RESEARCH PAPER

Gradient and categorical assimilation of pretonic vowels in Brazilian Portuguese

Magnun Rochel Madruga[1], Silke Hamann[2] and Maria Bernadete Marques Abaurre[3]

[1] School of Languages and Literature, Federal University of Minas Gerais, BR

[2] Amsterdam Center for Language and Communication, University of Amsterdam, NL

[3] Language Studies Institute, University of Campinas, BR

Corresponding author: Magnun Rochel Madruga (magnun@ufmg.br)

This paper addresses the acoustic realisations of the pretonic vowels /e, o/ that have been previously reported to undergo regressive vowel harmony in Brazilian Portuguese. It examines how the height of pretonic /e, o/ is affected by the phonological and phonetic height of the adjacent stressed vowel in three dialects: Northeastern (Bahia), Northern (Amazonas) and Southern (Rio Grande do Sul). A pseudoword reading task was performed with two speakers each of the three different dialects. The findings suggest that there is some kind of low harmony, in that /e, o/ are realized with markedly higher F1 before the stressed low vowels /ɛ, a, ɔ/ than before the stressed non-low vowels /i, e, o, u/. This effect was found for all dialects, but appears to be categorical (and thus phonological) for the Northern and Northeastern speakers, while gradient for the Southern speakers, where it is likely due to phonetic V-to-V coarticulation. More importantly, no effect of height harmony was found in any of the dialects: pretonic /e, o/ were not produced significantly higher before a stressed /i, u/. In addition, Northern and Southern speakers showed V-to-V coarticulation for the non-high pretonic vowels, illustrating with Northern speakers that a categorical harmony process can co-occur together with a gradient vowel assimilation in the same dialect.

Keywords: pretonic vowels; vowel harmony; vowel-to-vowel coarticulation; Brazilian Portuguese; categorical distinctions; phonetic gradience

1. Introduction

Brazilian Portuguese (BP) has a seven-vowel system organized in terms of frontness, backness, and height, where all back vowels are rounded. According to Camara Jr. (1977), this system is reduced from seven vowels in stressed position to five in pretonic position, see **Table 1**.

As we can see from **Table 1**, the distinction between /e/ *vs.* /ɛ/ and /o/ *vs.* /ɔ/ is neutralized in unstressed syllables such as the pretonic one (Camara Jr. 1977; see also Bisol 1989; Barbosa & Albano 2004; Wetzels 1995). The output of this neutralization is a mid-high vowel, as the alternations in (1) illustrate (adapted from Kenstowicz & Sandalo 2016: 2).

Table 1: BP vowel inventory in pretonic and stressed syllables (adapted from Camara Jr. 1977: 44).

	Pretonic		Stressed	
high	i	u	i	u
mid-high	e	o	e	o
mid-low			ɛ	ɔ
low		a		a

Art. 12, page 2 of 21
Madruga et al: Gradient and categorical assimilation
of pretonic vowels in Brazilian Portuguese

(1)   Alternations illustrating neutralization of mid vowels in pretonic position:
    a.   *bela*   ['bɛlɐ]   'pretty'   *beleza*   [be'lezɐ]   'beauty'
        pelo   ['pelʊ]   'hair'   *pelado*   [pe'ladʊ]   'naked'
    b.   *roda*   [ɦɔdɐ]   'wheel'   *rodada*   [ɦo'dadɐ]   'rounded'
        mofo   ['mofʊ]   'mould'   *mofado*   [mo'fadʊ]   'moulded'

The pretonic vowels in BP are furthermore affected by *Vowel Harmony* (henceforth: VH). This was first noted by Silveira (as cited in Camara Jr. 1970), who observed that /e/ and /o/ are realized as [i] and [u] respectively, when they are followed by a high vowel /i/ or /u/ in the adjacent stressed syllable. Silveira argues that vowel height harmony is a remnant of an earlier process that dates back to the 15th and 16th centuries (Naro 1971).

Bisol (1981), who conducted a detailed study on vowel harmony, proposes that BP has a height assimilation process where the feature [+high] of the stressed vowel is the harmonizing feature, as shown with the examples in (2) (from Bisol 1981):

(2)   Height Harmony in BP:
    a.   *perigo*   [pi'rigʊ]   'danger'
    b.   *formiga*   [fuɾ'migɐ]   'ant'
    c.   *peruca*   [pi'ɾukɐ]   'wig'

The literature on VH agrees that pretonic mid vowels undergo such a height agreement with adjacent stressed vowels in all BP varieties (e.g., Abaurre & Sandalo 2017; Alves 2008; Barbosa et al. 2019; Bisol 1989; Callou et al. 1992; Kenstowicz & Sandalo 2016; Oliveira 1991; Schwindt 1995, 1997, 2002; Silva 1989; Viegas 1987).

In the same year as Bisol (1981), Abaurre-Gnerre (1981) attested the existence of a different VH process in the southeastern Brazilian Capixada dialect, spoken in the state of Espírito Santo. She observed that pretonic vowels in this dialect go through a (cyclic) lowering process when there is /ɛ/, /ɔ/ or /a/ in stressed position. This is illustrated with the examples in (3), where (3a) and (3b) are from Abaurre-Gnerre (1981) and (3c) and (3d) from Miranda (2017).

(3)   Low Harmony in Capixaba dialect:
    a.   *perereca*   [pɛrɛ'rɛkɐ]   'tree frog'
    b.   *pororoca*   [pɔrɔ'rɔkɐ]   'tidal bore'
    c.   *melado*   [mɛ'ladʊ]   'melt'
    d.   *votada*   [vɔ'tadɐ]   'voted'

Based on her observations, Abaurre-Gnerre (1981) proposes that, in southeastern Capixaba, pretonic mid vowels undergo a process of *Low Vowel Harmony* (henceforth: Low VH), in which the trigger vowels /ɛ, a, ɔ/ are considered to have the feature [+low], which spreads onto the preceding unstressed [–high] vowels. A result of low VH is that though the vowel system in pretonic position is reduced to five phonemes (as in **Table 1**), the mid vowels in this position have two different realizations, depending on the height of the following stressed vowel: Mid-high [e, o] before [–low] vowels, and mid-low [ɛ, ɔ] before [+low] vowels.

Mid-low vowels in pretonic position have also been found in northern and northeastern BP dialects (Hora & Vogeley 2013; Lee 2006; Lee & Oliveira 2003; Silva 1989). However, there is no consensus in the literature on the cause of mid-low vowels in BP dialects. Most authors assume they are the result of low VH (e.g., Abaurre-Gnerre 1981; Abaurre & Sandalo 2009, 2017; Araújo 2007; Lee & Oliveira 2003; Bohn 2014; Bortoni et al. 1992; Hora & Vogeley 2013; Kenstowicz & Sandalo 2016; Lee 2006; Madruga 2017; Sandalo

2012; Sandalo et al. 2013), and thus form a phonetic inventory of seven vowels in pretonic position, while some argue that mid-low vowels in pretonic syllables cannot be explained by the quality of the stressed vowel, and are a characteristic of the dialect (e.g., Nascentes 1953, Pacehco, Oliveira, & Ribeiro 2013).

To summarize, three different vowel patterns have been described for BP, all having pretonic /e/ and /o/ as targets, but they differ in their triggers and outcome, see the overview in (4) to (6).

(4)   **Height Vowel Harmony**
        Trigger is stressed /i/:   *menino*   [miˈninʊ]   'boy'
        Trigger is stressed /u/:   *peruca*   [piˈɾukɐ]   'wig'

(5)   **Low Vowel Harmony**
        Trigger is stressed /ɛ/:   *peteca*   [pɛˈtɛkɐ]   'shuttlecock'
        Trigger is stressed /ɔ/:   *pororoca*   [pɔɾɔˈɾɔkɐ]   'tidal bore'
        Trigger is stressed /a/:   *melado*   [mɛˈladʊ]   'molasses; melt'

(6)   **Vowel Lowering** (not conditioned by stressed vowel)
        horrível   [ɔˈʀivew]   'horrible'
        perigo   [pɛˈɾigʊ]   'danger'
        beleza   [bɛˈlezɐ]   'beauty'

Most studies on VH in BP have not addressed the fact that both height VH and low VH have the same target, namely mid vowels in pretonic position, and might be considered one process, but see the experimental studies by Sandalo (2012), Kenstowicz and Sandalo (2016) and Madruga (2017) for exceptions.

In the present article, we argue that BP pretonic mid-vowels have a single pattern of dialect-independent low vowel assimilation rather than a (dialectally restricted) phonological process of low VH resulting in categorical changes. Our claim is that the quality of the vowel which participates in low assimilation is not necessarily changed into a different category, but shows gradient phonetic similarities to the adjacent vowel, and that the process is therefore better considered to be a phonetic Vowel-to-Vowel coarticulation across intervening consonants (for a general discussion of V-to-V coarticulation, see Magen 1971; Öhman 1966; Recasens 1985; Ohala 1994; for a similar differentiation between vowel harmony and V-to-V coarticulation in Iberian Spanish, see Henriksen 2017, and in French, see Nguyen & Fagyal 2008). Therefore, the goal of this study is to investigate the production of pretonic vowels and to provide further insights into the extent of height VH and low VH in BP, including possible dialectal differences.

For this, we conducted a production study using pseudowords, in contrast to the recent experimental studies by Sandalo (2012) and Kenstowicz and Sandalo (2016) who employed real words. While real words can exhibit word-specific harmony patterns or lexical exceptions to otherwise regular harmony processes, the use of pseudowords ensures that participants have no stored lexical forms and hence rely solely on the grapheme-to-phoneme mapping and the application of regular phonological processes to create phonological surface forms for these words.

The participants in our study represent three varieties of BP: The first is the dialect spoken in Bahia, a state with approximately 15 million people, representative of the Northeastern variety of BP; the second is the dialect spoken in the capital of the State of Amazonas, Manaus, the most populous city in the Amazonian region, with approximately 1.8 million people; this dialect is taken as representative of the Northern BP variety. And

the third dialectal variety is the dialect spoken in the state of Rio Grande do Sul, with a population of about 11 million (the fifth most populous state in Brazil (IBGE 2019)). This is taken as representative of the Southern Brazil variety. In the following, the three BP dialects from the Northeastern, Northern and Southern variety will be referred to as NE-D, N-D and Sou-D, respectively.

The remainder of this study is organized as follows. The method of the experiment is presented in §2. In §3, we focus on the acoustic characteristics of the VH targets /e/ and /o/, showing the overall lowering trend presented in the three dialects. In §4 we propose a more general discussion on the interplay between VH and V-to-V coarticulation, as we found categorical changes triggered by the stressed low vowels and gradient changes by non-low vowels. Finally, we make suggestions for future research in §5.

2. Method

2.1. Materials

The experiment[1] consisted of pseudowords with a trochaic three-syllable structure [CV.(ˈCV.pa)] (where the brackets indicate the foot). The final posttonic syllable /pa/ was kept invariable to avoid a possible dissimilatory effect on the stressed syllable (as observed by Rodrigues 2010). Initial and middle consonants were the voiceless stops /p, t, k/, which occurred with the five pretonic vowels /i, e, a, o, u/ in the first syllable and the seven stressed vowels /i, e, ɛ, a, ɔ, o, u/ in the second syllable, see **Table 2** for an overview. The total number of pseudowords was 315 (9 combinations of consonants × 5 unstressed vowels × 7 stressed vowels). We also included around 30% of phonologically unrelated distractor words. These together with the pseudowords were presented to each participant three times in randomized order, which resulted in a total of 1236 stimuli (945 pseudowords and 291 disctractors) that each participant had to read aloud.

The three-syllable pseudowords were embedded in the carrier sentence *Digo … baixinho* "(I) say CVCVpa softly". Recordings were analyzed acoustically after the segments had been manually labeled, and the phonetic measurements of the first and second formants (F1 and F2) of both pretonic and stressed vowels were automatically extracted using the software PRAAT, version 6.0.49 (Boersma & Weenink 2015). All acoustic measurements were extracted automatically with a PRAAT script. For duration measurements, the start and end points for vowels were considered to be the first and last periodic pulses on the waveform that had steady F1 and considerable amplitude. The start point of the C1 consonant coincides with the end of the last vowel /o/ of the word *digo,* and its end point was defined as the beginning of the first, pretonic vowel of the target word. For C2, the beginning of the consonant coincides with the end of the pretonic vowel, and the end of it coincides with the beginning of the second, stressed vowel of the pseudoword.

2.2. Participants

Six native speakers, i.e., two each of N-D, NE-D and Sou-D, performed the reading task. Each dialect group contained one male and one female speaker, and the speakers were aged between 22 and 31 years old (with a mean age of 25). An overview of the participants'

Table 2: Structure of first two syllables of the pseudowords.

C₁	V₁	C₂	V₂
/p, t, k/	/i, e, a, o, u/	/p, t, k/	/i, e, ɛ, a, ɔ, o, u/

---

[1] This research received approval from the Research Ethics Committee of both the University of Campinas (UNICAMP) and the Federal University of Minas Gerais (UFMG), protocol numbers 49001015.4.0000.5404 (UNICAMP) and 15189019.0.0000.5149 (UFMG).

Table 3: Overview of the details of the participants.

Speaker	Gender	Age	Place of Birth	Dialect
S1	Female	22	Salvador	Northeastern
S2	Male	25	Feira de Santana	Northeastern
S3	Female	27	Manaus	Northern
S4	Male	31	Manaus	Northern
S5	Female	24	Pelotas	Southern
S6	Male	28	Porto Alegre	Southern

details is given in **Table 3**. In order to recruit reliable, homogeneous and comparable dialectal data, all selected speakers were undergraduate or graduate students without prior background in phonetics and phonology. All the participants have lived in their place of birth until their last year of secondary education. The NE-D and Sou-D speakers were selected from groups of volunteers on the campus of the University of Campinas (UNICAMP) and the two N-D speakers were directly contacted on the campus of Federal University of Minas Gerais (UFMG) by the first author. All of them volunteered to participate in the experiment.

Participant S1 was an undergraduate student at UNICAMP and S2 to S4 were graduate students. S-5 and S-6 were undergraduate students at UFMG. Recordings of S1 to S4 occurred in a soundproof room at UNICAMP and recordings of S5 and S6 (N-D speakers) were performed in Manaus in a private soundproof room rented for this purpose. The recordings were carried out using a TASCAM DR-05 linear PCM Recorder, with a sample rate of 44.1 kHz and 16-bit quantization.

Sentences were presented in three blocks of approximately 300 pseudowords, on a computer screen. The spelling notations followed BP orthography, and the stressed vowels /i, e, ɛ, a, ɔ, o, u/ were represented unambiguously as <i, ê, é, a, ó, ô, u>, while the pretonic vowels were presented as <i, e, a, o, u>. The participants were asked to read the sentences at a normal speech rate. If they misread a word, changed its stress pattern, hesitated or paused within a sentence, they were asked to repeat that particular sentence. When participants still did not follow the instructions, the pseudoword was not analyzed.

2.3. Acoustic Measures

The first two formants (F1, F2) were measured using formant ceiling optimization (Escudero, Boersma, Rauber, & Bion 2009) for gender, and only 40% of the central portion of each vowel was considered. Extreme formant frequencies were checked manually using both FFT and LPC spectra computed over a 30ms centered window at the midpoint of the vowel. The formant frequencies were corrected when the formant had not been measured correctly and discarded when vowel duration was less than 10ms. This occurred in tokens where pretonic vowels were devoiced or completely deleted, and it occurred more frequently when /i/ was preceded by /t/, which is in this context produced as the affricate [tʃ] in all dialects of this study. A total of 4440 tokens were analyzed.

For each acoustic measurement, mean, median and standard deviation (SD) were computed for each dialect and phonological context. F1 and F2 of the pretonic and stressed vowels were normalized by the Lobanov method (Lobanov 1971) and then used as dependent variables in our statistical models.

2.4. Statistical Analysis

To determine differences among stressed and pretonic vowels of each dialect, repeated-measures MANOVA was used. Also, to determine the effect of stressed vowel on F1 of the target vowels /e/ and /o/, a linear mixed-effect model was run. All models used normalized

data. The analyses were conducted with the software R (R Core Team 2014). A repeated-measures MANOVA was run with the *manova()* function of the stats package and the linear mixed-effect model was run with the *lmer()* function of the package LME4 (Bates, Mächler, Bolker, & Walker 2015). In addition, some specific packages were used to plot vowel space and normalize the acoustic data, namely, PHONTOOLS (Barreda 2014), PHONR (McCloy 2016), and GGPLOT2 (Wickham 2016). The Supplementary Material presents, in detail, the geometric mean and standard deviation of the acoustic measurements of each vowel of each speaker.

3. Results

3.1. Acoustic Properties of the Pretonic and Stressed Vowels

We start off by describing the acoustic properties of the stressed vowels in order to determine a reference acoustic space for each vowel, which could possibly explain the variation of F1 in the pretonic vowel targets of VH. It is also our goal to identify possible differences in F1 and F2 of the stressed vowels among the dialects. **Table 4** presents the geometric means of F1 of the seven stressed vowels per dialect, and **Figure 1** shows their acoustic space. In this and the following figures, front vowels are situated in the left area (F2 > 1660 Hz) and high vowels in the top area (F1 < 400 Hz).

For the set of stressed vowels, the repeated-measures multivariate analysis of variance with dialect, gender and interaction between dialect and stressed vowel, and between

Table 4: F1 geometric means (in Hz) of the stressed vowels in the three dialects.

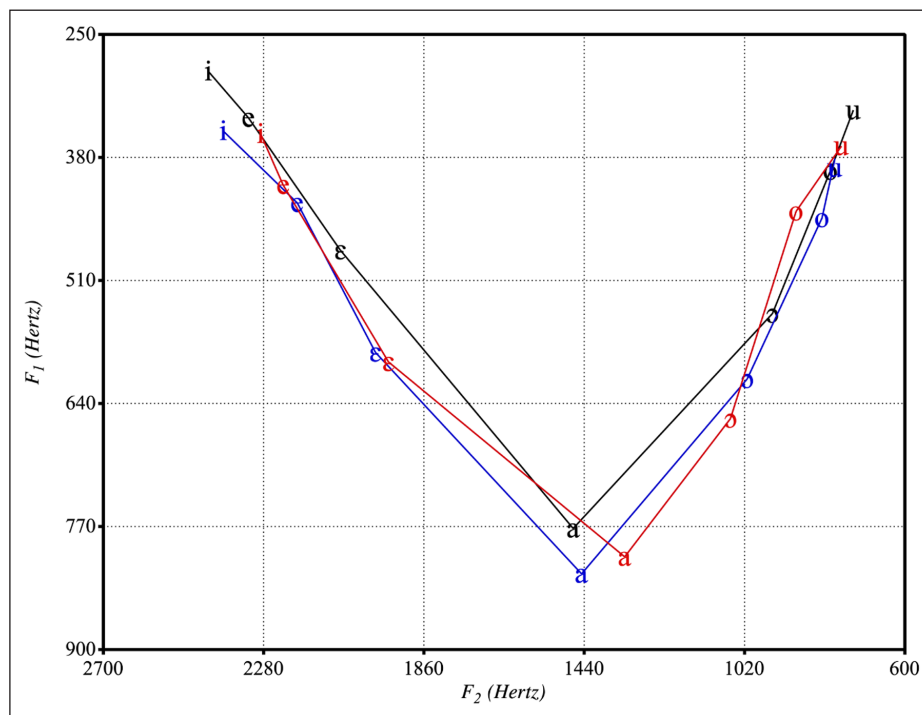|	i	e	ɛ	a	ɔ	o	u
Northeastern	289	338	478	772	545	394	330
Northern	352	428	586	820	614	444	391
Southern	355	409	596	802	656	437	368

Figure 1: Mean of the first and second formant values of the 4182 stressed vowel tokens, grouped by dialect (black = NE-D, blue = N-D, red = Sou-D).

dialect and gender as factors gives the following results. Dialect has a significant effect on F1 and F2 (Wilks' $\Lambda = 0.62$, $F(4, 7998) = 540.25$, $p < 0.001$), and so does gender (Wilks' $\Lambda = 0.70$, $F(2, 3999) = 827.15$, $p < 0.001$). Furthermore, the interaction of gender and dialect is significant (Wilks' $\Lambda = 0.81$, $F(4, 7998) = 213.72$, $p = 5332 \times 10{-}10$),[2] and also the interaction of dialect with stressed vowel (Wilks' $\Lambda = 0.01$, $F(36, 7998) = 1584.3$, $p < 0.001$). As there was an interaction between dialect and stressed vowel, we wondered whether the low vowels /ɛ/ and /ɔ/ showed different heights in the three dialects, since these vowels are taken as a reference for the behavior of the pretonic vowels. Tukey's post-hoc test revealed no significant inter-dialectal differences in F1 either for /ɛ/ or /ɔ/ ($p > 0.05$ for all pairs). This result indicates, therefore, that these mid-low vowels are in the expected F1 acoustic region in the three dialects and that their height can be used as a reliable reference in the following analyses.

The F1 values of the pretonic vowels are given in **Table 5**, and their F1 and F2 values are depicted in **Figure 2**.

For the pretonic vowels, dialect has a significant effect on F1 and F2 (Wilks' $\Lambda = 0.91$, $F(4, 8010) = 86.01$, $p < 0.001$), and so does gender (Wilks' $\Lambda = 0.63$, $F(2, 4005) = 1152.30$, $p < 0.001$). There are also significant interactions between gender and dialect

Table 5: F1 geometric means (in Hz) of the pretonic vowels in the three dialects.

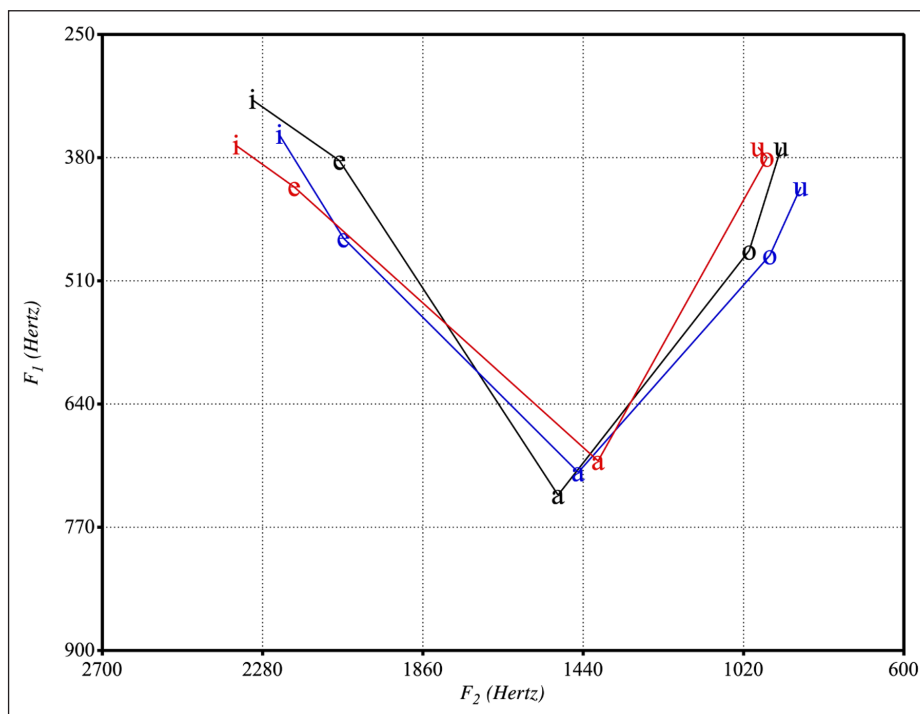|	i	e	a	o	u
Notheastern	319	383	736	478	369
Northern	356	465	712	483	411
Southern	367	411	700	380	369

Figure 2: Mean of the first and second formant of the 4400 pretonic vowel tokens, grouped by dialect (black = NE-D, blue = N-D, red = Sou-D).

---

[2] A reviewer rightfully pointed out that there is only one speaker per gender and dialect combination, and this interaction therefore means that there is a significant effect of speaker (which cannot be fully attributed to the speaker's gender or to their dialect affiliation).

(Wilks' $\Lambda = 0.93$, $F(4, 8010) = 65.63$, $p < 0.001$), and between dialect and category of pretonic vowel (Wilks' $\Lambda = 0.02$, $F(24, 8010) = 1914.16$, $p < 0.001$). Tukey's post-hoc test revealed significant inter-dialectal differences in F1 for the vowel /o/, which stands for a different height in the three dialects. In Sou-D, /o/ is extremely high and back, occupying almost the same space in **Figure 2** as /u/, which could point at a near merger of the two in this dialect. However, a closer look at the data showed that only the male speaker had overlapping realizations, and large variation for both categories, while the female speaker had clearly distinct realizations.

In the next section, we analyse the influence of height of the stressed vowel on the realization of these pretonic vowels in detail.

3.2. The Behavior of Pretonic /e/ and /o/ Predicted by the Stressed Vowel

It is not trivial to determine how pretonic /e/ and /o/ are affected in their height by the stressed vowels, i.e., whether they are raised or lowered, and what role the trigger vowels play in this process. To address this, the present section investigates how the height of the stressed vowels affects pretonic /e/ and /o/. As BP vowel harmony is essentially based on height distinction, we use only F1 as the acoustic correlate of the articulatory low/non-low contrast to determine the behavior of the targets /e/ and /o/ in the three dialects.[3]

In a first analysis, separate linear-mixed effect models were run for the F1 of /e/ and /o/ as function of dialect and a three-level factor height of stressed vowel (V_2 height), which was coded as follows: /i, u/ as high, /e, o/ as mid and /ɛ, a, ɔ/ as low. As fixed effects, we entered a two-way interaction between V_2 height and dialect. In terms of random effects, each speaker had a random intercept in the fitted model. The two-way interaction between V_2 height and dialect showed a significant effect on F1 of the pretonic /e/ ($F(4, 745) = 8.33$, $p < 0.001$). This result suggests that the height of the stressed vowel can predict the height of pretonic /e/, and that this is different across dialects. Similar results for the interaction V_2 height and dialect were also found for the pretonic /o/ ($F(4, 981) = 19.55$, $p < 0.001$).
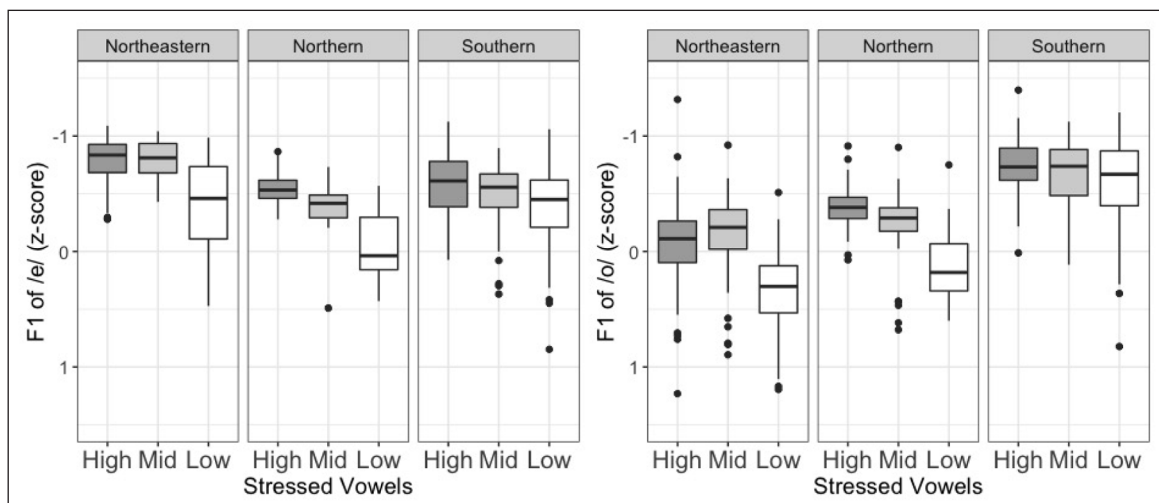

Figure 3: F1 of pretonic /e/ (left panel) and /o/ (right panel) as a function of the three dialects and the three stressed vowel groups.

---

[3] Besides formant frequencies, F1 bandwidth is sometimes also used as indicator of a vowel height distinction (Stevens 2000). Przezdziecki (2000) found that F1 was the most reliable correlate to distinct vowel height in Yoruba, a language with an identical seven-vowel system to BP. We refrained from testing bandwidth in the present study.

In **Figure 3**, we see the F1 (as z-score) of the pretonic /e/ on the left, and of pretonic /o/ on the right, with each three panels for the three dialects: NE-D on the left, N-D in the middle and Sou-D in the right panel. We can observe that /e/ has overall lowest values, i.e., is highest, in NE-D, middle values in Sou-D, and lowest values (and thus is highest) in N-D, as was already seen in **Figure 2**. With respect to a difference in values depending on the three vowel height categories, the low BP stressed vowels /ɛ, a, ɔ/ (the white boxes, at the right for each dialect panel), tend to affect the height of pretonic /e/ to a greater extent in NE-D and N-D (left and middle panel) than in Sou-D (right panel). In the latter, the values of /e/ in stressed low vowel context are almost the same as those in the other two vowel contexts. The high and mid vowels /i, u, e, o/, i.e., the dark grey and light grey boxes in each dialect panel, do not differ in their effect on the pretonic /e/, they lie within the same range for each dialect. These high and mid vowels thus seem to act together as one group, and we cannot infer that pretonic /e/ is raised only in the context of following high vowels. On the contrary, the actual realizations show that /e/ remains [e], whether it is followed by high or by mid stressed vowels.

Turning to the right panel for pretonic /o/, we can observe that its F1 values are overall high for NE-D and N-D, meaning that the vowel is lower, while in Sou-D the values are very low, meaning this vowel is very high (in accordance with **Figure 2**, where we saw that it overlapped with /u/). Like for /e/, the effect of the following low stressed vowels (the white boxes) on /o/ differs across dialects: They affect the height of /o/ to a greater extent in NE-D and N-D than in Sou-D. And again, the high (dark grey) and mid vowels (light grey boxes) behave together and do not differ in their effect on pretonic /o/ in any of the three dialects.

In order to determine the differences between the high, mid and low vowel groups for the three dialects, Tukey post-hoc tests for /e/ and /o/ were run, comparing all levels of height within each dialect. For /e/, the test returned a significant effect of the low vs. mid and low vs. high distinction for NE-D and N-D ($p < 0.001$), while we did not find a difference on the effect of mid vs. high on /e/'s height for the two varieties. In Sou-D, we found a significant difference also for low vs. high ($p < 0.001$) and low vs. mid ($p = 0.006$). Regarding the vowel /o/, the effect of levels of V_2 height was similar to what was found for /e/: for the NE-D and N-D dialects, there is a significant difference between low vs. mid and low vs. high ($p < 0.001$ for all pairs), and no significant difference between mid vs. high. For Sou-D, however, no significant difference was found at all; Sou-D pretonic /o/ is overall very high.

In a second analysis, we looked at the influence of the single stressed vowels on pretonic /e/ and /o/. Tukey's post-hoc test shows that there is no pair within the group of stressed non-low vowels (i.e., comparing all pairs within the group of /i, u, e, o/) or within the group of low vowels (i.e., /ɛ, a, ɔ/) that causes a significant difference in the F1 of pretonic /e/. The difference that consistently predicts the behavior of the pretonic targets is thus the above-reported group difference between low and non-low stressed vowel: Stressed high vowels result in a pretonic /e/ being produced as [e], while stressed low vowels trigger VH in pretonic /e/, causing it to lower to [ɛ]. This effect of low vs. non-low vowels acting as two separate groups is also visible in **Figure 4**, which shows the influence on F1 (z-score) split by all stressed vowels.

An overview for the pretonic /o/ is given in **Figure 5**.

For /o/, the comparison of vowel pairs across the low and non-low division is significant for NE-D and N-D in most pairs, apart from /u/ vs. /a/ and /o/ vs. /a/ in N-D ($p > 0.05$ for both). Most pairwise comparisons in Sou-D were not significant, with the exception of /ɔ/ vs. /i/($p = 0.003$), /ɛ/ vs. /i/($p = 0.002$) and /a/ vs. /i/($p < 0.001$), that is, all low vowels compared to /i/).
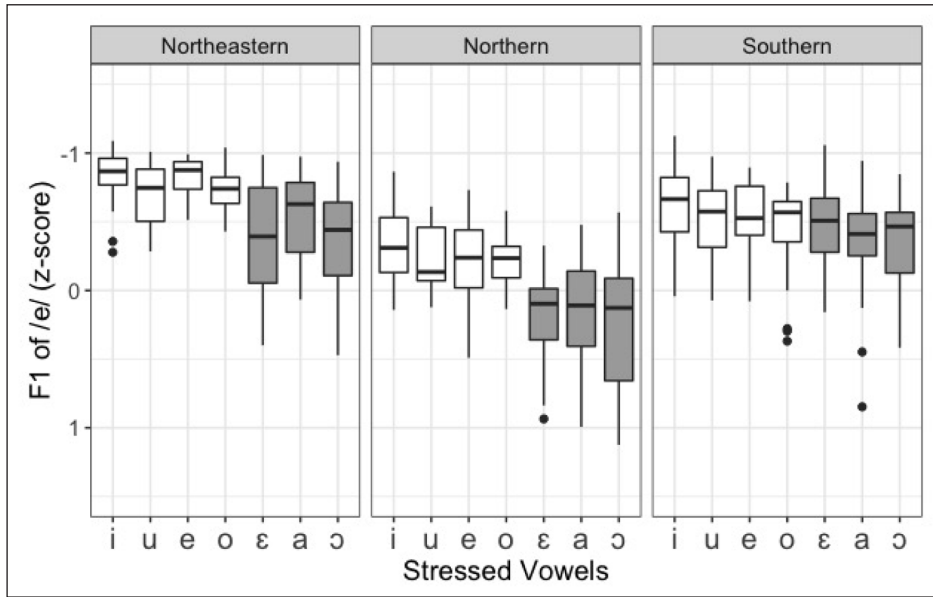
Figure 4: F1 (z-score) of /e/ as a function of the seven stressed vowels by dialect; white boxes = non-low vowels, grey boxes = low vowels.
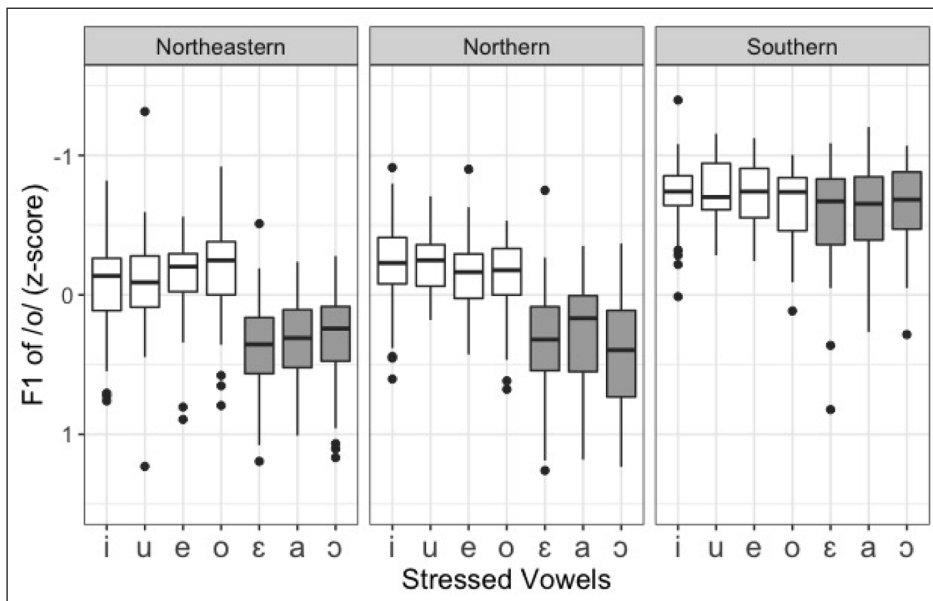

Figure 5: F1 (z-score) of /o/ as a function of the seven stressed vowels by dialect; white boxes = non-low vowels, grey boxes = low vowels.

To summarize, F1 of pretonic /e/ and /o/ is typically higher (the vowel is lower) when it is followed by a stressed low vowel /ɛ, a, ɔ/ as compared to a following stressed non-low vowel, indicating that all three dialects exhibit some kind of low harmony. Height harmony, thus, a realization with lower F1 values before the high vowels /i, u/ could not be observed. With respect to dialect-specific differences, we could observe that in N-D, the pretonic /e, o/ had generally higher F1, thus were realized lower, than in Sou-D, where they had lower F1 values. For NE-D, the two vowels were not realized homogeneously: /e/ patterns with the higher /e/ in Sou-D, whereas /o/ patterns with the lower /o/ in N-D.

We also saw some dialect-specific diferences in the realization of low harmony. In NE-D and N-D, pretonic /e, o/ seem to change more categorically to [ɛ, ɔ] when followed by /ɛ, a, ɔ/ while in Sou-D this effect seems more gradient. The following section has a closer look at this possible difference between two types of low harmony.

3.3. Gradient and Categorical Effects in the Assimilation of Pretonic Vowels

To investigate further the dialectal differences and especially the question whether we observe gradient or categorical effects of low vowel harmony, additional linear mixed-effect models for pretonic /e/ and /o/ were performed with pretonic F1 as function of stressed F1, vowel height of stressed vowel (coded low or non-low based on our previous findings), and dialect.

We found that the slope of the regression line between F1 of pretonic and F1 of stressed vowels is significantly positive for both /e/ and /o/ in each dialect ($p < 0.001$). Overall, this reflects the fact that pretonic /e/ and /o/ tend to be lowered before low vowels in all dialects, as we already reported in the previous section. The analysis shows that the strongest correlation between pretonic F1 and stressed F1 arises in N-D ($\tau > 0.58$ for /e/ and $\tau > 0.53$ for /o/), that there is also a robust correlation between the two in NE-D ($\tau > 0.30$ for /e/ and $\tau > 0.34$ for /o/), and that the correlation in Sou-D is similar to NE-D for /e/ ($\tau > 0.32$), but very weak for /o/ ($\tau > 0.17$).

In the following regression models, we analyzed for each dialect and pretonic vowel the influence of low and non-low stressed vowels. We hypothesised that a significantly positive slope of the regression line for each low and/or non-low category, evidences that pretonic vowels are sensitive to V-to-V coarticulation, even when they do not undergo a categorical change. **Table 6** summarizes the results of each regression model.

Table 6: Regression model for pretonic /e/ and /o/ followed by low and non-low stressed vowels. Each β coefficient indicates the slope of the F1-to-F1 correlation line (shown in Figures 6–8), and the associated p-value quantifies whether the slope significantly differs from zero.

Dialect	Pretonic Vowel	Stressed Vowel	β	(SE)β	t	p
Northeastern	/e/	low	−0.12	0.03	−3.33	0.001
		non-low	0.09	0.05	1.65	0.09
	/o/	low	0.06	0.03	1.72	0.08
		non-low	−0.01	0.06	−0.225	0.82
Northern	/e/	low	0.06	0.04	1.37	0.17
		non-low	0.30	0.05	5.70	<0.001
	/o/	low	0.06	0.04	1.34	0.18
		non-low	0.25	0.05	4.87	<0.001
Southern	/e/	low	0.12	0.06	1.96	0.05
		non-low	0.50	0.05	9.84	<0.001
	/o/	low	0.09	0.04	2.22	0.02
		non-low	0.39	0.09	4.24	<0.001

These correlations between pretonic F1 and stressed F1 are illustrated separately for the three dialects in **Figures 6, 7** and **8**, with pretonic /e/ on the left side, and pretonic /o/ on the right. In each figure, the effect of the stressed low vowels are in red, and of the stressed non-low vowels in green (both with their separate regression lines). These two groups are supposed to be fairly separate on the x-axis (the F1 of the stressed vowels), as low stressed vowels should have higher F1 values than non-low stressed vowels.

Let us start by looking at Sou-D in **Figure 6**. For the speakers of this dialect, the two stressed vowel groups (red dots vs. green dots) are indeed fairly separate on the x-axis, though more so for pretonic /e/ on the left than for pretonic /o/ on the right. This suggests that the Sou-D vowel targets are not changed to another vowel category. Furthermore, the slope of the regression lines for these two stressed vowel groups are in all cases positive (though lower, i.e. less steep, for the low vowels than for the non-low ones), indicating a phonetic dependency of the pretonic F1 on the stressed F1 within both categories, and thus V-to-V coarticulation. At the same time, the two stressed vowel groups totally

overlap in their values on the y-axis (for both pretonic vowels): The realizations of the pretonic vowels are the same, whether they occur before stressed low vowel or stressed non-low vowels, showing that there is no evidence for a categorical VH process occurring in this dialect, only the already-mentioned phonetic V-to-V assimilation.
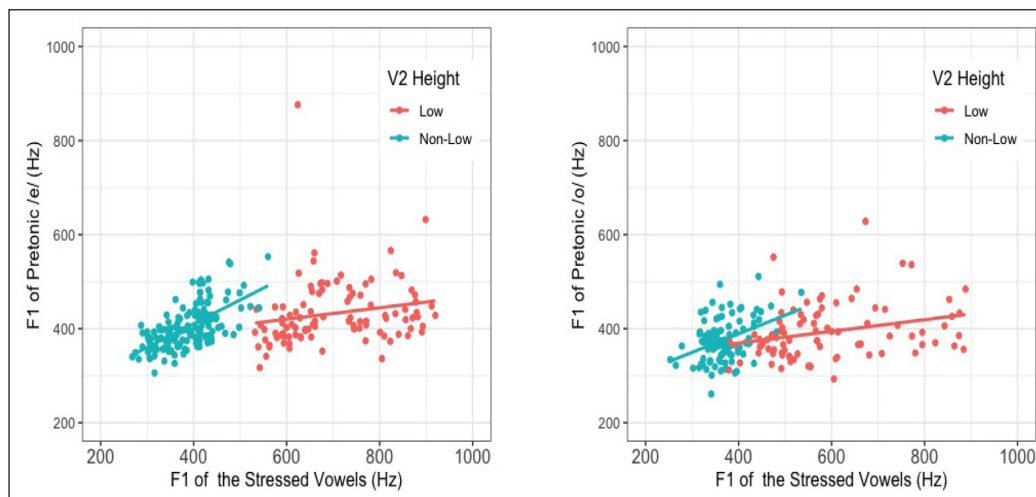

Figure 6: Correlation between stressed F1 (Hz) and pretonic F1 (Hz) for tokens produced by Sou-D speakers, with pretonic /e/ on the left, and pretonic /o/ on the right. Red dots = low stressed vowels, green dots = non-low stressed vowels.

Figure 7 presents the correlation of the F1 values of the pretonic vowels and F1 of the stressed vowels for the speakers of NE-D. As expected, the dots for low and for non-low stressed vowel context are quite separate on the x-axis. On the y-axis of **Figure 7**, there is more differentiation for the pretonic F1 values between low and non-low stressed vowel context than we saw for Sou-D in **Figure 6**, indicating a more consistent division between low and non-low in their influence on the pretonic vowel, thus more categorical low harmony. Support for the categorical nature of this lowering comes from the fact that the mean F1 values of the pretonic vowels in this context, i.e. 420 Hz (with 58 Hz SD) for /e/ and 529 Hz (with 72 Hz SD) for /o/, are very similar to the F1 values of stressed /ɛ/ and /ɔ/ in this dialect, namely 478 Hz and 545 Hz, respectively (cf. **Table 4**).

Looking at the regression lines for low and non-low vowel influence, they have fairly flat slopes, and the slope for the influence of low stressed vowels on pretonic /e/ is even significantly negative (–0.12, t = –3.33, p = 0.001). This is likely related to the fact the /e/ followed by stressed /a/ is a little bit higher than when followed by stressed /ɛ/ and /ɔ/ (see also **Figure 5**). Due to the flatness of the slopes, we have no evidence for V-to-V coarticulation in this dialect.

The F1 values of the pretonic vowels produced by N-D speakers are shown in **Figure 8**. Here, a very clear divide of low and non-low stressed vowel context on the x-axis can be observed, and also some division on the y-axis, again indicating a more categorical low harmony process than for the Sou-D speakers, similar to that observed for the NE-D speakers. Again, we find support for the categorical nature of lowering in the similarity of the mean F1 values of the pretonic vowels in this context, i.e. 511 Hz (with 60 Hz SD) for /e/ and 540 Hz (with 65 Hz SD) for /o/ to the F1 values of stressed /ɛ/ and /ɔ/, namely 586 Hz and 614 Hz, respectively (cf. **Table 4**).

In this dialect, the slopes of the regression lines within the vowel groups are positive, but significant only for the non-low stressed group, suggesting that there is some phonetic gradience grounded in V-to-V coarticulation for the production of the targets followed by non-low /i, u, e, o/, as observed in Sou-D as well, while following stressed low vowels do not cause a significant difference in pretonic F1.
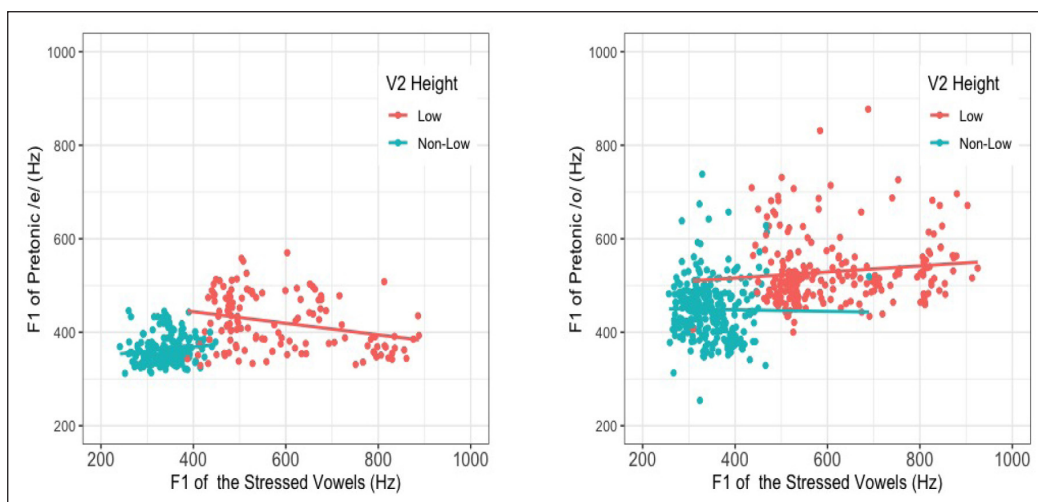
Figure 7: Correlation between stressed F1 (Hz) and pretonic F1 (Hz) for tokens produced by NE-D speakers, with pretonic /e/ on the left, and pretonic /o/ on the right.
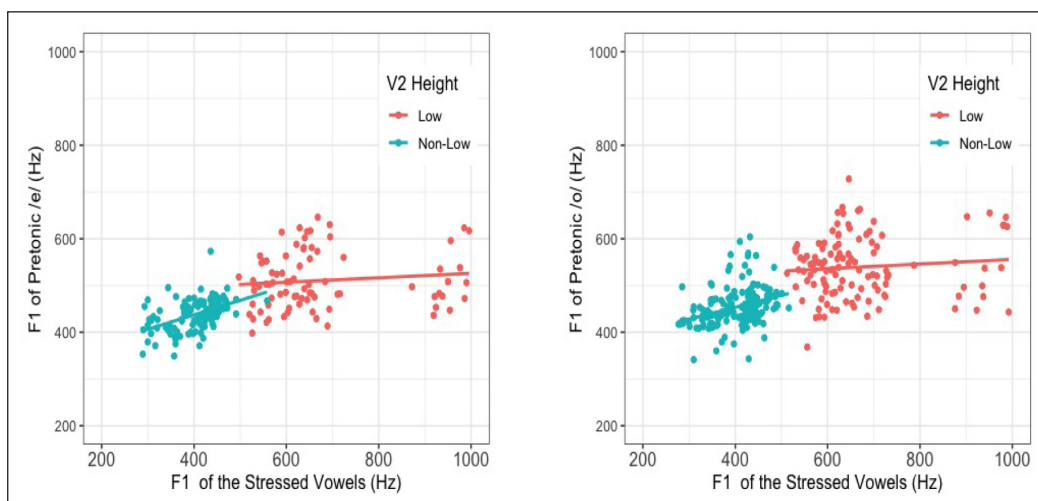

Figure 8: Correlation between stressed F1 (Hz) and pretonic F1 (Hz) for tokens produced by N-D speakers, with pretonic /e/ on the left, and pretonic /o/ on the right.

To summarize this section, we found the following cross-dialectal differences: In N-D and NE-D, pretonic /e, o/ tend to categorically become [ɛ, ɔ] triggered by stressed low vowels, which characterizes these two dialects of BP as having low vowel harmony. The non-low stressed vowels, on the other hand, caused V-to-V coarticulation in the F1 of the pretonic vowels in N-D but not in NE-D. For the Sou-D, we did not find categorical changes in the F1 of the pretonic vowels to defend a traditional harmonizing process, but these vowels were sensitive to the stressed vowel height: They show V-to-V coarticulation to the height of the following low and non-low stressed vowels.

Our data thus showed that within the two harmonizing dialects NE-D and N-D, a categorical change is happening when /e, o/ are followed by the stressed vowels /ɛ, a, ɔ/. The effect of stressed /i, u, e, o/ can differ: It might cause a V-to-V coarticulation effect as in N-D, but it might also result in more categorical behaviour in /e, o/ remaining unaffected as in NE-D. Sou-D exhibits a complete V-to-V coarticulation system, where low vowels force an assimilation, but its magnitude is not strong enough to change pretonic /e, o/ into [ɛ, ɔ]. We thus observed both categorical and gradient effects in harmonizing dialects, but only gradient effects as product of V-to-V coarticulation is present in the non-harmonizing variety.

4. Summary and General Discussion

Our experimental study has clarified the phonetic characteristics of vowel harmony in three dialects of BP. The pretonic mid-vowels /e, o/ lowered categorically when followed by the subset of low vowels /ɛ, a, ɔ/ in N-D and NE-D, while in Sou-D they only showed coarticulatory sensitivity to the stressed low vowels. Thus, low vowel assimilation (categorically or gradient) was observed for both /e/ and /o/ and seems to be systematic for all three varieties. We found no difference in influence between mid and high harmony triggers on the pretonic vowels in the analysis presented in §3.2, and hence no indication for height harmony in any of the dialects. Further analyses presented in §3.3 showed a difference in amount of lowering between the three dialects. For N-D and Sou-D the F1 values of pretonic /e, o/ were positively correlated to the F1 values of the non-low stressed vowels that follow them, suggesting that within-category V-to-V coarticulation is present in the non-harmonic system of Sou-D and in one of the harmonic systems, N-D. Our results can be summarized as given in **Table 7**.

Table 7: The behavior of pretonic /e, o/ in the three dialects.

Dialect	Harmony	Harmony Triggers	V-to-V Coarticulation
Notheastern	✓	/ɛ, a, ɔ/	–
Northern	✓	/ɛ, a, ɔ/	gradient in non-low contexts
Southern	non-harmonic	–	gradient in all vowel contexts

While NE-D and N-D showed predictable changes in their pretonic vowels resulting in phonetic [ɛ, ɔ], Sou-D showed a more gradient effect, where /e, o/ were sensitive to the height of the stressed vowel but did not lower to a different category. We interpret this as the presence of a categorical low/non-low harmony in NE-D and N-D, and a V-to-V coarticulation in Sou-D. One could go even further in the interpretation of our results on the difference in lowering between the dialects and say that Sou-D has an emergent vowel harmony system, similar to observations in languages that present both harmonizing and non-harmonizing dialects. For French, for instance, Nguyen and Fagyal (2008) report that the phonological height and F1 frequency of V_2 provided evidence that harmony shows a gradient pattern in non-harmonizing dialects of Southern French compared to the harmonizing dialects of Northern French. Moreover, Przezdziecki (2000: 105) shows that in Yoruba the magnitude of acoustic effects of V-to-V coarticulation is much smaller in non-harmonizing dialects than in harmonizing ones. Our findings on harmony patterns observed in BP seem to confirm the claim that V-to-V spreading is on the basis of a phonological right-to-left VH in this language. Although we need to be careful with interpreting our results because of our limited number of participants, it seems that a diachronic motivation is the basis of synchronic harmony, as proposed by Ohala (1994) for vowel harmony in general. Our findings might support the claim that V-to-V coarticulation is a more general speech phenomenon that exists independently of and often together with phonological harmony, and could phonologize into a harmony process across time.

The findings of our study show evidence exclusively of pretonic lowering in the three BP varieties, and therefore, differ from what has been found in earlier experimental work on vowel harmony in Brazilian Portuguese (Abaurre & Sandalo 2009; Barbosa et al. 2019; Abaurre & Sandalo 2017; Kenstowicz & Sandalo 2016; Sandalo 2012; Sandalo et al. 2013), namely that pretonic vowels undergo both height and low harmony, recall examples (4) and

(5), respectively: We found no evidence for height harmony. In these previous studies, the corpus comprised of at least 60% real and frequent words, such as *pepino* 'cucumber' and *coruja* 'owl'. While written with graphemes corresponding to non-high pretonic vowels, words like these are more frequently produced with pretonic high vowels [i] or [u], and show no alternations of [e ∼ i] or [o ∼ u] in this position. It is therefore very likely that BP speakers have stored these words with high pretonic vowels in their mental lexicon (showing a mismatch between orthography and underlying representation), and do not apply an active process of height harmony (see Becker, Nevins, Sandalo, and Rizzato (2018) who make a similar point with respect to [w ∼ j] plural alternations in BP). Our present study showed that for nonce words with the same orthographic presentation of pretonic vowels as the one found in the real words of earlier experimental studies, height harmony does not occur.[4]

The facts presented here have led us to argue that BP speakers only retain one aspect (or have innovated a different aspect) of VH, namely low harmony, but have lost the once productive height harmony. Variations of height within the subset of non-low vowels do not affect low harmony. Thus, although variations such as [e ∼ i] or [o ∼ u] can still be observed, the tendency is towards agreement with the subset of low vowels [ɛ, a, ɔ] while maintaining the mid-high vowels elsewhere in a pretonic position. These findings for pretonic vowels indicate that they are mainly sensitive to the height of the stressed vowels.

For Sou-D, we found that pretonic /o/ is realized very high (with very low F1 values), partly overlapping with the realisations of pretonic /u/, indicating a possible merger of the two back vowels pretonically for the male speaker. As we showed, the high realization of /o/ did not restrict its phonetic dependence on the following stressed vowel. Future studies need to clarify whether Sou-D is in the progress of an ongoing merger of pretonic back vowels.

We now turn to the point of how the observed low harmony process in N-D and NE-D could be represented phonologically. With respect to low harmony in BP dialects, the feature [ATR] has been proposed (e.g., Lee 2010; Bohn 2014; Hora & Vogeley 2013; Madruga 2017), where [–ATR] refers to the stressed trigger vowels /ɛ, a, ɔ/, spreading to the [+ATR] pretonic vowels. Such an account could be criticised for two reasons. The first is that cross-linguistically, [+ATR] harmony is much more common, and therefore one could assume [+ATR] is the marked realization that needs to spread. However, there are many well-attested languages whose dominant feature in VH is [–ATR], for instance Akan (Stewart 1967), Yoruba (Archangeli & Pulleyblank 1989), and Komo (Otero 2015), contradicting this claim.[5] A second reason against the use of [–ATR], or [ATR] in general, is its phonetic definition, which does not lend itself for the set of low vowels that trigger the process in BP. A phonetically more straightforward feature to account for this process would therefore be the binary [±low] (in parallel to the analysis by Nguyen & Fagyal 2008 for French, and Henriksen 2017 for Spanish), with /ɛ, a, ɔ/ being specified as [+low] and /i, e, u, o/ as [–low].[6] Low harmony could then be described as the spreading of [+low]

---

[4] One could argue that these results are only found in pseudowords because speakers tend to use faithful grapheme-to-phoneme mapping, which would explain why height harmony is not present. However, the speakers showed systematic differences in the pretonic vowels of these words, which are only explainable by the quality of the stressed vowel. This shows that speakers are applying a phonological process to these novel words.

[5] A detailed discussion about both types of [ATR] harmony can be found in Casali (2014, 2018), who asserts that the dominance of one feature value over another is correlated with the distinction of [ATR] among the high vowels of the inventory. According to this author, [+ATR] dominance is expected if there is a distinction in [ATR] among the high vowels, such as /i, u/ versus /ɪ, ʊ/, otherwise [–ATR] should be the active feature.

[6] See also Wetzels (1995) for a discussion on the role of a low/non-low distinction for the BP vowel system.

from the stressed to the pretonic vowels. Alternatively, a privative feature [low] could be used, where only the stressed vowels /ɛ, a, ɔ/ are assigned the feature [low], since this class triggers harmony, whereas the group of vowels that we described in the present article as non-low would remain unspecified and therefore does not trigger harmony.

5. Conclusions

In this paper, we studied the acoustic realizations of the pretonic vowels /e, o/ in three dialects of Brazilian Portuguese, namely Northeastern, Northern and Southern, by examining the production of non-words by two speakers of each variety. These pretonic mid-high vowels in Brazilian Portuguese have been traditionally described as undergoing two types of vowel harmony: A raising process caused by following stressed high vowels /i, u/, reported to be present in all dialects of the language, and a lowering process caused by the following stressed low vowels /ɛ, a, ɔ/, that has been portrayed as dialect-specific. In contrast to these earlier descriptions, our present data showed that vowel harmony is only triggered by stressed low vowels, i.e. that it is actually a low harmony process, occurring in two of the three dialects that we tested (Northern and Northeastern). Height harmony could not be observed in any of the three varieties.

A possible explanation on why there is a discrepancy between earlier studies and our own findings with respect to height harmony can be found in sociolinguistic studies, which have shown that the earlier reported type of height harmony has been decreasing in BP over the decades (Rocha & Brandão 2015; Schwindt 1995). These studies suggest that the observed height harmony, based on assimilation of [+high], is a residual from a process that was once active in Portuguese but that might not be active in contemporary spoken BP any longer. The result of this former harmony process is still observable in the present-day language in lexicalized forms: words that used to undergo height harmony are learned and stored by the younger generation of speakers as having high pretonic vowels in their underlying form (see Oliveira 1991, for this discussion). With the pseudowords in our experiment we could show that present-day speakers indeed no longer have an active process of height harmony.

To account for what we observed in our data, we propose that low harmony is an innovative process that spreads across dialects where previously gradient V-to-V assimilation was observed. Our results suggest that low harmony is already an active phonological harmony process in the Northern and Northeastern dialect, whereas in the Southern dialect it is still only gradient. However, due to the limited number of just two participants per dialect in our study, we cannot determine whether the findings indeed reflect dialectal trends or whether they are based on speaker-specific patterns. Future studies with more speakers are necessary to shed light on the question whether Northern and Northeastern dialects indeed have systematic low harmony, while Southern dialects have not. In the future, it might also be necessary to apply a more fine-grained distinction between dialect groups than the three areas that we distinguished in the present study and to take sociolinguistic stratification into account (as our participants were all university students).

We furthermore observed that along with a categorical process of low harmony, the Northern dialect also showed a gradient V-to-V assimilation of the pretonic vowels to the following high vowels, the class that does not cause low harmony. Similar to earlier findings by Nguyen and Fagyal (2008) for French and Przezdziecki (2000) for Yoruba, we thus found a co-occurrence of vowel harmony with vowel coarticulation within the same dialect. Future experimental studies on vowel harmony in Brazilian Portuguese as well as other languages would profit by incorporating this observation and considering the possibility that V-to-V assimilation effects can be found alongside with categorical vowel harmony in the same language.

Additional File

The additional file for this article can be found as follows:

Acknowledgements

Competing Interests

The authors have no competing interests to declare.

References

Abaurre, M. B. M., & **Sandalo, M. F.** (2009). Representação e subespecificação de vogais no português [Vowel representation and subspecification in Portuguese]. *Cadernos de Pesquisa em Linguística, 4*(1), 21–40.

Abaurre, M. B. M., & **Sandalo, M. F.** (2017). Coarticulação e harmonia vocálica [Coarticulation and vowel harmony]. *Cadernos de Estudos Linguísticos, 59*(3), 487–497. DOI: https://doi.org/10.20396/cel.v59i3.8650984

Abaurre-Gnerre, M. B. M. (1981). Processos fonológicos segmentais como índices de padrões prosódicos diversos nos estilos formal e casual do português do brasil [Segmental phonological processes as indexes of prosodic patterns in formal and casual spech style in Brazilian Portuguese]. *Cadernos de Estudos Linguísticos, 2,* 23–44.

Alves, M. M. (2008). *As vogais médias em posição pretônica nos nomes no dialeto de belo horizonte: estudo da variação à luz da teoria da otimalidade [Mid vowels in pretonic position in nouns in belo horionte dialect: study of variation in light of optimality theory]* (Doctoral dissertation, Federal University of Minas Gerais, Belo Horizonte). Retrieved from https://goo.gl/5moyhj

Araújo, A. A. D. (2007). *As vogais pretônicas no falar popular de Fortaleza: uma abordagem variacionista [Pretonic vowels in Fortaleza popular speech: a variationist approach]* (Doctoral dissertation, Federal Univesity of Ceará, Fortaleza). Retrieved from https://goo.gl/k1DXzj

Archangeli, D., & **Pulleyblank, D.** (1989). Yoruba vowel harmony. *Linguistic Inquiry, 20*(2), 173–217.

Barbosa, P., & **Albano, E.** (2004). Brazilian Portuguese. *Journal of the International Phonetic Association, 34,* 227–232. DOI: https://doi.org/10.1017/S0025100304001756

Barbosa, P., Papa, P. B., Silva, B. A., & **Mourão, N.** (2019). Harmonia vocálica e coarticulação vogal a vogal em duas variedades do português brasileiro [Vowel harmony and V-to-V coarticulation in two varieties of Brazilian Portuguese]. *DELTA: Documentação de Estudos em Linguística Teórica e Aplicada, 35*(2). DOI: https://doi.org/ 10.1590/1678-460x2019350202

Barreda, S. (2014). phontools: Functions for phonetics in r. [Computer software manual]. (R package version 0.2-2.0).

Bates, D., Mächler, M., Bolker, B., & **Walker, S.** (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*(1), 1–48. DOI: https://doi.org/10. 18637/jss.v067.i01

Becker, M., Nevins, A., Sandalo, F., & **Rizzato, É.** (2018). The acquisition path of [w]-final plurals in Brazilian Portuguese. *Journal of Portuguese Linguistics, 17*(1). DOI: https://doi.org/10.5334/jpl.189

Bisol, L. (1981). *Harmonização vocálica, uma regra variável [Vowel harmonization, a variable rule]* (Unpublished doctoral dissertation). Brazil: Federal University of Rio de Janeiro, Rio de Janeiro.

Bisol, L. (1989). Vowel harmony: a variable rule in Brazilian Portuguese. *Language Variation and Change, 1*(2), 185–198. DOI: https://doi.org/10.1017/S0954394500000065

Boersma, P., & **Weenink, D.** (2015). *Praat: doing phonetics by computer.* Amsterdam: Department of Language and Literature, University of Amsterdam.

Bohn, G. P. (2014). G[e]lat[i]na e b[ɛ]rnad[ɛ]te: um estudo sobre a adjacência na harmonia vocálica do português brasileiro [G[e]lat[i]na e b[ɛ]rnad[ɛ]te: a study about adjacency in Brazilian Portuguese vowel harmony]. *Letras de Hoje, 7*(2), 608–626. DOI: https://doi.org/10.15448/1984-4301.2014.2.17894

Bortoni, S., Gomes, C., & **Malvar, E.** (1992). A variação das vogais médias pretônicas no português de Brasília: um fenômeno neogramático ou de difusão lexical? [Mid pretonic variation in Portuguese spoken in Brasília: a neogrammatical phenomenon or lexical difusion]. *Revista de Estudos da Linguagem, 1*(1), 9–30. DOI: https://doi.org/10. 17851/2237-2083.1.1.9-30

Callou, D., Leite, Y., & **Moraes, J.** (1992). A elevação das vogais pretônicas no português do Brasil: processo(s) de variação estável [Pretonic vowel raising in Brazilian Portuguese]. *Letras de Hoje, 37*(1), 9–24.

Camara, J. M., Jr. (1970). *Estrutura da Língua Portuguesa [Portuguese Language Structure].* Rio de Janeiro: Editora Vozes.

Camara, J. M., Jr. (1977). *Princípios de Linguística Geral [Principles of General Linguistics].* Rio de Janeiro: Livraria Acadêmica.

Casali, R. F. (2014). Assimilation, markedness and inventory structure in tongue root harmony systems. *ROA 1207*, 201–239.

Casali, R. F. (2018). Markedness and dominance in the ATR harmony system of Diola-Fogny. *Journal of African Languages and Linguistics, 39*(2), 201–239. DOI: https://doi. org/10.1515/jall-2018-0008

Escudero, P., Boersma, P., Rauber, A. S., & **Bion, R. A.** (2009). A cross-dialect acoustic description of vowels: Brazilian and European Portuguese. *The Journal of the Acoustical Society of America, 126*(3), 1379–1393. DOI: https://doi.org/10.1121/1.3180321

Henriksen, N. (2017). Patterns of vowel laxing and harmony in Iberian Spanish: Data from production and perception. *Journal of Phonetics, 63*, 106–126. DOI: https://doi. org/10.1016/j.wocn.2017.05.001

Hora, D. D., & **Vogeley, A.** (2013). Harmonia vocálica no dialeto recifense [Vowel harmoni in Recife dialect (Brazilian Portuguese)]. *Organon, 28*(54), 63–81. DOI: https://doi.org/10.22456/2238-8915.37879

IBGE. (2019, 07). *Estimativas da população residente no brasil e unidades da federação com data de referência em 1 de julho de 2019 [Estimates of the population resident in Brazil and federative units with reference date on July 1, 2019]* (Tech. Rep.). Instituto Brasileiro de Geografia e Estatística [Brazilian Institute of Geography and Statistics]. Retrieved from https://agenciadenoticias.ibge.gov.br

Kenstowicz, M., & **Sandalo, F.** (2016). Pretonic vowel reduction in Brazilian Portuguese: Harmony and dispersion. *Journal of Portuguese Linguistics, 15*. DOI: https://doi.org/10.5334/jpl.7

Lee, S. H. (2006). Sobre as vogais pretônicas no Português Brasileiro [On the pretonic vowels in Brazilian Portuguese]. *Estudos Linguísticos, 35* (1), 166–175.

Lee, S. H. (2010). Contraste das vogais no PB e OT [Vowel contrast in BP via OT]. *Estudos Linguísticos, 39*(1), 35–44.

Lee, S. H., & **Oliveira, M. A. D.** (2003). Variação inter e intra-dialetal no português brasileiro: um problema para a teoria fonológica [Inter and intradialectal variation in Brazilian Portuguese: a problem for phonological theory]. In D. da Hora & G. Collischonn (Eds.), *Teoria linguística: fonologia e outros temas* (pp. 67–91). João Pessoa: Editora da UFPB.

Lobanov, B. M. (1971). Classification of Russian vowels spoken by different speakers. *The Journal of the Acoustical Society of America, 49*(2B), 606–608. DOI: https://doi.org/10.1121/1.1912396

Madruga, M. R. (2017). *The phonetics and phonology of Brazilian Portuguese [ATR] harmony* (Doctoral dissertation, State University of Campinas, Campinas). Retrieved from http://repositorio.unicamp.br/handle/REPOSIP/331442

Magen, H. S. (1971). The extent of vowel-to-vowel coarticulation in English. *Journal of Phonetics, 47*, 615–645. DOI: https://doi.org/10.1006/jpho.1996.0041

McCloy, D. R. (2016). phonr: tools for phoneticians and phonologists [Computer software manual]. (R package version 1.0-7).

Miranda, I. N. (2017). *Análise acústica das vogais orais tônicas e pré-tônicas e sua coarticulação na variedade capixaba [Acoustic analysis of oral pretonic and stressed vowels and their coarticulation in spoken Capixaba variety]* (Doctoral dissertation, State University of Campinas, Campinas). Retrieved from http://repositorio.unicamp.br/handle/REPOSIP/325061

Naro, A. J. (1971). The history of e and o in Portuguese: a study in linguistic drift. *Language, 25*(2), 187–205. DOI: https://doi.org/10.2307/412380

Nascentes, A. (1953). *A gíria brasileira [Spoken Brazilian Portuguese]*. Rio de Janeiro: Editora Acadêmica.

Nguyen, N., & **Fagyal, Z.** (2008). Acoustic aspects of vowel harmony in French. *Journal of Phonetics, 36*, 1–27. DOI: https://doi.org/10.1016/j.wocn.2007.07.001

Ohala, J. J. (1994). Towards a universal, phonetically-based, theory of vowel harmony. In *Third international conference on spoken language processing.*

Öhman, S. E. (1966). Coarticulation in VCV utterances: Spectrographic measurements. *The Journal of the Acoustical Society of America, 39*(1), 151–168. DOI: https://doi.org/10.1121/1.1909864

Oliveira, M. A. D. (1991). The neogrammarian controversy revisited. *International Journal of the Sociology of Language, 89*(1), 93–106. DOI: https://doi.org/10.1515/ijsl.1991.89.93

Otero, M. A. (2015). [+ATR] dominant vowel harmony except when it's not? evidence from Ethiopian Komo. In *44th Annual Conference on African Linguistics* (pp. 212–220).

Pacheco, V., Oliveira, M., & **Ribeiro, P. D. J.** (2013). Em busca da melodia nordestina: as vogais médias pretônicas de um dialeto baiano [In search of northeastern melody: the pretonic mid vowels of a Bahia dialect]. *Linguística [online], 29*(1), 165–187.

Przezdziecki, M. (2000). Vowel harmony and vowel-to-vowel coarticulation in three dialects of Yoruba. *Working Papers of the Cornell Phonetics Laboratory*, *13*(1), 5–24.

R Core Team. (2014). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria. Retrieved from http://www.R-project.org/

Recasens, D. (1985). Coarticulatory patterns and degrees of coarticulatory resistance in Catalan CV sequences. *Language and Speech, 28*(2), 97–114. DOI: https://doi.org/10.1177/002383098502800201

Rocha, F. D. M. V., & **Brandão, S. F.** (2015). Vogais médias pretônicas na fala da região sudeste: um panorama geo-sociolinguístico [Pretonic mid vowels in southeastern:a geo-sociolinguistic panorama]. *Signum: Estudos da Linguagem, 18*(1), 333–364. DOI: https://doi.org/10.5433/2237-4876.2015v18n1p333

Rodrigues, L. R. (2010). *Relações gradientes V-V em sequênicas VCV no português brasileiro [Gradient V-to-V patterns in VCV sequences in Brazilian Portuguese]* (Doctoral dissertation, Universidade Estadual de Campinas, Campinas – SP, Brasil). Retrieved from http://repositorio.unicamp.br/jspui/handle/REPOSIP/269060

Sandalo, M. F. (2012). Harmonia e redução vocálica no português do Brasil [Harmony and reduction in Brazilian Portuguese]. *Letras de Hoje, 47*(3), 268–274. DOI: https://doi.org/10.22456/2238-8915.37270

Sandalo, M. F., Abaurre, M. B., & **Madruga, M. R.** (2013). Dispersão e harmonia vocálica em dialetos do português do Brasil [Vowel harmony and dispersion in dialects of Brazilian Portuguese]. *Organon, 28*(54), 13–30. DOI: https://doi.org/10.22456/2238-8915.37270

Schwindt, L. C. (1995). *Harmonia vocálica em dialetos do sul do país [Vowel harmony in southern dialects of Brazil]*. Porto Alegre. Retrieved from https://docs.google.com/file/d/0B98IqtmAZ-MNMkNMOVBBU1VOUDQ/edit

Schwindt, L. C. (1997). A harmonia vocálica em dialetos do sul do país: uma análise variacionista [Vowel harmony in southern dialects of Brazil: a variationist analysis]. *Revista Graphos, 1*(3), 55–65.

Schwindt, L. C. (2002). A regra variável de harmonização vocálica no RS [The variable rule of vowel harmonization in Rio Grande do Sul state]. In L. Bisol & C. Brescancini (Eds.), *Fonologia e variação: recortes do português brasileiro* (pp. 161–182). Porto Alegre: EDIPUCRS.

Silva, M. B. D. (1989). *As pretônicas no falar baiano: a variedade culta de Salvador [The pretonics in Brazilian Portugue spoken in Bahia: the educated variety in Salvador]* (Unpublished doctoral dissertation). Universidade Federal do Rio de Janeiro, Rio de Janeiro.

Stevens, K. N. (2000). *Acoustic Phonetics* (Vol. 30). MIT Press. DOI: https://doi.org/10.7551/mitpress/1072.001.0001

Stewart, J. M. (1967). Tongue root position in Akan vowel harmony. *Phonetica, 16*(4), 185–204. DOI: https://doi.org/10.1159/000258568

Viegas, M. D. C. (1987). *Harmonia vocálica em dialetos do sul do país [Vowel harmony in sourthern dialects of Brazil]* (Unpublished doctoral dissertation). Belo Horizonte: Federal University of Minas Gerais.

Wetzels, W. L. (1995). Mid-vowel alternations in the Brazilian Portuguese verb. *Phonology, 12*(2), 281–304. DOI: https://doi.org/10.1017/S0952675700002505

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. New York: Springer-Verlag. Retrieved from https://ggplot2.tidyverse.org. DOI: https://doi.org/10.1007/978-3-319-24277-4_9