Weight effects and the parametrization of the foot: English *vs.* Portuguese

Guilherme D. Garcia[1] and Heather Goad[2]
[1]Department of English, Ball State University, USA
[2]Department of Linguistics, McGill University, Canada
[1]gdgarcia@bsu.edu, [2]heather.goad@mcgill.ca

Abstract

This paper argues that even though English and Portuguese present similar stress patterns on the surface, these two languages are fundamentally different: whereas English builds feet, Portuguese does not. To support this argument, we focus on weight effects on stress. We experimentally show that weight effects in English are consistent with an analysis of stress that employs feet. In contrast, weight effects in Portuguese cannot be optimally accounted for by a foot-based analysis. Further evidence for the foot in English comes from word minimality constraints, which are never violated in the language, unlike in Portuguese.

Stress, weight, foot, word minimality, lexicon, English, Portuguese

1. Introduction

Prosodic Phonology assumes that syllables are organized into feet, the domain where word-level prominence is realized (Nespor & Vogel, 1986; Selkirk, 1984). One of the central motivations for feet cross-linguistically is the observation that languages systematically constrain the window of syllables in which stress can fall:[1] indeed, in the vast majority of languages, stress falls within a trisyllabic window at the left or right edge of the word—a bisyllabic foot with one additional syllable at an edge (see Gordon (2016) for a comprehensive review). Besides delimiting the domain of stress, feet also express *where* within this domain stress is expected to fall.

Although stress is not formally expressed in all languages, the foot has nevertheless been proposed to be universal (see, e.g., Selkirk, 1996; Vogel, 2010). This position has been challenged by some researchers for languages like French and Turkish where prominence assignment does not have the typical signatures of word-level stress (e.g., Jun & Fougeron, 2000; Özçelik, 2014). In the present paper, we question the universal status of the foot from the perspective of Portuguese. On the face of it, Portuguese has a very similar stress system to English, a language for which the presence of the foot has not been questioned. In both languages, regular stress in non-verbs (nouns and adjectives) seemingly can be captured by binary left-headed weight-sensitive feet (i.e., moraic trochees). In English, stress falls on the penultimate syllable if that syllable is heavy (e.g., a(gén)⟨da⟩) and on the antepenultimate syllable otherwise (e.g., (Cána)⟨da⟩). In Portuguese, stress falls on the final syllable if that syllable is heavy (e.g., jor(nál) 'newspaper') and on the penultimate syllable otherwise (e.g., sa(páto) 'shoe') (see, e.g., Bisol, 1992).[2] The principal difference between these two systems seems to be extrametricality, given that the final syllable is not visible for footing in English (e.g., Hayes, 1982), but it is in Portuguese.

Even though English and Portuguese stress look similar on the surface, we will show that they are fundamentally different with regard to footing. In English, weight effects found in experimental data (§3) and in the lexicon (§5) are as predicted if we assume that the language builds moraic trochees. In Portuguese, on the other hand, weight effects are not consistent with any foot type, and thus pose a major challenge for foot-based approaches (Garcia, 2017a). We experimentally show that antepenultimate stress is favored when antepenultimate syllables are heavy in Portuguese, but that such an effect is not found in English. Furthermore, existing words in English are at least one binary foot in length—the same is true of productive phenomena such as truncation and hypocorization, which never yield monomoraic outputs. In other words, English never violates word minimality (§4), which is indirectly imposed by the Prosodic Hierarchy and the Foot Binarity condition (e.g., McCarthy & Prince, 1995). In Portuguese, however, we commonly find existing words which violate word minimality, that is, words which are monomoraic and, therefore, smaller than a (binary moraic) foot. Sub-minimal words are also found in productive phenomena such as hypocorization. In short, we will see that English and Portuguese motivate distinct formal systems that regulate lexical stress despite having similar rhythmic patterns on the surface.

The paper is organized as follows. First, we review stress and footing in Portuguese and English (§2). Second, we present and statistically model experimental results on English stress based on a parallel experiment conducted earlier by Garcia (2019) on Portuguese (§3); we show that the results motivate footing in English, but question this for Portuguese. Third, in §4, we demonstrate that our experimental results are consistent with differences in the truncation and hypocorization patterns in Portuguese *vs.* English. We then turn, in §5, to the English lexicon, which we show is consistent with our experimental results. Finally, in §6, we discuss the implications of our results for the status of the foot in Prosodic Phonology.

2. Stress and footing

2.1. Portuguese

Primary stress in Portuguese is constrained by a trisyllabic window, as mentioned above: *marítimo* 'maritime', *martélo* 'hammer', *papél* 'paper'. As a result, pre-antepenultimate stress is illicit in the language (**máritimo*). Even though both verbs and non-verbs respect this trisyllabic window, stress in these two classes of words is driven by different factors: stress in verbs is heavily influenced by morphological factors (see Wetzels (2007) for a review), while stress in non-verbs relies mostly on phonological factors, namely, weight (Bisol, 1992; Garcia, 2017b; Lee, 2007; Wetzels, 2007). In this paper, we focus on stress in non-verbs, which is typically assigned *as per* (1)—H stands for a heavy syllable, L for a light syllable, and X for any syllable (H or L).

(1) **Portuguese stress in non-verbs**

Final stress if the final syllable is heavy:	*papél* 'paper', *rapáz* 'boy'
Else, penultimate stress:	*martélo* 'hammer', *varánda* 'veranda'

Traditionally, all stress patterns that deviate from (1) are considered to be irregular. These include all words in the Houaiss Dictionary (Houaiss et al., 2001) with antepenultimate stress (13% of non-verbs; Garcia (2014)), regardless of the weight profile involved (H́LL: *fósforo* 'match' (noun), ĹHL: *pénalti* 'penalty', ĹLH: *júpiter* 'Jupiter'). Irregular cases also include words with penultimate stress which have a heavy final syllable (XX́H; *esténcil* 'stencil', *nível* 'level'; 11% of non-verbs), and words with final stress which have a light final syllable (XXĹ: *jacaré* 'alligator', *tatú* 'armadillo'; 3% of non-verbs). Approximately 72% of the Portuguese lexicon can be accounted for by the algorithm in (1) (Garcia, 2017b), which makes it relatively robust. In spite of this, researchers do not agree on what type of feet Portuguese builds, as well as what extra machinery must be employed to account for the various irregular patterns found in the language.

Bisol (1992) proposes that regular stress in Portuguese requires both moraic and syllabic trochees: moraic trochees capture XXH́ words, which contain a heavy final syllable and bear final stress; syllabic trochees capture XX́L words, which contain a light final syllable and bear penultimate stress. Bisol also assumes that both syllabic and moraic trochees are employed in irregular patterns. She proposes that the final syllable in words with antepenultimate stress is exceptionally marked as extrametrical. As a result, these words have the same foot structure as regular penultimate stress (i.e., they involve syllabic trochees).

Bisol's approach does not straightforwardly extend to cases of word-final stress on light syllables. To capture this pattern, some scholars assume that Portuguese builds both trochees and iambs (Bonilha, 2004; Lee, 2007). Bonilha (2004), for example, proposes that iambs are built in words such as *urubú* 'vulture' and *abacaxí* 'pineapple' due to the word-final vowels in question (/i, u/): underlyingly high vowels in word-final open syllables virtually always attract stress. According to Bonilha, /i, u/, 'when positioned at the end of the prosodic word, are considered good peak elements' (p. 41). This assumption, however, is inconsistent with the fact that, among vowels, high vowels have the lowest sonority (Ladefoged & Johnson, 2011; de Lacy, 2006). Indeed, in (Brazilian) Portuguese, /e, o/ in final unstressed syllables are reduced to [i, u], respectively, consistent with the low sonority of the latter. If final stress on light syllables were truly driven by sonority, then XXL words ending in /a/ would be the best candidates for final stress—but this is not the case.

Lee (2007) also assumes that both iambic and trochaic feet play a role in the grammar of Portuguese. Lee proposes an optimality-theoretic account and, thus, takes advantage of the position that constraints that strive for outputs conforming to both foot types will be present in every grammar: FtForm = Iamb and FtForm = Trochee. Iambic feet are built in XLĹ words such as *jacaré* 'alligator': ja(caré), and trochaic feet are built in XĹL words such as *caválo* 'horse': ca(válo). One concern with this approach is that having two foot types active in a single language overgenerates the possible parses available. For example, a XLH́ word could be parsed with a final moraic trochee (i.e., XL(H́)) or bisyllabic iamb (i.e., X(LH́)).

Finally, some analyses of Portuguese assume that theme vowels play a role in stress assignment (e.g., Lee, 2007; Pereira, 1999, 2007). Theme vowels are always unstressed, and consist of {a, e, o} in Portuguese—in a word such as gát-o 'cat', the theme vowel (-o) indicates gender (masculine). In these analyses, stress is assumed to fall on the last vowel of the stem: gát]-o, jornál] 'newspaper', café] 'coffee'. As a result, feet are not necessary to account for regular stress patterns: if theme vowels are never stressed, then the final vowel in words like *café* cannot be thematic, and must instead be part of the stem. A significant challenge for this approach is that we only know if a given vowel is thematic if it is not stressed. As the following pairs of words show, {a, e, o} can be thematic or not, depending on where stress falls: fóm-e 'hunger' *vs.* café 'coffee'; córb-a 'snake' *vs.* sofá 'sofa'; gát-o 'cat' *vs.* robó 'robot' (see critique in Garcia (2017b)). In addition, no mechanism (e.g., extrametricality) is available to capture words with antepenultimate stress, which predicts that no generalizations hold for words of this shape. However, Garcia's (2017b) examination of the Portuguese lexicon suggests otherwise: antepenultimate stress is statistically more likely to occur in LLL words than in HLL words.

This observation follows if moraic trochees are built in the language and if final syllables are extrametrical in words with antepenultimate stress (e.g., Bisol, 1992). On this view, LLL should be preferred to HLL because in the latter word shape, both possible parses are non-optimal: the medial syllable could be left unparsed, as in (2a), which is a cross-linguistically marked metrical configuration; alternatively, an uneven trochee could be built, as in (2b), which is a highly disfavored foot type (Hayes, 1985; Prince, 1990). In contrast, ĹLL words face neither of these problems, as shown in (2c), which could thus explain why words of this shape are more frequent than H́LL words in the Portuguese lexicon.

(2) **Antepenultimate weight effects**

ĹLL $\succ$ H́LL due to metrical optimization:

a. (H́)L⟨L⟩ $\rightarrow$ Unparsed syllable
b. (H́L)⟨L⟩ $\rightarrow$ Uneven trochee
c. (ĹL)⟨L⟩

As we have seen, although much work on Portuguese adopts a foot-based approach to stress, no general consensus emerges across proposals. A particularly worrisome finding is that more than one foot type has been proposed to be simultaneously active in the language, either different types of trochees (Bisol, 1992) or different types of feet—trochees and iambs (Bonilha, 2004; Lee, 2007; Wetzels, 1992).[3] Further, stem-based approaches assume that the foot plays, at best, a minor role in the language. This lack of consistency within and across proposals stems from conflicting patterns in the language, which are more intricate than what has traditionally been assumed. We return to the question of footing in Portuguese in §3.1 and §4.1. We first examine stress in English non-verbs.

2.2. English

As already mentioned, the stress systems of Portuguese and English are, on the face of it, very similar. There has not been much debate, however, as to which metrical structures best characterize the English system (see Chomsky & Halle, 1968; Halle & Idsardi, 1995; Halle & Vergnaud, 1987b; Hayes, 1982; Liberman & Prince, 1977; Selkirk, 1980; among others). In English non-verbs, stress falls on the penultimate syllable if that syllable is heavy, and on the antepenultimate syllable otherwise, as shown in (3b) and (3c). The examples in (3b) show that heavy penultimate syllables contain a coda consonant (*veránda*) or a long vowel (*oppónent*). Final stress in nouns and adjectives tends to be avoided (Giegerich, 2005, p. 185), but can be found in words ending in VV(C) syllables (Halle & Vergnaud, 1987a).[4]

(3) **English stress in non-verbs**

a. Final stress in VV(C)$]_{\omega}$ words — *canóe, políce*
b. Penultimate stress if the penultimate syllable is heavy: XH́X — *veránda, oppónent*
c. Antepenultimate stress otherwise: X́LX — *Cánada, ártifice*

Given the behavior of word-final syllables shown in (3b) and (3c), extrametricality has played a central role in metrical accounts of English stress: Hayes (1982), for example, proposes that the final syllable in nouns is extrametrical, and is therefore invisible during stress assignment: ve(rán)⟨da⟩. For words with final stress, such as those in (3a), Hayes proposes a rule (Long Vowel Stressing) which assigns a foot to such syllables. We can thus summarize the stress algorithm in English non-verbs as follows: starting at the right edge of the word, stress is final if this syllable contains a VV(C) rhyme. Else, the penultimate syllable is checked. If a heavy syllable is found, stress is penultimate. Else, stress is antepenultimate. This algorithm can account for over 80% of the words in a subset of the Carnegie Mellon University Pronouncing Dictionary (Weide, 1993) containing 6,531 nouns and adjectives (excluding disyllables); see further §5. Although this might not seem substantially higher than the 72% observed earlier for Portuguese (§2.1), unlike in Portuguese, the vast majority of exceptions in English involve words where extrametricality exceptionally does not hold (e.g., va(nílla), ho(tél)).

Because English is a weight-sensitive language, and because final stress is typically avoided in non-verbs, the foot type standardly assumed for the language is the moraic trochee. This highlights an important difference between English and Portuguese: there is wide agreement in the literature that moraic trochees, and not syllabic trochees (or iambs), capture stress in the former language but not in the latter.

In sum, we have established that English supports (a particular type of) footing, while the evidence from Portuguese is less clear. Although weight effects are robustly observed in both languages, a question that must be addressed is whether weight effects, in and of themselves, motivate footing and whether the same conclusion can be reached for both languages on this matter. Both languages show that heavy syllables of particular profiles attract stress in final and penult positions. Evidence that weight regulates footing would come from either the absence of a weight effect in antepenultimate position, or the opposite weight effect in said position, i.e., stressed light syllables should be preferred over stressed heavy syllables, ĹLL ≻ H́LL, as seen earlier in (2). In the next section, we probe this question by experimentally examining whether weight effects in antepenultimate position are generalized by native speakers of English. To situate the experiment, we first summarize results from an earlier study on Portuguese, as our ultimate goal is to compare how weight effects manifest themselves in speakers' behavior in the two languages.

3. Experimentally probing the productivity of weight patterns

3.1. Portuguese

The observation that both Portuguese and English show heavy syllables of particular profiles attracting stress in final and penult positions can be captured with a WEIGHT-TO-STRESS constraint relativized to different positions in the stress domain. Indeed, Garcia (2017b) argues for an account along these lines for Portuguese: weight is positionally defined, such that the interpretation of a heavy syllable is determined relative to factors such as where in the word the syllable is located. Although the algorithm for Portuguese in (1), where patterns are treated as either regular or irregular and where syllables are analyzed as either heavy or light, can capture approximately 72% of the Portuguese lexicon, Garcia (2017b) shows that a probabilistic approach is more accurate at predicting stress location as it is able to capture some of the so-called irregular patterns. The probabilistic approach in Garcia (2017b) focuses on the Portuguese lexicon, but a subsequent study (Garcia, 2019) has shown that speakers' grammars also display a gradient weight effect, whereby final stress is more strongly affected by weight than penultimate stress, which is, in turn, more strongly affected by weight than antepenultimate stress. However, a critical difference between the behavior of speakers and the lexicon is the way in which weight interacts with stress in antepenultimate position. While the lexicon showed that weight effects were *negative* in penultimate position, in that antepenultimate stress is statistically more likely to occur in LLL words than in HLL words, in the experiment, the effect was *positive*: when speakers were asked to judge minimal pairs of nonce words which only differed in their stress location, they showed a statistically credible preference for antepenultimate stress in HLL words over LLL words. We suggest that this finding poses another challenge for the existence of the foot in Portuguese, a proposal for which we provide further support below (§4.1).

Given the mismatch observed between the lexicon and the grammar of Portuguese, it behooves us to ask whether the same mismatch holds of English. Although both Portuguese and English have exceptional words that cannot be captured by the algorithms in (1) and (3), respectively, we have seen that an important difference between the two languages concerns the nature of the forms that do not conform to these algorithms. In Portuguese, the non-conforming forms are sufficiently varied, which has led researchers to question the kind of foot that the language builds; in English, the non-conforming forms have not led to a rejection of moraic trochees but, instead, to a recognition that many words in the language violate extrametricality. One interpretation of the Portuguese data is that the grammar of present-day speakers has no foot, which would make a mismatch between the grammar and the more conservative lexicon not completely unexpected. We should not, however, expect to find a grammar–lexicon mismatch in English: if the foot regulates stress in English, then the language should not exhibit a preference for antepenultimate stress in HLL words relative to LLL words, given that an optimal parse cannot be provided for words of the former shape (see (2)). We experimentally examine this issue in the next sections.

We then turn, in §5, to probe the structure of the lexicon.

3.2. English

Although weight effects on English stress have been the focus of much research, not many experiments have empirically probed such effects in native speakers' grammars and even fewer have included antepenultimate stress. Guion et al. (2003) examined weight effects by employing nonce words, but only bisyllabic words were used, so nothing can be determined from this study about weight effects on antepenultimate stress. In a more recent study, Domahs et al. (2014) included longer words in a production task, which were orthographically presented to native speakers. Their results are overall consistent with the lexical patterns in the language (see §5), but not much is said about how weight affects antepenultimate stress. Furthermore, we cannot be sure that participants' preferences were guided solely by weight because of the profiles of the consonant clusters employed in some of the stimuli. Several forms were not phonotactically well-formed in English (e.g., *thimravas*, *posragols*) with the possible result that these stimuli could have skewed participants' responses as they would likely have been analyzed as compounds.

Most experimental studies examining weight effects in English have employed orthographic stimuli, which is problematic because grapheme–phoneme correspondences in English are far from isomorphic. Notably, although the quality and length of unstressed vowels is very distinct from that of stressed vowels, these contrasts are not reliably encoded. As a result, if the same orthographic form yields different responses, within or across participants in an experimental setting, it is not possible to know *a priori* if these responses involve the same or different sequences of phonemes.

Instead of using orthographic forms, the present study employs an auditory judgment task involving minimal pairs that differ by stress location. As we will see below, the task focuses specifically on the presence or absence of a heavy syllable in trisyllabic nonce words.

3.3. Methodology

3.3.1. Stimuli

The experiment was designed to optimize comparison with the earlier experimental results from Portuguese (Garcia, 2019). We employed a forced-choice judgment task where the stimuli being compared differed only in stress location, as previously mentioned.

All stimuli were generated by a script in R (R Core Team, 2019), that were then manually checked for phonotactic well-formedness. Stimuli containing attested but uncommon sequences were removed. As well, violations of the OCP (Leben, 1973; McCarthy, 1986) were avoided by removing or adapting words which contained sequences of identical vowels or sequences of obstruents/nasals which shared the same place of articulation, aside from coda–onset clusters.

180 stimuli were selected on the basis of three main conditions: weight profile, coda type, as well as onset complexity, as the latter has been shown to impact stress location (Davis, 1988; Kelly, 2004; Ryan, 2011, 2014; Topintzi, 2010). Three weight profiles were used: LLL, HLL and LHL; LLL words served as the baseline. In HLL and LHL words, heavy syllables always contained a coda, rather than a long vowel, to optimize comparison with Portuguese, which lacks long vowels. The coda in the heavy syllable was either a voiceless obstruent (/p, t, k, f, s/) or a sonorant (/m, n, ŋ, l, r/). All final syllables were of the shape [CəC], a common profile for final light syllables in English. Antepenultimate and penultimate vowels were drawn from the set /ɪ, ɛ, ɑ/; vowels were not reduced to schwa when unstressed (spectrally verified in Praat (Boersma & Weenink, 2019)), to ensure that the stimuli being compared only differed in stress location. Finally, onset complexity

was varied. When a complex onset was present, it was located either in the antepenultimate or penultimate syllable. Figure 1 provides an overview of the experimental conditions involved, as well as the number of stimuli per condition.

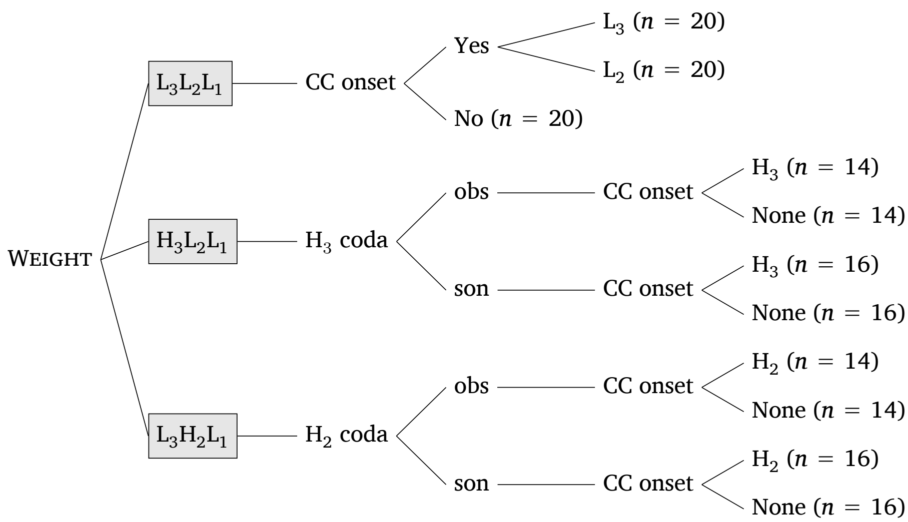

Figure 1: Experimental conditions. Stimuli (n = 180) were controlled for weight, coda type (obstruent or sonorant), and onset size (singleton or complex). Complex onsets are represented by 'CC' in the figure.

The stimuli were recorded by a male native speaker of Canadian English with extensive training in phonetics. To ensure that vowel quality would remain as constant as possible, phonetic transcriptions of all stimuli were made available to the speaker prior to recording. Each nonce word was recorded with both antepenultimate and penultimate stress, which resulted in 180 minimal pairs that differed only in the location of stress. Representative examples are provided in Table 1.

Table 1: Examples of stimuli used in the experiment.

LLL	HLL	LHL
prɪ.tɑ.rək	nɑr.pɛ.lət	mɛs.tɪ.nəp
lɑ.prɛ.sən	prɛn.dɪ.nəf	pɛ.trɑŋ.kəp
sɑ.pɪ.nər	krɪm.pɛ.dən	dɛ.lɪs.pən

3.3.2. Task

The experiment involved a forced-choice judgment task, as mentioned, developed in Praat (Boersma & Weenink, 2019). Participants were auditorily presented with minimal pairs and were asked to choose which of the two pronunciations sounded more natural ('English-like'). They were explicitly told that all of the words were invented and represented objects, not actions or qualities. The stimuli were pseudo-randomized, as was the order in which the different stress patterns were presented. Participants were also asked to rate their level of certainty on a 6-point scale. This allowed them to modulate their otherwise binary responses. Finally, reaction times for each response were also recorded.

3.3.3. Participants

The participants were native speakers of North American varieties of English ($n = 25$; 21 females) living in CITY at the time of testing. Most of them spoke other languages (e.g., French) at different proficiency levels, but none or them was bilingual from birth. Nearly all participants were students at UNIVERSITY; their level of education ranged from undergraduate to Master's/PhD, and their age ranged from 19 to 29. Four participants were excluded from the analysis due to their response patterns: their preference for antepenultimate stress was almost identical between LHL and LLL words, contradicting the most robust weight pattern present in the English lexicon, namely, that heavy syllables in penultimate position attract stress. All of the remaining participants ($n = 21$; 17 females) consistently dispreferred antepenultimate stress in LHL words, as expected.

3.4. Predictions

We predict that the grammar of English stress will influence well-formedness judgments in an experimental context: speakers' judgments will be regulated by moraic trochees, such that a *positive* weight effect will be observed in penultimate position (LH́L ≻ LĹL), but no such weight effects will be observed in antepenultimate position. More concretely, in penultimate position, we predict that speakers will prefer LH́L, given that the grammar of English favors the parse L(H́)⟨L⟩ over L(ĹL), which has a well-formed foot but no extrametricality, and over L(Ĺ)⟨L⟩, which contains a subminimal foot to respect extrametricality. In and of itself, a preference for LH́L does not motivate foot structure, as the same effect could be captured with WEIGHT-TO-STRESS relativized to different positions in the stress domain (see §3.1 on Portuguese). Coupled with the absence of weight effects in antepenultimate position, however, a role for foot structure emerges: we predict that speakers will not prefer H́LL over ĹLL, given that a positive weight effect in antepenultimate position would lead to a marked parsing (see (2)).

Although we predict that the weight effects discussed immediately above will be particularly robust, concerning syllable shape, we additionally make the following predictions: more sonorous coda segments should pattern as heavier than obstruent codas (Gordon, 2006) and, as a result, should be more stress-attracting; syllables with onset clusters should be more stress-attracting than syllables without (consistent with, e.g., Davis, 1988; Kelly, 2004; Olejarczuk & Kapatsinski, 2013; Ryan, 2011, 2014; Topintzi, 2010).[5] Finally, we anticipate that speakers will be more certain and faster when choosing penultimate stress in LHL words, and antepenultimate stress elsewhere.

3.5. Results and analysis

3.5.1. Overall weight effects

We start by analyzing the main variable of interest, namely, weight. In Figure 2, we can see the mean percentage of preference for antepenultimate stress across LLL, HLL and LHL words for English. Standard errors from the mean, as well as by-participant means (gray lines) are also provided. Preference for antepenultimate stress is above 50% for LLL and HLL words, but below 50% for LHL words. LLL and HLL words have distinct variances, but have very similar mean percentages of preference for antepenultimate stress.

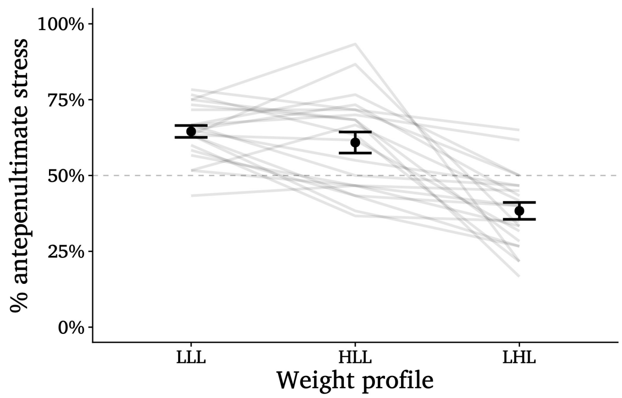

Figure 2: Overall weight effects on stress: Percentages of preference for antepenultimate stress.

To statistically model the effect of weight on speakers' responses, a Bayesian hierarchical logistic regression was run with a by-speaker random slope (weight) and intercept, as well as a by-word random intercept. LLL was used as the reference level for weight, and is represented by the intercept of the model. Accordingly, we interpret the effect size of HLL and LHL in relation to LLL (our baseline). The model was run using Stan (Carpenter et al., 2017) through the `brms` package (Bürkner, 2016) in R.[6] As will be discussed below, the model's estimates confirm what is observed in Figure 2, namely, that relative to LLL words, LHL words clearly affect speakers' responses, reducing the probability of preference for antepenultimate stress. HLL words have a slightly negative effect on speakers' preference for antepenultimate stress, but the posterior distribution is too close to zero for us to confidently conclude that antepenultimate heavy syllables have an effect—as shown in Figure 3, zero is not only included in the 95% credible interval, but also in the 50% credible interval of the posterior distribution.

Table 2: Mean parameter estimates and associated estimated errors, credible intervals, $\hat{R}$, and ESS (n_{eff}).

Parameter	**Mean $\hat{\beta}$**	**Est Error**	**2.5%**	**97.5%**	**$\hat{R}$**	**n_{eff}**
Intercept (LLL)	0.68	0.14	0.42	0.94	1.0	2499
HLL	−0.14	0.21	−0.55	0.28	1.0	1996
LHL	−1.23	0.23	−1.67	−0.79	1.0	2061
MODEL: `stress ~ weight + (weight | speaker) + (1 | word)`						

Table 2 lists the mean estimates (Mean $\hat{\beta}$) as well as the 95% credible intervals (CI) in the posterior distributions estimated. For example, the mean $\hat{\beta}$ for the intercept (0.68) represents the mean of the posterior distribution for this parameter (in log-odds)—the positive intercept captures the preference for antepenultimate stress in LLL words, as observed in Figure 2. The 95% CI in question goes from 0.42 (2.5%) to 0.94 (97.5%), and represents the most probable parameter values given the data. $\hat{R}$ is used to inspect the convergence of the model (an $\hat{R}$ of 1 indicates the model has converged). Finally, n_{eff} refers to the ESS (Effective Sample Size), i.e., the number of sampling steps assuming an uncorrelated chain.

Unlike frequentist approaches, which provide a single parameter estimate and the probability of the data given such an estimate (assuming that the null hypothesis is true; p-value), Bayesian approaches provide an entire distribution of credible parameter values. Thus, even though the mean $\hat{\beta}$s in Table 2 are the most probable parameter values,[7] a distribution of parameter values can be inspected.[8]

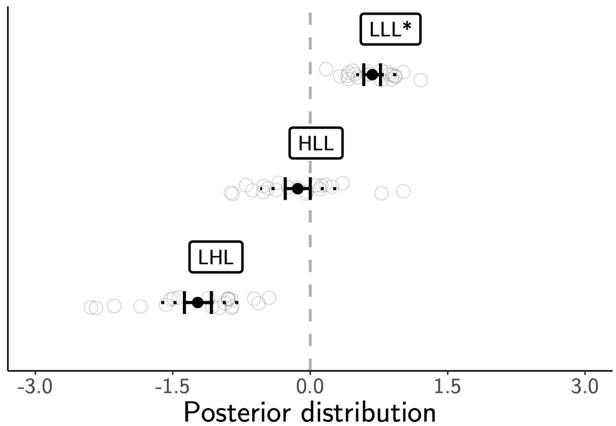

Figure 3: Parameter estimates and associated posterior distributions: Mean (•), 50% (solid line) and 95% (dotted line) credible intervals. Circles represent by-speaker random effects (mean estimates).

As we can see from the table, the mean estimate for HLL is negative (-0.14). The 95% credible interval of the posterior distribution of HLL ranges from -0.55 to 0.28. As a result, the distribution includes zero as a credible parameter value. Given that our reference level is LLL, this means that the effect of HLL words is mostly negative relative to LLL words, but that we cannot conclude that these two weight profiles have reliably different effects on the basis of our model.

On the other hand, the posterior distribution of LHL excludes zero, and has a mean of -1.23. This is the log-odds of antepenultimate stress given a LHL word (relative to a LLL word). Simply put, a LHL word lowers the odds of antepenultimate stress by a factor of 3.4 ($e^{|\hat{\beta}|}$). If we again pick mean($\hat{\beta}$) as a single point estimate, the overall probability of choosing antepenultimate (over penultimate) stress in LHL words is 22% (compared to 66% for LLL words).

For the model in question, non-informative priors were used. We refer to this model as the 'naïve model', given that the model naïvely assumes that LLL, HLL and LHL words have the same probability of eliciting a preference for antepenultimate stress. Two models with mildly informative priors were also run to test whether the weight effects change or if the models themselves had a better fit once we take into consideration speakers' (assumed) knowledge of English stress. In these alternative models, the priors for the intercept were normally distributed around 1 with a standard deviation of 1—which can be represented as Intercept $\sim \mathcal{N}(1, 1)$, i.e., this assumes that antepenultimate stress is preferred in LLL words: ĹLL $\succ$ LĹL. The prior distributions of HLL were assumed to be normally distributed around 0 (HLL $\sim \mathcal{N}(0, 1)$) in one model (assumption: H́LL $\approx$ ĹLL), and around -1 in another model (assumption: ĹLL $\succ$ H́LL). Finally, the prior distributions of LHL were assumed to be normally distributed around -1 (LHL $\sim \mathcal{N}(-1, 1)$) in both models—assumption: ĹLL $\succ$ ĹHL. These priors are an attempt to approximate what we assume characterizes speakers' knowledge of English stress patterns, that is, a preference for antepenultimate stress in LLL words; weight effects in penultimate syllables; and no weight effects in antepenultimate syllables.[9] All prior distributions in question are sufficiently wide to be substantially affected by the experimental data being modelled if such data contradict the priors of the model.

The alternative models with mildly informative priors just described yielded similar results to those found by our naïve model. Their fits were not statistically different from that of our naïve model, as measured by their WAIC[10] values. Another way to assess the fit of a model is to inspect the Leave-One-Out (LOO) cross-validation, which has been argued to be the preferred method to perform model comparisons (Vehtari et al., 2017). This method also showed statistically similar fits between our naïve model and the two alternative models described above.

In sum, all models yield similar results: a positive weight effect in penultimate position and no weight effect in antepenultimate position. These response patterns are consistent with the presence of the foot in English.

3.5.2. Participants' level of certainty and reaction times

As previously mentioned, participants were also asked to rate their level of certainty for each response provided on a 6-point scale. Figure 4 shows that their levels of certainty mirror their response patterns: for LLL and HLL words, participants' level of certainty is nearly identical: in both cases, antepenultimate stress yields higher certainty. For LHL words, on the other hand, we observe a clearly different trend, as participants' certainty levels are slightly higher for words with penultimate stress. This effect is statistically credible, as confirmed in a (naïve) hierarchical ordinal regression, with by-speaker and by-word random intercepts. The model also added the interaction between stress and weight profile as a random effect.[11] The interaction of weight and stress in HLL words was not credibly different from the interaction of weight and stress in LLL words (Mean $\hat{\beta} = -0.05$, 95% CI = $[-0.42, 0.32]$). In contrast, the difference was credible between LHL and LLL words (Mean $\hat{\beta} = 0.84$, 95% CI = $[0.48, 1.21]$).[12] Simply put, speakers' certainty is only affected by weight in penultimate syllables.

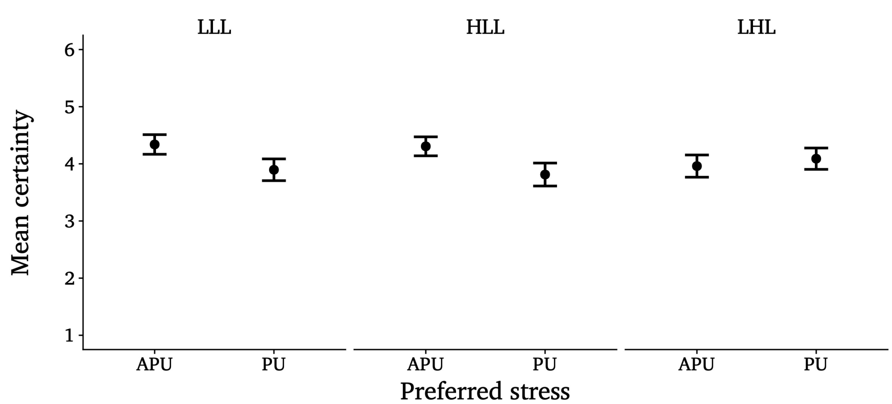

Figure 4: Participants' certainty on a 6-point scale by weight profile and preferred stress pattern. APU refers to antepenultimate stress; PU refers to penultimate stress.

Similar results can be observed if we inspect participants' reaction times: whereas antepenultimate stress yields faster responses in LLL and HLL words, penultimate stress yields faster reaction times in LHL words. In other words, weight in antepenultimate syllables does not seem to affect participants' reaction times (Figure 5).

A (naïve) mixed-effects linear regression was run with by-speaker and by-word random intercepts. As with the ordinal model discussed above, the interaction between weight and stress was added to the model in question as a by-speaker random effect.[13] The interaction of weight and stress in HLL words was again not credibly different from the interaction of weight and stress in LLL words (Mean $\hat{\beta}$ = 0.13, 95% CI = [−0.07, 0.32]). In contrast, the difference was credible between LHL and LLL words (Mean $\hat{\beta}$ = −0.23, 95% CI = [−0.37, −0.08]).

Even though certainty levels and reaction times can be seen as secondary metrics in the present study, they are useful complements to the overall findings regarding weight and stress. The fact that both participants' certainty levels and reaction times are consistent with their response patterns increases the reliability of the results discussed thus far.

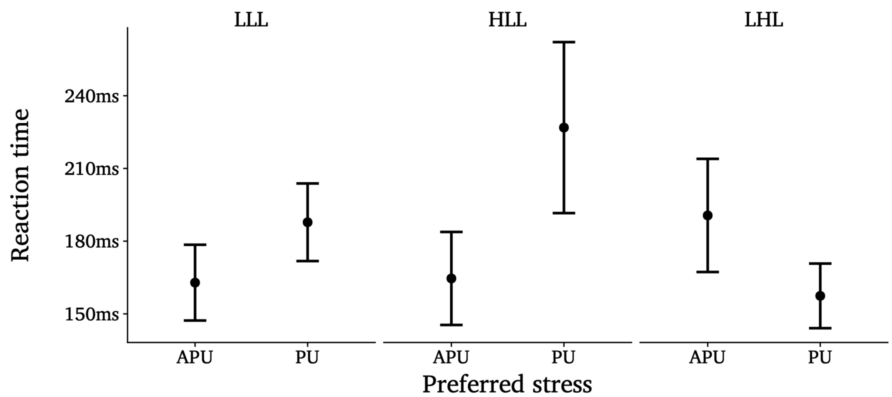

Figure 5: Participants' reaction times by weight profile and preferred stress pattern. APU refers to antepenultimate stress; PU refers to penultimate stress.

3.5.3. Sonority effects

Next, we further examine weight effects by inspecting whether the quality of the coda in HLL and LHL words affected native speakers' stress preference. Sonorants are predicted to have a stronger effect on stress relative to obstruents (following, e.g., Zec (1995) and Gordon (2006)). Figure 6 plots the preference for antepenultimate stress (y-axis) by weight profile and coda type—means and standard errors are provided. As already seen in Figure 2, antepenultimate stress is preferred (to penultimate stress) in HLL words (>50%), but dispreferred in LHL words (<50%). Here, as predicted, we see that LHL words with sonorant codas disfavor antepenultimate stress more strongly relative to LHL words with obstruent codas. The same pattern is observed in HLL words, where sonorant antepenultimate codas favor antepenultimate stress more than obstruent codas. In other words, even though we observe an overall neutral weight effect in antepenultimate heavy syllables (relative to light syllables), we observe a qualitative weight effect between sonorants and obstruents when we *only* examine HLL words. We return to this in the discussion (§6).

To model the effect of coda type in HLL and LHL words, a (naïve) model was run with main effects as well as the interaction of weight and coda type. This additional model excludes LLL words, where no coda effect can be assessed. By-speaker random slopes for the interaction and random intercepts, as well as by-word random intercepts, were added. The result is shown in

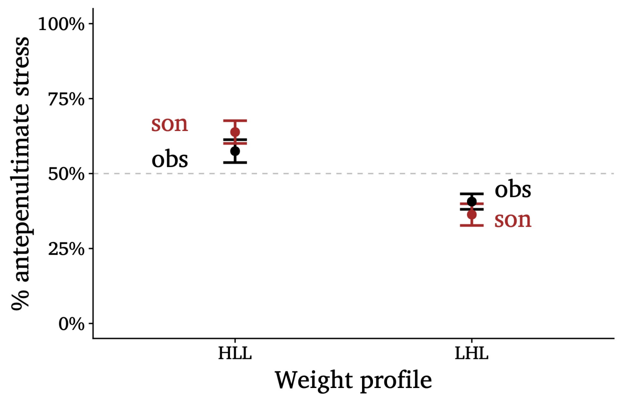

Figure 6: Effect of coda type on stress preference.

Figure 7. As we can see, the overall pattern still favors antepenultimate stress, as denoted by the almost entirely positive posterior distribution in (A), which represents the log-odds of antepenultimate stress in a HLL word with an obstruent in coda position. The posterior distribution shown in (B) refers to LHL words with an obstruent coda. Unsurprisingly, the entire distribution is negative, given that LHL words disfavor antepenultimate stress. The distribution in (C) shows that having a sonorant coda in HLL words positively impacts the preference for antepenultimate stress (relative to an obstruent coda). This reflects the pattern we see in Figure 6. Lastly, the entirely negative posterior distribution in (D) indicates that the interaction between weight and coda type statistically impacts speakers' choices. However, this effect is not robust enough to impact stress preference overall once LLL words are included in the analysis—see Table 2 and Figure 3.

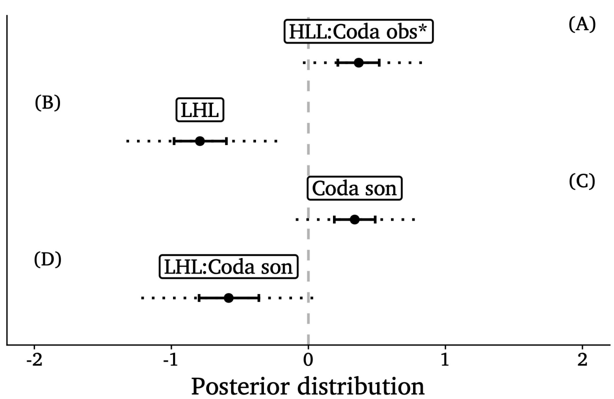

Figure 7: Parameter estimates and associated posterior distributions: Mean (•), 50% (solid line) and 95% (dotted line) credible intervals. HLL and obstruent codas are used as reference (*).

3.5.4. Onset effects

Finally, let us briefly examine the effects of onset complexity on stress preference. Weight effects in English have been shown not to be restricted to syllable rhymes; indeed, as mentioned earlier, several studies have demonstrated that onsets also contribute to syllable weight (Davis, 1988; Kelly, 2004; Olejarczuk & Kapatsinski, 2013; Ryan, 2011, 2014; Topintzi, 2010). In other words, syllables with more segments in onset position are more likely to attract stress, a tendency that is observed not only in the English lexicon but also in experimental contexts (Ryan, 2011, 2014).

The LLL words used in the present study are particularly useful here, given that no coda effects are possible and only onset complexity varies. In such words, three possible onset types were included in the stimuli: singleton in all syllables, complex onset in the antepenultimate syllable, and complex onset in the penultimate syllable (see Figure 1).

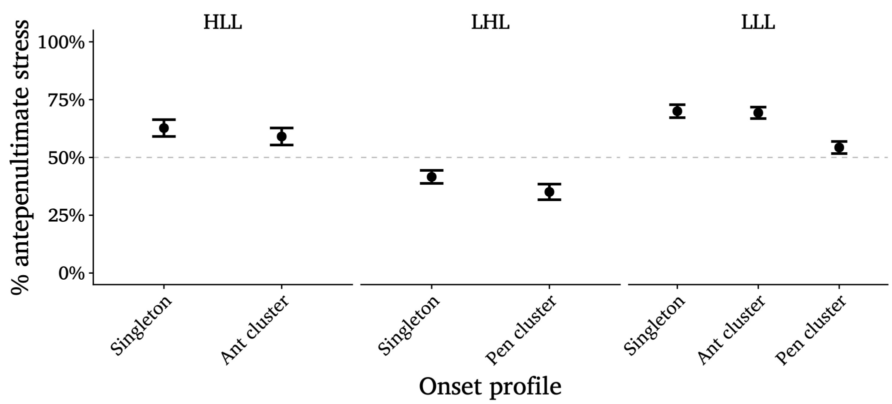

Figure 8: Preference for antepenultimate stress as a function of onset and weight profiles. Complex onsets in penultimate position negatively affect speakers' preference for antepenultimate stress.

As we can see in Figure 8, onset complexity seems to have an effect on speakers' responses, especially in LLL words, where no codas are present. Having an onset cluster in the penultimate syllable appears to affect speakers' responses quite considerably, decreasing their preference for antepenultimate stress. This effect is statistically credible, as confirmed in a (naïve) hierarchical logistic regression with by-speaker random slope (weight and onset complexity) and intercept, as well as a by-word random slope: Mean($\hat{\beta}$) = -0.53, 95% CI = $[-0.88, -0.19]$. As expected, antepenultimate clusters do not show an effect relative to antepenultimate singleton onsets. Finally, the weight-attracting properties of clusters in antepenultimate syllables for HLL words are expected to be negligible—and weaker when compared to penultimate syllables in LHL words. The trends we observe for HLL and LHL words in Figure 8 seem to be consistent with that expectation.

4. Beyond stress: word minimality

Thus far, we have suggested that the neutral weight effect found for antepenultimate position in English speakers' grammars supports a foot-based approach to stress in this language. At the same time, parallel experimental results collected earlier found a positive weight effect for antepenultimate position in Portuguese speakers' grammars (Garcia, 2019), which challenges a foot-based approach to stress in that language. If our interpretation of these cross-language differences is along the right lines, we should expect to find other prosodic phenomena that support and call into question the existence of the foot in English and Portuguese, respectively. In this section, we provide additional evidence along these lines, from minimal lexical words, as well as from patterns of hypocorization and truncation. We begin with Portuguese.

4.1. Portuguese

4.1.1. Minimal lexical words

We have seen that feet play a central role in earlier metrical approaches to stress in Portuguese (whether they are trochaic or both trochaic and iambic in shape). Given that lexical words are prosodic words, that prosodic words must contain at least one foot, and that feet strive to be binary to be well-formed (McCarthy & Prince, 1995), *if* Portuguese were to build feet, we would expect lexical words in the language to minimally contain two syllables or two moras—a condition known as *word minimality*.

In contrast to this expectation, sub-minimal lexical words are common in Portuguese. Over 70% of all possible CV combinations are found in the language. Representative examples are provided in Table 3. Many such words, including those in the table, are quite common, as can be inferred from their meanings. This would appear to pose a problem for metrical approaches to Portuguese stress, since lexical words that are smaller than a binary foot are seemingly freely tolerated in the language.

In and of itself, however, the existence of CV words may not be a substantial problem for metrical analyses that aim to build a grammar of Portuguese employing feet. After all, it is possible that sub-minimality is not productive, and is therefore restricted to lexical items for which a diachronic explanation can be found, namely, the loss of final codas and/or declensions. Although this explanation could hold for some CV words (e.g., *só* from Latin *sōlus* 'lonely'), it predicts that speakers of Portuguese should not generalize the CV pattern to novel words—much like they do not generalize the negative weight effect in antepenultimate syllables found in the lexicon (§3.1). This, however, is not the case, as we will see in the following section on hypocorization.

Table 3: Common CV words (nouns and adjectives) in Portuguese.

Word	**Gloss**	**Word**	**Gloss**
chá	'tea'	*pá*	'shovel'
dó	'pity'	*pé*	'foot'
fé	'faith'	*pó*	'dust'
má	'bad (f)'	*nú*	'nude'
nó	'knot'	*só*	'lonely'

4.1.2. Hypocorization

In his work on hypocorization in Portuguese, Gonçalves (2004) proposes that the melodic material in names is mapped to a moraic trochaic template to form the hypocoristic. Although this seems to be supported for several hypocoristics, like those in column (a) in Table 4, outputs such as those in column (b), where hypocorization results in a sub-minimal word, are also very common in the language. Further, some disyllabic hypocoristics alternate with monosyllabic forms: *Fabiána* $\rightarrow$ *Fábi* $\sim$ *Fá*.

Table 4: Hypocoristic patterns in Portuguese.

(a)	Name	Hypocoristic	(b)	Name	Hypocoristic
	Fabiána	Fábi		Felícia	Fé
	Isabél	Bél		Guilhérme	Guí ([gi])
	Rafaél	Ráfa		Luciána	Lú
	Robérto	Béto		Tiágo	Tí

In addition to the subminimal forms in column (b) in Table 4, other outputs that depart from bimoraic trochees are observed in hypocorization in Portuguese. Specifically, when hypocoristics are reduplicated, both iambic and trochaic shaped outputs emerge: *Viviane* → *Viví* ∼ *Vívi*; *Bibiana* → *Bibí* ∼ *Bíbi*. Indeed, there seems to be a preference for iambs, as all trochaic reduplicated hypocoristics can also be realized as iambs, but not the other way around: *Fátima* → *Fafá* but **Fáfa*; *Luciána, Luíza* → *Lulú* but **Lúlu*. Since trochees are more restricted than iambs in such cases, this contradicts the argument for trochees as the main metrical pattern observed in Portuguese. Instead, it seems that no particular foot shape is emerging as dominant.

4.1.3. Truncation

The inconsistency of foot types proposed in previous analyses of stress in Portuguese can also be observed in truncation; Table 5 shows that both iambic (a) and trochaic (b) profiled outputs emerge in truncated forms. In fact, minimal pairs can even be found: *professór* 'teacher' → *prófi*, but *profissionál* 'professional' → *profí*. Araújo (2002) proposes that the stress pattern in these truncated forms can be predicted from the location of secondary stress in the source word. In *pròfessór*, secondary stress is found word-initially; thus, the truncated form bears penultimate stress: *prófi*. In this case, the resulting metrical structure corresponds to a trochaic foot. The stress pattern in the truncated form of *profissionál*, on the other hand, is faithful to the secondary stress in the peninitial syllable of the source word: *profí*. In this case, the resulting metrical structure corresponds to an iambic foot.

Table 5: Truncation patterns in Portuguese.

	Word	Truncated form	Footing
(a)	*refrìgeránte* 'soda'	refrí	trochee → iamb
	dèpressáo 'depression'	depré	trochee → iamb
(b)	*cervéja* 'beer'	cé(r)va	trochee → trochee
	neuróse 'neurosis'	néura	trochee → trochee

Although the position of secondary stress can account for *refrìgeránte* → *refrí*, it fails to account for *dèpressáo* → *depré* (**dépre*).[14] It is also challenged by the fact that the location of secondary stress can vary in Portuguese. For example, *profissional* can be pronounced as *profissionál* or as *pròfissionál* and *refrigerante* can be pronounced as *refrìgeránte* or as *rèfrigeránte*. We thus need to assume that *profissionál* is the source of *profí* and that *refrìgeránte* is the source of *refrí*. In sum, the patterns of truncation discussed above show little metrical consistency, as both iambs and trochees are generated under different conditions. This is not what we would expect to find in a language that builds feet.

4.1.4. Summary

We have seen that metrical approaches to Portuguese stress assume inconsistent footing to account for the different patterns observed in the language. The same inconsistencies are found in patterns of truncation, which result in iambic or trochaic shaped outputs, depending on the word being analyzed. Sub-minimal words are also commonly attested in the Portuguese lexicon and, crucially, in hypocorization, which indicates that derived words that violate word-minimality are productive. Taken together, this ambiguity in the language has led researchers to propose (i) moraic and syllabic trochees, (ii) trochees and iambs, as well as (iii) binary and degenerate feet. This has important implications for language acquisition, as learners attempting to construct a grammar for Portuguese will not be able to easily establish which foot type accurately characterizes the language. Indeed, Ferreira-Gonçalves (2010) observes that words with both iambic and trochaic profiles are found in children's early productions, which is what we would expect if no particular foot shape emerges as optimal from the input to which learners are exposed.

The discussion thus far has shown that no robust empirical evidence for a consistent metrical structure exists in Portuguese. This is reflected in previous studies on the phonology of the language as well as in the gradient weight patterns discussed in §3.1. Indeed, the finding that Portuguese speakers' grammars extend the gradient weight effects to antepenultimate syllables undermines a role for the foot altogether in the language, given the marked parsings that result in (2). Consequently, if footing is what caused ĹLL words to be more frequent than H́LL words in the Portuguese lexicon in the past, we have to conclude that this preference is not reflected in the synchronic grammar of the language.

Our proposal that the foot does not exist in Portuguese is consistent with the hypothesis that the presence or absence of this constituent in the prosodic hierarchy is parametric (implied in McCarthy & Prince (1995) and argued for in Özçelik (2013, 2014)). Indeed, the conclusion that the foot is absent from Portuguese shows that even languages with seemingly ordinary patterns of prominence (unlike Turkish and French mentioned earlier) can cast doubt on a foot-based analysis of stress. Finally, since under a parametric account, Portuguese would have no foot projection, Headedness will not ban the prosodic representations in Figure 9. Rather, this undominated constraint (Selkirk, 1996) will be vacuously satisfied at the foot level (following Özçelik (2013, p. 55)). We return to this issue in §6.

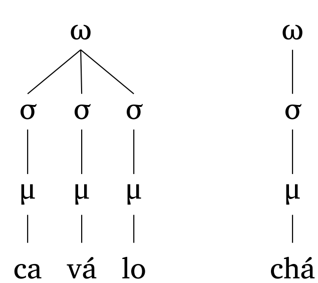

Figure 9: Prosodic structure of *caválo* 'horse' and *chá* 'tea' assuming Foot = No in Portuguese

4.2. English

Our examination of stress, minimal lexical words, hypocorization, and truncation in Portuguese has shown that no robust empirical evidence for a consistent metrical structure exists in the language. In combination with experimental support for positive weight effects in antepenultimate position (Garcia, 2019), we have suggested that no compelling evidence exists for the foot in the language. The experimental results for Portuguese contrast with what was observed earlier for English (§3.5.1), namely, a neutral effect for weight in antepenultimate position. The latter finding is consistent with English building feet, a proposal that has not, to our knowledge, been challenged in the literature on stress in this language. The cross-language difference we are proposing, however, would be strengthened if English showed minimal word, truncation, and hypocorization effects different from those in Portuguese, specifically, patterns that are consistent with the language building binary moraic trochees. In the following section, we show that this is indeed the case.

4.2.1. Minimal lexical words, truncation, and hypocorization

Unlike Portuguese, where lexical words that violate word minimality are commonly attested, English has no such words: every lexical word must have at least two moras. This restriction bans CV words, but allows CVV and CVC as the smallest lexical words. Accordingly, *bee* [biː] and *bit* [bɪt] are well-formed, but *[bɪ] is not, as shown in Figure 10. Word minimality constraints are straightforwardly captured if English builds moraic trochees and every foot is binary.

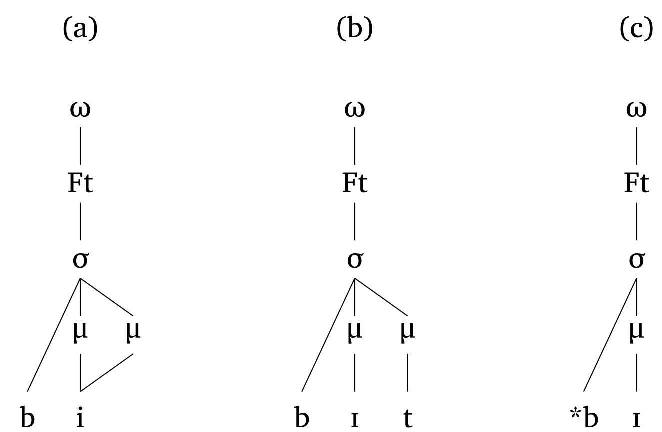

Figure 10: Word minimality in English

Word minimality also regulates truncation and hypocorization in English. Truncation never yields sub-minimal outputs: *bro(ther)*, *sis(ter)*, and *doc(tor)* all have two moras: [broʊ], [sɪs], [dɒk], respectively, but never *[brʌ], *[sɪ], *[dɒ].

The same holds true of hypocoristics: *Nicholas*, *Susan*, and *Joseph* are shortened to [nɪk], [suː], and [d͡ʒoʊ], and never to *[nɪ], *[sʊ], or *[d͡ʒo]/*[d͡ʒʌ]. These comparisons illustrate the interaction between vowel length, weight, and footing: feet in English must be bimoraic to be licit, and this has consequences for the shapes of the truncated forms we observe in the language.

The patterns discussed above all motivate footing in English. Crucially, if we assume feet in the language, we predict the (near)[15] non-existence of sub-minimal words.[16] Finally, we have observed an interaction between stress and weight—positive in penultimate position and neutral in antepenultimate position—that also supports a consistent metrical structure.

5. English Lexicon

The robust evidence for moraic trochees in English predicts that no mismatch between the lexicon and speakers' behavior should be found in the language. In this section, we use a subset of the CMU Pronouncing Dictionary (Weide, 1993) to examine whether this prediction is upheld. The subset of CMU employed is based on the filtered wordlist used in Moore-Cantwell (2016), a recent study which examined the English stress system in detail. However, to control for the possible conflicting effects of multiple heavy syllables, only words with one heavy syllable were selected (as coded in CMU).[17] Additionally, only trisyllabic nouns or adjectives were used, and words with final stress were removed. These conditions are in part motivated by the shape of the stimuli in the experimental study reported on in §3. The resulting word list contained 4,573 words.

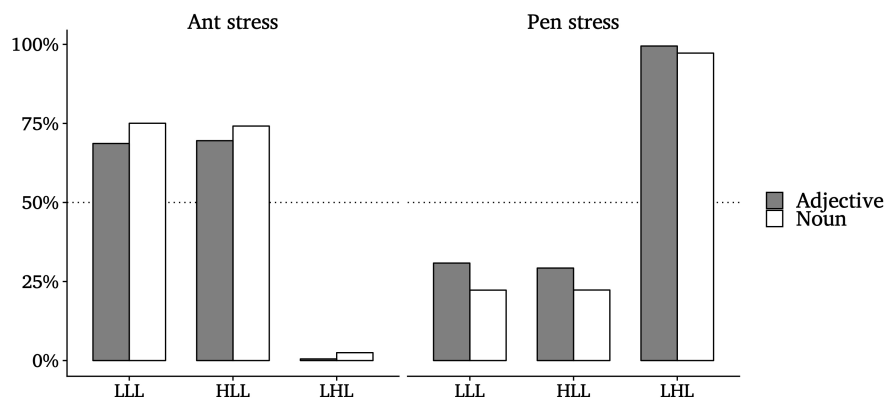

Figure 11: Stress and weight patterns in the CMU Dictionary ($n = 4{,}573$).

In Figure 11, we can see that almost all LHL trisyllabic words plotted bear penultimate stress, a finding which is consistent with the generalization for English stress in (3b). LLL and HLL words, on the other hand, have antepenultimate stress most of the time. Importantly, LLL and HLL words pattern together, which shows that having a heavy antepenultimate syllable does not impact antepenultimate stress. In other words, antepenultimate heavy syllables pattern with light syllables. This is also consistent with the generalization for English stress in (3c).

Like the absence of sub-minimal words discussed above, the patterns observed in Figure 11 motivate moraic trochees in English. If antepenultimate heavy syllables patterned as they do in Portuguese (§2.1), antepenultimate stress would be more common in HLL words than in LLL words, which could lead us to question the role of the foot in English.

Weight-sensitivity in penultimate syllables in English, of course, poses no problem for moraic trochees because no non-extrametrical syllables to the right of the stressed syllable remain unparsed in the stress domain. Weight in antepenultimate syllables, however, does lead to a marked metrical structure. In other words, the interaction between weight and footing predicts the presence of weight effects in penultimate syllables, and is consistent with the absence of such effects in antepenultimate syllables.

We have established that English, unlike Portuguese, offers compelling evidence for footing. Crucially, weight effects on English stress are predicted if we assume moraic trochees in the language. Moraic trochees also predict why monomoraic words (i) do not exist in the English lexicon, and (ii) do not emerge in truncation or hypocorization. Finally, the patterns observed in the experimental results in §3.5 are also found in the lexicon, i.e., no statistical difference between LLL and HLL words.

6. Discussion

The statistical models discussed in §3.5 show that speakers' behavior is consistent with the lexical patterns in Figure 11. Crucially, these results are consistent with moraic trochees in English. In other words, if English builds moraic trochees, then weight effects should be constrained in antepenultimate syllables in order for all non-extrametrical syllables to be parsed, and that is what we empirically observe in the data analyzed in the previous section. If footing constrains weight effects in English, then the observation that heavy syllables pattern with light syllables in antepenultimate position is not surprising. Interestingly, whereas the weight of antepenultimate syllables does not impact the probability of antepenultimate stress, within HLL words, an effect of coda type was found. We can conclude that this effect, albeit present, is not strong enough to impact stress propensity once antepenultimate stress in LLL words is taken into account. This fine-grained weight effect can only be accounted for if we assume a gradient notion of weight: both heavy syllables with obstruent and sonorant codas are effectively treated as light, but the former are 'lighter' than the latter—see Ryan (2016) for an overview of gradient weight.

The presence of sonority effects in antepenultimate position can be understood as the result of a conflict between metrical optimization and weight-sensitivity in the English grammar. That footing takes precedence over weight-sensitivity can be observed in the overall weight effect (or lack thereof) found in antepenultimate syllables, as well as in the facts about the English lexicon discussed in §2.2. To optimize footing in HLL words, it is necessary to override weight-sensitivity. However, if weight is understood as gradient, not categorical, then it is possible that the heavier a syllable is, the more costly it becomes to override its weight in favor of an unmarked metrical parsing. This would predict the effect of coda sonority observed in the data, and is in line with the assumption that the grammar is probabilistic and constraint-based (e.g., Hayes & Wilson, 2008).

We have seen that onsets also had an effect on participants' stress preference. When located in penultimate syllables, complex onsets were found to decrease speakers' preference for antepenultimate stress in LLL words. Unlike coda effects, however, no onset effects were captured in antepenultimate position. This is unsurprising given that onset effects are known to be weaker than coda effects. As a result, it is possible that onset effects are too weak to be statistically detectable in antepenultimate syllables, where weight effects are regulated by footing. In other words, it is expected that if some weight effect can be detected within antepenultimate syllables, rhymes are the most likely candidates.

In summary, we have argued that whereas English provides strong evidence that motivates footing, Portuguese does not. Stress in English is regulated by both optimal footing and weight-sensitivity: heavy syllables attract stress as long as this does not result in a marked metrical structure, i.e., an unparsed syllable in the middle of the word or an uneven trochee. Stress in Portuguese, on the other hand, does not motivate footing. Indeed, the gradient weight effects observed in Garcia (2017a), coupled with the violations of word-minimality discussed above, argue *against* the foot. As a result, if one attempts to pursue a foot-based approach, then the issues raised in this paper will present a significant challenge.

One important consequence of the argument put forth in this study is that, despite apparent similarities in their stress patterns, Portuguese and English differ fundamentally in their prosodic representations. This conclusion entails that feet are parametric, as implied in McCarthy & Prince

(1995). The question, then, is whether other languages exist which also lack feet. As pointed out by other researchers, French and Turkish may fit that description. In French, the domain of obligatory prominence is the phonological phrase rather than the PWd (Jun & Fougeron, 2000; Dell, 1984). In Turkish (Özçelik, 2013, 2014), where regular stress is characterized as PWd-final, the cues to prominence are often absent (Levi, 2005). Thus, even though Portuguese stress looks like English stress, its prosodic structure may be more similar to French or Turkish than it is to English.[18]

A question that arises once we conclude that Portuguese has no evidence for the foot is how the stress domain is constrained in this language. Note that the question implies that we cannot define a stress domain without feet, but that is not the case. Different proposals have been put forth which demonstrate that feet cannot account for the full stress typology observed across languages (e.g., van der Hulst, 2012; Kager, 2012). Accent-First Theory (van der Hulst, 2012), for example, is neutral as to whether syllables are grouped into feet. In this theory, stress and rhythm are formalized as separate processes, which means that primary stress is not the result of rhythm. Therefore, the question of whether feet are well-motivated in a given language is orthogonal to the question of how one can constrain the domain of stress in said language.

Finally, further research is needed to examine how the interaction of weight-sensitivity and metrical optimization impact the representation of weight itself and, in turn, the way syllables are parsed into feet given the empirical results discussed in this paper. For example, the representational status of heavy antepenultimate syllables remains to be determined (i.e., whether they are actually represented as heavy) in light of the statistical analysis presented above. Our results suggest that these syllables should be represented as light.

7. Final remarks

In this paper, we have argued that even though English and Portuguese have similar stress patterns, these two languages are fundamentally different. On the one hand, Portuguese does not offer compelling evidence for footing, given that weight effects are found across all syllables in the stress domain. On the other hand, English offers robust evidence for the foot, as the weight effects observed in the language do not favor the stressing of heavy over light syllables in antepenultimate position, an observation that follows from the assumption that the language builds moraic trochees. Footing also predicts the truncation and hypocorization patterns observed in English, as well as the absence of sub-minimal words.

In contrast to English, Portuguese presents multiple violations of word-minimality, and truncation patterns yield non-uniform metrical patterns. Indeed, feet are of little value in the language if their only function is to restrict the stress window to trisyllabic, given that alternatives such as Accent-First Theory accomplish this goal without assuming the foot. English and Portuguese therefore present different formal systems that regulate stress: whereas English stress is the result of the interaction between feet and weight, Portuguese stress is the result of weight. In summary, evidence *for* the foot in English is as robust as evidence *against* the foot in Portuguese.

Notes

[1]In this paper, 'stress' is to be equated with 'main stress'.

[2]Portuguese words are not phonetically transcribed in this paper as weight information is predictable from the orthography: all vowels are short, and coda consonants are realized either as C or as V due to lenition, both of which pattern the same in terms of their weight.

[3]Dactyls have also been proposed (Wetzels, 2007).

[4]Final stress can also be found in words with final short vowels in borrowings from French, which tend to be faithful to the source language's final stress pattern (e.g., *hotél*).

[5]Note, however, that because onset effects are predicted to be weaker than coda effects (Ryan, 2011), capturing such effects requires more statistical power.

[6]All models presented in this paper were run using four chains.

[7]Technically, the most probable parameter value would be the mode of the distribution. However, because the posterior distributions in question approximate a Gaussian distribution, the mean and the mode have very similar values.

[8]Note that credible intervals are not the same as confidence intervals, which are not a probability distribution, despite being frequently misinterpreted as such (see Kruschke (2010) and McElreath (2016) for details).

[9]Note that the standard deviations of our (mildly informed) prior distributions allow for either negative or positive effects as well, depending on the empirical patterns found in the data being modeled.

[10]WAIC, or *Watanabe-Akaike Information Criterion* (Watanabe, 2010), is a method to assess the fit of a (Bayesian) model. It is calculated by taking averages of the log-likelihood over the posterior distribution taking into account individual data points. For more information on WAIC, see McElreath (2016, p. 191).

[11]`certainty ~ weight * stress + (weight * stress | speaker) + (1 | word)`.

[12]The reference levels used were 'LLL' for `weight`, and 'antepenultimate' for `stress`.

[13]`log(reaction_time) ~ weight * stress + (weight * stress | speaker) + (1 | word)`.

[14]Araújo (2002) argues that *depré* is a case of pseudo-truncation, since the source word cannot be unambiguously determined. Unlike in the other cases discussed, where the source word is clear, in the case of *depré*, both *dèpressáo* 'depression' and *dèprimída* 'depressed' can be the source word. Note, though, that the resulting prosodic shape is not predictable from either possible source word.

[15]Potential exceptions to this are CV́CV words like *city*, which may appear to be subminimal: (cí)⟨ty⟩. In such cases, building a binary foot conflicts with extrametricality: both (CV́CV) and (CV́)⟨CV⟩ are viable parses. The existence of exceptional final stress, however, indicates that extrametricality can be violated in English. In contrast, the fact that subminimal words are not attested in the language indicates that foot binarity cannot be violated. In an optimality-theoretic account, where extrametricality is captured by NONFINALITY (No foot is final in ω; Kager (2011, p. 151)), these observations motivate the ranking FT-BIN ≫ NONFINALITY (Goad, 2016). As a result, the optimal parse for words like *city* must be (CV́CV).

[16]In some languages, feet are well-motivated even though sub-minimal words are attested. One example is Japanese, where word-minimality is violated by a handful of lexical items (e.g., *ya* 'arrow'; *ko* 'child'). Itô (1990) argues that word-minimality (bimoraicity) is enforced in the language as a *lexical* constraint (Kiparsky, 1985), and therefore does not affect underived words. As a result, word-minimality is respected in truncated hypocoristics and shortened loanwords, unlike in Portuguese.

[17]The word list in question already codes word-final VC rhymes as light (e.g., *narcótic* is coded as HLL).

[18]That being said, foot structure may be motivated in a language for reasons other than stress. Guzzo et al. (2018) argue that high vowel deletion motivates iterative iambic footing in Québec French in the absence of lexical stress.

References

Araújo, G. A. (2002). Truncamento e reduplicação no português brasileiro. *Revista de Estudos da Linguagem*, *10*(1), 61–90. doi: 10.17851/2237-2083.10.1.61-90

Bisol, L. (1992). O acento e o pé métrico binário. *Cadernos de Estudos Linguísticos*, *22*, 69–80. doi: 10.20396/cel.v22i0.8636897

Boersma, P., & Weenink, D. (2019). *Praat: doing phonetics by computer [Computer program].*

Bonilha, G. F. G. (2004). A influência da qualidade da vogal na determinação do peso silábico e formação dos pés: o acento primário do português. *Organon*, *18*(36), 41–56. doi: 10.22456/2238-8915.31153

Bürkner, P.-C. (2016). `brms'*: Bayesian regression models using Stan. R package version 1.5.0.*

Carpenter, B., Gelman, A., Hoffman, M., Lee, D., Goodrich, B., Betancourt, M., … Riddell, A. (2017). Stan: a probabilistic programming language. *Journal of Statistical Software, Articles*, *76*(1), 1–32. Retrieved from `https://www.jstatsoft.org/v076/i01` doi: 10.18637/jss.v076.i01

Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper & Row.

Davis, S. (1988). Syllable onsets as a factor in stress rules. *Phonology*, *5*(1), 1–19. doi: 10.1017/S0952675700002177

de Lacy, P. (2006). *Markedness: reduction and preservation in phonology*. New York: Cambridge University Press.

Dell, F. (1984). L'accentuation dans les phrases en français. In F. Dell & J.-R. Vergnaud (Eds.), *Les répresentations en phonologie* (pp. 65–112). Paris: Hermann.

Domahs, U., Plag, I., & Carroll, R. (2014). Word stress assignment in German, English and Dutch: quantity-sensitivity and extrametricality revisited. *The Journal of Comparative Germanic Linguistics*, *17*(1), 59–96. doi: 10.1007/s10828-014-9063-9

Ferreira-Gonçalves, G. (2010). Aquisição prosódica do português: o acento em suas formas marcadas. *Revista Virtual de Estudos da Linguagem (ReVEL)*, *8*(15), 61–81.

Garcia, G. D. (2014). Portuguese Stress Lexicon [Computer software manual]. (Comprehensive list of non-verbs in Portuguese. Available at `http://guilhermegarcia.github.io/psl.html`)

Garcia, G. D. (2017a). *Weight effects on stress: lexicon and grammar* (Unpublished doctoral dissertation). McGill University.

Garcia, G. D. (2017b). Weight gradience and stress in Portuguese. *Phonology*, *34*(1), 41–79. doi: 10.1017/S0952675717000033

Garcia, G. D. (2019). When lexical statistics and the grammar conflict: learning and repairing weight effects on stress. *Language*, *95*(4), 612–641. doi: 10.1353/lan.2019.0068

Giegerich, H. J. (2005). *English phonology: an introduction* (8th ed.). New York: Cambridge University Press. (First published in 1992)

Goad, H. (2016). Phonological processes in children's productions: convergence with and divergence from adult grammars. In J. Lidz, W. Snyder, & J. Pater (Eds.), *The oxford handbook of developmental linguistics* (pp. 43–67). Oxford: Oxford University Press.

Gonçalves, C. A. (2004). A morfologia prosódica e o comportamento transderivacional da hipocorização no português brasileiro. *Revista de Estudos da Linguagem*, *12*(1), 7–38. doi: 10.17851/2237-2083.12.1.7-38

Gordon, M. (2006). *Syllable weight: phonetics, phonology, typology*. New York: Routledge.

Gordon, M. (2016). *Phonological typology*. Oxford: Oxford University Press.

Guion, S. G., Clark, J. J., Harada, T., & Wayland, R. P. (2003). Factors affecting stress placement for English nonwords include syllabic structure, lexical class, and stress patterns of phonologically similar words. *Language and Speech*, *46*(4), 403–426. doi: 10.1177/00238309030460040301

Guzzo, N., Goad, H., & Garcia, G. (2018). What motivates high vowel deletion in Québec French: Foot structure or tonal profile? *Proceedings of the Linguistic Society of America*, *3*(1), 1-10. Retrieved from https://journals.linguisticsociety.org/proceedings/index.php/PLSA/article/view/4306 doi: 10.3765/plsa.v3i1.4306

Halle, M., & Idsardi, W. (1995). General properties of stress and metrical structure. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 403–443). Cambridge, MA, and Oxford, UK: Blackwell.

Halle, M., & Vergnaud, J.-R. (1987a). *An essay on stress*. Cambridge, MA: MIT Press.

Halle, M., & Vergnaud, J.-R. (1987b). Stress and the cycle. *Linguistic Inquiry*, *18*(1), 45–84.

Hayes, B. (1982). Extrametricality and English stress. *Linguistic Inquiry*, *13*(2), 227–276.

Hayes, B. (1985). Iambic and trochaic rhythm in stress rules. In *Annual Meeting of the Berkeley Linguistics Society* (Vol. 11, pp. 429–446).

Hayes, B., & Wilson, C. (2008). A maximum entropy model of phonotactics and phonotactic learning. *Linguistic Inquiry*, *39*(3), 379–440. doi: 10.1162/ling.2008.39.3.379

Houaiss, A., Villar, M., & de Mello Franco, F. M. (2001). *Dicionário eletrônico Houaiss da língua portuguesa*. Rio de Janeiro: Objetiva.

Itô, J. (1990). Prosodic minimality in Japanese. *CLS*, *26*(2), 213–239.

Jun, S.-A., & Fougeron, C. (2000). A phonological model of French intonation. In A. Botinis (Ed.), *Intonation* (pp. 209–242). Dordrecht: Springer.

Kager, R. (2011). *Optimality theory* (11th ed.). Cambridge: Cambridge University Press. (First published in 1999)

Kager, R. (2012). Stress in windows: language typology and factorial typology. *Lingua*, *122*(13), 1454–1493. doi: 10.1016/j.lingua.2012.06.005

Kelly, M. H. (2004). Word onset patterns and lexical stress in English. *Journal of Memory and Language*, *50*(3), 231–244. doi: 10.1016/j.jml.2003.12.002

Kiparsky, P. (1985). Some consequences of Lexical Phonology. *Phonology Yearbook*, *2*, 85–138. doi: 10.1017/S0952675700000397

Kruschke, J. K. (2010). Bayesian data analysis. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*(5), 658–676.

Ladefoged, P., & Johnson, K. (2011). *A course in Phonetics* (6th ed.). Boston: Wadsworth.

Leben, W. R. (1973). *Suprasegmental phonology.* (Unpublished doctoral dissertation). Massachusetts Institute of Technology.

Lee, S.-H. (2007). O acento primário no português: uma análise unificada na Teoria da Otimalidade. In G. A. Araújo (Ed.), *O acento em português: abordagens fonológicas* (pp. 120–143). São Paulo: Parábola.

Levi, S. V. (2005). Acoustic correlates of lexical accent in Turkish. *Journal of the International Phonetic Association*, *35*(1), 73–97. doi: 10.1017/S0025100305001921

Liberman, M., & Prince, A. (1977). On stress and linguistic rhythm. *Linguistic Inquiry*, *8*(2), 249–336.

McCarthy, J. J. (1986). OCP effects: Gemination and antigemination. *Linguistic Inquiry*, 207–263.

McCarthy, J. J., & Prince, A. (1995). Prosodic Morphology. In J. A. Goldsmith (Ed.), *The handbook of phonological theory* (pp. 318–366). Cambridge, MA: Blackwell.

McElreath, R. (2016). *Statistical rethinking: a Bayesian course with examples in R and Stan* (Vol. 122). Boca Raton: Chapman & Hall/CRC.

Moore-Cantwell, C. (2016). *The representation of probabilistic phonological patterns: neurological, behavioral, and computational evidence from the English stress system* (Unpublished doctoral dissertation). University of Massachusetts.

Nespor, M., & Vogel, I. (1986). *Prosodic phonology*. Dordrecht: Foris.

Olejarczuk, P., & Kapatsinski, V. (2013). *The syllabification of medial clusters: evidence from stress assignment. Poster presented at the 87th Annual Meeting of the Linguistic Society of America, Boston.*

Özçelik, Ö. (2013). *Representation and acquisition of stress: the case of Turkish* (Unpublished doctoral dissertation). McGill University.

Özçelik, Ö. (2014). Prosodic faithfulness to foot edges: the case of Turkish stress. *Phonology*, *31*(2), 229–269. doi: 10.1017/S0952675714000128

Pereira, M. I. (1999). *O acento de palavra em português—uma análise métrica* (Unpublished doctoral dissertation). Universidade de Coimbra.

Pereira, M. I. (2007). Acento latino e acento em português: que parentesco? In G. A. Araújo (Ed.), *O acento em português: abordagens fonológicas* (pp. 61–83). São Paulo: Parábola.

Prince, A. (1990). Quantitative consequences of rhythmic organization. *CLS*, *26*(2), 355–398.

R Core Team. (2019). R: a language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from `http://www.R-project.org/`

Ryan, K. M. (2011). Gradient syllable weight and weight universals in quantitative metrics. *Phonology*, *28*(3), 413–454. doi: 10.1017/S0952675711000212

Ryan, K. M. (2014). Onsets contribute to syllable weight: statistical evidence from stress and meter. *Language*, *90*(2), 309–341. doi: 10.1353/lan.2014.0029

Ryan, K. M. (2016). Phonological weight. *Language and Linguistics Compass*, *10*(12), 720–733. doi: 10.1111/lnc3.12229

Selkirk, E. (1980). The role of prosodic categories in English word stress. *Linguistic Inquiry*, *11*(3), 563–605.

Selkirk, E. (1984). *Phonology and Syntax: The Relation between Sound and Structure*. Cambridge, MA: MIT Press.

Selkirk, E. (1996). The prosodic structure of function words. In J. L. Morgan & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 187–214). Lawrence Erlbaum Associates.

Topintzi, N. (2010). *Onsets: suprasegmental and prosodic behaviour*. New York: Cambridge University Press.

van der Hulst, H. (2012). Deconstructing stress. *Lingua*, *122*(13), 1494–1521. doi: j.lingua.2012.08.011

Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and computing*, *27*(5), 1413–1432. doi: 10.1007/s11222-016-9696-4

Vogel, I. (2010). The phonology of compounds. In S. Scalise & I. Vogel (Eds.), *Crossdisciplinary issues in compounding* (pp. 145–163). Amsterdam: John Benjamins.

Watanabe, S. (2010). Asymptotic equivalence of Bayes cross validation and Widely Applicable Information Criterion in singular learning theory. *Journal of Machine Learning Research*, *11*(Dec), 3571–3594.

Weide, R. (1993). *Carnegie Mellon Pronouncing Dictionary*.

Wetzels, W. L. (1992). Mid vowel neutralization in Brazilian Portuguese. *Cadernos de Estudos Linguísticos*, *23*, 19–55. doi: 10.20396/cel.v23i0.8636844

Wetzels, W. L. (2007). Primary word stress in Brazilian Portuguese and the weight parameter. *Journal of Portuguese Linguistics*, *5*, 9–58. doi: 10.5334/jpl.144

Zec, D. (1995). Sonority constraints on syllable structure. *Phonology*, *12*(1), 85–129. doi: 10.1017/S0952675700002396