The Computation of Weight in Portuguese: Syllables and Intervals

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1. Introduction

The relationship between weight and stress in weight-sensitive languages has been the topic of research of numerous scholars. Moraic Theory (Hyman 1985), for example, formalizes such a relationship by assigning weight-bearing units (μ) to specific constituents in the syllable. This allows us to categorically differentiate between [CV_μ] (i.e., light) and [$CV_\mu C_\mu$] (i.e., heavy) syllables in languages where such a distinction may be relevant. Portuguese is one such language: Syllables with a coda consonant or a (falling) diphthong contain two moras and are therefore heavy, whereas CV syllables contain one mora and are light.

More recently, however, probabilistic approaches have changed the maxim of categoricity often assumed in phonological analyses. With more statistical power, we are now able to perform more comprehensive and detailed analyses, which in turn help us adjust our own theoretical assumptions. Weight and stress have benefitted greatly from such approaches, and we now know that the computation of weight is not as categorical as we thought. Instead, more intricate, subtle patterns can emerge once we examine enough data. In this paper, I show that this is in fact the case for Portuguese.

Previous analyses of Portuguese stress assume a categorical view of weight, namely, syllables are either heavy or light (Bisol 1994, Lee 1994, Wetzels 1997, among others). The present study provides empirical evidence that supports a *gradient* pattern once we look at all words in the lexicon. Furthermore, the behaviour of onsets in the language suggests that weight is not computed in terms of syllables. Rather, the data motivate an interval-based account, where rhythmic units span from one vowel up to (but not including) the next vowel (Steriade 2012).

As we will see, the analysis proposed here is more accurate, more parsimonious and more empirically motivated than a syllable-based account. In other words, a probabilistic interval-based approach accounts for *more* words in the language by employing *fewer* predictors—in fact, only *one* predictor is used in this paper, namely, weight.

The paper is organized as follows: In §2, I briefly review Portuguese stress and describe the relevant facts regarding weight effects in the language. In §2.1, I differentiate syllables and intervals, reviewing the predictions one could derive from each weight domain. In §3.1, I describe the corpus used in this paper. The patterns in the corpus are discussed in §4, and are the basis for the analysis provided in §5. Finally, in §6 I briefly summarise the main results of this study.

2. Portuguese stress

Let us first review the traditional assumptions about Portuguese stress.[1] Unlike English, where weight effects are observed in both verbs and non-verbs (e.g., Hayes 1982), Portuguese weight effects are only observed in non-verbs (nouns and adjectives). For that reason, this paper will not discuss stress in verbs.[2]

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1 For a full discussion on Portuguese stress, please see Garcia (2014).

2 See Wetzels (2007) for a comprehensive discussion.

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Portuguese stress respects the trisyllabic window, i.e., we do not find words with pre-antepenultimate (PAPU) stress in the language.[3] The overall stress pattern in Portuguese is traditionally assumed to be as follows: Final (U) stress if the final syllable is heavy (*papél* 'paper'), and penult (PU) stress otherwise (*páto* 'duck'). Antepenult stress (APU), albeit relatively common, is unpredictable (*abóbora* 'pumpkin').

Syllables in Portuguese can be either heavy or light (there are no superheavy syllables in the language). A heavy syllable contains a coda consonant (*pomár* 'orchard') or a falling diphthong (*mausoléo* 'mausoleum').[4] We can therefore see that the traditional view assumes a categorical weight distinction: There is no such a thing as a 'heavi*er*' syllable under these assumptions.

A second important assumption often made by scholars (Bisol 1994, Lee 1994, Bisol 2005, Lee 2007) is that only word-final syllables are sensitive to weight. In other words, penult CVC and penult CV syllables are identical vis-à-vis their effect on stress. The third and final assumption is that antepenult stress is completely idiosyncratic in the language (Câmara & Neto 1977 and many others since then). This entails that no systematic weight effect should be found in this position.

A final assumption brings us to the role of onsets in stress assignment. This is not an assumption about Portuguese *per se*, but rather about stress across languages, as the classic view of syllable weight (e.g., Hyman 1985) is based on the fact that onsets do not contribute to weight. However, more recent studies have shown that this assumption is not correct (Gordon 2005, Kelly 2004, Topintzi 2010, Ryan 2014). This brings us to the question of whether onsets play a role in Portuguese stress. To my knowledge, previous analyses have either assumed no role exists or ignored onsets altogether.

(1) Key traditional assumptions about Portuguese stress
  a. Weight is categorical: Syllables are either light or heavy.
  b. Weight effects are constrained to the word-final syllable of the word.
  c. Antepenult stress is completely idiosyncratic/unpredictable.
  d. Onsets do not contribute to weight.

As pointed out by Wetzels (2007), there seems to be enough evidence to question assumptions (1-b) and (1-c). For example, antepenult stress appears to be blocked by a penult CVC syllable, thus CV́.CVC.CV words are extremely rare in the language, and only exist in the form of borrowings such as *perfórmance*. If only word-final syllables were weight-sensitive, then why would the shape of the penult syllable affect the likelihood of APU stress? At the same time, if we can predict when APU stress is practically impossible, would (1-c) still be an accurate generalization?

To investigate (1-a) and (1-d), one needs a considerable amount of data, since both weight gradience and onset effects will likely require information on proportions over a corpus, for example. Before discussing the characteristics of the corpus used in this study, let us briefly discuss (1-d) in more detail: Even though onsets have played a marginal role in the discussion of weight computation, their behaviour will ultimately indicate which domain of weight computation is more compatible with a given language, namely, syllables or intervals.

2.1. Onset effects and the domain of weight computation

The crucial structural difference between syllables and intervals is how onsets are parsed. For example, a CVCCVCCV word in Portuguese will almost always be syllabified as [$\text{CVC}_3.\underline{\text{C}}\text{VC}_2.\underline{\text{C}}\text{V}_1$] (onsets are underlined). In interval theory, this word would be parsed as [$\langle\text{C}\rangle\text{VC}\underline{\text{C}}_3.\text{VC}\underline{\text{C}}_2.\text{V}_1$]. Note that (i) all intervals begin with a V (hence a V-to-(V) interval), and (ii) the leftmost pre-vocalic segments are extrametrical (Steriade 2012), i.e., they do not count in the computation of weight. As we can see, onsets belong to different rhythmic units when we compare syllables and intervals: An onset in syllable i is parsed into interval $i - 1$.

Another important distinction between syllables and intervals is the presence of an internal hierarchy in (traditional) syllable theory (i.e., rhymes, which encompass the nucleus and the coda, and onsets).

[3] The very few exceptions are the result of epenthesis due to dispreferred phonotactic patterns (for example, /ˈtɛk.ni.ko/ → [ˈtɛ.ki.ni.ko]).

[4] Coda size in Portuguese is limited to one segment in the vast majority of cases. Complex codas are restricted to [ns] sequences, e.g., *trans.por.te* 'transport'.

Interval theory only assumes linear sequences of segments: The longer an interval, the heavier it will be—and, as a result, the more likely to attract stress it will become.

Given the different parsings described above, we can examine which domain of weight computation is more compatible with a given language by investigating onsets and their effect on stress. If onsets do affect stress in Portuguese, then the question is whether the patterns we see are in line with syllables or intervals. As we will see (§5), the Portuguese lexicon seems to be considerably more consistent with intervals.

3. Methodology

3.1. The Portuguese Stress Corpus

The corpus used in this study was based on a complete list of non-verbs present in the most comprehensive dictionary in Portuguese (Houaiss, Villar & de Mello Franco 2001). A MatLab script syllabified all words in the corpus, and a Python script extracted all the relevant segmental information. Finally, an R (R Core Team 2014) script cleaned and filtered the corpus, adding information about intervals and syllables. The analysis that follows is based on the resulting corpus (n=154,083), to which I will refer as the Portuguese Stress Corpus, or PSC (Garcia 2014).

Two frequency corpora (Klautau 2013 and Dave 2012) were also used to examine whether the proportion of final, penult and antepenult stress in the corpus was similar to that of spoken Portuguese.[5] Of all the words in the PSC, 18% have final stress, 69% have penult stress, and 13% have antepenult stress.

In total, 53 factors are present in the PSC, most of which are directly or indirectly relevant predictors of stress in Portuguese. In this paper, I will focus on 12 such predictors: 9 for a syllable-based model and 3 for an interval-based model. Given the trisyllabic window in the language and the structural assumptions in both weight domains, these numbers are not arbitrary. Because onsets, nuclei and codas are different constituents under syllable theory, each syllable needs three different predictors. Intervals, on the other hand, consist of strings of segments, and the only predictor needed for each interval is the number of segments in that interval.

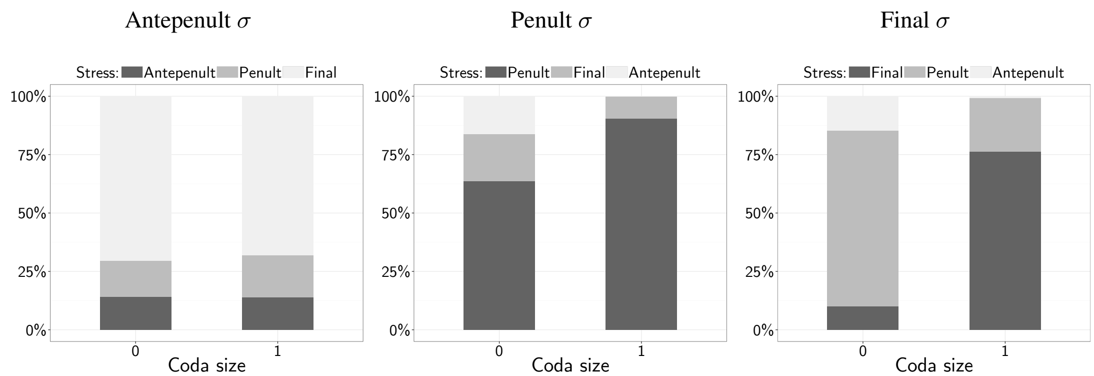
4. Data

In this section, we will see that the PSC shows weight effects that seem much more intricate than what is often assumed. Let us first explore the data through the lens of syllables. In Fig. 1, we observe proportions of words by stress position depending on whether a coda consonant is present. As expected, word-final codas indeed have a clear effect on stress—this is consistent with previous analyses. Penult codas, however, also seem to have an effect, in that more words with a penult coda have penult stress than words *without* a penult coda. This trend is interesting in itself, as it suggests some weight effect is also found word-internally—*contra* previous analyses.

We can see in Fig. 1 that the presence of a coda consonant in the antepenult syllable does not seem to influence the location of stress. This is unsurprising, given the irregular status often attributed to this stress position. Here we already see some evidence for a gradient view of weight, whereby word-final codas have a more robust effect on stress than penult codas, which in turn have a more robust effect than antepenult codas (where no effect is suggested by the plots in Fig. 1).

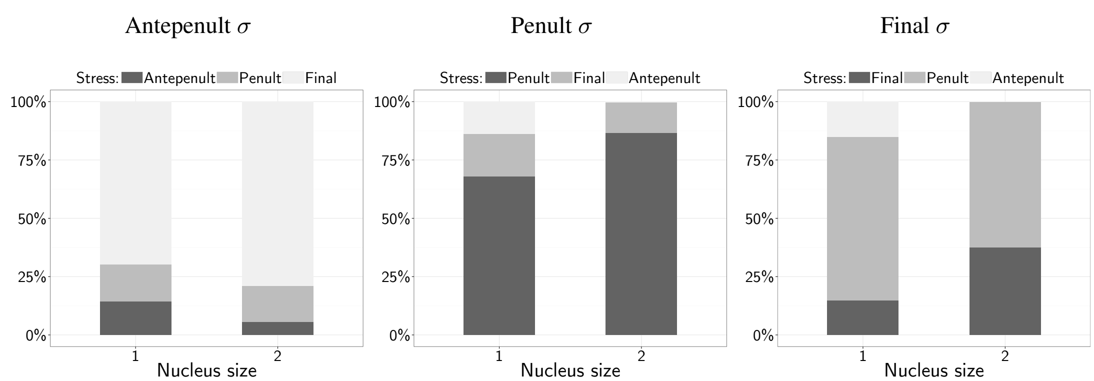
[5] Even though the objective here is not to examine spoken Portuguese, it was important to check how different the lexicon was when compared to a frequency corpora vis-à-vis stress. Overall, the all corpora had relatively similar proportions (see Garcia (2014)).

Figure 1: Coda size effects by syllable and stress pattern



Let us now turn to syllabic nuclei. In Fig. 2, we can see that nucleus size appears to have an effect on the location of stress. For final and penult nuclei, diphthongs positively affect stress, whereas for antepenult nuclei, the opposite pattern is observed—that is, words with antepenult stress in Portuguese rarely have a diphthong in the antepenult syllable. In fact, the proportion of antepenult diphthongs increases as stress moves towards the right edge of the word: For antepenult stress, 1%; for penult stress, 10%; and for final stress, 20%. This trend is naturally problematic for both syllables and intervals.

Figure 2: Nucleus size effects by syllable and stress pattern



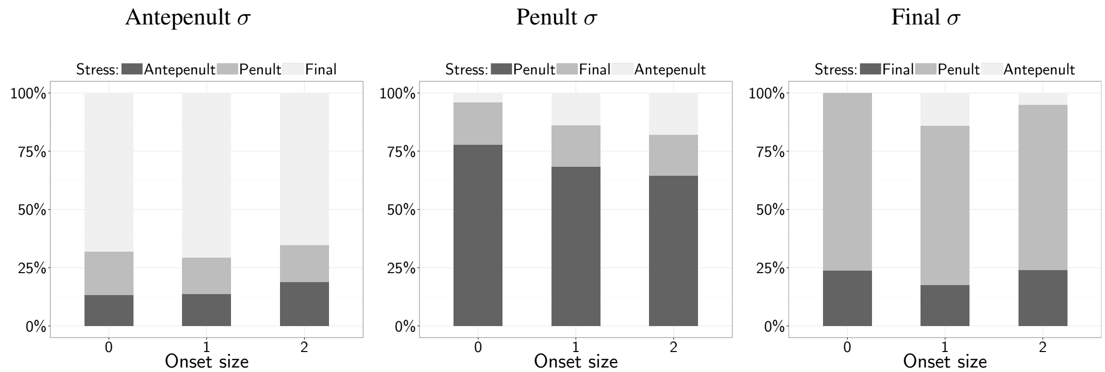
Finally, let us examine onsets, which play a crucial role in our comparison between syllables and intervals. In Fig. 3, onset size is shown for all three positions in the stress domain. Under syllable theory, we should expect a positive (or null)[6] effect of onset size on stress, but that is not what we see for final and penult syllables. In final position, even though we observe a higher proportion of final stress with final onset clusters (relative to singleton onsets), that proportion is practically identical in words with no final onsets at all. In penult syllables, the trend is clearly negative: As (penult) onset size increases, the proportion of words with penult stress decreases. We still need to verify whether such effects are significant (§5), but here we already see a possible problem for syllable theory: Why would onset size *negatively* correlate with stress?

Antepenult onsets differ from penult and final onsets, in that the data suggest a positive trend in Fig. 3. In this particular position, the patterns observed are consistent with what we would predict under syllable theory if onsets played a role in stress assignment. Indeed, the antepenult position presents a distinct behaviour across all syllabic constituents: No apparent coda effect, negative nucleus effect and positive onset effect—all of which contrast with the other positions in the stress domain.

Figures 1, 2 and 3 provide an overview of the Portuguese lexicon under syllable theory. Let us now look at the data under interval theory. In Fig. 4, we see all three intervals in the stress domain. In the *x*-axis, we find the number of segments in each interval—note that each bar also contains the proportion

[6] If onsets have no effect on stress in the language.

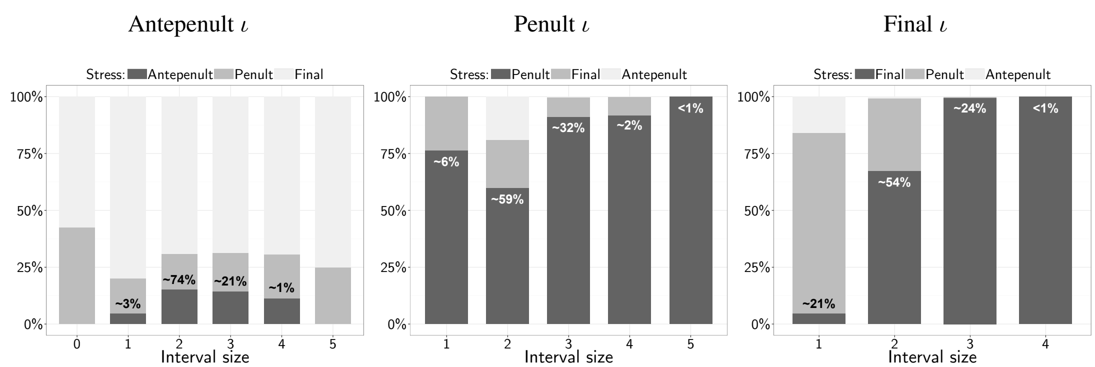
Figure 3: Onset size effects by syllable and stress pattern



of words for each interval size. For example, even though the final interval may contain up to four segments, more than 99% of all words in the PSC have fewer segments in that interval.

Overall, we can see that longer intervals correlate with higher proportions of words for all three positions. These trends are consistent with interval theory—note that the vast majority of words in Fig. 4 present a positive correlation between interval size and stress.

Figure 4: Intervals and stress patterns



The data thus far indicate that weight effects in the language are more intricate than previously assumed: The trends observed under syllables and intervals appear to contradict the key assumptions in (1). First, weight effects in the PSC seem to be inconsistent with a categorical view of weight, as we observe gradient patterns in the data. Second, we see no evidence suggesting that weight is only relevant word-finally. Third, antepenult stress may not be as idiosyncratic as previously thought. Finally, the data suggest some effect of onsets on stress, even though such an effect is inconsistent with syllable theory.

In the next section, we will analyse in detail the weight effects discussed above. Given the onset behaviour observed in the PSC, we will also compare a statistical model based on syllables and a model based on intervals, and assess which model best captures the patterns in the PSC.

5. Analysis and discussion

Two Ordinal Regression models (Agresti 2010) will be discussed in this section. The syllable model predicts stress based on the presence of onsets, complex nuclei and codas (Figs. 1, 2 and 3). In total, our syllable model will include nine binary predictors (2-a). The interval-based model, on the other hand, will include three predictors (2-b), namely, the interval size of each interval in the stress domain (Fig. 4).[7]

[7] Segmental quality is not discussed here—see Garcia (2014).

(2) Statistical models based on syllables (σ) and intervals (ι)

a. `stress ~ [on + nuc + co] + [on + nuc + co] + [on + nuc + co]`

b. `stress ~ interval.3 + interval.2 + interval.1`

Ordinal Regressions, also known as Cumulative Link Models, treat responses as ordered factors. As a result, the stress domain in Portuguese is treated as a 3-point scale: 1 = final stress, 2 = penult stress and 3 = antepenult stress. Unlike binomial Logistic Regressions, which require responses to be binary, Ordinal Regressions allow for multinomial responses.[8] Thus, instead of two binomial models for each domain under examination (syllables and intervals), only one model is necessary—and a single effect size in log-odds ($\hat{\beta}$) is generated for each predictor. If the effect size of a particular predictor is significant, we conclude that the location of stress is affected by such a predictor. Based on the 3-point scale described above, positive effect sizes ($\hat{\beta} > 0$) indicate that antepenult stress is favoured, whereas negative effect sizes ($\hat{\beta} < 0$) indicate that final stress is favoured. Ordinal Regressions also generate different thresholds (θ), which indicate the intercept of each cumulative logit. These intercepts ($n - 1$, where n is the number of responses) adjust how each $\hat{\beta}$ should be interpreted depending on which point in the scale we examine.

5.1. Syllable model

In the syllable model in Table 1, we can see that only one of the nine predictors has no effect on stress, namely, antepenult codas (`coda.ant`). The trends observed in Figs. 1, 2 and 3 are confirmed by the model, namely, weight effects are spread across the stress domain in a much more intricate way than previously assumed (1). For example, having a coda in the penult syllable increases the odds of penult stress by a factor of 3 ($e^{|\hat{\beta}|}$).

The second important fact about the results in Table 1 is the negative effect of final and penult onsets, which confirm the trends observed in Fig. 3—this is consistent with interval theory, as we saw in §2.1. Antepenult onsets, on the other hand, have a *positive* effect on stress, i.e., having an antepenult onset favours antepenult stress. Even though this contradicts the extrametricality assumed in Steriade (2012), we could hypothesize that parsing is exhaustive in Portuguese: Onsets[9] at the left edge of the stress domain are parsed into the leftmost available rhythmic unit—this hypothesis receives further support once we examine disyllables, where penult onsets have a *positive* effect, rather than the negative effect seen in Table 1 (see Garcia (2014:p. 35) for a more extensive discussion on edge effects).

The syllable model presented here accounts for 74.75% of all words in the PSC. Given that 72% of the Portuguese lexicon is comprised of words with regular stress, we can see that some of the irregular cases are also accounted for by the model. For example, antepenult stress is traditionally assumed to be completely irregular in Portuguese, but two of the three antepenult predictors are highly significant ($p < 0.00001$). Interestingly, diphthongs in the antepenult position lower the odds of antepenult stress by a factor of 2.9—this is unexpected in a quantity-sensitive language, where longer nuclei should in principle be more stress-attracting.

Finally, it is important to note that the effect size of the predictors in Table 1 is positionally defined, and present a gradient pattern: Weight-sensitivity decreases as we move away from the right edge of the word. In addition, within each syllable, onsets have the weakest effect. We can therefore conclude that weight effects are gradient both across and within syllables in Portuguese.

5.2. Interval model

In the interval model, we can see that all three intervals have a highly significant effect on stress in Portuguese. In Table 2, the effect size of each interval decreases as we move away from the right edge of the word (same trend observed in the syllable model): $\hat{\beta}_U = -1.99, \hat{\beta}_{PU} = -0.21, \hat{\beta}_{APU} = 0.31$. Results again show that weight effects are not constrained to the word-final position in the word.

Despite having only three predictors, the interval model is more accurate than the syllable model

[8] The data were also modelled with two Logistic Regressions, for the purposes of comparison. See Garcia (2014) for a more thorough discussion on the statistical methods used in this study.

[9] That is, pre-vocalic segments, since intervals do not assume constituency.

Table 1: Coefficient values for σ model ($\hat{\beta} > 0 \Rightarrow$ higher likelihood of antepenult stress), with associated odds ratio ($e^{|\hat{\beta}|}$), standard errors, Wald z values and significances

σ **predictor**	$\hat{\beta}$	$e^{\lvert\hat{\beta}\rvert}$	**se**($\hat{\beta}$)	z **value**	p **value**
`onset.fin`	1.52	4.59	0.02	53.97	< 0.00001
`nucleus.fin`	-2.86	17.55	0.02	-137.99	< 0.00001
`coda.fin`	-4.68	108.10	0.02	-194.62	< 0.00001
`onset.pen`	0.50	1.65	0.02	23.75	< 0.00001
`nucleus.pen`	-1.32	3.75	0.02	-46.18	< 0.00001
`coda.pen`	-1.09	3.00	0.01	-63.85	< 0.00001
`onset.ant`	0.24	1.27	0.02	11.64	< 0.00001
`nucleus.ant`	-1.06	2.90	0.02	-40.50	< 0.00001
`coda.ant`	-0.02	1.02	0.01	-1.646	0.0999
$\theta = \{-1.64, 3.34\}$	AIC: 186433.21		Accuracy: 74.75%		$\kappa = 40.79$

(78.26% *vs.* 74.75%). The better fit of the model is also observed in its lower AIC.[10] In other words, this model is not only more empirically motivated (given the onset effects observed in the PSC), but also more parsimonious. One final advantage of intervals is the much lower collinearity (κ) found in the data—syllabic constituents are highly collinear in Portuguese (see Table 1).[11]

Table 2: Coefficient values for ι model ($\hat{\beta} > 0 \Rightarrow$ higher likelihood of antepenult stress), with associated odds ratio ($e^{|\hat{\beta}|}$), standard errors, Wald z values and significances

ι **predictor**	$\hat{\beta}$	$e^{\lvert\hat{\beta}\rvert}$	**se**($\hat{\beta}$)	z **value**	p **value**
`int1`	-1.99	7.33	0.01	-197.70	< 0.00001
`int2`	-0.21	1.23	0.01	-33.40	< 0.00001
`int3`	0.31	1.37	0.01	48.04	< 0.00001
$\theta = \{-2.18, 2.60\}$	AIC: 181389.03		Accuracy: 78.26%		$\kappa = 13.57$

Table 3 summarises both models presented above according to the number of predictors used as well as the AIC values, collinearity and accuracy. Clearly, an interval-based model is more advantageous in accounting for the stress patterns in the Portuguese lexicon. Crucially, we can see that a model based solely on the number of segments in each interval is capable of accounting for the vast majority of words in the PSC.

Table 3: Model comparison

Weight domain	**Predictors**	AIC	κ	**Accuracy**
Syllable	9	186433.21	40.79	74.75%
Interval	3	180035.58	15.38	78.29%

[10] Akaike Information Criterion, Akaike (1974).

[11] Note, however, that the standard errors are considerably low in both models, which makes each effect more reliable in spite of a high κ value.

6. Final remarks

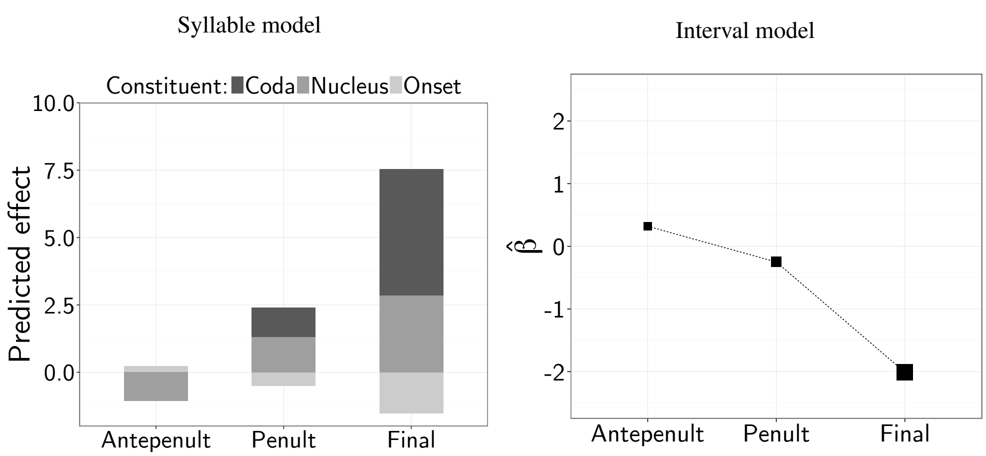
Recall that the objective of this paper was to investigate how weight is computed in the Portuguese lexicon. In doing so, we inevitably revisited the key assumptions about weight and stress in the language (repeated here as (3)). We saw in sections 4 and 5 that the assumptions in (3) are inaccurate, as none of them is consistent with the data. In other words, our understanding of how weight affects stress in Portuguese is incorrect regardless of the domain of weight we choose. Finally, the analysis presented here argues for an interval-based account, given the patterns observed in the lexicon as well as the statistical comparison in Table 3.

(3) Key traditional assumptions about Portuguese stress

a. Weight is categorical: Syllables are either light or heavy.
b. Weight effects are constrained to the word-final syllable of the word.
c. Antepenult stress is completely idiosyncratic/unpredictable.
d. Onsets do not contribute to weight.

In Fig. 5, we can see that both models clearly mirror the weight gradience observed in the PSC,[12] namely, final syllables/intervals are more weight-sensitive than word-internal syllables/intervals. Such differences may explain why traditional approaches have assumed weight-sensitivity was restricted to the final syllable of the word.

Figure 5: Weight gradience: $\hat{\beta}$ by predictor in both models



Further research is needed to investigate to what extent the patterns observed in the PSC are also found in native speakers' behaviour. How do speakers and the lexicon examined here compare vis-à-vis the domain of weight computation? The effect of onsets is considerably small relative to the effect of codas and nuclei in the corpus, which means such an effect may not be captured/generalizable by native speakers. This, in turn, will impact our interpretation of the way weight is computed in speakers' grammars.

This paper shows that intervals best capture the computation of weight in Portuguese. An important question is, thus, how intervals and syllables interact across *other* phonological processes in the language. If weight and stress are computed in intervals, how do we account for the phenomena that have hitherto been explained based on syllables? Could intervals also account for such phenomena? The approach presented here does not reject the role of syllables in Portuguese, but a comprehensive analysis is needed to accurately evaluate which representation best captures the empirical data across phenomena other than stress in the language.

[12] In the syllable model, `coda.ant` is not shown.

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