

## Regulating the interaction between lexical statistics and the grammar: a naturalness bias in learning weight

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**Background:** Previous studies on phonological learning have shown that unnatural patterns are harder to learn (Hayes et al. 2009, Becker et al. 2011, Becker et al. 2012, Hayes and White 2013). The present study shows that when a conflict arises between the grammar and an unnatural lexical pattern, speakers can not only underlearn this pattern, but can learn the *opposite* pattern (e.g., Jarosz 2017). The pattern in question involves weight effects in antepenultimate syllables in Portuguese.

In the vast majority of languages that are sensitive to weight, syllable weight is binary, i.e., a syllable is either light or heavy (see Gordon (2006) for a comprehensive review). In such languages (e.g., Latin and English), heavy syllables are more likely to attract stress. In addition, if a language is weight-sensitive, weight is not expected to have a negative effect on stress, by definition.

Portuguese, like Latin and English, is also weight-sensitive, and is traditionally analysed as having a binary weight distinction: syllables that have a complex rhyme are heavy (H); all other syllables are light (L). Furthermore, Portuguese weight effects have long been assumed to be constrained to the word-final syllable (Bisol 1992, 2013; Lee 2007; cf. Wetzels (2007) on indirect weight effects in penultimate position). The standard generalization regarding stress assignment in the language is given in (1).

(1) **Portuguese stress: standard generalization**

Final if the final syllable is heavy (H):	morál ‘morale’, pomár ‘orchard’
Penultimate otherwise:	caválo ‘horse’, martélo ‘hammer’, piménta ‘pepper’
Antepenultimate stress is irregular:	pántano ‘swamp’, atónito ‘astonished’

However, once we examine a comprehensive corpus, the generalizations in (1) do not hold. First, weight-sensitivity is not constrained to the word-final syllable. Second, it is not binary: syllable weight gradiently affects all three syllables in the stress domain—weight effects weaken as we move away from the right edge of the word. Crucially, the weight effects of antepenultimate syllables found in the Portuguese lexicon (Houaiss et al. (2001), 154,610 entries) contradict the typological prediction mentioned above, in that weight has a *negative* effect on antepenultimate stress, i.e., LLL words are significantly more likely to attract antepenultimate stress than HLL words. Importantly, because Portuguese has no long vowels and codas are not deleted due to stress, trochaic shortening (Hayes 1995) is not a likely explanation for this unnatural effect.

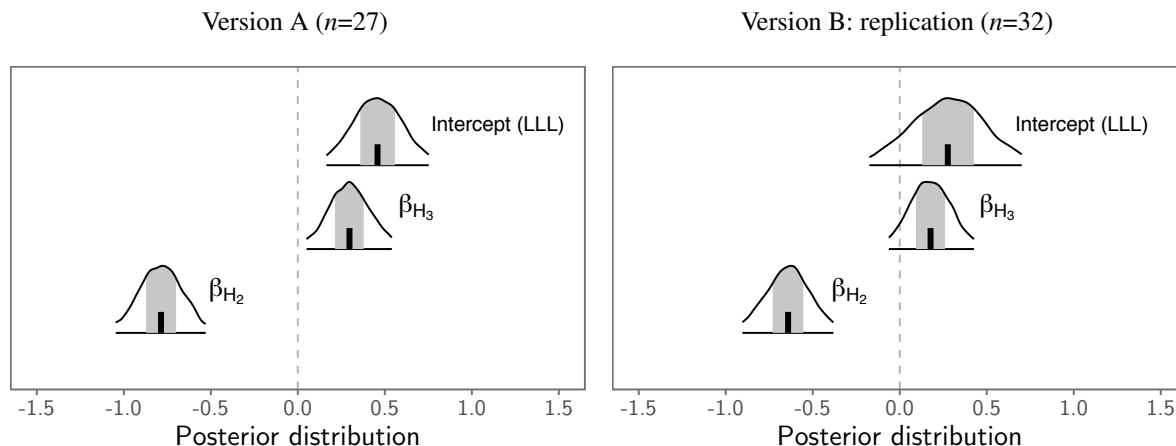
**Questions:** The two questions this paper investigates are (i) *Do speakers’ grammars capture the weight gradient present in the data, given the subtlety involved?* and (ii) *How do speakers’ grammars deal with the unnatural weight effect in antepenultimate syllables?*

**Methods:** As a baseline, smaller lexica (10,000 words) were randomly simulated ( $n = 10,000$ ) from the Houaiss corpus to ensure that the typologically contradictory pattern observed in the data is not restricted to a specific subset of words in the lexicon. The distribution of effects found in all simulated lexica confirm both the weight gradient and the negative antepenultimate weight effects. The negative effect in question is also statistically credible if only frequent words are modelled. An auditory judgment experiment was then run containing trisyllabic nonce words ( $n = 240$ ) and different weight profiles (LLL, HLL, LHL), where  $H = (C)CVC$  and  $L = (C)CV$ . LLH words were used as control, given that weight effects are most robust word-finally. Participants were all native speakers of Brazilian Portuguese ( $n = 27$ ). They were presented minimal pairs differing only with regard to the position of stress. They were then asked to choose which version of the word sounded more natural to them—all choices were binary and no orthographic forms were provided. Participants were also asked to indicate their level of confidence in their judgment using a 6-point scale. To confirm that the results found were robust, the experiment was replicated months later with a different group of participants ( $n = 32$ ). The experimental data were modelled using hierarchical logistic regressions in R (R Core Team 2017).

**Results:** In Fig. 1, we can see that participants in both Version A and Version B (replication) preferred heavy stressed syllables in antepenultimate and penultimate positions—final stress is not shown,

but yielded the expected positive effect given (1). Finally, speakers’ confidence levels are in line with the response patterns found in the data, in that stress on heavy syllables yielded more confident responses.

**Figure 1:** Statistical models. Posterior distributions in Versions A and B. Models predict the log-odds of antepenultimate stress given a weight profile:  
 $\text{stress} \sim \text{weight} + (1 + \text{weight} \mid \text{speaker}) + (1 \mid \text{word})$



**Discussion:** The effect sizes ( $\hat{\beta}$ ) in Fig. 1 confirm that weight does play a *positive* role in all three positions in the stress domain, but weakens as we move away from the right edge of the word (*as per* the distance from zero of the distributions in Fig. 1). Crucially, the negative weight effects of antepenultimate syllables found in the Portuguese lexicon are *not* mirrored in speakers’ responses. Rather, the behaviour observed indicates that participants’ grammars have regularized the weight effects in the language, i.e., weight positively impacts stress across all positions in the stress domain. Finally, these data not only show that the grammar generates patterns that are consistent with the typology, but also that even statistically subtle lexical effects (such as the weight gradient observed) can be captured and, importantly, generalized to novel words. In summary, these results show that naturalness can indeed regulate the interaction between lexical statistics and the grammar.

The probabilistic analysis proposed in this paper can be formalized within a Maximum Entropy Grammar (Hayes and Wilson 2008) with positionally defined weight constraints (WEIGHT-TO-STRESS PRINCIPLE, WSP (Prince 1990, Gordon 2004, Ryan 2011)), which assigns violation marks to heavy syllables that are not stressed. The constraint in question is defined as  $\text{WSP}_n$ , where  $n$  represents any position in the stress domain—which is determined by the interaction of other constraints in the grammar. Crucially, the cost of violating  $\text{WSP}_n$  depends on how strong weight effects are in position  $n$ .

Weight effects are strongest at the right edge of the word (position 1), and weakest at the left edge of the stress domain (antepenultimate syllable, position 3). As a result, the gradient weight effects in Portuguese are captured by assigning relative weights to  $\text{WSP}_{\{3,2,1\}}$  such that  $\text{WSP}_3 < \text{WSP}_2 < \text{WSP}_1$ —weights were learned using the MaxEnt Grammar Tool (Wilson 2006). This analysis accurately captures the typologically consistent behaviour observed in speakers’ judgments. Tableau 1 illustrates the evaluation of a HLL input: a candidate with antepenultimate stress is predicted to surface 56% of the time.

**Tableau 1:** Stress assignment in a hypothetical HLL word.

$P(x)$  **A** and  $P(x)$  **B** represent actual proportions in the data (Versions A and B)

$w = 0.24$

HLL	$\text{WSP}_3$	$h(x)$	$P^*(x)$	$P(x)$	$P(x)$ <b>A</b>	$P(x)$ <b>B</b>
ĤLL	0	0	1	0.56	0.67	0.56
HĤL	1	0.24	0.79	0.44	0.33	0.44