PHONETIC AND PHONOLOGICAL VOWEL REDUCTION IN BRAZILIAN PORTUGUESE

Sejin Oh[1,2]

[1]The Graduate Center, CUNY; [2]Haskins Laboratories
soh@gradcenter.cuny.edu

ABSTRACT

The current study examined the phonetic and phonological status of vowel reduction in Brazilian Portuguese. Specifically, we tested the influence of duration on the realization of /a/ in five prosodic positions: word-initial pretonic, medial pretonic, tonic, medial posttonic, and final posttonic. The results revealed that, while both speech rate and prosodic position had a clear effect on the phonetic duration of /a/, F1 values were far better predicted by the vowel's prosodic position (non-posttonic vs. posttonic). Correlations between duration and F1 were statistically significant but generally weak in all positions. We argue that these findings suggest that vowel reduction in Brazilian Portuguese primarily reflects phonological patterning rather than phonetic undershoot, although phonetic reduction is also apparent. That is, Brazilian Portuguese has a mixed system of phonological and phonetic reduction. We discuss the results in the context of cross-linguistic studies of vowel reduction, and the relation between phonetics and phonology.

Keywords: Phonological vowel reduction, phonetic undershoot, speech rates, Brazilian Portuguese

1. INTRODUCTION

Phonological vowel reduction occurs when phonemic contrasts are categorically neutralized in certain phonological contexts or prosodic positions (e.g., unstressed syllables), while phonetic reduction occurs when cues to a contrast are gradiently weakened as the result of undershoot [2, 3, 7, 8, 11, 15, 16, 19, 20]. However, phonological vowel reduction and phonetic reduction are similar in that they are generally accompanied by qualitative change in vowel and reduced duration. Crosswhite [8] argued that they are similar in terms of the end results, but the causal relation is reversed. In the target undershoot, reduced duration causes vowel undershoot, while raising of vowel height driven by phonological reduction results in reduced duration. Consequently, the decreased articulation time is expected to trigger phonetic undershoot, but never lead to phonological reduction.

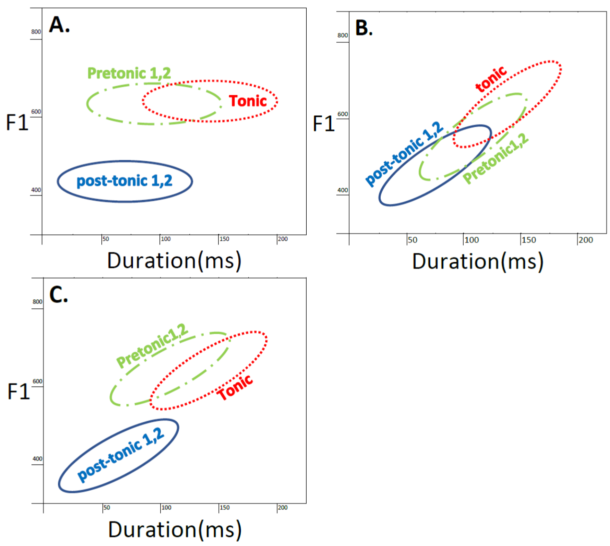
A fundamental question in any study of vowel reduction is whether it is phonetic or phonological in nature. Barnes [3] is one of only a few studies that have specifically tested this, examining vowel reduction in Russian. Russian exhibits two reduction patterns whose phonological status is uncertain. First, mid vowels reduce to their high counterparts in unstressed syllables. However, a second process is present that reduces remaining non-high vowels to [ə]. The first pattern, referred to as "Degree 1 reduction," is described as "moderate" reduction, while the second one, "Degree 2," is more "severe" (see also [2, 8]). Using hyperarticulated speech, Barnes [3] found that Degree 2 reduction was highly dependent on duration (longer duration results in less reduction), while Degree 1 reduction was not. This suggests that Degree 1 reduction in Russian requires reference to a phonological process, while no such process need be posited for Degree 2 reduction, as it can be accounted for by phonetic undershoot.

The general aim of the present study was to investigate the phonetic versus phonological status of vowel reduction in Brazilian Portuguese (henceforth, BP), which is reported to exhibit two different patterns of reduction in unstressed syllables [10, 14, 17, 21, 22, 23]. In stressed syllables, BP has a seven-vowel inventory, /i, e, ɛ, a, ɔ, o, u/. In pretonic syllables, /ɛ, ɔ/ are neutralized to /e, o/, respectively. For example, the underlying /ɛ/ in the word *be'leza* 'beauty' becomes [e] in this context. In posttonic syllables, the vowels undergo a further reduction, in which /e, i/ neutralize to [i], /o, u/ to [u], and /a/ becomes [ɐ]. For example, the underlying /a/ in the word *'seca* 'sack' is realized as [ɐ]. The first pattern is referred to as "Degree 1 reduction," and the second one as "Degree 2 reduction" [2, 3].

Regarding the influence of duration on vowel reduction in BP, Major [17] impressionistically observed that phrase-final lengthening can influence the presence of Degree 2 reduction in BP. Furthermore, even pretonic vowels can show raising to a certain degree in casual and/or fast speech. On the other hand, experimental data from Kenstowicz and Sandalo [14] suggest that syllable position does a better job of differentiating height contrasts than normalized durations does, while the interactions between duration and position were also significant. However, Kenstowicz and Sandalo [14] lacked sufficient durational variation to examine the influence of duration on Degree 2 reduction. The goal here was therefore to investigate the influence of duration, manipulated via speech rate, on degree 2 reduction in BP, focusing on the reduction of /a/ to [ɐ].

Three different predictions can be made regarding the phonetic versus phonological status of Degree 2 reduction in BP. If it is a phonological process, duration should not significantly affect /a/'s quality; rather, stress-dependent position predicts the realization of the low vowel /a/. However, if it is a phonetic process, the reduction of low vowel /a/ to [ɐ] should be highly dependent on changes in duration, as shown in Figure 1A and 1B, respectively. Furthermore, if BP is a mixed system, changes in duration affect F1, but do not alter the overall pattern of reduction, as shown in Figure 1C.

Figure 1: Predictions depending on the phonetic versus phonological status of Degree 2 reduction in BP: A) Phonological reduction; B) Phonetic reduction; C) Mixed system



2. METHODS

2.1. Participants

11 speakers of Brazilian Portuguese participated in the experiment (10 female, 1 male; Mean Age: 29.5).

2.2. Speech materials and procedure

Two sets of data were collected to examine the vowel /a/ in five prosodic positions: word-initial pretonic, medial pretonic, tonic, medial posttonic, and final posttonic. One set, List A, consisted of 17 trisyllabic words with final stress (σσσ́; e.g. *galopar* 'gallop') in which 14 initial pretonic, 6 medial pretonic and 17 tonic /a/ tokens were collected. Another, List B, consisted of 19 trisyllabic words with antepenultimate stress (σ́σσ; e.g. *pétala* 'petal'), in which 7 medial posttonic and 14 final posttonic /a/ tokens were collected. The target words were produced in a carrier sentence (*Repita* ___ *de novo* 'repeat ___ again'). To elicit three different speech rates, a priming methodology was used. The priming stimuli consisted of the same carrier phrase containing (instead of a target word) the nonce word "*shushushu*" with slow and fast primes created via synthesis from a normal-rate speech sample. Speakers were to imitate the prime, inserting a target word (with either ultimate or antepenultimate stress) in place of the nonce word.

The main experiment consisted of three sessions: 1) slow, 2) normal, and 3) fast elicitations. Each session consists of two sets: Set A (ultimate stress) and Set B (antepenult stress), corresponding to the lists. For each session, participants were asked to listen to each priming stimulus first and then produce each sentence three times, trying to produce the sentence with the same tempo with the priming stimulus. The speech materials were recorded using a microphone (Shure SM48) in a soundproof booth. The recorded speech was saved as .wav files with a sampling rate of 44.1 kHz.

2.3. Data analysis

Of the 5,742 vowels collected, 280 vowels (5.3%) were discarded due to vowel deletion, disfluency, devoicing or severe creak. Vowel onset and offset were manually marked in Praat based on the onset and offset of a second formant. We obtained the formant information (at the midpoint) and the duration of each vowel using a Praat script [9]. The raw formant values (Hz) were normalized using a mel scale and transformed to z-scores for each speaker. The raw duration values (in ms) were also transformed to z-scores.

To examine unstressed vowel reduction at three different speech rates in BP, we examined (a) the duration of the vowel in each position, (b) the first formant of the vowels in each position, and (c) the correlation between duration and F1 frequency for vowels in each position.

2.4. Statistical models

A statistical analysis was carried out using the mixed-effects regression with the *lme4* package in R [4]. Separate models were run with normalized F1 as an outcome variable and prosodic position (5 levels: word-initial pretonic, medial pretonic, tonic, medial posttonic, and final posttonic) and duration as fixed factors. Speakers and the item were added in the models as random factors, and models were constructed in an incremental fashion by adding fixed factors that tested for main effects and interactions. A similar approach was used for testing the effects of prosodic position and speech rate on duration, and for testing the effects of prosodic position and speech rate on F1. Corrections for multiple comparisons were carried out using the *multcomp* package in R [6, 13].

3. RESULTS

3.1. Normal speech rate

The boxplots in Figure 2 illustrates the distributions of duration and F1 (again, z-transformed) for /a/ in the five prosodic positions at normal speech rate. Statistical analyses returned a significant effect of prosodic position [$\chi^2(4) = 147.76$, $p<.001$] and duration [$\chi^2(1) = 70.802$, $p<.001$] on F1, and a significant interaction between these two factors [$\chi^2(4) = 61.752$, $p<.001$]. In addition, there was a significant effect of prosodic position on duration [$\chi^2(4) = 1647.7$, $p<.001$]. Post-hoc testing showed that posttonic vowels were significantly different from non-posttonic vowels in terms of F1 ($p<0.001$ for all pairs), while the durations of medial pretonic and posttonic vowels, as well as initial pretonic and final posttonic are not significantly different from each other ($p>0.1$ for both pairs). That is, when the durations of pretonic and posttonic vowels are comparable, prosodic position was the primary determinant of F1.

Figure 2: Duration (A) and F1 (B) of the vowel /a/ in the five prosodic positions at normal speech rate[1].

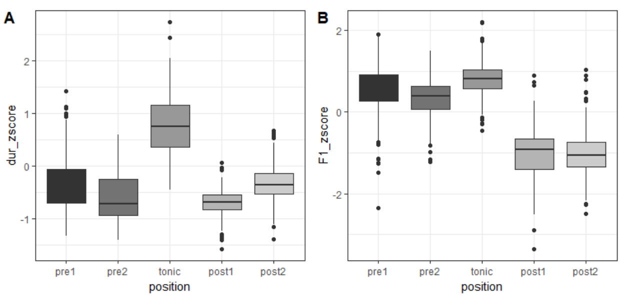
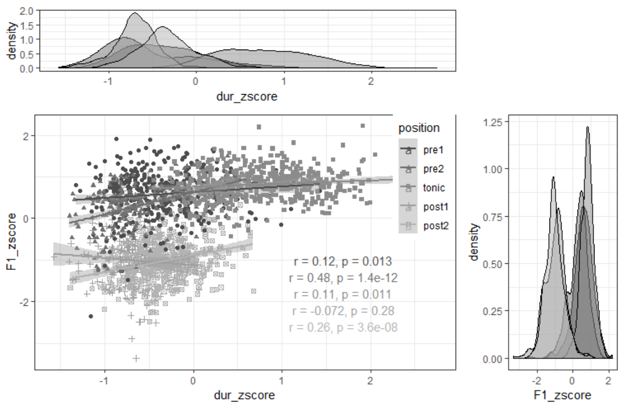


Figure 3: Scatterplots & density plot of duration and F1 at normal speech rate.



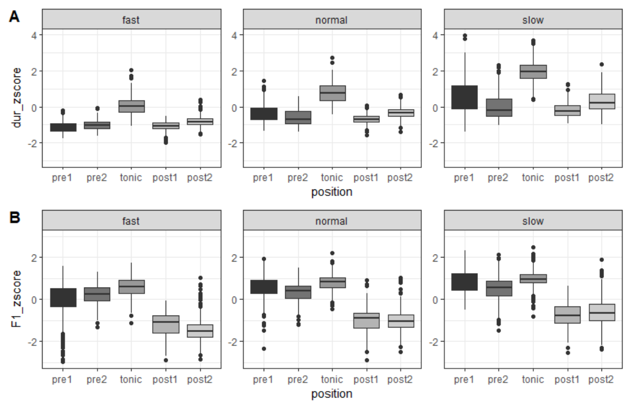
Also apparent in Figure 3 are two categories in terms of F1: posttonic (including final and medial posttonic) vs. non-posttonic (including initial and medial pretonic, and tonic). This indicates that duration alone is not able to account for reduction of these vowels at normal speech rate, consistent with the results from Kenstowicz and Sandalo [14].

3.2. All speech rates

The pattern just described for the normal speech rate also held for slow and fast speech rates, as shown in Figure 3. To explore the effect of duration on vowel reduction in BP, we examined the relation between duration and F1, collapsing for speech rate.

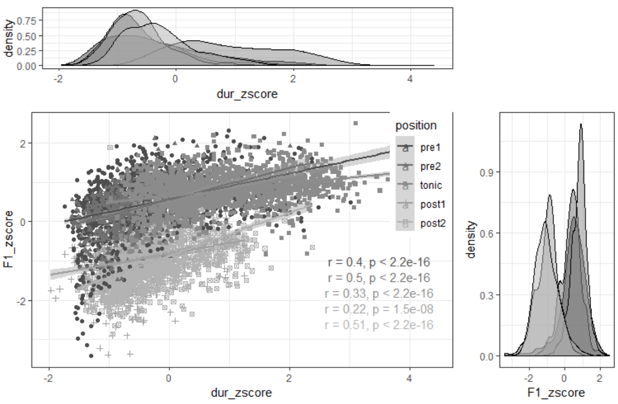
Much as for normal speech rate, analyses that collapsed for speech rate showed a significant effect of prosodic position [$\chi^2(4) = 165$, $p<.001$] and duration [$\chi^2(1) = 1032.5$, $p<.001$] on F1, and a significant interaction between these two factors [$\chi^2(4) = 260.27$, $p<.001$]. In addition, there was a significant effect of prosodic position on duration [$\chi^2(4) = 1957.5$, $p<.001$]. Post-hoc testing also revealed that the duration of pretonic and posttonic vowels are comparable ($p>0.1$ for all pairs), while posttonic vowels are significantly different from non-posttonic vowels in terms of F1 ($p>0.1$ for all pairs). In addition, as shown in Figure 4, the density plot of F1 indicated that there were two categories: posttonic vs. non-posttonic. That is, even when duration is quite long, posttonic positions rarely reach the F1 value which pretonic and tonic vowels do. This finding suggests that BP speakers have different F1 targets for posttonic vowel; Degree 2 reduction thus only targets posttonic syllables.

Figure 3: Duration (A) and F1 (B) for /a/ by prosodic position for three different speech rates.



Finally, there was a significant effect of speech rate on both duration [$\chi^2(2) = 2859.3$, $p<.001$] and F1 [$\chi^2(2) = 996.74$, $p<.001$]. Separate analyses revealed that duration was significantly longer, and F1 values were significantly higher, as speech rates decrease ($p<0.001$ for all pairs; except fast-normal pair in the medial pretonic, $p<0.01$).[2] Furthermore, weak but significant positive correlations between F1 and duration were observed at all prosodic positions, as shown in Figure 4. This finding, like those above, suggests that changes in duration, while they affect F1, do not alter the overall pattern of reduction.

Figure 4: Scatterplots & density plot of duration and F1 at all speech rates.



4. DISCUSSION

The present study investigated the phonetic versus phonological status of vowel reduction in BP by examining the influence of duration on reduction patterns in the language. The results revealed that although longer vowel duration was associated with higher F1 in a statistically significant way, F1 was overall much better predicted by prosodic position than by duration. We argue that these findings suggest that Degree 2 reduction in BP primarily reflects phonological patterning, although phonetic reduction is also apparent. A positive correlation between F1 and duration can be understood as reflecting phonetic undershoot, but the observation that duration does not affect the overall patterns of raising for /a/ serves as good evidence for a systematic and categorical relation between vowel reduction and prosodic position, supporting its phonological status. This suggests that Brazilian Portuguese has a mixed system where phonological reduction can coexist with a local and/or mild phonetic reduction, predicted by Figure 1C.

The overall pattern found in the current study is different from Barnes [2, 3] for Russian, which also exhibits two patterns of reduction. In particular, Barnes [2, 3] argued that Degree 2 reduction in Russian is a phonetic process, while we argued that the one in Brazilian Portuguese can be understood to be a mixed system of phonological and phonetic reduction. However, one speaker (out of eleven) who participated in our study also exhibit the phonetic reduction pattern. Unlike the majority, BP5 does not show any categorical behaviour in any prosodic position. Instead, BP5 exhibits a severe overlap across the five prosodic positions in terms of F1. Such speaker variation suggests that Degree 2 reduction may reflect the phonologization of an earlier phonetic process; whereas most speakers have already phonologized the Degree 2 reduction, some speakers have only a phonetic process (See [2, 3, 5] for a further discussion).

The present study confirmed the findings from Kenstowicz and Sandalo [14], in that the Degree 2 reduction is primarily determined by metrical structure. However, we further demonstrated the extent to which F1 differences for the low vowel are also a function of duration. Based on their results, Kenstowicz and Sandalo [14] proposed that Degree 2 reduction reflects metrical structure in BP, targeting posttonic syllables due to their flat prosodic structure. In particular, they argued that the parameter setting in the metrical structure is binary left-headed for line 0 and right-headed constituents for line 1, and the final syllable is extrametricality, as shown in Figure 5.

If Degree 2 reduction targets syllables with no stress as proposed in [14], how do we explain the lack of Degree 2 reduction in trisyllabic words with ultimate stress? If the initial pretonic has a secondary stress and the medial pretonic has no stress as proposed by [1, 18][3], the medial pretonic (penult syllable in 5c) would undergo Degree 2 reduction, which is not consistent with our findings. Positing the presence of secondary stress for both initial and medial pretonic vowels would descriptively solve the problem, but would be highly inconsistent with previous work on BP metrical phonology [1, 18], and metrical theory more generally [12]. Alternatively, we argued that the medial pretonic syllables bear a ternary stress, and Degree 2 reduction targets syllables with no stress. That is, the medial pretonic syllable in 5C is no longer a target of degree 2 reduction since it bears a ternary stress. However, to support our claim, a future study would be necessary to investigate whether the medial pretonic in BP has acoustic correlates of the ternary stress.

Figure 5: Metrical structures in BP: A. Antepenult, B. Penult, and C. Ultimate stresses. (A & B are adapted from [14]; C from [18])

	A.			B.			C.		
2	*				*				*)
1	(*)			(*	*)		(*)	(	*)
0	(*	*)	*	(*)	(*)	*	(*)	(*	*)
grid level	σ	σ	σ	σ	σ	σ	σ	σ	σ

5. REFERENCES

[1] Arantes, P., & Barbosa, P. A. (2006). Secondary stress in Brazilian Portuguese: the interplay between production and perception studies. *In Proceedings of Speech Prosody 2006 conference* (pp. 73–76). Dresden, Germany

[2] Barnes, J. 2006. *Strength and weakness at the interface: positional neutralization in phonetics and phonology* (Vol. 10). Walter de Gruyter.

[3] Barnes, J. 2007. *Phonetics and phonology in Russian unstressed vowel reduction: A study in hyperarticulation.* Ms., Boston University.

[4] Bates, Douglas M., Martin Maechler, Ben Bolker & Steven Walker. 2014. *Lme4: Linear mixed-effects models using Eigen and S4.* R package version 1.0–6. http://CRAN.R-project.org/package = lme4.

[5] Blevins, J. 2004. *Evolutionary phonology: The emergence of sound patterns*. Cambridge University Press.

[6] Bretz, F., Hothorn, T., & Westfall, P. 2010, *Multiple Comparisons Using R*, CRC Press, Boca Raton.

[7] Crosswhite, K. M. 2000. Vowel reduction in Russian: a unified account of standard, dialectal, and "dissimilative" patterns. *University of Rochester working papers in the language sciences,* vol. Spring, 107-171.

[8] Crosswhite, K. 2001. *Vowel reduction in optimality theory*. Psychology Press.

[9] Crosswhite, K. 2017. *Formant and duration and pitch logging script.* From http://web.archive.org/web/20030620172734/ling.rochester.edu/people/cross/scripts.html

[10] Fails, W. C., & Clegg, J. H. 1992. A spectrographic analysis of Portuguese stressed and unstressed vowels. *Romance Linguistics: The Portuguese Context. Bergin and Garvey, Westport,* 31-42.

[11] Fourakis, M. 1991. Tempo, stress, and vowel reduction in American English. *The Journal of the Acoustical Society of America*, *90*(4), 1816-1827.

[12] Hayes, B. 1995. *Metrical stress theory: Principles and case studies*. University of Chicago Press.

[13] Hothorn, T., Bretz, F., & Westfall, P. 2008, Simultaneous Inference in General Parametric Models. *Biometrical Journal*, *50*(3), 346–363; See vignette ("generalsiminf", package = "multcomp").

[14] Kenstowicz, M., & Sandalo, F. 2016. Pretonic vowel reduction in Brazilian Portuguese: Harmony and dispersion. *Journal of Portuguese Linguistics,* 15.

[15] Liljencrants, J., & Lindblom, B. 1972. Numerical simulation of vowel quality systems: The role of perceptual contrast. *Language*, 839-862.

[16] Lindblom, B. 1963. Spectrographic study of vowel reduction. *The journal of the Acoustical Society of America*, 35(11), 1773-1781.

[17] Major, R. C. 1985. Stress and rhythm in Brazilian Portuguese. *Language*, 259-282.

[18] Moraes, J. D. 1998. Brazilian Portuguese In: Hirst, D. and di Cristo, A. eds. *Intonation Systems*, 179-94.

[19] Nadeu, M. 2014. Stress-and speech rate-induced vowel quality variation in Catalan and Spanish. *Journal of Phonetics*, 46, 1-22.

[20] Nadeu, M. 2016. Phonetic and phonological vowel reduction in Central Catalan. *Journal of the International Phonetic Association*, 46(1), 33-60.

[21] Nobre, M. A., & Ingemann, F. 1987. Oral vowel reduction in Brazilian Portuguese. *In honor of Ilse Lehiste*, *6*, 195.

[22] Wetzels, W. L. 1992. Mid vowel neutralization in Brazilian Portuguese. *Cadernos de Estudos Lingüísticos*, 23*,* 19-55.

[23] Wetzels, L. 2011. The representation of vowel height and vowel height neutralization in Brazilian Portuguese (Southern Dialects). *Tones and Features. Berlin: De Gruyter*, 331-60.

---

1 The the x-axis represents the five prosodic positions, where pre1 is for first pretonic, pre2 is for second pretonic, post1 is for non-final posttonic, and post2 is for final posttonic. (This coding for prosodic position applies also for other figures in the paper).

2 For describing effect of speech rates on the duration and F1 in each prosodic position, mixed-effects models were run separately for subsets of the data.

3 A secondary stress would fall on each even pretonic syllable, counted from right to left, starting from the primary stressed one, characterizing a strong/weak alternation (trochaic feet) [1, 18].