Journal of
Portuguese Linguistics

Garcia, G. D., & Guzzo, N. B. (2022). Lexical access in Portuguese stress. *Journal of Portuguese Linguistics*, 21: 7, pp. 1–24. DOI: https://doi.org/10.16995/jpl.8188

Open Library of Humanities

Lexical access in Portuguese stress

Guilherme D. Garcia, Université Laval, Canada, guilherme.garcia@lli.ulaval.ca
Natália Brambatti Guzzo, Saint Mary's University, Canada, nataliaguzzo@me.com

Categorical approaches to lexical stress typically assume that words have either regular or irregular stress, and imply that only the latter needs to be stored in the lexicon, while the former can be derived by rule. In this paper, we compare these two groups of words in a lexical decision task in Portuguese to examine whether the dichotomy in question affects lexical retrieval latencies in native speakers, which could indirectly reveal different processing patterns. Our results show no statistically credible effect of stress regularity on reaction times, even when lexical frequency, neighborhood density, and phonotactic probability are taken into consideration. The lack of an effect is consistent with a probabilistic approach to stress, not with a categorical (traditional) approach where syllables are either light or heavy and stress is either regular or irregular. We show that the posterior distribution of credible effect sizes of regularity is almost entirely within the region of practical equivalence, which provides strong evidence that no effect of regularity exists in the lexical decision data modelled. Frequency and phonotactic probability, in contrast, showed statistically credible effects given the experimental data modelled, which is consistent with the literature.

1. Introduction

Lexical stress (or word-level prominence), which has been the focus of considerable research in the field of phonology, can contrast meaning in many languages. For example, *présent* (noun) and *presént* (verb) in English differ in their stress pattern (penultimate and final, respectively) — an acute accent represents primary stress. In Portuguese, the words *sábia* (adjective), *sabía* (verb), and *sabiá* (noun) all have different meanings ('wise', 'knew', 'Rufous-bellied thrush', respectively).

Notwithstanding its potential to contrast meaning, as a suprasegmental phenomenon, stress has a number of unique characteristics that separate it from segmental processes. First, stress is *culminative*, which means we have one primary stress per (lexical/content) word. Even though we can have multiple stresses in a single word, they all culminate in a single primary stress (e.g., *ìnternàtionalizátion*; a grave accent represents secondary stress).

Second, stress is *relative*, which means that, to perceive syllable n as stressed, we compare it to syllables $n - 1$ and $n + 1$ within the same word. Acoustically, stress is thus manifested through longer duration (as in the case of Portuguese; e.g., Major, 1985; Massini-Cagliari, 1992; Vogel et al., 2018), higher pitch, higher intensity, or a combination of two or more of these cues (as in the case of English; e.g., Beckman, 1986). In addition, stressed and unstressed syllables may differ in vowel quality, with unstressed syllables exhibiting vowel reduction (as in the case of English and Portuguese; e.g., Hayes, 1982; Mateus & d'Andrade, 2000).

One common tendency when examining stress across languages is to classify it into regular or irregular. In English, for example, regular stress in nouns falls on the penultimate syllable if that syllable is heavy (*agénda*), and on the antepenultimate syllable otherwise (*Cánada*). This stress pattern corresponds essentially to what is observed in Latin. Final stress (primary or secondary) in nouns is not very frequent (final syllables are typically assumed to be extrametrical), but can occur if the final syllable contains a long vowel or diphthong (followed or not by a coda; e.g., *divíne*), or two coda consonants (e.g., *ovért*). As we can see, English stress is affected by the weight of a syllable: if a syllable contains a coda consonant (*n* in *agénda*) or a long vowel or diphthong (*o* in *Arizóna*, first *i* in *decísive*), it is heavy, and therefore stress-attracting — for a detailed discussion on English stress and the notion of extrametricality, see, e.g., Hayes (1982). A nonce word such as *pódectal*, for example, violates the generalization in question and is considered unnatural by native speakers (Garcia, 2020; Liberman & Prince, 1977). This word would therefore be considered irregular, as would words like *giráffe* and *canál*, which have final stress even though their final syllables are not sufficiently heavy to override extrametricality in the language.

Although *regular* and *irregular* are traditionally used to classify stress patterns across languages, there is some disagreement in the definition of these terms. Generally speaking, regular patterns are predictable, while irregular patterns are idiosyncratic. In some analyses, predictability in stress assignment may arise due to the pattern being subject to a rule (e.g., Hayes, 1982; Liberman & Prince, 1977). Other analyses assume that regular patterns are the most frequent (or dominant) in the language (e.g., Andrikopoulou et al., 2021; Burani & Arduino, 2004; Colombo & Sulpizio, 2015; Jouravlev & Lupker, 2014). Others propose that regular stress corresponds to (a) the most productive pattern in the language, in that it is the pattern chosen by native speakers for novel words (e.g., Hermans & Wetzels, 2012), or (b) the default pattern (e.g., Sulpizio & McQueen, 2012).

In languages with variable stress, stress is almost never completely predictable, since many exceptions may be observed. For this reason, Hayes (1982, p. 237) proposes that English stress is both listed in the lexicon and derived by rule. A similar take can be applied to other languages where stress is at least in part predictable or regular, such as Portuguese. The notion of irregular stress is therefore often tied to the notion of lexical storage, which is relevant to any discussion about lexical retrieval (or lexical access), the topic of the present paper.

In this study, we examine the dichotomy between regular and irregular stress in Portuguese and its implications for lexical retrieval. By analyzing latencies in a lexical decision task, we can indirectly test whether regular and irregular stress show any difference in processing times. As we will see, our experiment could not capture any difference in lexical decision times between the two stress categories in question, even when factors such as neighborhood density, frequency, and phonotactic probability are considered. The lack of an effect is discussed in light of Bayesian estimation and regions of practical equivalence (ROPE). We argue that these results, along with recent findings on Portuguese stress, pose challenges to the traditional categorical analysis of stress in Portuguese.

The paper is organized as follows: in section 2, we examine the stress patterns in Portuguese and discuss both traditional and more recent approaches to the subject, contrasting categorical analyses with a more recent probabilistic approach to stress. In section 3, we discuss the notion of lexical storage as well as previous research investigating the role of regularity in lexical retrieval, with a focus on studies that examine stress patterns. In section 4, we detail our experimental and statistical methods, and in section 5 we summarize our results and present our statistical analysis. Finally, section 6 discusses the relevance of the present study.[1]

2. Stress in Portuguese

2.1. Traditional approaches

Portuguese stress has been the object of numerous studies throughout the years (e.g., Bisol, 1992, 2013; Garcia, 2017a; Hermans & Wetzels, 2012; Lee, 1994, 2007; Lopez, 1979; Magalhães, 2008; Massini-Cagliari, 1999; Mateus, 1975; Wetzels, 2007). The language presents distinct stress patterns in verbs and non-verbs, similarly to other Romance languages (such as Spanish and Italian), as well as English. In Portuguese, while it is generally agreed upon that stress in verbs is heavily influenced by morphology, the role of morphology on the stress of non-verbs is considerably less clear, with most studies assuming that its influence is relatively small (see Garcia, 2019).

---

[1] The data and code used in this paper can be accessed at https://osf.io/sx49t/.

Like in most languages with stress, the stress patterns in Portuguese are traditionally classified as either regular or irregular (or as either productive/predictable or unproductive/unpredictable; e.g., Hermans & Wetzels, 2012). In non-verbs, two patterns are classified as regular: (a) final stress with a heavy syllable, and (b) penultimate stress with a light final syllable; see (1). Therefore, regular patterns seem to be accurately predictable based on syllable weight (at least in the final syllable). These patterns account for approximately 70% of the lexicon (Garcia, 2014). In (1—2) below, H and L represent heavy and light syllables, respectively, while X represents either H or L. As the examples in (1) suggest, both coda consonants and diphthongs can make a syllable heavy in Portuguese — similar to what we observe in English.

(1) Regular stress in Portuguese non-verbs

(a) Heavy final syllable → final stress (U) — $\mathrm{XX\underline{H}}$
jornál 'newspaper', *papái* 'daddy'

(b) Else, penultimate stress (PU) — $\mathrm{X\underline{X}L}$
caválo 'horse', *varánda* 'veranda'

(2) Irregular stress in Portuguese non-verbs

(a) Heavy final syllable with non-final stress — $\mathrm{X\underline{X}H}$ or $\mathrm{\underline{X}XH}$
(i) *jóvem* 'young'
(ii) *Júpiter* 'Jupiter'

(b) Light final syllable with final stress — $\mathrm{XX\underline{L}}$
(i) *café* 'coffee'
(ii) *jacaré* 'alligator'

(c) Antepenultimate stress (APU) — $\mathrm{\underline{X}XX}$
(i) *fósforo* 'match *n*'
(ii) *ótimo* 'great'

Nearly all approaches to stress in Portuguese are categorical (e.g., Bisol, 1992, 2013; Lee, 1994, 2007; Lopez, 1979; Magalhães, 2008; Mateus, 1975; Wetzels, 2007). In other words, they treat stress as either regular or irregular, thus mirroring the classification in (1) and (2) above. With respect to the regular patterns in (1), most of these approaches assume that they are the result of Portuguese building binary (moraic) trochees at the right edge of the word (Lee, 2007) — or strong-weak prosodic units equivalent to trochees (Bisol, 1992). In this case, a word such as *jornál* is parsed as jor(nál)$_{\text{Ft}}$, while a word such as *cválo* is parsed as ca(vá.lo)$_{\text{Ft}}$.[2]

[2] Alternatively, Lee (2007) proposes that morphological profile determines stress assignment, in that stress falls on the final vowel of the root (see also Pereira, 2007). It follows from this proposal that words with final stress on a light syllable (2b; e.g., *café*) are not exceptional, since stress is also assigned to the final root vowel in these cases. Despite the definitive role of morphology in this proposal, Lee (2007) still assumes that foot structure is involved in stress assignment in Portuguese, with words being parsed as either trochees or iambs.

However, these approaches often differ in how they account for the irregular patterns in (2), and which of such patterns are in fact irregular. In general, the patterns listed in (2) have been considered to be lexically-marked. In other words, the lexical representation of these words exhibits stress (or, in the case of constraint-based analyses, stress is present in the input; e.g., Lee, 2007). In the case of words with antepenultimate stress (2c), various prosodic profiles have been proposed: (i) they have an extrametrical syllable (e.g., Bisol, 1992, 2013; Magalhães, 2008), (ii) they correspond to dactylic feet (e.g., Massini-Cagliari, 1999), or (iii) they have a final degenerate foot (e.g., Hermans & Wetzels, 2012). An item such as *fósforo* has thus been represented as (fós.fo)$_{\text{Ft}}$<ro> (the extrametrical syllable is shown within angled brackets), (fós.fo.ro)$_{\text{Ft}}$, or (fós.fo)$_{\text{Ft}}$(ro)$_{\text{Ft}}$, respectively.

In the case of penultimate stress with a heavy final syllable (see 2a.i), similar analyses have been proposed: (i) the final coda (or its corresponding mora) is extrametrical (e.g., Bisol, 1992, 2013; Magalhães, 2008; Wetzels, 2007), (ii) words with this profile exhibit spondaic feet (e.g., Massini-Cagliari, 1999), or (iii) the final coda has a dependent mora, which allows the final syllable to correspond to a foot by itself (e.g., Hermans & Wetzels, 2012). Given these proposals, an item such as *jóvem* has thus been represented as (jó.ve)$_{\text{Ft}}$<m>, (jó.vem)$_{\text{Ft}}$, and (jó)$_{\text{Ft}}$(vem)$_{\text{Ft}}$, respectively.

Words with final stress on a light syllable (2b) have been represented (i) as having a final catalectic consonant, which renders the syllable heavy (e.g., Bisol, 1992, 2013), (ii) as having a final long vowel (which is not necessarily long on the surface; e.g., Massini-Cagliari, 1999), or (iii) as having the final syllable marked as a foot head (e.g., Hermans & Wetzels, 2012). The proposal in (i) is based on the observation that words derived from items with stress on a final light syllable tend to exhibit a linking consonant between the root and the suffix (e.g., *café* 'coffee' → *cafeṯéira* 'coffee maker'), even though such linking consonants may also follow roots with penultimate stress in derivation (e.g., *láma* 'mud' → *lamaç̲ál* 'mire'). Despite the representational differences, the proposals (i)—(iii) all assign the final syllable to an independent foot.

These analyses of Portuguese stress have one thing in common: they use prosodic constituency not only to account for the regular patterns, but also to represent the irregular patterns. However, these approaches resort to distinct strategies to deal with the prosodic representation of irregular patterns: while some propose multiple types of feet (e.g., Hermans & Wetzels, 2012; Massini-Cagliari, 1999; see also Lee, 2007), others rely on specific mechanisms, such as extrametricality and catalexis (e.g., Bisol, 1992, 2013; Magalhães, 2008). Indeed, a recent approach argues that while (Brazilian) Portuguese builds maximally disyllabic feet, some irregular patterns can be accounted for by recursive feet with an internally-layered binary structure (Martínez-Paricio & Vigário, 2019). Regardless of which approach is used, these analyses treat the irregular patterns as being unpredictable, and for this reason they require at least some lexical marking.

Although the studies mentioned above do not discuss how stress in Portuguese is processed, it is implied that speakers would memorize words with stress only in cases where stress cannot be predicted, as in (2). For all the other items, speakers would apply the stress rules resulting in the patterns in (1). This expectation is intuitive insofar as our cognitive apparatus is commonly assumed to work hard only when it is necessary — an assumption that is not necessarily true, but which makes intuitive sense. In effect, this notion can be traced back to the early generative view that regular and irregular morphology belong to two completely different components, i.e., only irregular forms are stored (*dual-route models*, e.g., Pinker, 1991, 1997). In the case of stress, it thus seems reasonable to assume that only a minor portion of the lexicon would have to be stored, while the other portion (much larger than the first) would be subject to rule application. We return to this point below, after discussing a more recent approach to stress in Portuguese.

2.2 Probabilistic approach

An alternative approach to the regular-irregular separation is presented in Garcia (2017b). In his proposal, words are assigned stress probabilistically as they enter the lexicon based on the distribution of stress patterns already present in the language. Once stress is assigned, it is no longer derived, which entails that all words are stored with their primary stress in Portuguese. As a result, the categorization in (1) and (2) above becomes merely illustrative, and, consequently, processing is not expected to differ in principle between them (cf. categorical approaches). Crucially, the algorithm that assigns stress probabilistically is fed by the prior distribution of stress and weight patterns in the lexicon. This approach has four main advantages over traditional categorical analyses, namely, (i) it captures important sub-patterns in Portuguese, such as (2a.i); (ii) it mirrors speakers' behaviors experimentally (Garcia, 2019), further challenging a clear-cut categorical separation between regular and irregular forms; (iii) it is more accurate at capturing the stress patterns in Portuguese (Garcia, 2017b), as shown in **Figure 1**; and (iv) it is agnostic as to whether feet are relevant prosodic domains in the language. Below we briefly examine each of these advantages.

As can be seen in (1) and (2), both coda consonants and diphthongs can make a syllable heavy in Portuguese — both rising and falling diphthongs have some effect on stress, although falling diphthongs have a much stronger effect (Garcia, 2017b; see also Harris, 1983 for Spanish). This variance in weight effects is tied to yet another observation that challenges traditional approaches, namely, that weight-sensitivity is better understood as *gradient*, not categorical: heavy syllables can vary in their heaviness once we statistically model the effects of weight in the lexicon — this variation is also affected by the position of the syllable within the stress domain in the language. Finally, despite the importance of heavy syllables in determining stress location, it is important to note that most syllables in Portuguese are light. As a result, it's not surprising that penultimate (PU) stress is the most common pattern in the language — nearly 70% if we include both (1b) and (2a.i) above.

When we first inspect (1) and (2), it is not clear whether stress and weight combinations within regular and irregular stress are equally regular or irregular. However, a simple analysis of the Portuguese lexicon will reveal that such combinations vary wildly in their frequency. For example, even though both X$\underline{\text{X}}$L and XX$\underline{\text{H}}$ are regular patterns in the language, the former accounts for nearly 60% of the lexicon, whereas the latter represents less than 15%. The discrepancy is even larger when we turn to irregular stress: $\underline{\text{X}}$H accounts for more than 11% of the lexicon, while X$\underline{\text{L}}$ accounts for less than 4%. Naturally, there are different reasons for these asymmetries (e.g., etymological, metrical), but the fact is that a binary categorization of stress will necessarily miss important sub-patterns in the lexicon, just like a binary categorization of weight will miss the gradient effect of heavy syllables alluded to above. A probabilistic approach addresses these issues by incorporating all sub-patterns in the lexicon into a single grammar, which is then adjusted accordingly when stress is assigned to novel forms.

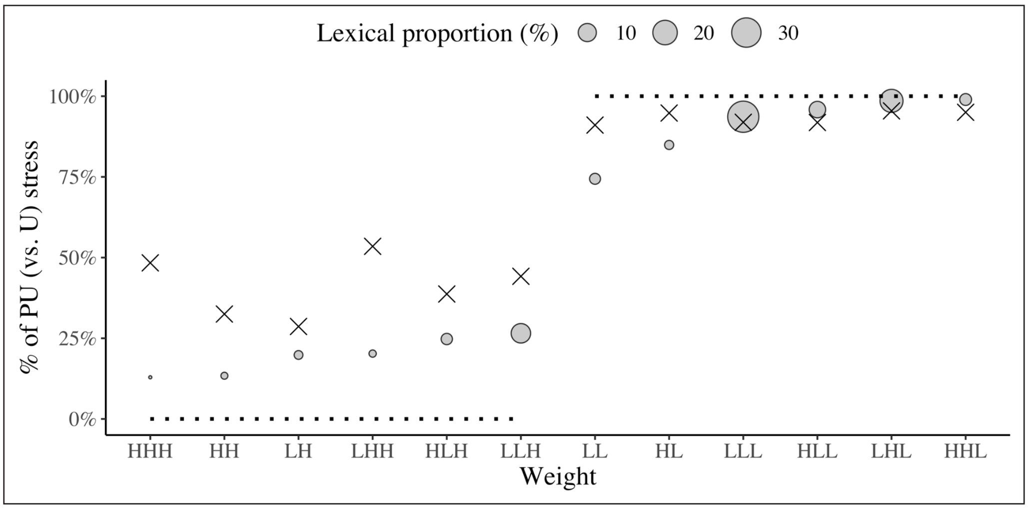

Figure 1: Percentage of penultimate vs. final stress by weight profile in the Portuguese Stress Lexicon. Gray circles represent actual data (circle size illustrates lexical representativeness). Dotted lines represent predicted probabilities based on categorical approaches. ×s represent predictions based on a probabilistic approach. Adapted from Garcia (2017b).

The second advantage of a probabilistic approach involves speakers' grammars. Clearly, an appropriate analysis of stress should not only capture patterns in the lexicon, but also account for what the grammar does. We should not, for example, assume that the lexicon is an accurate representation of the patterns generalized by the grammar — even if the correlation between the two is expected to be high to some extent. Indeed, it is not uncommon that certain patterns in the lexicon are no longer productive, and therefore tell us very little about the grammar *per se*. For example, it is possible that weight effects are gradient in one's lexicon, but not in one's grammar, in which case a categorical approach, which underperforms in the lexicon, could be suitable for the grammar. As it turns out, however, the patterns and sub-patterns discussed above can also be observed in speakers' generalizations when they are asked to rate the naturalness of a given stress position in nonce words (Garcia, 2019).

The third advantage mentioned above, i.e., higher accuracy, can be understood as the result of capturing more patterns in the lexicon and in the grammar. When we allow our models to accommodate fine-grained lexical details, they can make more accurate predictions as long as the grammar and the lexicon are not substantially different overall. This is a natural consequence of a model that is not constrained by categorical assumptions (e.g., syllables are either heavy or light).

Finally, the fourth advantage of the probabilistic model in question involves the status of the foot in Portuguese — even though not all analyses of Portuguese stress are foot-based, most are. As discussed in detail in Garcia and Goad (2021), however, very little (if any) evidence exists for feet in Portuguese. The language does not seem to have a minimal word requirement, since many lexical items, truncated forms, and hypochoristics are simply CV (e.g., *pá* 'shovel', *bi* for *bissexual* 'bisexual', and *Gui* for the proper name *Guilherme*, respectively), and truncated forms and hypochoristics may exhibit both iambic and trochaic rhythm (e.g., *prófi* for *professor* 'teacher', but *profí* for *profissional* 'professional', and *Vívi* and *Viví* for the proper name *Viviane*). As a result, it is advantageous that the probabilistic approach in Garcia (2017b, 2019) does not rely on this particular prosodic domain — especially given the typological limitations of foot types already discussed in the literature (Kager, 2012; van der Hulst, 2012).

In summary, a probabilistic approach is more accurate at predicting patterns both in the lexicon (Garcia, 2017b) and the grammar (Garcia, 2019). Even though the probabilistic approach in question is based solely on syllable weight, other factors are naturally allowed in the grammar — including metrical biases, for example. The main goal of these analyses was to demonstrate how a model based solely on weight can already outperform categorical approaches, which are typically based on feet, as discussed above.

3. Lexical storage

We saw above that a categorical approach misses important generalizations found in the data (both in the lexicon and in the grammar). An implication of such an approach is that regular and irregular stress are retrieved differently, since only one is derived by rule application. This implication follows from previous studies on the processing of regular and irregular morphology, which propose that storage is reserved to irregular forms, while regular forms are decomposed, i.e., a dual-route model (see e.g., Pinker & Ullman, 2002).[3] Consequently, reaction times for the retrieval of irregular and regular morphological forms should be different. In addition, regularity should also influence accuracy. These effects have indeed been observed in analyses of the English past tense (e.g., Kielar et al., 2008) and German verbal and nominal inflection (e.g., Sonnenstuhl et al., 1999).

[3] Definitions of *regular/irregular* in word formation processes, although not necessarily identical to those used in the discussion of stress assignment, are also somewhat divergent across studies (see e.g., Albright & Hayes, 2003; Berent et al., 2002; Clahsen, 1999).

However, although the stress patterns observed in Portuguese are traditionally classified as regular or irregular, such a classification does not depend on morphological structure. In other words, it is not the case that suffixed forms exhibit a particular stress pattern, while monomorphemic forms exhibit another pattern. Regarding suffixed forms, although it is true that the attachment of certain suffixes (e.g., *-ico/a*) always results in an irregular stress pattern (e.g., *económ-ico, fón-ica* 'economic', 'phonic'), other suffixes yield regular stress patterns (e.g., stress-bearing *-(i)dáde* in *serenidáde* 'serenity', and *-ál* in *lamaçál* 'mire'). On the other hand, as previously mentioned, monomorphemic forms also exhibit both regular and irregular stress patterns. Thus, these observations suggest that morphological structure *per se* is not a particularly robust factor for the processing of stress patterns in Portuguese.

At the same time, given the distribution of heavy and light syllables within the trisyllabic window for Portuguese stress, certain stress patterns are much more predictable than others in the lexicon, which supports their classification as *regular* (in opposition to the others, which are *irregular*). It is thus reasonable to predict that lexical access should differ between so-called regular and irregular stress patterns. Similarly to what has been proposed for regular and irregular morphology, one could therefore assume that forms with irregular stress are stored with their target stress pattern, while forms with regular stress are derived by rule. As a result, regular forms would need *more* processing than irregular forms, since they must be assigned stress as they are retrieved in the lexicon. Simply put, irregular stress would only need to be retrieved, while regular stress would need to be retrieved and then derived. Such a mismatch in processing would yield longer reaction times for the retrieval of forms with regular stress relative to forms with irregular stress.

This prediction is consistent with the assumptions of the traditional approaches to stress in Portuguese, as well as with the idea that our grammars deal with regular and irregular patterns differently. However, several studies have challenged the proposal that there is a clear-cut divide between regular and irregular forms in lexical retrieval. For example, in analyses based on morphology (especially inflection), it has been shown that storage is not only reserved to irregular forms. Instead, regular forms may be stored as well, given factors such as the frequency of the regularly inflected form (see Baayen, 2007 and Cutler, 2012 for comprehensive reviews; see also Pinker & Ullman, 2002). Furthermore, factors such as neighborhood density and phonotactic probability have also been shown to affect lexical decision times involving regular and irregular morphology, and therefore may also play a role in the retrieval of regularly and irregularly stressed items (Cutler, 2012; Vitevitch & Luce, 1999; Vitevitch & Rodríguez, 2005).

However, it is also possible that, for certain grammatical phenomena, regular forms are retrieved faster given that they are overall more frequent and productive in the language. Results from lexical decision tasks suggest that this might be the case for stress. In an investigation of word recognition in Italian focusing on low frequency items only, Colombo and Sulpizio

(2015) found that participants are faster to identify target stimuli as words when they had penultimate stress (the default pattern in Italian, referred to as *dominant* by the authors) as opposed to antepenultimate stress (an irregular pattern in Italian, referred to as *non-dominant* by the authors). Other factors, such as stress neighborhood consistency (or stress friends, i.e., the stress pattern with which the word ending was consistent), were not statistically significant.

Other studies have also observed an advantage for regular stress patterns, although not necessarily in faster reaction times. Arciuli and Cupples (2006) examined the processing of English nouns and verbs through a series of experiments. Their objective was to find whether processing is favored by regular stress patterns (trochaic for nouns, such as *wízard* and *dánger*, but iambic for verbs, such as *invént* and *forgét*). In their lexical decision task, participants made fewer errors with words with regular stress. Even though these results suggest that stress regularity constrains lexical retrieval, they also cannot be completely disentangled from a potential effect of morphology in the processing of specific stress patterns — in effect, the authors observed that participants were overall significantly faster with verbs than nouns in the lexical decision. Furthermore, high-frequency words were identified faster than low-frequency words, regardless of their stress pattern, which (a) supports the idea that lexical retrieval is modulated by frequency effects and (b) further points to the importance of examining lexical frequency when investigating differences between regular and irregular stress.

Differences between regular and irregular stress patterns were also observed through other experimental methods. For example, using eye-tracking with auditory stimuli, Sulpizio and McQueen (2012) investigated whether Italian speakers use stored knowledge of lexical stress in word recognition. In an experiment with novel words, participants recognized items with penultimate stress (i.e., the most frequent pattern in Italian) earlier than items with antepenultimate stress, which suggests that speakers use a default mechanism for penultimate stress assignment.

However, examination of another language where stress is variable did not reveal any differences between regular and irregular patterns. Specifically, Andrikopoulou et al. (2021) investigated whether regular and irregular stress in Greek (penultimate and antepenultimate, respectively, referred to as dominant and non-dominant by the authors) are retrieved differently in a series of experiments using eye-tracking. With both real and nonce words, participants responded faster to items with matching primes, regardless of stress position, which suggests that lexical representations in Greek are fully specified for stress.

Finally, stress may influence not only the processing but also the production of words. Slowiaczek (1990), for example, found that English-speaking participants produce correctly stressed items faster than incorrectly stressed items. However, Slowiaczek (1990) notes that it is not possible to determine whether these findings indicate a pre-lexical effect (i.e., stress helps access the item) or a post-lexical effect (i.e., stress is used to check a previously accessed item).

Other studies have also found an effect of stress in production. For example, Jouravlev and Lupker (2014), in an examination of Russian, found that participants make more production errors in adjectives that are irregularly stressed (i.e., have stress on the second syllable as opposed to the first, which is the regular pattern for adjectives in the language). They also noted that participants are overall faster and more accurate naming words with stress consistent endings (i.e., words with more stress friends). On the other hand, Burani and Arduino (2004), did not find an effect of stress regularity (penultimate vs. antepenultimate) in a read-aloud task in Italian, although they did obtain an effect of stress friends: when words with antepenultimate stress have more stress friends than words with penultimate stress, they are read faster.

Given these observations, establishing a directional hypothesis is not necessarily practical, as different studies obtained distinct effects for regular and irregular stress patterns. However, it seems reasonable to assume that, if processing is tied to phonological regularity, then a categorical approach predicts that processing should be different between regular and irregular stress, a result that would be consistent with a dual-route model. A scenario where no difference is found would be more consistent with different types of single-route models (e.g., Bybee, 1985; Rumelhart & McClelland, 1987; among many others).

In the next section, we describe a lexical decision task where we test this prediction, i.e., whether latencies differ between so-called regular and irregular stress patterns in Portuguese. If an effect of regularity on reaction times is statistically detected, such a result would be more consistent with a categorical notion of stress, where regular and irregular stress are retrieved differently — naturally, such an approach would still face important challenges, some of which were discussed earlier. An effect of regularity on lexical retrieval could nevertheless indicate that an approach based on the categorical notion of regularity has at least *some* empirical evidence in its favor. Conversely, the absence of a difference would be more consistent with the probabilistic view discussed above.

4. Methods

To examine whether regular and irregular stress elicit different reaction times, we developed an auditory lexical decision task with trisyllabic words ($n = 360$) using Praat (Boersma & Weenink, 2022). All the stimuli had different syllable shapes and segmental qualities. Three weight profiles were used: HLL, LLL, and LLH. For HLL and LLL words, stress was either antepenultimate or penultimate; for LLH words, stress was either penultimate or final. Real ($n = 180$) and nonce ($n = 180$) words were pseudorandomly presented to participants ($n = 51$), who were all native speakers of Brazilian Portuguese (BP).[4] Nonce words were created by substituting the onset of the final syllable of real words, i.e., the point of recognition. For example, the (real) word *moletóm* ‘sweater’ served as the base for the (nonce) word *moleróm*. All stimuli were recorded by a female

[4] The experiment was approved by the Research Ethics Board Office at McGill University (REB #21-0615). All procedures were performed in accordance with the Declaration of Helsinki.

native speaker of BP, and were preceded by an article to ensure their interpretation as nouns. Each item was accompanied by the question *Esta é um palavra real em português?* ‘Is this a real word in Portuguese?’, which was presented on the computer screen in orthographic form only.

As a cut-off point, only participants with at least 80% accuracy were analyzed ($n = 37$). The total number of responses was 12,949 (excluding outliers at ± 2.5 standard deviations), of which 11,423 were accurate (~88%). In addition to stress and weight, three other key variables were considered: frequency, which was extracted from Tang’s (2012) word corpus of Brazilian Portuguese film subtitles;[5] phonotactic probability (bigram), calculated based on the Portuguese Stress Lexicon (Garcia, 2014); and phonological neighborhood density, which counts the number of words that differ from a given target word by a single phoneme.

These three variables may have potential effects on speakers’ reaction times. For example, more frequent words may be recognized more quickly. Furthermore, nonce words with a higher phonotactic probability typically yield faster reaction times (Vitevitch et al., 1999). At the same time, real words with a denser phonological neighborhood have been shown to be retrieved more slowly (Goldinger et al., 1991) — see Vitevitch et al. (1999) and references therein for a discussion on this apparent contradiction.

The reaction time data were modeled with a hierarchical Bayesian linear regression using Stan (Stan Development Team, 2019) in R (R Core Team, 2021) via the brms package (Bürkner, 2018) — this model specification is shown in (3) below. Reaction times, our response variable, were log-transformed. The main predictor in the model in question, `regular`, captures the dichotomy in (1) and (2), being set to 1 (yes) if stress is final in LLH words (LL$\underline{\text{H}}$) or penultimate in HLL and LLL words (H$\underline{\text{L}}$L and L$\underline{\text{L}}$L), and to 0 (no) otherwise (i.e., $\underline{\text{H}}$LL, $\underline{\text{L}}$LL, L$\underline{\text{L}}$H) — our reference level is `regular = 1`. As mentioned above, we also examined the main effect of frequency, phonotactic probability, as well as neighborhood density — all three variables were standardized[6] and log-transformed. We included by-speaker and by-item random intercepts as well as a by-speaker random slope for `regular` (Barr et al., 2013). Default brms priors were used for all variables.

In addition to participants’ reaction times, we also modeled their accuracy (0/1) in a second model (logistic regression), shown in (4) below. This model has the same specification for fixed and random effects as the model shown in (3). Both models include only real words, given that nonce words have no frequency.[7]

---

[5] Notice that not all real words in the experiment are present in the corpus in question. As a result, some real words (35 of 180) have frequency 0 in the corpus.

[6] This allows us to directly compare the magnitude of their effects. Note that rescaled variables are centered around zero and each unit represents 2 standard deviations (Gelman, 2008).

[7] A reviewer points out that nonce words could be assigned an arbitrarily low frequency value, which would allow both real and nonce words to be included in the same model. Even though we do not pursue that line of analysis here, it is indeed possible, especially if the variable real is not included in such a model, thus avoiding the potentially high collinearity introduced between the variables `freqStd` and `real` (i.e., all `real = "no"` words will have the same frequency).

(3) Statistical model (Gaussian)

```
RTspeaker ~ regular + bigramStd + densityStd + freqStd +
(1 + regular | speaker) + (1 | word)
```

(4) Statistical model (Bernoulli)

```
correct ~ regular + bigramStd + densityStd + freqStd +
(1 + regular | speaker) + (1 | word)
```

Traditional (Frequentist) statistics estimates the probability of observing some data given some parameter $\neq$ under the assumption that the null hypothesis is true, i.e., $P(D|\neq)$, also known as *p*-value. Bayesian statistics, on the other hand, estimates the probability of the parameter given the data, i.e., $P(\neq|D)$, a more relevant datum, as we are ultimately interested in the effect, not the data. This distinction, in and of itself, is advantageous given the various well-known issues associated with *p*-values (Kruschke et al., 2012; McElreath, 2020; Nuzzo, 2014).

Furthermore, Frequentist models typically provide a single point-estimate for any given effect size. In contrast, Bayesian models provide a probability distribution of effect sizes, which we refer to as *posterior distribution*. As a result, we can define any given interval within said distribution and establish that parameter values within that interval are more plausible (given the data) than those outside said distribution. This interpretation is substantially different (and considerably more intuitive) from that of Frequentist confidence intervals — see discussion in Kruschke (2013) for a simple example. As we explore the results below, we will analyze two different intervals, namely, 50% and 95% highest density intervals (HDI), also referred to as credible intervals (CrI).[8] Finally, in Frequentist statistics, we cannot confirm the null hypothesis. In Bayesian statistics, in contrast, we can establish a region of practical equivalence (ROPE) and determine that the HDIs that fall completely within said region represent a null effect (Kruschke, 2015). For an introduction to Bayesian data analysis applied to linguistic data, see Garcia (2021).

5. Results and analysis

We start by inspecting and statistically analyzing our main results, i.e., the effect of our predictors on participants' reaction times (3). **Figure 2** plots the main results from our lexical decision task. In what follows, we first explore the main trends in the figure, and then we model the data accordingly. In **Figure 2**, the stress window in Portuguese is presented along the *x*-axis, log-transformed reaction times are displayed along the *y*-axis, and the horizontal facets display the different weight profiles used in the task. Violet and white box plots represent regular and irregular patterns, respectively.

[8] Note that both 50% and 95% are completely arbitrary numbers, just like 95% confidence intervals are arbitrary in Frequentist statistics — see discussion in McElreath (2020), who employs 89% intervals. Any number we pick for these intervals will be arbitrary.

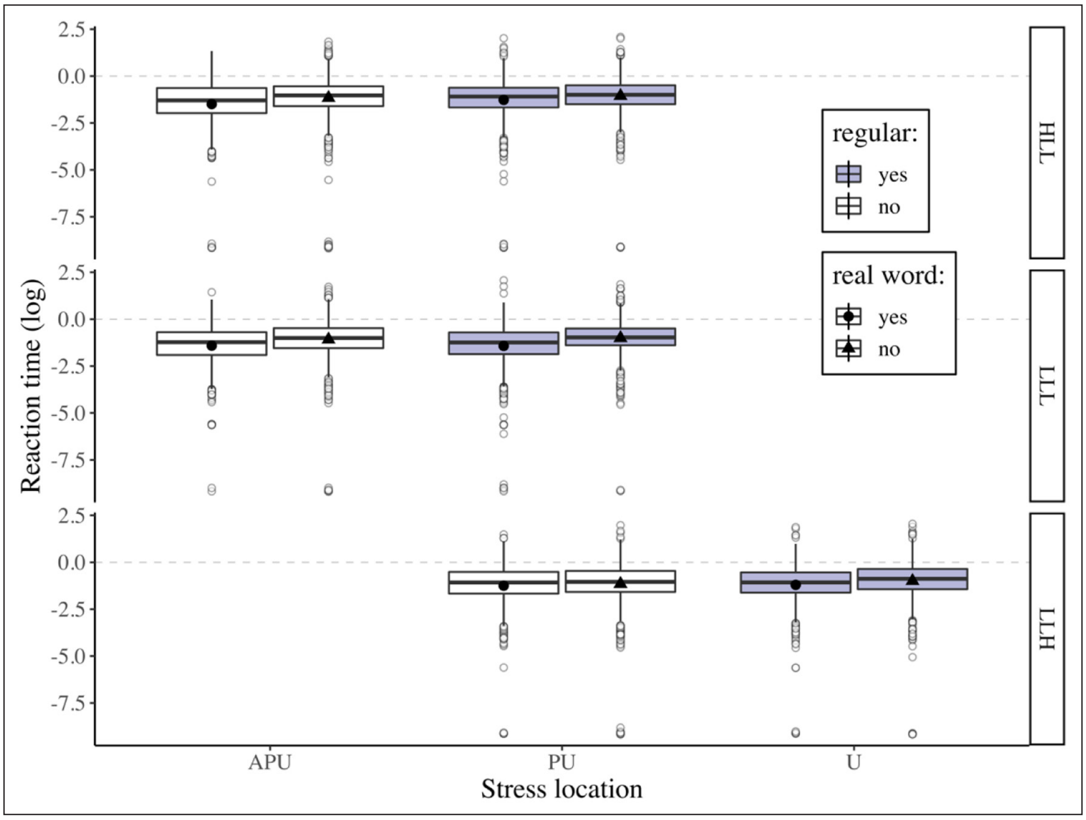

Figure 2: Box plots showing reaction time (log) by stress location by weight profile. Solid black circles and triangles represent means and associated standard errors (not visible) for real and nonce words, respectively. Violet box plots represent regular patterns. Only correct responses are plotted.

For every pair of box plots, the box plot on the left represents real words (solid black circle representing the mean), while the box plot on the right represents nonce words (solid black triangle representing the mean). As we can see, real words seem to yield faster reaction times overall, which is not surprising (e.g., Vitevitch & Luce, 1999). Indeed, the overall difference in means between real and nonce words was 0.21 log(s), which is equivalent to ~810 ms ($\hat{\beta}$ 0.21, 95% *HDI* = [0.08,0.34]).

The most important aspect of **Figure 2** involves regular (in violet) vs. irregular patterns (in white). No apparent reaction time difference can be observed between both groups of stimuli. Note that the figure includes only correct responses, but the trend observed remains if we also include incorrect responses.

Phonological neighborhood density has no clear effect on reaction times in our data. Frequency and phonotactic probability, on the other hand, were negatively correlated with reaction times: higher frequency words and words with higher phonotactic probability yielded faster reaction times overall, as can be seen in **Figure 3** and **Figure 4**, respectively, consistent with the well-known lexical frequency effect (e.g., Gardner et al., 1987) and phonotactic effect (e.g., Vitevitch et al., 1999). Both effects are virtually the same for words with regular and irregular stress. In addition, as we can see in the figures, the effects are almost completely linear, and are indeed statistically credible, as discussed below.

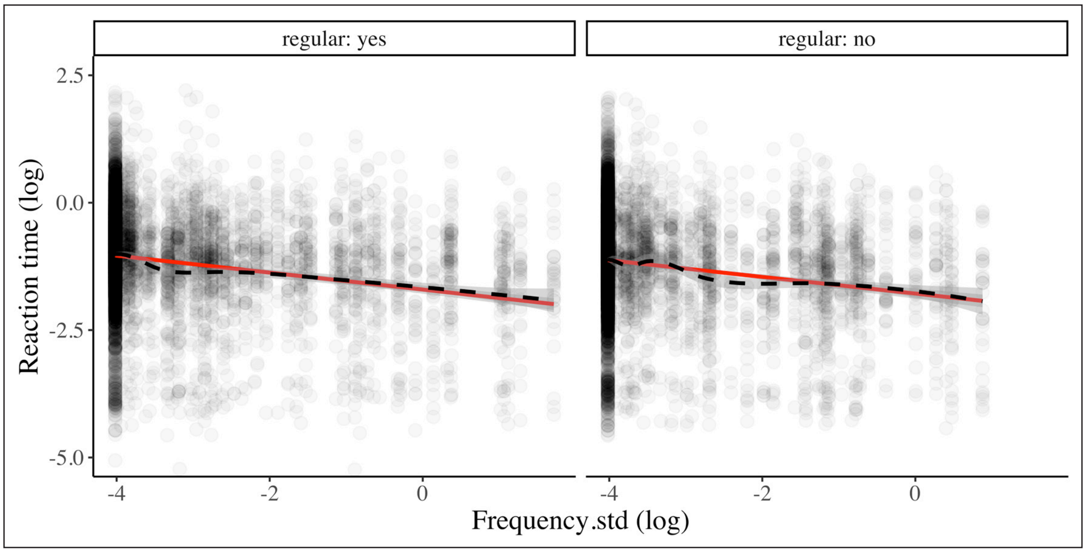

Figure 3: Linear effect of (log) frequency (standardized) on reaction times (shown in red). Both stimuli with regular and irregular stress show the same negative trend: higher frequency words tend to have faster reaction times. Dashed line in black represents LOESS trend (locally estimated scatterplot smoothing).

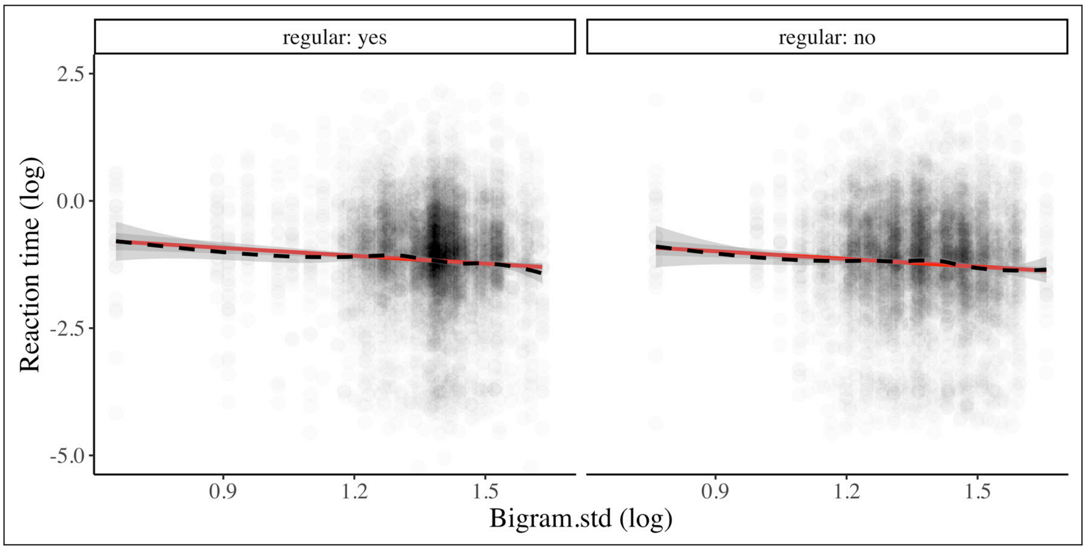

Figure 4: Linear effect of (log) phonotactic probability (standardized) on reaction times (shown in red). Both stimuli with regular and irregular stress show the same negative trend: higher probability words tend to have faster reaction times. Dashed line in black represents LOESS trend (locally estimated scatterplot smoothing).

The statistical results are summarized in **Figure 5**, which plots the posterior distributions of effect sizes ($\hat{\beta}$; *x*-axis) for each predictor of interest (*y*-axis) in our model, specified in (3). The black point range underneath each distribution represents the 95% and 50% HDIs. Values within an HDI are more probable given the data. The mean of each posterior distribution is listed on the right-hand side, along with its respective 95% HDI. The shaded area around zero (dashed line) represents the ROPE for effect sizes. Recall that this region represents a narrow range of values for a given parameter that are considered to be practically equivalent to zero (Kruschke, 2015). As a result, in Bayesian estimation, it is possible to conclude that an effect is null (cf. Frequentist analyses). Finally, the percentages on the left-hand side represent the amount of each 95% HDI contained within the ROPE.

Notice that most HDIs in **Figure 5** include zero as a probable effect size, except for frequency ($\hat{\beta}$ = –0.16, 95% *HDI* = [–0.2,–0.12]), which is therefore the only predictor with a robust statistically credible effect in the model. The negative effect of frequency indicates that more frequent words are statistically correlated with faster (lower) reaction times, also consistent with previous studies, as mentioned above. To be more specific, for each frequency unit increase (recall that the variable was standardized and log-transformed), reaction times decrease by 0.16 log(s) on average — this can be inferred from **Figure 3**. Phonotactic probability has a wide posterior distribution, but most of its credible parameter values are negative, consistent with the literature (more probable words are recognized faster).

The intercept in our model represents the predicted reaction time (in log(s)) when all other predictors are set to zero, i.e., words with regular stress assuming that frequency, phonotactic probability, and neighborhood density are held at zero. This, however, does not offer an intuitive interpretation, as variables were log-transformed after being standardized[9] — none of them has zero as its possible (raw) value, apart from the real words not found in the corpus, as already mentioned. As a result, **Figure 5** does not show the posterior distribution for the intercept.

The crucial effect in **Figure 5** is that of regularity on reaction times. As we can see in the figure, the 95% HDI of regularity (`regular: no`) not only includes zero, but is almost entirely within the ROPE (96.8%). Even though one cannot be certain that regularity has a null effect, these results are strong evidence that a null effect is extremely plausible, which would further challenge the traditional notion that stress assignment is either rule-based (derived) or exceptional (stored), and would strengthen the argument for the probabilistic approach discussed above.

Let us now turn to our second model, specified in (4), which examines the effect of our predictors on participants' accuracy. **Figure 6** shows the posterior distributions for all predictors.

[9] To handle negative values, we added a constant value to each of the standardized variables in question prior to the log-transformation.

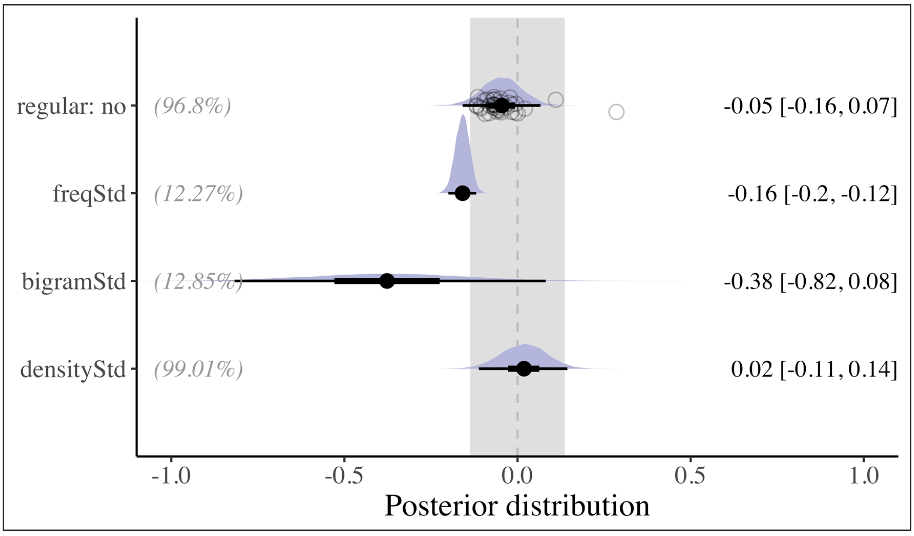

Figure 5: Posterior distributions of effect sizes ($\hat{\beta}$) in reaction time model. Ranges underneath each distribution represent the 95% and 50% highest density intervals. Shaded area represents the region of practical equivalence (ROPE). Percentages represent the amount of each 95% HDI that is contained within the ROPE. Gray circles represent by-participant random effects.

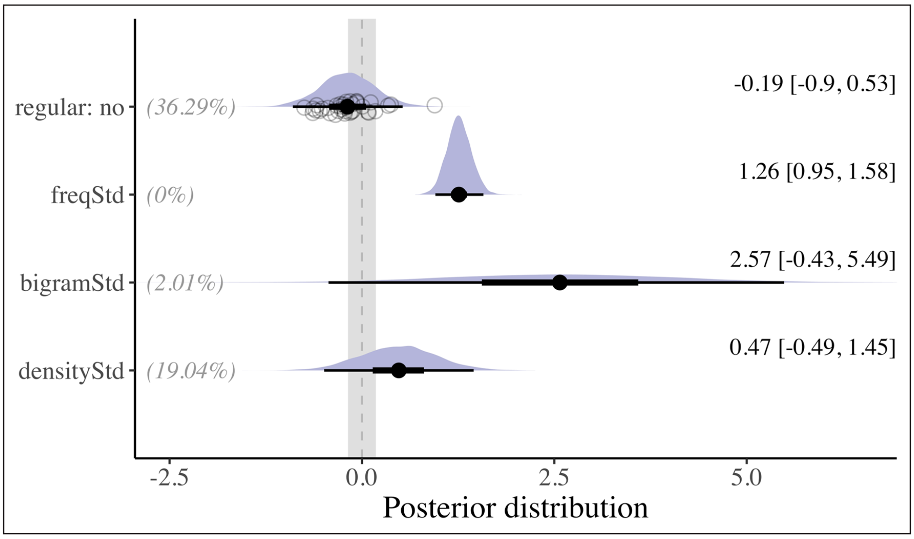

Figure 6: Posterior distributions of effect sizes ($\hat{\beta}$) in accuracy model. Ranges underneath each distribution represent the 95% and 50% highest density intervals. Shaded area represents the region of practical equivalence (ROPE). Percentages represent the amount of each 95% HDI that is contained within the ROPE. Gray circles represent by-participant random effects.

In **Figure 6**, we see that frequency shows the most robust statistically credible effect on accuracy (i.e., it is the only predictor whose credible interval does not include zero as a potential effect size). The positive effect ($\hat{\beta}$ = 1.26, 95% *HDI* = [0.95,1.58]) indicates that more frequent words elicit more accurate responses, a result that is consistent with the literature (e.g., Arciuli & Cupples, 2006). Crucially, regularity again has no statistically credible effect: not only does the 95% (and 50%) HDI include zero, over 35% of the posterior distribution of the effect in question is contained within the ROPE. Neighborhood density and phonotactic probability also include zero as a credible parameter value in their HDIs, even though the direction of the effect is consistent with what we would expect — the posterior distribution of phonotactic probability also offers evidence for a positive effect, i.e., more probable words yield more accurate responses. We can conclude that regularity does not show statistically credible effects on reaction times nor on accuracy.

6. Conclusion

In our lexical decision task, word frequency was the only predictor whose posterior distribution did not include zero as a statistically credible effect — participants responded faster to and were more accurate with words that are more frequent. In addition, phonotactic probability yielded effects that are consistent with the literature. We did not find, however, any effect of stress regularity on participants' reaction times nor accuracy. This suggests that the retrieval of forms with regular and irregular stress in Portuguese does not exhibit any substantial distinction, contrary to what one might expect based on traditional proposals that argue that regular and irregular stress patterns are represented differently.

These results are therefore in line with a probabilistic approach of stress assignment in Portuguese (Garcia, 2017b, 2019). According to this approach, stress patterns are not simply regular or irregular (in the sense that a stress rule applies to some but not all items). Instead, some patterns are more probable than others, in that they are more likely to apply to novel words. In this probabilistic approach, more probable (i.e., frequent) stress-weight patterns are more likely to emerge, but are not necessarily assumed to be retrieved faster than less probable patterns, all else being equal. Naturally, all else is rarely equal, and phonotactics and/or the frequency of stress patterns (regardless of weight), among other factors, could mean faster retrieval even if a given stress-weight pattern is not very frequent *per se*. In other words, stress assignment probabilities need not match lexical retrieval probabilities.

These observations contrast with some experimental findings regarding the effect of stress on lexical retrieval. For example, studies focusing on penultimate (regular) and antepenultimate (irregular) stress in Italian have obtained faster reaction times for penultimate stress (Colombo & Sulpizio, 2015; Sulpizio & McQueen, 2012). In Colombo and Sulpizio (2015), as previously mentioned, items with both antepenultimate and penultimate stress were low frequency. Despite the target words matched in frequency, it is possible that type frequency played a role in participants' responses, as participants may have been more familiar with words with penultimate stress, which would explain their faster reaction times with this pattern.

In other studies that found differences between regular and irregular stress (albeit not necessarily in reaction times), it is difficult to determine the effect of stress on participants' responses separately from morphology. This is the case of Arciuli and Cupples (2006), which found that English-speaking participants were more accurate in the lexical decision task with regularly stressed forms (i.e., trochaic rhythm for nouns and iambic rhythm for verbs), and Jouravlev and Lupker (2014), which found that Russian-speaking participants were more accurate in naming regularly-stressed adjectives. Participants' higher accuracy with regular stress given specific morphological classes may also be explained based on type frequency: the patterns labeled as *regular* are in effect more frequent in the language given their morphological class. Further research is needed to investigate the potential role of morphology in the lexical retrieval of stress patterns in the case of Portuguese.

However, our results mirror the observations for regular and irregular stress in other studies, such as Burani and Arduino (2004), which found no difference between regular and irregular patterns in Italian in a read-aloud task, and Andrikopoulou et al. (2021), which found a priming effect (but no regularity effect) on participants' reaction times for stress patterns in Greek. In line with Andrikopoulou et al. (2021), our results suggest that there is no particular representation for regular stress (or default stress, in their terms) in Portuguese. Our observations are also consistent with recent studies that found no processing differences between regular and irregular morphological patterns (see e.g., Nieder et al., 2021).

As we reviewed traditional approaches to Portuguese stress, we noted that a categorical approach (a) is less accurate when capturing patterns in the lexicon and in the grammar, and (b) relies on metrical patterns which are not consistent given the different foot types proposed in the literature as well as the existence and productivity of subminimal words in the language. In this paper, we have presented an additional challenge to categorical approaches, namely, the lack of an effect of regularity on reaction times and accuracy in a lexical decision task. Ultimately, it seems that the categorization of stress patterns into regular and irregular provides no analytical advantage to the study of stress in Portuguese.

Competing interests

The authors have no competing interests to declare.

References

Albright, A., & **Hayes, B.** (2003). Rules vs. Analogy in English Past Tenses: A Computational/Experimental Study. *Cognition*, *90*, 119–161. DOI: https://doi.org/10.1016/S0010-0277(03)00146-X

Andrikopoulou, A., **Protopapas, A.**, & **Arvaniti, A.** (2021). Lexical stress representation in spoken word recognition. *Journal of Experimental Psychology: Human Perception and Performance*, *47*(6), 830–851. DOI: https://doi.org/10.1037/xhp0000929

Arciuli, J., & **Cupples, L.** (2006). The processing of lexical stress during visual word recognition: Typicality effects and orthographic correlates. *Quarterly Journal of Experimental Psychology*, *59*(5), 920–948. DOI: https://doi.org/10.1080/02724980443000782

Baayen, R. H. (2007). Storage and computation in the mental lexicon. In G. Jarema & G. Libben (Eds.), *The mental lexicon: core perspectives* (pp. 81–104). Amsterdam: Elsevier. https://pure.mpg.de/rest/items/item_60468_2/component/file_60469/content

Barr, D., **Levy, R.**, **Scheepers, C.**, & **Tily, H.** (2013). Random effects structure for confirmatory hypothesis testing: keep it maximal. *Journal of Memory and Language*, *68*(3), 255–278. DOI: https://doi.org/10.1016/j.jml.2012.11.001

Beckman, M. E. (1986). *Stress and non-stress accent*. Berlin: Walter de Gruyter. DOI: https://doi.org/10.1515/9783110874020

Berent, I., **Marcus, G. F.**, **Shimron, J.**, & **Gafos, A. I.** (2002). The scope of linguistic generalizations: evidence from Hebrew word formation. *Cognition*, *83*(2), 113–139. DOI: https://doi.org/10.1016/S0010-0277(01)00167-6

Bisol, L. (1992). O acento e o pé métrico binário [Stress and the binary metrical foot]. *Cadernos de Estudos Linguísticos*, *22*, 69–80. https://periodicos.sbu.unicamp.br/ojs/index.php/cel/article/view/8636897

Bisol, L. (2013). O acento: duas alternativas de análise [Stress: two analyses]. *Organon*, *28*(54), 281–321. DOI: https://doi.org/10.22456/2238-8915.41192

Boersma, P., & **Weenink, D.** (2022). *Praat: doing phonetics by computer version 6.2.14* [Computer software]. https://www.fon.hum.uva.nl/praat/

Burani, C., & **Arduino, L. S.** (2004). Stress regularity or consistency? Reading aloud Italian polysyllables with different stress patterns. *Brain and Language*, *90*(1–3), 318–325. DOI: https://doi.org/10.1016/S0093-934X(03)00444-9

Bürkner, P.-C. (2018). Advanced Bayesian multilevel modeling with the R package brms. *The R Journal*, *10*(1), 395–411. DOI: https://doi.org/10.32614/RJ-2018-017

Bybee, J. L. (1985). *Morphology: A study of the relation between meaning and form*, *9*. Amsterdam: John Benjamins Publishing. DOI: https://doi.org/10.1075/tsl.9

Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Behavioral and Brain Sciences*, *22*(6), 991–1013. DOI: https://doi.org/10.1017/S0140525X99002228

Colombo, L., & **Sulpizio, S.** (2015). When orthography is not enough: The effect of lexical stress in lexical decision. *Memory and Cognition*, *43*(5), 811–824. DOI: https://doi.org/10.3758/s13421-015-0506-6

Cutler, A. (2012). *Native listening: language experience and the recognition of spoken words*. Cambridge, MA: MIT Press. DOI: https://doi.org/10.7551/mitpress/9012.001.0001

Garcia, G. D. (2014). *Portuguese Stress Lexicon* [Digital lexicon]. https://guilhermegarcia.github.io/psl

Garcia, G. D. (2017a). *Weight effects on stress: lexicon and grammar* [PhD thesis]. McGill University. DOI: https://doi.org/10.31219/osf.io/bt8hk

Garcia, G. D. (2017b). Weight gradience and stress in Portuguese. *Phonology*, *34*(1), 41–79. DOI: https://doi.org/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: https://doi.org/10.1353/lan.2019.0068

Garcia, G. D. (2020). Language transfer and positional bias in English stress. *Second Language Research*, *36*(4), 445–474. DOI: https://doi.org/10.1177/0267658319882457

Garcia, G. D. (2021). *Data visualization and analysis in second language research* (1st ed.). Routledge. DOI: https://doi.org/10.4324/9781003032243

Garcia, G. D., & **Goad, H.** (2021). *Weight effects and the parametrization of the foot: English vs. Portuguese* [Manuscript submitted for publication]. DOI: https://doi.org/10.31219/osf.io/pc6hg

Gardner, M. K., Rothkopf, E. Z., Lapan, R., & **Lafferty, T.** (1987). The word frequency effect in lexical decision: finding a frequency-based component. *Memory and Cognition*, *15*(1), 24–28. DOI: https://doi.org/10.3758/BF03197709

Gelman, A. (2008). Scaling regression inputs by dividing by two standard deviations. *Statistics in Medicine*, *27*(15), 2865–2873. DOI: https://doi.org/10.1002/sim.3107

Goldinger, S. D., Pisoni, D. B., & **Logan, J. S.** (1991). On the nature of talker variability effects on recall of spoken word lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(1), 152. DOI: https://doi.org/10.1037/0278-7393.17.1.152

Harris, J. W. (1983). *Syllable structure and stress in Spanish: a non-linear analysis*. Cambridge, MA: MIT Press, Linguistic Inquiry Monographs.

Hayes, B. (1982). Extrametricality and English stress. *Linguistic Inquiry*, *13*(2), 227–276. https://bit.ly/3nP1UVL

Hermans, B., & **Wetzels, L.** (2012). Productive and unproductive stress patterns in Brazilian Portuguese. *Revista Letras & Letras*, *28*, 77–114. https://seer.ufu.br/index.php/letraseletras/article/view/25851

Jouravlev, O., & **Lupker, S. J.** (2014). Stress consistency and stress regularity effects in Russian. *Language, Cognition and Neuroscience*, *29*(5), 605–619. DOI: https://doi.org/10.1080/01690965.2013.813562

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

Kielar, A., Joanisse, M. F., & **Hare, M. L.** (2008). Priming English past tense verbs: Rules or statistics? *Journal of Memory and Language*, *58*(2), 327–346. DOI: https://doi.org/10.1016/j.jml.2007.10.002

Kruschke, J. K. (2013). Bayesian estimation supersedes the t test. *Journal of Experimental Psychology: General*, *142*(2), 573–603. DOI: https://doi.org/10.1037/a0029146

Kruschke, J. K. (2015). *Doing Bayesian data analysis: a tutorial with R, JAGS, and Stan* (2nd ed.). London: Academic Press. DOI: https://doi.org/10.1016/B978-0-12-405888-0.00008-8

Kruschke, J. K., Aguinis, H., & **Joo, H.** (2012). The time has come: Bayesian methods for data analysis in the organizational sciences. *Organizational Research Methods*, *15*(4), 722–752. DOI: https://doi.org/10.1177/1094428112457829

Lee, S.-H. (1994). A regra de acento do português: outra alternativa [Portuguese stress rule: an alternative]. *Letras de Hoje*, *24*(4), 37–42. https://revistaseletronicas.pucrs.br/ojs/index.php/fale/article/view/15770

Lee, S.-H. (2007). O acento primário no português: uma análise unificada na Teoria da Otimalidade [Primary stress in Portuguese: a unified analysis in Optimality Theory]. In G. A. Araújo (Ed.), *O acento em português: abordagens fonológicas* [Stress in Portuguese: phonological approaches] (pp. 120–143). São Paulo: Parábola Editorial.

Liberman, M., & **Prince, A.** (1977). On stress and linguistic rhythm. *Linguistic Inquiry*, *8*(2), 249–336. https://www.jstor.org/stable/4177987?origin=JSTOR-pdf

Lopez, B. S. (1979). *The sound pattern of Brazilian Portuguese (Cariocan dialect)* [PhD thesis]. University of California, Los Angeles.

Magalhães, J. S. (2008). O acento dos não verbos no português brasileiro no plano multidimensional [Portuguese stress in non-verbs based on the multidimensional plan]. *ALFA: Revista de Linguística*, *52*(2), 405–430. https://periodicos.fclar.unesp.br/alfa/article/view/1525

Major, R. C. (1985). Stress and rhythm in Brazilian Portuguese. *Language*, *61*(2), 259–282. DOI: https://doi.org/10.2307/414145

Martínez-Paricio, V., & **Vigário, M.** (2019). Minimal recursive feet in Brazilian Portuguese? Paper presented at *Recursivity in Phonology: below and above the word*. http://filcat.uab.cat/pagines_clt/recphon2019/abstracts/martinez-paricio_vigario.pdf

Massini-Cagliari, G. (1992). *Acento e ritmo* [Stress and rhythm]. São Paulo: Editora Contexto.

Massini-Cagliari, G. (1999). *Do poético ao linguístico no ritmo dos trovadores: três momentos da história do acento* [From the poetic to the linguistic in the rhythm of troubadours: three moments in the history of stress]. Araraquara: College of Letters and Sciences, Laboratório Editorial, UNESP.

Mateus, M. H., & **d'Andrade, E.** (2000). *The phonology of Portuguese*. New York: Oxford University Press.

Mateus, M. H. (1975). *Aspectos da Fonologia do Português* [Aspects of Portuguese Phonology]. Lisboa: INIC.

McElreath, R. (2020). *Statistical rethinking: a Bayesian course with examples in R and Stan* (2nd ed.). Chapman & Hall/CRC. DOI: https://doi.org/10.1201/9780429029608

Nieder, J., Van De Vijver, R., & **Mitterer, H.** (2021). Priming Maltese Plurals: Representation of sound and broken plurals in the mental lexicon. *The Mental Lexicon*, *16*(1), 69–97. DOI: https://doi.org/10.1075/ml.20008.nie

Nuzzo, R. (2014). Scientific method: statistical errors. *Nature News*, *506*, 150–152. DOI: https://doi.org/10.1038/506150a

Pereira, M. I. (2007). Acento latino e acento em português: que parentesco? [Latin and Portuguese stress: is there a relationship?] In G. A. Araújo (Ed.), *O acento em português: abordagens fonológicas* [Stress in Portuguese: phonological approaches] (pp. 61–83). São Paulo: Parábola Editorial.

Pinker, S. (1991). Rules of language. *Science*, *153*, 530–535. DOI: https://doi.org/10.1126/science.1857983

Pinker, S. (1997). Words and rules in the human brain. *Nature*, *387*, 547–548. DOI: https://doi.org/10.1038/42347

Pinker, S., & **Ullman, M.** (2002). Combination and structure, not gradedness, is the issue. *Trends in Cognitive Sciences*, *6*, 472–474. DOI: https://doi.org/10.1016/S1364-6613(02)02013-2

R Core Team. (2021). *R: a language and environment for statistical computing*. http://www.r-project.org/

Rumelhart, D. E., & **McClelland, L.** (1987). On Learning the Past Tenses of English Verbs. https://web.stanford.edu/~jlmcc/papers/PDP/Chapter18.pdf

Slowiaczek, L. M. (1990). Effects of lexical stress in auditory word recognition. *Language and Speech*, *33*(1), 47–68. DOI: https://doi.org/10.1177/002383099003300104

Sonnenstuhl, I., Eisenbeiss, S., & **Clahsen, H.** (1999). Morphological priming in the German mental lexicon. *Cognition*, *72*, 203–236. DOI: https://doi.org/10.1016/S0010-0277(99)00033-5

Stan Development Team. (2019). *Stan Modeling Language Users Guide and Reference Manual* (2.27). https://mc-stan.org/users/documentation/

Sulpizio, S., & **McQueen, J. M.** (2012). Italians use abstract knowledge about lexical stress during spoken-word recognition. *Journal of Memory and Language*, *66*(1), 177–193. DOI: https://doi.org/10.1016/j.jml.2011.08.001

Tang, K. (2012). A 61 million word corpus of Brazilian Portuguese film subtitles as a resource for linguistic research. UCL *Working Papers in Linguistics*, *24*, 208–214. https://bit.ly/3ORHlmQ

van der Hulst, H. (2012). Deconstructing stress. *Lingua*, *122*(13), 1494–1521. DOI: https://doi.org/10.1016/j.lingua.2012.08.011

Vitevitch, M. S., & **Luce, P. A.** (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language*, *40(3)*, 374–408. DOI: https://doi.org/10.1006/jmla.1998.2618

Vitevitch, M. S., Luce, P. A., Pisoni, D. B., & **Auer, E. T.** (1999). Phonotactics, Neighborhood Activation, and Lexical Access for Spoken Words. *Brain and Language*, *68*(1–2), 306–311. DOI: https://doi.org/10.1006/brln.1999.2116

Vitevitch, M. S., & **Rodríguez, E.** (2005). Neighborhood density effects in spoken word recognition in Spanish. *Journal of Multilingual Communication Disorders*, *3*(1), 64–73. DOI: https://doi.org/10.1080/14769670400027332

Vogel, I., Athanasopoulou, A., & **Guzzo, N. B.** (2018). Timing properties of (Brazilian) Portuguese and (European) Spanish. In L. Repetti & F. Ordóñez (Eds.), *Romance Languages and Linguistic Theory 14. Selected papers from the 46th Linguistic Symposium on Romance Languages (LSRL)* (pp. 325–340). DOI: https://doi.org/10.1075/rllt.14.19vog

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