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Consonantal voicing and apocope in Brazilian Portuguese

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Abstract

This paper investigates the nature of apocope in Brazilian Portuguese (BP) and its interaction with consonantal voicing and noise. Apocope results in the emergence of word-final consonants that were historically restricted in BP. It develops as a consequence of the weakening and loss of word-final unstressed high front vowels. The findings reported in this paper indicate that apocope is implemented gradually at both lexical and phonetic levels. We propose that this phonetic reduction stems from the real-time weakening of the final unstressed high front vowel, triggering progressive changes that also affect adjacent segments. Voiceless consonants are more likely to favor apocope than voiced ones and tend to interact with consonantal noise. Notably, the noise duration of sibilant tends to increase when apocope occurs. Additionally, apocope contributes to vowel shortening in closed syllables. This study advances our understanding of apocope as a phenomenon shaped by multiple interacting factors that gradually reshape word structure in a gradual fashion across both phonetic and lexical domains.

Keywords: apocope, voicing, noise, word-final consonants, Exemplar Models.

1. Introduction

This paper evaluates the nature of apocope in Brazilian Portuguese (BP) and its interaction with consonantal voicing and noise. Apocope is defined as the loss of a word-final sound, typically a vowel (Campbell & Mixco 2007). When a word-final vowel is lost then word-final consonants emerge in a language. Apocope of unstressed final vowels has been observed across many languages such as English, Catalan, and French (Dauer 1980; Fischer 1980; Wheeler 2007; Minkova 2014). European Portuguese (EP) is also a language where apocope took place as in chave [ʃavɨ] > [ʃav] ‘key’ or longe [lõʒɨ] > [lõʒ] ‘far away’ where nowadays the pronunciation without the word-final vowel is the standard one (Mira Mateus 1975; Mira Mateus & Andrade 1998). Traditionally, Portuguese presented a restricted set of four word-final consonants. Consider (1).

(1)	**Consonant**	**Orthography**	**Representation**	**EP**	**BP**	**Gloss**
	a. /N/	*som*	/soN/	[sõ]	[sõ]	*sound*
	b. /l/	*mil*	/mil/	[miɫ]	[miw]	*Thousand*
	c. /R/	*mar*	/maR/	[maɾ]	[mah]	*sea*
	d. /S/	*luz*	/luS/	[luʃ]	[lus]	*light*

Examples in (1) show the four consonants that are phonologically attested word-finally in Portuguese (Câmara Jr. 1999; Bisol 1999; Cristófaro Silva 2023). Several of these consonants have undergone phonological processes where a consonant was avoided word-finally mainly in BP. In (1a) a former nasal consonant was lost historically as the preceding vowel became nasal. In (1b) the word-final lateral vocalized to a posterior glide in most varieties of BP whereas in EP the lateral is usually preserved. In (1c) the word-final rhotic vary considerably. In EP it is usually a tap whereas in BP it may be a tap, a posterior fricative, a retroflex or be omitted. In (1d) the sibilant is preserved in both varieties being either alveopalatal or alveolar: *luz* [luʃ] ~ [lus] ‘light’.

Different varieties of Portuguese have taken distinct phonological routes regarding the segmental material in word-final position. EP expanded the set of word-final consonants as a consequence of apocope, whereas BP tends to avoid word-final consonants by inserting epenthetic vowels word-finally particularly in neologisms and loanwords, as illustrated in (2).

(2)	**Orthography**	**English**	**BP**
	drink	[drɪŋk]	[ˈdɾĩki]
	blog	[blɒg]	[ˈblɔgi]
	slide	[slaɪd]	[izˈlaɪʤi]
	chat	[ʧæt]	[ˈʃaʧi]

Examples in (2) illustrate the insertion of a high front epenthetic vowel in word-final position to prevent word-final consonants in BP (Collischonn 1996, 2000). Epenthetic vowels also appear word-internally in BP, breaking up clusters of obstruent consonants as in *pacto* [ˈpakitu] ‘pact’ or *adaptar* [adapiˈtah] ‘to adapt’ (Cristófaro Silva & Almeida 2008; Nascimento 2017). The facts illustrated previously support the view that BP generally tends to favor open syllables, that end in vowels, rather than consonant-final syllables or complex consonantal sequences. However, such a tendency appears to be shifting, with an emerging tendency towards favoring closed syllables. We propose that this shift is driven by a broader mechanism of vowel reduction – common in stress-timed languages (Bybee *et al.* 1998) – that promotes apocope in BP. [1] Consider (3).

(3)	**Orthography**	**Transcription**	**Gloss**
	a. *cheque*	[ˈʃɛki] ~ [ˈʃɛk]	*check*
	b. *sangue*	[ˈsɐ̃gi] ~ [ˈsɐ̃g]	*blood*
	c. *chave*	[ˈʃavi] ~ [ˈʃav]	*key*
	d. *peixe*	[ˈpeʃi] ~ [ˈpeʃ]	*fish*

Apocope is a recent ongoing phenomenon in BP, whereby an unstressed high front vowel ceases to occur word-finally resulting in the occurrence of word-final consonants. This innovative pattern has been documented across several varieties of BP among children and adults and is characterized as a variable and productive phenomenon (Pagel 1993; Viegas & Oliveira 2008; Rolo & Mota 2012; 2021; Dias & Seara 2013; Araújo 2020). The motivation for apocope lies in the low prominence of unstressed vowels, which makes them susceptible to reduction, particularly in word-final position, an especially conducive context to vowel weakening and loss (Lemle 1966; Câmara Jr. 1999; Major 1981; Bisol 2003; Battisti 2012; Marusso 2003; Abaurre, Sandalo & González-López 2014). High vowels are the shortest in duration among all vowels, being a factor that further contributes to apocope in BP (Keating 1985). Additionally, because apocope occurs at word boundaries, it aligns with the broader cross-linguistic tendency for sound changes to be more frequent and robust at word edges (Harris 2011).

The weakening and loss of high front vowels in BP was first reported in the 1960s (Lemle 1966). However, more detailed investigations across different BP varieties began to be carried out in the 1990s. Pagel (1993) proposed that weakened vowels were often realized as voiceless variants when adjacent to voiceless consonants. More recent studies have examined the broader emergence of word-final consonants in BP, suggesting that this is a widespread and systematic phenomenon in the language. Rolo and Mota (2012) showed that word-final vowel loss occurs before both voiced and voiceless consonants. Dias and Seara (2013) conducted experimental research demonstrating that unstressed word-final vowels are significantly reduced in both duration and articulatory magnitude compared to stressed vowels. Vieira and Cristófaro-Silva (2015) argued that word-final vowel loss is a phonetically gradual phenomenon that has reached an advanced stage of implementation in BP. Assis (2017) found that apocope gradually restructures the temporal organization of words. Araújo (2020) also observed that the weakening and loss of word-final vowels is a phonetically gradual and ongoing process, variably implemented in different acoustic realizations. These findings indicate that vowel reduction, in its more advanced stages, reflects apocope.

Meneses and Albano (2015) offer an alternative interpretation of the reduction of unstressed word-final vowels following a sibilant [s], as in passe [ˈpasi] ~ [pas]

[1] An interesting issue to be addressed in future research is the consequences of apocope to the suprasegmental structure of BP as a stress-timed language.

'entry ticket'. According to their analysis, the vowel is neither elided nor lost. Instead, its prototypical acoustic properties are drastically altered due to gestural overlap in articulatory coordination. Under this view, a "devoiced vowel" lacks phonation correlates but remains present, temporally overlapping with a voiceless sibilant. However, as previously discussed, apocope in BP is not limited to voiceless contexts or to adjacency to sibilants. It also occurs adjacent to sonorants, illustrating the broader scope of the phenomenon. Examples such as aquele > [aˈkel] 'that', longe > [lõʒ] 'distant', and nome > [nõm] 'name' demonstrate that vowel loss extends beyond voiceless sibilant-adjacent environments (Pagel 1993; Viegas & Oliveira 2008; Rolo & Mota 2012, 2021; Assis 2017).

The facts discussed above indicate that the loss of word-final high front vowels in BP reflects a general tendency toward allowing a wider range of consonants in word-final position. In the remainder of this paper, we investigate the extent to which apocope occurs in BP, focusing on its lexical distribution and its phonetically gradual implementation. Our aim is to corroborate previous findings while expanding the analysis to include the acoustic properties of the word-final high front vowel, with particular attention to its duration in relation to the type of preceding consonant. Specifically, we examine how voicing and the degree of consonantal noise interact to promote higher rates of apocope.

In addition to expanding on previous findings regarding the implementation of apocope, this study also examines its effects on adjacent segments. We hypothesize that apocope has implications for the temporal and articulatory organization of speech in the language, which can be revealed through detailed experimental analysis. To this end, we investigated the duration of noise intervals in word-final consonants and the duration of the primarily stressed vowel. In conditions where apocope occurs, we expect longer consonantal noise durations and shorter stressed vowel durations, as a consequence of syllable restructuring.

The theoretical framework adopted in this study is based on Exemplar Models (Johnson 1997; 2007; Pierrehumbert 2001; Bybee 2001), a perspective well aligned with the experimental approach advocated by Laboratory Phonology (Pierrehumbert, Beckman & Ladd 2011). Exemplar-based approaches are particularly suited for modelling apocope as a phenomenon that is both lexically specific and phonetically gradual, consistent with the mechanism of reductive phenomena commonly found in stress-timed languages (Bybee *et al*. 1998).

2. Exemplar Models

The study of sound change is an interesting area of research as it involves the transition from one sound to another across time. A crucial issue in this debate is whether sound change occurs gradually or abruptly centering on its spreading in the lexicon as well as its phonetic implementation (Wang 1969; Labov 1981; Oliveira 1992). With the expansion of experimental methods, mainly through the development of Laboratory Phonology (Pierrehumbert, Beckman & Ladd 2011), the traditional view of sound change as abrupt has been challenged. Phonetically motivated sound changes, such as segmental deletion or assimilation, are better understood as being phonetically implemented in a gradual fashion. This is because either a new sound enters the system, as in the cases of allophones, or a sound ceases to occur, which tends to create a novel phonological pattern in the language. Analogical sound changes, on the other hand, may appear to spread abruptly because they often involve reanalysis of an existing sound in the language rather than gradual articulatory drift.

The sound change investigated in this paper is phonetically motivated and involves the reduction of temporal and articulatory gestures – making it well suited for experimental through the investigation of language-specific phonetic detail involved in its development. Exemplar Models is thus a useful theoretical framework that accommodates the experimental investigation of sound changes by examining its gradual implementation (Johnson 1997; 2007; Pierrehumbert 2001; Bybee 2001). Within this view, sound systems are dynamic and ever-changing, presenting emergent features accounting for the development of languages as they are shaped continuously by speakers' linguistic experiences.

Exemplar-based approaches assume that words or constructions are the primary units of linguistic representation, each associated with multiple stored exemplars which contain detailed linguistic and non-linguistic information in which the utterance occurs. Sound changes take place within words and therefore are lexically implemented. Exemplars arise from experiences stored in the speaker's memory so that several instances of a lexical item, with detailed information, are retained in the mental representations alongside detailed acoustic and articulatory properties. Highly used exemplars tend to be more central to their phonological categories, being thus more robust and contributing to the spreading of the sound change by propagating innovative patterns. Accordingly, different words are expected to present different rates of properties which trigger the pathway that implements the sound change.

A key feature of exemplar representations is that sound change is non-local. That means that a change in a segment may affect adjacent segments. For example, the nasal vowel [õ] in Portuguese derives from the former Latin nasal consonant that triggered the nasalization of the preceding vowel and eventually was deleted: *bonum* > [bõ] 'good'. This case illustrates how segmental loss can alter the shape of syllable structure as well as some of its segments so that the word has a new configuration. This view is compatible with the assumption that words are the core property of phonological representations. Exemplar Models are compatible with perspectives that consider dynamic systems, which holds that any change can have cascading effects throughout the linguistic system (Beckner *et al*., 2009). Within this perspective, phonological representations are inherently variable and subject to change.

In this paper we consider the nature of apocope in BP and its interaction with consonantal voicing and noise. Our goal is to account for the conditions under which apocope is implemented drawing on experimental data. The following section presents the methodological procedures of the experiment conducted for this study.

3. Methodology

A picture-naming experiment was designed for data collection. The experiment was conducted with 20 monolingual speakers of BP, from Belo Horizonte (MG), Southeastern Brazil. The sociolinguistic profiles of the participants were controlled considering Belo Horizonte as their place of birth and permanent residence, age, gender. Participants declared they had basic or no knowledge of English during recordings. The group was evenly divided by gender with participants aged between 18 and 26 years. All participants had completed high school and were enrolled as undergraduate students as of September 2022. No auditory or speech impairments were reported by any participants. All participants signed a term of consent detailing their voluntary collaboration in accordance with the approval of Coep (Ethics and Reseach Committee of the Federal University of Minas Gerais – CAAE: 15116119.9.0000.5149).

Participants were asked to name pictures embedded in carrier sentences presented in a slideshow. Data were collected in an acoustically treated room using a *Zoom* H4n portable recorder, configured to capture uncompressed audio in PCM format (.wav files) with a sampling rate of 44,100 Hz and 16-bit quantization. The experiment included 24 target words ending in a high front vowel, along with 18 distractor words ending in either [a] or [u].[2] All words, both target and distractors, had lexical stress attributed to their penultimate syllable. Stimuli were presented via a *Microsoft PowerPoint* (.pptx) file, and participants controlled the pace of the presentation. Each session lasted approximately 12 minutes. Participation was voluntary.

All target words ended in an unstressed high front vowel following an obstruent consonant. This final vowel was the segment potentially subject to apocope. A total of 12 obstruent consonants were selected to precede the word-final vowel: six voiceless ([p, k, ʧ, f, s, ʃ]) and six voiced ([b, g, ʤ, v, z, ʒ]). The stimuli were presented in twelve-syllable carrier sentences in which the target word appeared in sentence-medial position. Target words were previously presented in isolation to participants for memorization in an introductory round. As an example, *Lá na roça tem um bode perigoso* 'In the farm there is a dangerous goat', was created for the target word *bode* 'goat', as shown in Table 1.

Table 1. Example of a carrier sentence used in the experiment

Syllable position in the sentence											
1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**
Lá	*na*	*ro*	*ça*	*tem*	*um*	*bo*	*de*	*pe*	*ri*	*go*	*so*

Source: Table created by the authors

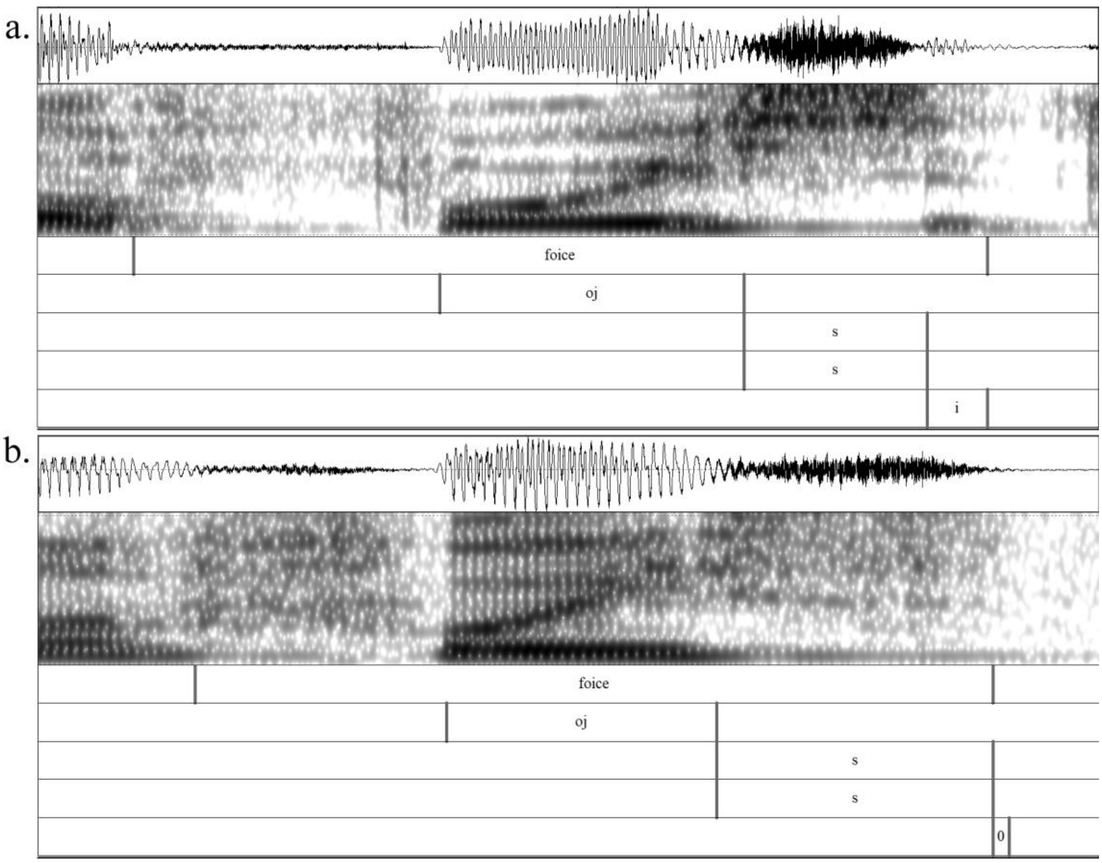
The example in Table 1 illustrates the structure of all carrier sentences used in the experiment. The unstressed word-final high front vowel that may be subject to apocope was positioned in the 8th syllable of the sentence, indicated in light grey. The 7th syllable contained the stressed vowel of the target word that immediately precedes the word-final syllable. The syllable following the target word, i.e., the 9th syllable, began with the voiceless stop [t]. For cases where the onset of the 8th syllable was an affricate [ʧ, ʤ], the 9th syllable began with [p] instead, in order to avoid homorganic clusters such as [ʧt] and [ʤt]. The choice of a voiceless obstruent in this position was intended to enhance the acoustic detectability of any residual vowel correlates in post-tonic position. Additionally, the 11th syllable, marked in dark grey in Table 1, carried the lexical stress of the final word in the sentence, thus corresponding to sentence

[2] Target words: *gripe, naipe, clube, quibe, leque, tanque, dengue, sangue, dente, leite, bode, rede, bife, chefe, couve, neve, foice, tosse, bronze, gaze, lanche, peixe, hoje, monge*. Distractors: *blusa, bola, bolsa, cama, casa, cola, fusca, gato, lata, livro, mala, ovo, poço, porta, rato, roça, sopa, vinho*.

stress. This consistently created a rhythmic contour across stimuli that favors vowel weakening (Kuijpers & Donselaar 1998).

The total data considered in the analysis consisted of 1,160 observations (60 target words produced by 20 participants, minus 40 discarded items). Discarded items comprise cases where participants failed to produce the target word. For example, the expected word was 'pop', and the participant produced 'music'. Data analysis was conducted in two stages. The first stage investigated the conditions under which apocope occurred, with a focus on its lexical distribution and phonetically gradual implementation. The second stage examined the acoustic properties of the word-final high front vowel, of the noise interval for the preceding consonant, and of the primarily stressed vowel, with particular focus on segmental duration. Apocope implementation was assessed considering the preceding consonant type. Additionally, the interaction between voicing and consonantal noise was considered as a potential factor contributing to increased apocope rates. Results were based on acoustic analysis of the recordings performed using soundwave graphs and spectrograms generated in *Praat* (Boersma & Weenink 2021). Any intervals of periodicity in the waveform were identified as a word-final vowel, as shown in Figure 1.a. When no such periodicity was observed a word-final consonant was assumed to occur, as shown in 1.b.

Figure 1. Word-final vowel realization for the word *foice* 'sickle'



Source: Figure created by the authors

In addition to identifying the presence or absence of the vowel which may be subject to apocope and its duration, manual annotation in *Praat* was also performed to select: the entire target word (which was used to calculate relative vowel duration), the final consonant, and the primarily stressed vowel. For stops and affricates, voice onset time (VOT) values were measured as the interval between the release of the consonantal occlusion and either the onset of voicing or the onset of the following occlusion in cases no vowel was acoustically present. For fricatives, the entire consonant was considered.

Following manual annotation, segmental duration values in milliseconds were automatically extracted using a script (Lennes 2002) in *Praat*. Statistical and graphical analyses were conducted in *R* (R Core Team 2021), employing mixed-effects models (Baayen, Davidson & Bates 2008). Graphs were generated using the ggplot2 package (Wickham 2016), and model comparisons were performed using the lme4 package (Bates *et al.* 2015). For the analyses in which more than two levels of a variable were considered, bar plots were ordered in descending order considering the rate of vowel absence, and box plots were ordered in ascending order based on the median observation of relative vowel duration.

To test the hypotheses, the best-fitting models were selected. Categorical analysis of apocope, i.e., presence or absence of a vowel, was conducted using mixed-effects logistic regression models, with the absence of acoustic correlates of the vowel treated as the response variable. Phonetic detail – namely, the duration of the final vowel, of the noise interval of the final consonant, and of the primarily stressed vowel – was analysed using mixed-effects linear regression models, with segment duration as the response variable. Random intercepts for lexical item and speaker were included in all models. Nested models were compared using likelihood ratio tests with chi-square distribution. For all statistical tests, a 95% confidence level was adopted.

4. Results and Discussion

Results show that the vowel was absent in 57.7% of the cases, corroborating previous findings that apocope is currently a widespread tendency in BP. It was also observed that word-final vowels may be omitted following a range of both voiced and voiceless obstruents. Consider Table 2.

Table 2. Vowel absence according to preceding consonant (%)

[ʧ]	[k]	[ʃ]	[ʤ]	[p]	[f]	[s]	[z]	[ʒ]	[v]	[b]	[g]
82.5	80.0	73.7	71.8	66.7	63.2	55.0	52.8	48.6	39.5	28.9	27.5

Source: Table created by the authors

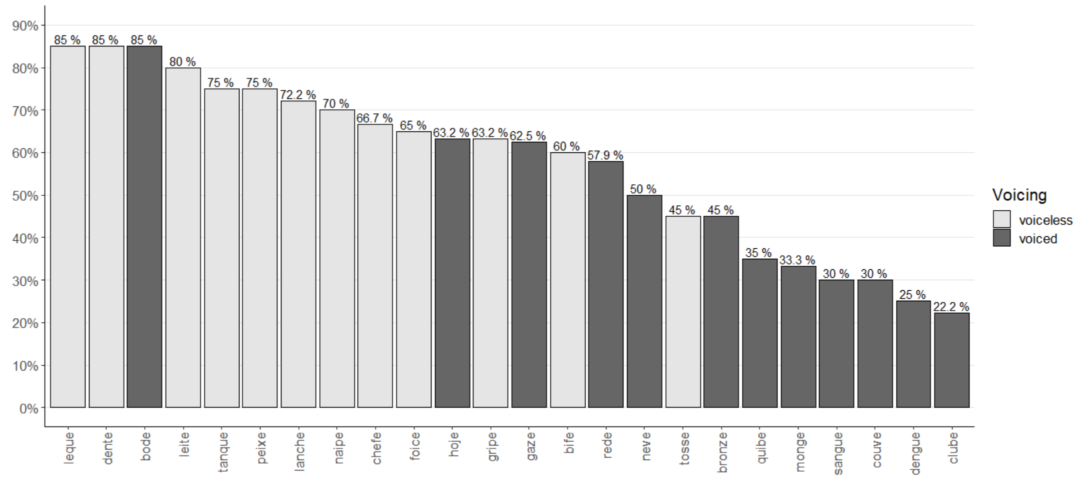
Table 2 presents the rate of apocope according to the preceding consonant. Consonants in dark grey cells are voiced, while those in light grey cells are voiceless. The lowest rates of apocope are found when the preceding consonant is voiced – [g], [b], [v], [ʒ], and [z] – which are grouped toward the end of Table 2. In contrast, voiceless consonants show the highest rates of apocope and appear on the left-hand side of the table. These results indicate that voiceless consonants are more likely to favour apocope than their voiced counterparts (Pagel 1993), although all the consonants analysed were found to occur word-finally as a result of apocope.

The only voiced consonant to exhibit a high rate of apocope is the affricate [ʤ], with 71.8%. Similar results were reported by Assis (2017). According to her, one possible explanation for [ʤ] showing a higher rate of apocope than the voiceless consonants [p, f, s] is that affricates are relatively recent additions to BP, having emerged as allophones of the alveolar stops /t/ and /d/ (Câmara Jr. 1999). In BP, affricates typically occur when the following vowel is [i]. As previously discussed, a key phonetic feature of BP is the reduction of post-tonic word-final vowels. It is therefore plausible that affricates entered the language at a time when word-final vowel reduction was already underway, making them more susceptible to this process. This proposal also accounts for the fact that [ʧ] presents the highest rate of apocope (82.5%). It is also worth noting that VOT values for [k] have been shown to correspond to levels of aspiration typically associated with increased consonantal noise (Klein 1999; Kupske 2017). Taken together, these findings suggest that both voicing and the degree of consonantal noise interact to favour higher rates of apocope.

Statistical analysis indicate that both voicing and consonant type significantly affect the occurrence of apocope. Voiceless consonants favour apocope more than voiced ones ($\chi^2 = 15.14$, df = 1, $p < 0.01$), and sibilant consonants favour apocope more than non-sibilants ($\chi^2 = 4.57$, df = 1, $p = 0.03$). Additionally, a significant interaction was found between voicing and the presence of consonantal noise (as in sibilants) ($\chi^2 = 5.35$, df = 1, $p = 0.02$). These results suggest that apocope is influenced by multiple phonetic factors and that interactions between these factors also play a role. In the following sections, we will explore in greater detail the interaction between voicing and noise.

We have just examined the extent to which apocope applies in BP and the voicing conditions that favour its occurrence. We now consider at what extent apocope is lexically and phonetically gradual. First, we analyse apocope rates across different lexical items in order to assess its lexical implementation. Consider Figure 2.

Figure 2. Vowel absence according to lexical item (%)



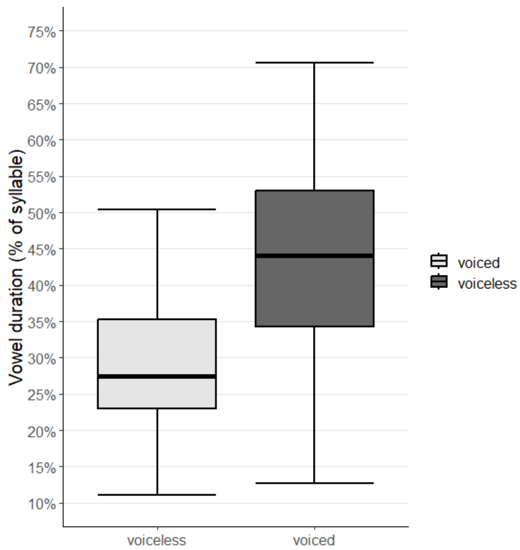
Source: Figure created by the authors

As illustrated in Figure 2, the light grey bars represent words ending in voiceless consonants, while the dark grey bars represent words ending in voiced consonants. Apocope rates vary from 85% to 22.2% depending on the lexical item, indicating that apocope is lexically implemented in a gradual fashion as different words exhibit different rates of vowel loss, as predicted by Exemplar Models.

Although each word shows its own rate of apocope, the general tendency observed for voiceless consonants to favour apocope more than voiced ones remains consistent across individual lexical items. The observed lexical variation in Figure 2, where words differ in how frequently they undergo apocope, may be linked to token frequency, an important factor that should be addressed in future studies, as the present experiment did not control for frequency effects.

Phonetic reduction involves the online weakening of the word-final unstressed high front vowel, leading to gradual changes in the set of exemplars associated with each word. This results in vowels with progressively reduced gestural magnitude, eventually culminating in full vowel deletion. In the remainder of this paper, we examine the phonetically gradual implementation of apocope in BP. Consider Figure 3.

Figure 3. Relative vowel duration according to the preceding consonant voicing



Source: Figure created by the authors

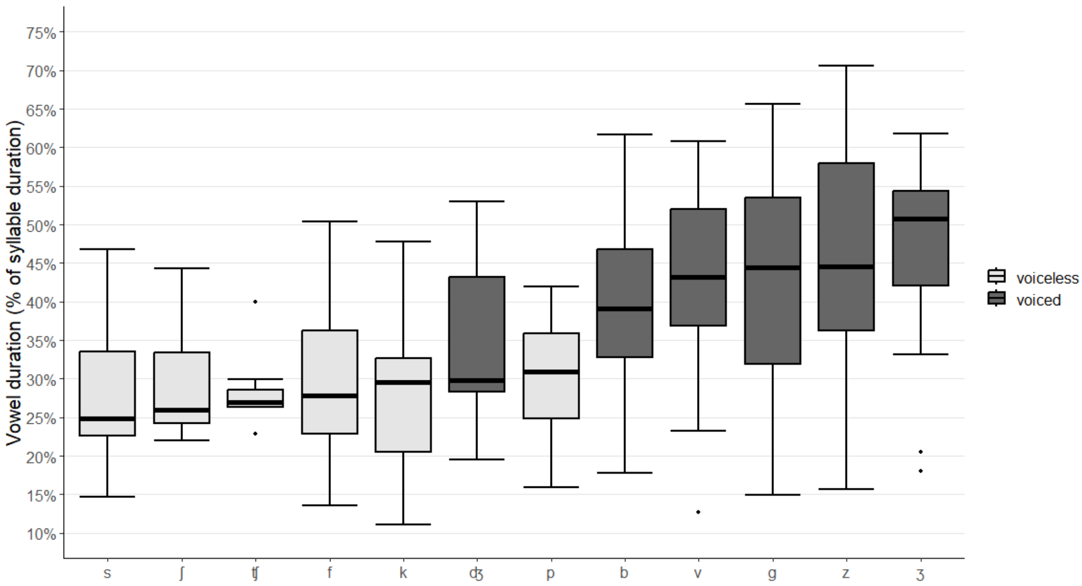
Figure 3 illustrates the duration of the word-final high front vowel when the preceding consonant is voiceless (light grey) or voiced (dark grey). The percentage is displayed as the proportion of vowel duration relative to the total syllable duration, i.e., the percentage of the syllable occupied by the final vowel.[3] Results show that word-final vowels are shorter (27.5% of syllable duration) when adjacent to voiceless consonants compared to when they are preceded by voiced consonants (44% of syllable duration) ($\chi^2 = 35.7$, df = 1, $p < 0.01$). This suggests that vowel reduction and eventual loss are closely linked to consonantal voicing, as the duration of the word-final vowel varies according to the voicing of the preceding consonant. These findings corroborate the general tendency for apocope observed in (5).

We then analysed the duration of high front vowels in relation to each consonant to investigate the gradual phonetic implementation of apocope. Previous

[3] Results were also tested considering word duration and were equivalent and statistically significant for the effects of voicing ($\chi^2 = 5.45$, df = 1, p = 0.03) and of sibilant noise ($\chi^2 = 5.47$, df = 1, p = 0.02).

studies have suggested that apocope unfolds in a phonetically gradual manner (Cristófaro Silva & Almeida 2008; Nascimento 2017; Assis 2017). Consider Figure 4.

Figure 4. Relative vowel duration according to the preceding consonant



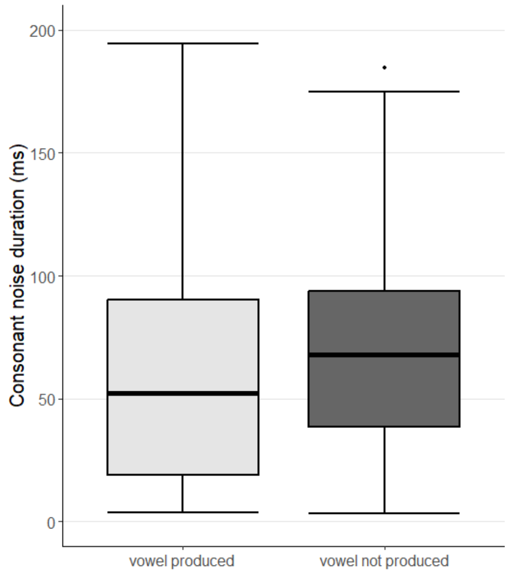
Source: Figure created by the authors

Figure 4 displays relative vowel duration for each consonant, which are in ascendant order based on the median of relative duration. Voiced consonants are represented by dark grey bars, while voiceless consonants are shown with light grey bars.

The consonants [s, ʃ, ʧ, k, f, ʤ] exhibit the lowest durational values for the word-final vowel, ranging from 25.3% to 34.6% of syllable duration. These consonants also correspond to the highest rates of apocope, as shown in Table 2. As a general observation, voiceless consonants and/or consonants with longer noise intervals (e.g., fricatives, affricates, and aspirated stops) tend to be associated with shorter word-final vowels and higher apocope rates. This suggests that these consonants may represent a pathway of change that promotes apocope in BP. Statistical tests revealed that both voicing and consonantal noise significantly affect vowel duration. Voiceless consonants are associated with shorter vowel durations compared to voiced consonants, as shown in Figure 3. We also found that sibilants exhibit shorter vowel durations compared to non-sibilants ($\chi^2 = 2.36$, df = 1, $p < 0.03$). However, no interaction effect was found between voicing and consonantal noise ($\chi^2 = 1.26$, df = 1, $p = 0.26$).

Since the typical acoustic properties of the word-final vowel are altered when adjacent to voiceless sibilants, we examined how vowel loss affects the duration of the preceding consonant. Our goal was to explore how the noise intervals in the consonant might contribute to the description of apocope. For stops and affricates, VOT values were considered, defined as the interval between the end of the consonant occlusion and the onset of the voiced interval corresponding to the vowel or the following occlusion in cases where no vowel was acoustically attested. For fricatives, the entire consonantal duration was considered. The noise intervals reflect a relatively random distribution of acoustic energy across different frequency bands. Consider Figure 5.

Figure 5. Consonant noise duration according to word-final vowel production (ms)

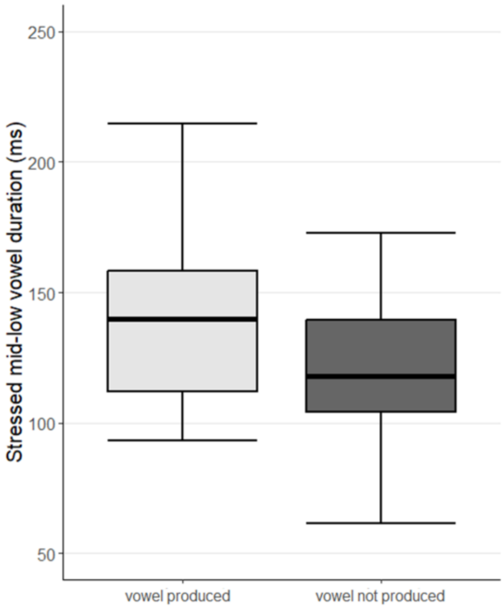


Source: Figure created by the authors

Figure 5 displays the results for noise duration in cases where the final vowel was produced (light grey boxplot) and those where the vowel was absent (dark grey boxplot). Noise duration is significantly longer when the vowel is absent compared to when it is present ($\chi^2 = 38.285$; df = 1; $p < 0.01$). These results indicate that apocope affects the acoustic properties of the preceding consonant, particularly its noise characteristics. Noise duration emerges as a consistent property that characterizes apocope beyond the vowel-zero alternation. Consonantal noise, especially in sibilants (both voiced and voiceless), is not only associated with higher rates of apocope but is also crucial for acoustically characterizing the phenomenon. Our findings align with those of Meneses & Albano (2015), who explored the temporal overlap between unstressed final vowels and the articulation of sibilants. We extend this perspective by demonstrating that apocope is favoured not only when sibilants are adjacent to vowels subject to apocope, but that consonantal noise plays a central role in promoting the temporal and articulatory reduction that leads to apocope.

Finally, we examined whether vowel shortening in closed syllables occurs as a result of apocope in BP. Several languages have shown that vowels preceding a consonant in the same syllable, i.e., in a closed syllable, are shorter than vowels in an open syllable, i.e., at the absolute end of the syllable (Bloomfield 1976; Lehiste 1970; Keating 1985). Preliminary results by Assis (2017) demonstrated that the duration of primarily stressed vowels in open syllables, such as [a] in *passe* [ˈpasi] 'entry ticket', was longer than in cases where apocope occurred, as in [ˈpas], where the primarily stressed vowel was in a closed syllable. The present study, consistent with Assis (2017), also investigates how vowel shortening in closed syllables could characterise apocope. Given that vowel duration in BP is intrinsically influenced by vowel quality (Escudero *et al.* 2009), we focused on cases where a mid-low vowel, such as [ɛ] or [ɔ], appeared in primarily stressed position, either with or without apocope, as in *cheque* [ˈʃɛki] ~ [ˈʃɛk]. The results are shown in Figure 6.

Figure 6. Stressed mid-low vowel duration according to word-final vowel production (ms)



Source: Figure created by the authors

The boxplots in Figure 6 display the durational values for the primarily stressed vowel. The light grey boxplot represents cases where the word-final vowel was produced, resulting in the primarily stressed vowel occurring in an open syllable. The dark grey boxplot shows cases where apocope took place, leading to the primarily stressed vowel occurring in a closed syllable. A significant difference between the two samples was observed: the primarily stressed vowel is longer when the final vowel is produced compared to when the final vowel is absent ($\chi 2 = 3.93$; df = 1; $p < 0.01$).

The experimental results we presented in this section support the view that apocope is lexically and phonetically gradual. We have shown that the segmental loss of the word-final high front vowel impacts the whole temporal and articulatory organisation of words. The general tendency for apocope to be favoured when the preceding consonant is voiceless and/or a sibilant suggests a synchronic pathway of change through which the phenomenon is implemented. This interpretation supports the view posited by Exemplar Models that sound change is promoted in a lexical and phonetic gradual fashion.

5. Conclusions

This paper explored apocope in Brazilian Portuguese (BP) and its interaction with consonantal voicing and noise, focusing on the Southeast variety of BP from Belo Horizonte. The results confirmed that apocope is an ongoing phenomenon in BP (57.7%) and is lexically and phonetically implemented in a gradual fashion (Johnson 1997; 2007; Bybee 2001; Pierrehumbert 2001), corroborating previous findings in the literature for several other varieties of BP. Our contribution detailed that the temporal and articulatory reduction of the vowel subject to apocope occurs at different rates depending on the preceding consonant. We also showed that voiceless consonants favour apocope more than voiced ones, and this difference is statistically significant. Noise also contributes to the implementation of apocope. Sibilant consonants, that are characterised by intense distribution of acoustic energy in relatively high frequency bands, generally favour apocope when compared to non-sibilant consonants. A statistical interaction between voicing and noise was also attested for the implementation of apocope.

The effects of apocope in word structure were also assessed. Noise duration is significantly longer when the word-final vowel is absent compared to when it is produced. This suggests that apocope affects the acoustic properties of the preceding consonant, particularly its noise (Meneses & Albano 2015). Furthermore, primarily stressed vowels are also influenced by apocope, showing longer duration in open syllables when the word-final vowel is produced compared to shorter duration in cases where apocope results in a closed syllable (Keating 1985). These findings indicate that consonant lengthening and vowel shortening in closed syllables occur when apocope takes place, suggesting that the temporal and articulatory reorganization caused by apocope extends over the entire word.

Our results contribute to a broader understanding of apocope in BP and open doors for future research. High vowels may also undergo reduction and loss word-internally in pre-tonic positions in BP (Napoleão Souza 2014; Nascimento 2017). Vowel loss is likely to have an impact on the suprasegmental structure of the language. Future work which controls prosodic properties may shed some light on the current rhythmic nature of BP. Another interesting issue is to investigate whether vowel shortening in closed syllables also applies word-internally, as well as the role of voicing and noise in these cases, would be valuable. Additionally, a comparative study between cases of epenthetic vowel insertion and word-internal vowel deletion could enhance our understanding of syllable structure reorganization in BP (Cristófaro Silva 2024).

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