

Word stress effects on syllable onset in Brazilian Portuguese

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Abstract. *This study addresses duration patterns related to Brazilian Portuguese word stress. It has been generally assumed that stress affects some parts of the syllable, such as the vowel, but not others, like the consonant that precedes it. In this study, experimental data was used to test to what extent the consonant in a syllable onset is affected by stress. Results show that in stressed syllables consonants are longer than in post-stressed syllables. The lengthening impacts fricatives, nasals and even plosives.*

1. Introduction

This study addresses Brazilian Portuguese (BP) word stress and presents an experimental evaluation of the duration patterns involved in stress realization. Word stress refers to the prominence of a syllable within a word [Gordon and van der Hulst 2020] and is usually manifested through differences in duration and intensity [Fry 1955]; [Fry 1958]; [Lehiste 1970]; [Goffman and Malin 1999]. While understood as a syllabic property [Lieberman and Prince 1977], word stress can also affect segmental properties. Indeed, in stressed syllables, vowels and consonants may display enhanced articulation [de Jong 1995], whereas in unstressed syllables they are more prone to reduction and deletion. In many languages, onset consonants are affected by fortition phenomena in stressed syllables and lenition phenomena in unstressed syllables (cf. [Gordon 2011]): for example, in West Tarangan, aproximants /j/ and /w/ are realized as the obstruents [dʒ] and [g]; conversely, in Kupia, the stops /p t/ are lenited respectively to a fricative and a tap in the onset of unstressed syllables. However, it has been generally assumed that stress affects some parts of the syllable, such as the vowel, but not others, like the consonant that precedes it. Indeed, most works on the topic seem to not distinguish a stressed syllable from a stressed vowel, based on the fact that the vowel is usually the longer and most sonorous element of the syllable.

A syllable is a basic unit of speech formed by the grouping of vowels and consonants, organized in nuclear and marginal elements. The nucleus is a mandatory position and is usually occupied by a vowel, while the margins are occupied by consonants. The marginal positions before and after the nucleus are traditionally called onset and coda, respectively. Syllable structure can vary across languages regarding the maximal and minimum composition of the nucleus, onset and coda, as well as the presence/absence of the later two. However, syllables with onsets are the most frequent syllables in a language and are attested all the world's languages. Therefore, this constituent should not be regarded as secondary.

Different accounts were proposed to represent syllable structure and they differ with respect to the constituents and association principles proposed [Lieberman and Prince 1977]; [Halle and Vergnaud 1987]; [Hayes 1985]; [Hayes 1989];

[Hayes 1995]; [Hyman 1985]). In some of those phonological accounts, the nucleus and the coda are grouped forming an intermediate constituent called rhyme. The rhyme is the formal expression of an asymmetry between onset, nucleus and coda and is based on the finding that in many languages there are phonological phenomena triggered by the number of elements associated to the nucleus and the coda, but not the to syllable onset, what is referred to as syllable weight sensitivity. However, it has been argued that the onset may also contribute to the syllable's overall sound and weight and that the alleged unimportance of the onset for syllable weight is not grounded on empiric data [Topintzi 2010].

In this study, we evaluate the role of the onset in the phonetic manifestation of word stress in Brazilian Portuguese, based on experimental data. In BP, there are three possible locations for the stressed syllable in a word: on the final syllable, as in *jacaré* ('alligator'), on the penultimate syllable, as in *sacola* ('bag'), and on the antepenultimate syllable, as in *xícara* 'cup'. In BP, word stress plays an important role in phonological patterns, such as mid-vowel neutralization and open-syllable nasalization [Bisol 2010]. Furthermore, vowels present different inventories in stressed, prestressed and post-stressed syllables [Bisol 2010]; [Câmara Júnior 1970]. Acoustically, stressed syllables are longer and more intense than unstressed ones [Albano 2001]; [Cantoni 2022].

Previous studies on BP stress are restricted to the effect of word stress on the nucleus. However, an effect on the onset has been attested for other languages, e.g. Estonian, in which onset consonantal lengthening serves as the most reliable cue to stress [Gordon 1997]. In this study the following hypotheses were tested: (1) Word stress is a syllabic property and, in BP, as in many languages, it involves segmental lengthening. As such, not only the vowels, but also the consonants in the onset position are expected to be longer than unstressed ones. (2) Continuant consonants, like fricatives, are produced without a complete blocking of the airstream in the oral cavity and are longer than non-continuant consonants, like plosives and nasals. We expect that the lengthening caused by stress would be restricted to or larger in continuant consonants.

2. Method

2.1. Data set

The data set evaluated in this study was gathered in an experiment carried out with 10 participants (5 female, 5 male), with ages ranging from 26 to 48 years, with a graduate degree of education. They were all native speakers of Brazilian Portuguese from Belo Horizonte, with no history of speech or hearing disorder. The experiment followed current research ethical practices and was registered in the ethical committee (COEP - UFMG, CAAE 66987823.0.0000.5149). The recordings took place in a sound-proof booth, with a professional head-worn microphone, a mixing table and a computer and were stored as non-compressed files. The sentences read by the participants were presented in slides that had been randomly ordered. In the experiment, speakers produced words with similar consonants in stressed or post-stressed positions. Eight pairs of words containing fricatives, nasals and plosives in syllable onsets were selected, according to the availability in the data set, as shown in Table 1.

Each test word was produced in three different carrier sentences that corresponded to final position (*Eu digo [word]* 'I say [word]') or medial position (*Eu digo [word]*

Table 1. Target words used in the study

Consonant	Stressed syllable			Post-stressed syllable		
[f]	<i>buffet</i>	[bi'fe]	'buffet'	<i>bife</i>	['bifi]	'steak'
[f]	<i>sofá</i>	[so'fa]	'sofa'	<i>fofa</i>	['fofə]	'cute (she)'
[s]	<i>missô</i>	[mi'so]	'miso'	<i>passo</i>	['pasu]	'step'
[p]	<i>tupi</i>	[tu'pi]	'Tupi'	<i>crepe</i>	['krepi]	'crepe'
[g]	<i>sagu</i>	[sa'gu]	'yuka balls'	<i>lago</i>	['lagu]	'lake'
[m]	<i>fumê</i>	[fu'me]	'smoky'	<i>fome</i>	['fomi]	'hunger'
[m]	<i>sumô</i>	[su'mo]	'sumo'	<i>rumo</i>	['humu]	'direction'
[n]	<i>Geni</i>	[ʒe'ni]	proper name	<i>gene</i>	['ʒeni]	'gene'

setenta vezes 'I say [word] seventy times' and *Eu digo [word] noventa vezes* 'I say [word] ninety times'). In the latter case, if the participant produced a pause between the target word and the final word, the sentence was marked as a pre-pausal position, meaning a non-final pause. After removal of 23 mispronounced words, the data set contained a total of 457 observations. There was a total of 153 tokens in final position, 186 in medial position and 118 in pre-pausal position.

2.2. Measurements and coding

This study intended to evaluate how the duration of consonants, vowels and syllables varies as a function of the stress level of the syllable. In each recording, the consonants and vowels were manually segmented and labeled using Praat [Boersma and Weenink 2023], and the duration of the tokens was measured with a script. The duration of syllables was calculated as the sum of adjacent labeled consonants and vowels, since only CV syllables were tested.

The data was coded for the following variables: consonant manner (fricative, nasal or plosive), voicing (voiced or voiceless) and the position in the sentence (final, medial or pre-pausal), which are known to impact consonant duration [Turk and Sawusch 1996]. Since the design was not balanced for voicing (there were only voiceless fricatives and nasals are voiced), voicing and manner could be partially confounded.

2.3. Statistical analysis

The data was fit to a linear mixed model, which is compatible with the unbalanced number of observations per category and allows for the specification of the random variability related to sampling units. The *lme4* [Bates et al. 2015] R package was used. In a model comparison approach, the full model was compared to submodels with a decreasing number of factors. A factor was considered relevant to the model if the likelihood ratio test of a model with and without it reached significance level ($p < 0.05$). The full model had fixed effects and interactions for each coded variable and intercept random effects for speakers and words ($duration \sim stress * manner * voicing * position + (1 | word) + (1 | speaker)$). The best-fit model was further compared to an equivalent regression model without the random effects.

3. Results

Consonants in the onset of stressed syllables are longer than in post-stressed syllables, as depicted in Figure 1. Furthermore, not only continuant consonants (such as [s, f]) are

lengthened, as anticipated, but similarly non-continuant ones (such as [p, g, m, n]). The onset lengthening by stress seems to hold for all participants, regardless of individual speech rates, as shown in Figure 2.

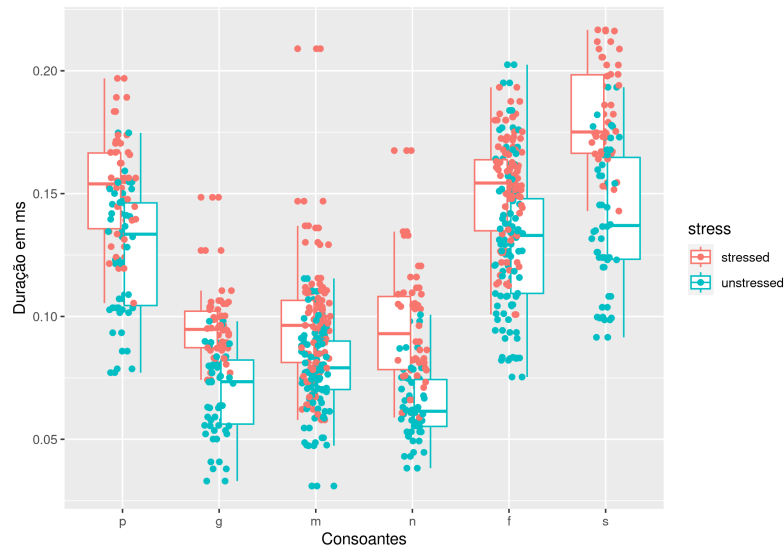


Figure 1. Consonant duration according to the type of consonant and the stress level of the syllable.

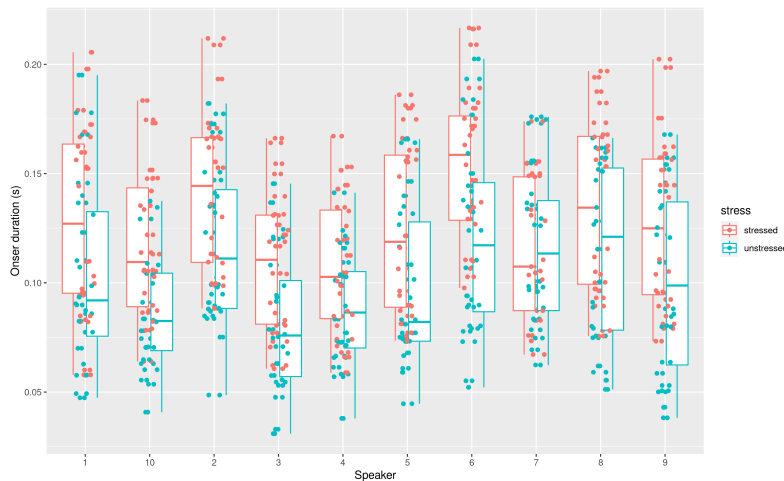


Figure 2. Consonant duration according to the phrase position and the stress level of the syllable.

Regarding phrase position, consonant duration is more affected by stress in the medial position, followed by pre-pausal, and only slightly affected in final position, as shown in Figure 3.

The full linear mixed model for onset duration distribution described in section 2.3 did not converge, possibly due to the number of observations not being enough. The convergence issue was remediated by dropping the interaction between voicing and the other fixed effects. This model was the best-fit model, by comparison to all the models with less effects. It also displayed the lowest AIC value. The residuals were randomly

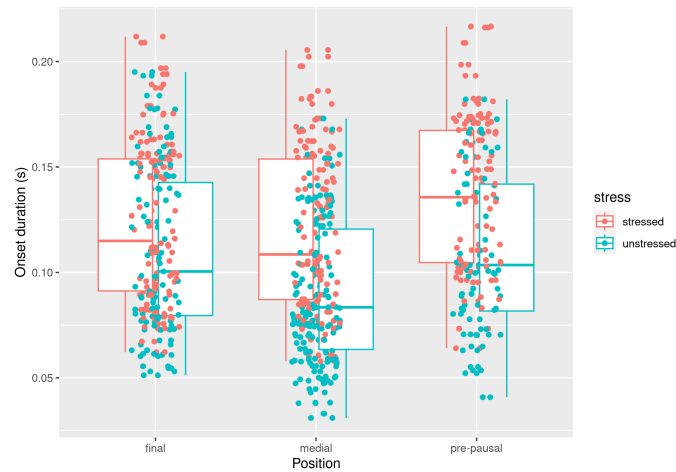


Figure 3. Consonant duration according to the phrase position and the stress level of the syllable.

scattered relative to the fitted values. There was a significant main effect of stress ($\beta = -0.0236, t = -2.46, p = 0.03$) and a significant stress by manner interaction for nasals ($\beta = -0.0474, t = -2.205, p = 0.04$). The model effects are displayed in Figure 4.

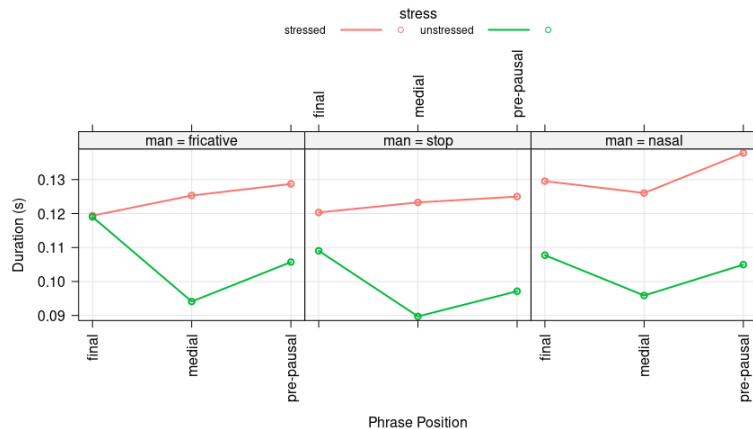


Figure 4. Effects of the linear mixed model of onset duration predicted by stress, manner, phrase position and voicing, with interactions

The lengthening effect of the onset is paralleled by a lengthening of the nucleus, as expected. Figure 5 shows that syllable and consonant durations are correlated ($r = 0.73$). The same is true for syllable and vowel duration ($r = 0.89$), as shown in Figure 6, although vowels seem to contribute slightly more to syllable lengthening than consonants. Therefore, both onset and nucleus are affected by stress lengthening, and not only the nucleus, as traditionally assumed.

It is important to mention limitations of our study with regards to the lack of control of the vocalic environment in syllables. Vowels with different heights have different intrinsic durations due to jaw-opening levels [Turk and Sawusch 1996]. Overall, lower vowels are expected to be longer than high ones, all other things being equal. Additionally, it has been reported that consonantal length is impacted by the height of the following

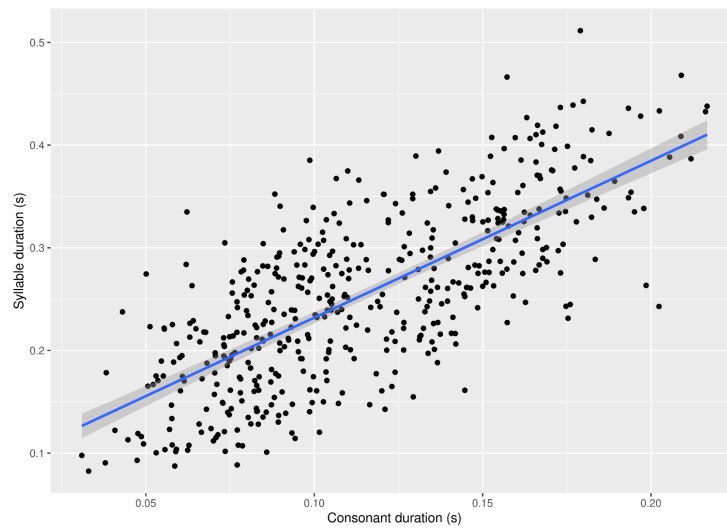


Figure 5. Syllable duration as a function of consonant duration.

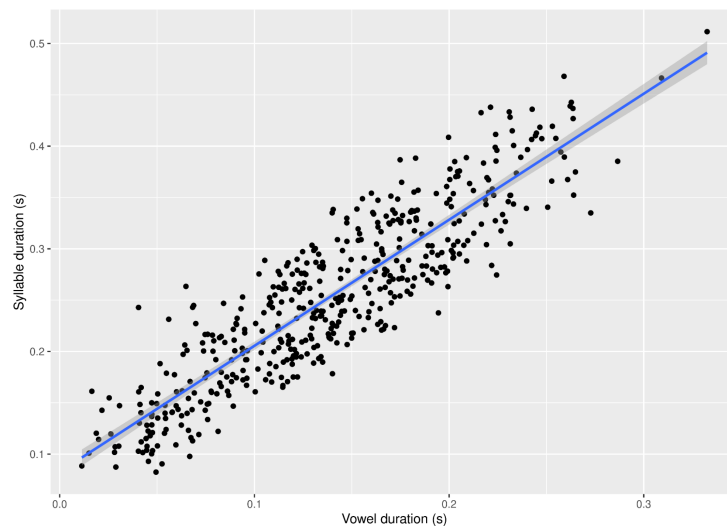


Figure 6. Syllable duration as a function of vowel duration.

vowel [Madruga 2017], in a compensatory lengthening effect. These two facts together should be considered while interpreting the data, especially in contexts where consonants were compared to each other, although having different vowels paired to each other. A design improvement with complete cases could possibly contribute to a better-fitting of the model, as well as a better explanation of the multiple phenomena involved in segment duration.

4. Conclusion

In this study, the duration patterns related to Brazilian Portuguese word stress were addressed. Experimental evidence was shown that consonants are longer in stressed syllables than in post-stressed syllables and that the lengthening impacts fricatives, nasals and even plosives. This result points to the relevance of the onset to prosodic phenomena and the need to review phonological accounts that regard the onset as hierarchically marginal

with respect to the nucleus and the coda. In future work, we intend to expand the analysis to prestressed syllables and to other syllable types, in order to assess the stress lengthening effect in the coda and in complex syllables. The role of the onset, vowel and coda in stress perception will also be evaluated.

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