or not [b] is moraic (Armin Mester, p.c.). It is well-known that languages do not contrast syllabification and so this prediction is not borne out.

This minimal specification of geminates, as proposed by Hayes (1989), is consistent with the principle of lexical minimality, a tenet of underspecification theory (Stanley 1967, Chomsky & Halle 1968, Archangeli 1988, et al.).[14] Lexical minimality assumes that only the minimum phonological information necessary to distinguish words is present underlyingly. Other features are predictable and so do not need to be specified underlyingly, although they are present in the surface form (principle of full specification). Thus, geminates are minimally specified as mora-bearing, and their length is assumed to be derivable. However, underspecification has lost its power within optimality theory (OT) (Prince & Smolensky 1993) as there are no phonological conditions on inputs (richness of the base means that the grammar must be able to deal with fully specified inputs). Smolensky (1993) shows many processes that had previously been analyzed with reference to underspecification can be reanalyzed within OT where markedness constraints play the crucial role. Inkelas (1994) and Artstein (1998) show that given the structure of OT, an output cannot be more marked than its input. It can be as marked, where markedness in the input is preserved due to faithfulness constraints, or it can be less marked, due to markedness constraints. This means that underspecification is usually not useful since it can only be assumed for alternations of unmarked structure. Given the representation of a geminate as an underlyingly mora-bearing consonant, the constraint ONSET (which requires that all syllables have an onset) is relied on to force phonological length on the surface. However, if the markedness constraint against long segments/geminates is ranked above ONSET, the predicted lengthening will not occur. This is shown in (25). (The constraint MAXLINKμ requires that underlying segmental links to moras must be preserved.) The notation in candidate (c) represents consonantal length, split across two syllables.

(25)

/CVC$_\mu$V/	MAXLINK$_\mu$	*GEMINATE/*LONG	ONSET
☞ a. CVC$_\mu$.V			*!
b. CV.CV	*!		
c. CVC$_\mu$.:V		*	

Under this ranking, the cross-linguistically dispreferred form, candidate (a), is in fact optimal. This is a problem, since an intervocalic consonant is always syllabified as an onset, not a coda. In fact, one of Hyman's (1985) motivations for moraic structure was to prevent such a form from

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[14]I thank Armin Mester for pointing out the connection between the geminate-weight hypothesis and underspecification theory.
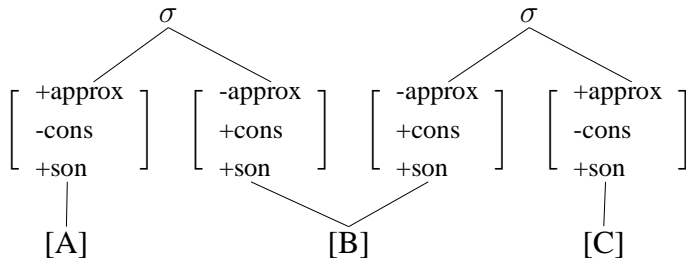
being predicted. We see from (25), however, that an intervocalic moraic consonant is not always forced to geminate in OT.

There are multiple reasons to think that geminates should be represented with underlyingly length. First, their representation in standard moraic theory relegates phonological length to a reflex of their moraic status and the constraint ONSET. This denies geminates inherent length, although duration is the primary perceptual distinction between geminates and singleton consonants (Lahiri & Hankamer 1988, Hankamer, Lahiri & Koreman 1989, Abramson 1999). Second, as I have shown, nothing ensures that intervocalic moraic consonants do, in fact, surface as geminates. Third, the representation of initial and final geminates is problematic for standard moraic theory, since even if the segment is weight-contributing there is nothing to force consonantal length (gemination). Finally, there have been many arguments in the literature for inherent geminate length, based the fact that geminates do not always behave as heavy. Vago (1992) and Ringen and Vago (2002) discuss cases where geminates pattern with consonant clusters rather than with (other) moraic segments with respect to quantity sensitive processes. Selkirk (1990) and Tranel (1991) express skepticism of the geminate-weight hypothesis prediction that all geminate codas are weight-contributing, especially in languages where CVC is light. Although Davis (1994), for example, presents two languages, Hindi and Korean, in which CVC syllables are light but syllables closed by geminates as heavy, Curtis (2003) shows that these data are subject to reanalysis. Curtis, after an extensive study of geminates and language systems that have geminates, concludes that geminates must be represented with inherent length.

Segments themselves already denote singleton length, and two identical segments in a row will result in a phonologically long segment. The assumption that segments have inherent (singleton) length must be assumed under standard moraic theory as weightless consonants, such as onsets, must have (singleton) length. A onset cluster, as a sequence of two weightless segments, will be longer than a single onset consonant. If there were two adjacent identical segments such a sequence would be realized (with no further assumptions) as a long vowel or a geminate.

A segment's features are assumed to be headed by a root node which contains the major class features (Schein & Steriade 1986, McCarthy 1988). It is usually assumed that adjacent identical segments are marked, and that adjacent segments with the same value of a feature will share that feature. I therefore borrow from Selkirk (1990) the idea that adjacent identical root nodes may occur, and, when they share all other features, represent a long vowel or geminate. This idea has seen a recent revival in the literature (see, for example, Ringen & Vago 2002 and Curtis 2003). My proposal differs from Selkirk's because I do not also assume a moraic tier. This is shown in (26) for a sonorant geminate, but represents the assumed structure of phonological length generally. Capital letters represent all features below the root node. (While an onset and rime node are assumed, they are not shown here.)

(26)   Compositional representation of length

$$\sigma \qquad\qquad \sigma$$

$$\begin{bmatrix} +\text{approx} \\ -\text{cons} \\ +\text{son} \end{bmatrix} \quad \begin{bmatrix} -\text{approx} \\ +\text{cons} \\ +\text{son} \end{bmatrix} \quad \begin{bmatrix} -\text{approx} \\ +\text{cons} \\ +\text{son} \end{bmatrix} \quad \begin{bmatrix} +\text{approx} \\ -\text{cons} \\ +\text{son} \end{bmatrix}$$

$$[\text{A}] \qquad\qquad [\text{B}] \qquad\qquad [\text{C}]$$

The representation of length illustrated above is consistent with the standard assumptions that, first, a sequence of two segments is longer than a single segment, and secondly, that adjacent identical features are shared. While we see all features (representationally) being shared by the geminate in (26), it is standard to assume that adjacent root nodes share features they have in common (for example, it is common for codas to share the place features of the following onset (the Coda Condition of Ito 1986)). The root nodes are not assumed to have any prosodic status. On the (standardly necessary, but generally unspoken) assumption that every segment, headed by a root node, contributes length, the compositional representation of length allows us to capture long vowels and geminates.

It was shown in (25) that the geminate-weight hypothesis incorrectly predicts that an intervocalic moraic consonant may surface as only a coda. The proposed representational theory of length instead predicts that such a candidate will never surface, as it can be seen in (31) to be harmonically bounded. Generic "C" and "V" are used to represent consonantal and vocalic root nodes. Further features, where relevant, are again represented by capital letters.

(27)   Standard moraic theory

1. **Moraic status:** Weight-bearing segments are associated with a mora.

2. **Moraic distinction:** Segment length is encoded by moraic association.

The first claim, that moras have the status of prosodic constituents and are associated directly to segments, leads to the necessity of assuming final-consonant extrametricality or NONFINALITY for languages with CVC weight asymmetry. I have argued that the proportional increase theory of weight is preferable to both of these approaches. However, a theoretical consequence of determining syllable weight as proposed is that moras cannot be taken to be associated to individual segments. This affects both the claims in (27), as if the first claim does not hold then there can be no distinction made between segments on the basis of whether or not they are associated with a mora. I consider these claims in turn.

Taking moras to be associated with individual segments does not always lead to the correct prediction of syllable weight. The CVC weight asymmetry is a case in point. While segmentally-associated moras have been taken to be a unit of tone association (e.g. Hyman 1985), Zhang (2002) has demonstrated that tone association does not match up to the mora count of a syllable, even in languages in which tones had been thought to associate with individual moras. He shows, for example, that contour tones are allowed on word final syllables that are not allowed non-finally.

The additional length in final position due to final lengthening enables more tones to occur on the syllable. This cannot be due to additional moras since the syllables in final position behave differently than syllables of the same shape in non-final positions. Zhang therefore argues that tones are sensitive to the phonetic duration of a syllable and that the mora is not an appropriate unit for tone association. Thus we are not able to assume that moras are associated directly to segments without significant repairs and exceptions to the system.

In the absence of segmentally-associated moras we need to be able to identify weight-contributing segments. I assume syllabic structure of an onset and rime node, where the weight-contributing segments are parsed into the rime node.[15]

(28)   Assumed syllable structure (e.g. Fudge 1987)
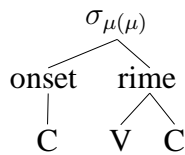
$$\sigma_{\mu(\mu)}$$

onset   rime

C   V   C

The segments that contribute to syllable weight may be identified by locating the sonorant peak of the syllable as this will be the syllable nucleus.[16] Note that, given richness of the base, the grammar must also be able to identify the weight-contributing segments under standard moraic theory assumptions. Standard moraic theory relies on the grammar to correctly assign moras to segments that are in mora-bearing positions but are underlyingly mora-less.[17] Here, such segments identified by the grammar are taken to be dominated by a rime node, uniting those segments that contribute to the weight-determining algorithm.

Assuming a rime node also gives us an option for capturing compensatory lengthening other than the moraic theory analysis put forth by Hayes (1989). Under the analysis presented by Hayes, when a coda consonant associated with a mora deletes, the preceding vowel will associate to the mora that was left behind. The lengthening is motivated by mora preservation and explains why we do not find lengthening in response to onset deletion. Given the proposed weight criterion in which weight is a property of syllables, not segments, we could see compensatory lengthening as weight preservation of the syllable.(Also see Kavitskaya (2002) for phonetic accounts of compensatory lengthening that cast doubt on an auto-segmental analysis of weight.)

The assumption under standard moraic theory that geminates are consonants with an underlying mora, as shown in (29), is also problematic.

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[15]The split of onset and rime is sufficient for my purpose here, but in a language that treats CVC as light lower levels of the rime (nucleus, coda) will be relevant as only the nucleus contains weight-contributing segments.

[16]I do not detail the process of parsing syllabic structure but see, for example, Zec (1988), Clements (1990), and the notion of harmonic alignment in Prince and Smolensky (1993).

[17]Bermúdez-Otero (2001) and Campos-Astorkiza (2004) argue that DEP_μ should not penalize epenthesized moras for underlying segments that are in a weight-bearing position, showing that it is problematic if the constraint does. Under the theory of weight proposed here there are no faithfulness constraints relativized to moras, avoiding such issues.
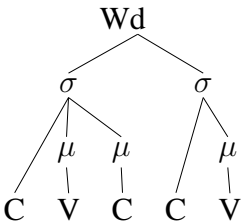
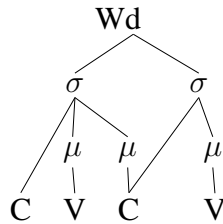(29)   A geminate in moraic theory (the geminate-weight hypothesis)

$$\mu$$
$$|$$
$$C$$

Under this assumption, which I will refer to as the geminate-weight hypothesis, length is a consequence of weight.[18] A moraic consonant is not necessarily long, however; it will only be realized as a geminate if the structure of the word requires consonantal length.

(30)   Moraic consonants

a. singleton coda   b. geminate coda

Wd   Wd

σ   σ   σ   σ

μ   μ   μ   μ   μ   μ

C   V   C   C   V   C   V   C   V

The moraic consonant in (a) is realized as a singleton whereas the moraic consonant in (b) is realized as a geminate. This is due to whether or not there is a following consonant. If there is not, the moraic consonant will lengthen to fill the onset of the following syllable, as well as serving as the coda of the syllable that contains its mora. However, this is not sufficient to predict gemination as we also find geminates in words like *febbre* ('fever') in Italian where the consonant is geminated although there is a following consonant. Rather, the geminate-weight hypothesis predicts that we should find syllabification contrasts like hypothetical *feb.re* and *fe.bre*, based on whether or not [b] is moraic (Armin Mester, p.c.). It is well-known that languages do not contrast syllabification and so this prediction is not borne out.

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[18]Ham (2001) finds that coda geminates are longer than onset geminates. This has been taken as phonetic evidence for the mora as a segmental unit of weight (Cohn 2003). However, it may also be attributed to a difference between the phonetic realization of segments in the onset and those in the rime.

[19]I thank Armin Mester for pointing out the connection between the geminate-weight hypothesis and underspecification theory.

puts). Smolensky (1993) shows many processes that had previously been analyzed with reference to underspecification can be reanalyzed within OT where markedness constraints play the crucial role. Inkelas (1994) and Artstein (1998) show that given the structure of OT, an output cannot be more marked than its input. It can be as marked, where markedness in the input is preserved due to faithfulness constraints, or it can be less marked, due to markedness constraints. This means that underspecification is usually not useful since it can only be assumed for alternations of unmarked structure. Given the representation of a geminate as an underlyingly mora-bearing consonant, the constraint ONSET (which requires that all syllables have an onset) is relied on to force phonological length on the surface. However, if the markedness constraint against long segments/geminates is ranked above ONSET, the predicted lengthening will not occur. This is shown in (25). (The constraint MAXLINKµ requires that underlying segmental links to moras must be preserved.) The notation in candidate (c) represents consonantal length, split across two syllables.

(31)   CVC.C parsing harmonically bounded

/C V C C V/ [A] [A]	MAX	*GEMINATE/*LONG	ONSET
a. CVC.V	*		*!
☞ b. CV.CV	*		
☞ c. C V C. C V [A]		*	

   Because candidate (a) incurs more violations than the other candidates it will never surface, regardless of the constraint ranking, a desirable theoretical result.

   I have shown that the additional tenets of standard moraic theory are problematic and that the insights moraic theory seeks to capture may be captured, in some cases more successfully, by not taking moras to be associated directly to segments.

5   Conclusion

The proportional increase theory of weight has been proposed as a weight-determining criterion and shown to correctly predict syllable weight in Norwegian. The weight of a given syllable shape in a particular position is determined based on the relationship between the duration of the syllable's rime and that of a CV syllable in the same position (corrected for speaking rate). If an average (corrected) rime is at least 60% greater than that of a CV in the same position, the syllable is categorized as heavy. If the proportional increase of a syllable does not regularly reach this threshold then the syllable is categorized as light. This weight-determining algorithm accounts naturally for the CVC weight asymmetry. A non-final CVC was shown to surpass the proportional increase threshold, whereas a final CVC fell notably short of it. This difference is due to the fact that a final CV is markedly longer due to final lengthening. Therefore, additional length, beyond that added by a final consonant, is needed in order for a rime's duration to increase 60%.

   The proposed theory has been argued to be superior to the approach taken within standard moraic theory, which assumes segmentally-associated moras and final consonant extrametricality. The proposed weight criterion is perceptually motivated and does not need to single out the final

position. While the effectiveness of the proportional increase theory of weight needs to be investigated for other languages traditionally analyzed with final consonant extrametricality, the results shown for Norwegian are very promising.

Further, the proportional increase theory of weight explains another fact about CVC weight asymmetry that is well known: that this asymmetry is between non-final positions and final position. Although there are some cases where extrametricality has been claimed to be needed word-initially, extrametricality is overwhelmingly claimed for word-final, not word-initial, constituents. The limitation of the CVC weight asymmetry to non-final versus final position is explained in the proposed theory, as the word-level domain of final lengthening is the final rime. Extrametricality, on the other hand, should be able to apply at either word edge and its initial/final asymmetry is unexplained.

It is a consequence of the proportional increase theory of weight that moras must be taken to be properties of syllables, rather than of individual segments. While this is not at odds with the tenets and insights of classical moraic theory, it is inconsistent with standard moraic theory since there is no longer a moraic tier. I have argued that there are problems with taking moras to be associated with segments, especially with respect to the geminate-weight hypothesis, and that the proposed view of moras is compatible with phonological theory.

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