Nasal Coda and Vowel Nasality in Brazilian Portuguese

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1. Vowel nasality in Brazilian Portuguese

1.1. The nasal vowel an its nasal coda

Despite different theoretical perspectives and methodologies, nasal vowels in Brazilian Portuguese are characterized by their variability. Such variability can be understood in terms of vowel height related to velum movement (Clumeck, 1976; Cagliari, 1977) or in terms of segmental right context (Almeida, 1976; Cagliari, 1977; Shosted, 2006; Lovatto, 2008; Medeiros et al., 2008). Brazilian Portuguese has five nasal vowels /ɜ̃, ẽ, ĩ, õ, ũ/ that occur in syllables such as V^nCV_o, $CV^nC_oV_o$, CV^n, where C can be either a plosive or a fricative consonant. There are longer words containing nasal vowels in Brazilian Portuguese, like *encantando* (enchanting), but for methodological reasons they will not be investigated in this study. In **S**outh**e**astern Brazilian Portuguese dialect, /ẽ/ and /õ/ diphthongize (ẽȷ̃ and õw̃, respectively) and for this reason have not been selected as targets for this or previous studies.

The main goal of this study is to provide a better explanation of the nasal coda in Brazilian Portuguese, by means of comparing nasal to nasalized vowels in terms of acoustic features. Our claim is that the nasal vowel gesture in Brazilian Portuguese must be understood as two gestures not aligned in time. In other words, the nasal gesture starts after the vocalic gesture and goes beyond the closure gesture, in words like *campa* (['kɜ̃^{n}pɐ], gravestone), allowing for nasal quality relatively late in the vowel. The nasal coda is this nasal gesture that goes beyond the obstruent closure.

Thus, the present paper is organized as follows: an introductory view is presented in sections 1 and 2; and a main study and an auxiliary study are presented in sections 3 and 4. The main study is a comparison between nasal and nasalized vowels, seeking a better understanding of different nasalization based on aerodynamical data, as well as on acoustic duration. The purpose of the auxiliary study is to compare oral and nasal codas to open syllables in similar contexts (e.g. *capa*, *campa*, *caspa*). In section 5 our proposal is discussed and in section 6 we offer a conclusion.

1.2. Some previous discussion

Although it seems trivial to admit the existence of nasal vowels in Brazilian Portuguese, the biphonemic account claims that there are only nasalized vowels in Brazilian Portuguese, as they are followed by a nasal consonant. According to other views, nasal consonant loss could be pointed out as responsible for full nasalization in Romance languages, so that the emergence of this lost consonant would be advocated. Hypotheses raised in two previous studies developed by the author questioned phonological analyses that explained vowel nasality in Brazilian Portuguese in terms of underlying forms. Hypothesis 1 was that the element following the nasal vowel was not a full consonant, and hypothesis 2, alternative to hypothesis 1, was that a nasal appendix would emerge in right-hand segmental contexts, plosive or fricative (Medeiros 2007, Medeiros et al. 2008). In addition, it was argued for hypothesis 1 that nasality was installed earlier than commonly stated, by means of FFT

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analysis for the very first pulses. In order to verify the right-hand context behavior, visual inspection of spectrograms were done with minimal pairs like *pinta/pincha* ([ˈpĩⁿtɐ], spot, ([ˈpĩⁿʃɐ], to cast (3rd person). As a nasal murmur was not detected before fricatives, we argued in favor of the absence of a consonantal element, and thus, against an obligatory consonant that would nasalize the vowel. As to hypothesis 2, it predicted that obstruent right contexts would give rise to a nasal appendix in a gestural coordination, implying velum movement partially overlapping both vowel and consonant gestures. Afterwards, hypothesis 2 was corroborated and an element both before plosive and fricative contexts was found. Therefore, aerodynamical data would bring us evidence for a nasal peak located at the very beginning of the fricative turbulence, and durational measures of nasal vowels plus obstruent sequences (nasal vowel plus plosive/fricative) indicated similarity between them.

These findings led us to reconsider these hypotheses and to reevaluate the adequacy of the term nasal appendix, used to designate the consonantal element following the nasal vowel. If we reason in terms of gestural overlapping, we can not advocate a segmental emergence, but rather a particular gestural orchestration that would gradually attain vowel nasality, by means of overlapping heterossyllabic gestures (nasal and the obstruent), preserving a nasal murmur after the vowel. Thus, we understood that *nasal coda* would be a more appropriate term to describe the phenomenon involving the complex gesture that constitutes a nasal vowel in Brazilian Portuguese.

2. Our proposal and hypothesis

According to a broad generativist approach, nasal and nasalized vowels are not different, for both: (i) have been called “nasalized” and (ii) are considered to be followed by a nasal consonant (e.g., Wetzels, 1991). According to a more common sense (iii) they possess similar nasal quality (“by ear”). Facing these tenets and keeping this work inspired by the very initial idea of explaining the nasal vowel in Brazilian Portuguese as complex gesture and not as underlying oral vowels that become nasalized in a phonetic level, we propose a comparison between nasal and nasalized vowels.

Our hypothesis for vowel nasality is that a nasal vowel is distinct from a nasalized vowel in Brazilian Portuguese both phonetically and phonologically. It remains important to emphasize that this proposal is not in favor of a dichotomy between phonetics and phonology, but rather seeks to clarify approaches that would use nasal and nasalized designations for vowels just to refer, respectively, to phonetic and phonological level, or even without a clear distinction.

Clarifying the difference between nasal and nasalized vowels, this study departs from a dynamic perspective, proposing the first gestural investigation on Brazilian Portuguese vowel nasality. Therefore, this study takes an opposing stance from previous investigations on Brazilian Portuguese vowel nasality, for it claims that there is gestural overlapping in the formation of nasality, rather than the simple sequence of an oral vowel plus a nasal consonant, or even the emergence of a nasal segment.

2.1. Nasal vowels seen in a gestural account

Some views about nasal vowels in Brazilian Portuguese, as mentioned in the introduction, are the following: (i) vowel nasalization should be understood as an oral vowel plus a nasal consonant (V + NC), better known as the biphonemic approach (Câmara, 1971 ; Bisol, 2002) (ii) full nasalization in romance languages (Kawasaki, 1986) and (iii) emergence of a nasal coda in an oral vowel context (Shosted, 2006). Our proposal is that these views capture only isolated aspects of the nasalization issue, like representation or like the phonetic detail, respectively the biphonemic and the emergence views, and that an account based on a nasal vowel gesture in Brazilian Portuguese would be more profitable.

A gestural account provides a dynamical phonological analysis that would not be feasible if we departed from a phonological unit such as the segment or the phoneme. Articulatory Phonology (Browman and Goldstein, 1992) provides us with a dynamic phonological unit, i. e. the gesture, which is at the same time a unit of action and a unit of contrastive information. Thus, studying the nasal vowel in the Articulatory Phonology framework enables us to explain the continuous and gradient aspects of its nasality without the need for an underlying representation which does not allow for nasal vowels in Brazilian Portuguese.

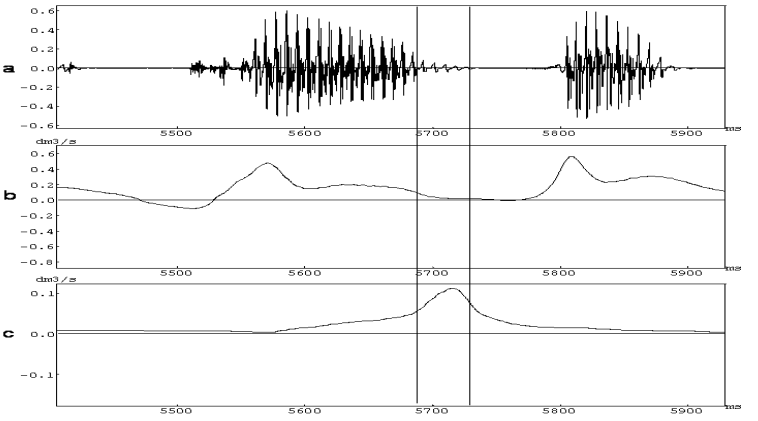

Figure 1: The word *campa* [ˈkɜ̃mpɐ] spoken by subject VP. Nasal coda is between lines, following the low nasal vowel. (a) waveform; (b) oral airflow; (c) nasal airflow. (Medeiros et al. 2008)

How can we consider that the nasal vowel in Brazilian Portuguese comprehends a vocalic gesture and a nasal gesture, not aligned in time? Figure 1 illustrates a peak of nasal airflow just at the end of the nasal vowel which is aerodynamic evidence of a nasal coda, or a nasal appendix. This peak, between lines in the figure, was found in a previous work, whose results were: (i) lip closure just after the nasal vowel determined through aerodynamical curves, (ii) onset defintion for a nasal appendix (NAP), and (iii) NAP - designation we will henceforth abandon - characterization: average nasal airflow was 0.090 dm3/s and average duration was 44 ms (Medeiros et al., 2008).

Would there be a similar nasal peak for nasalized vowels? Figure 2 below depicts a medial nasal consonant, showing ascending nasal airflow before the nasal consonant, and relative maintenance of this flow through its length. Compared to nasal codas, initial nasal consonants (e.g. *mapa* ,[ˈmapɐ], map) showed a nasal airflow pattern as a plateau-like, instead of a peak (Medeiros et al, 2008). This plateau is also attributable to our present data and is due to the fact that a nasal full consonant has to align nasal airflow during its closure avoiding a fast descent. Actually, as seen in Figure 2, nasal airflow starts before closure, and remains through the final vowel[1].

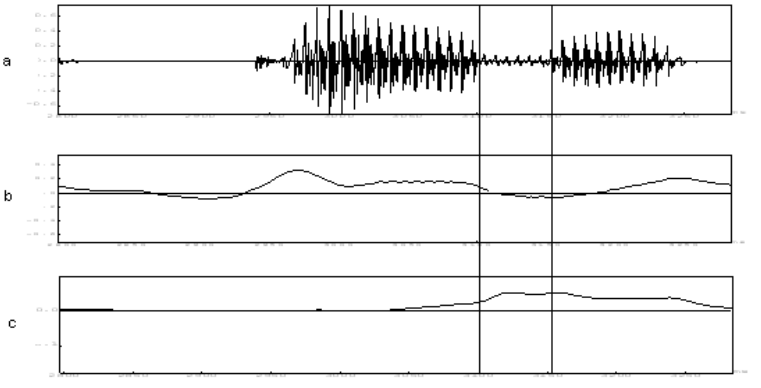

Figure 2: The word *cama* [ˈkɜmɐ] spoken by subject VP. Nasal consonant is between lines, following the low nasal vowel. (a) waveform; (b) oral airflow; (c) nasal airflow.

[1]Although this is perceived as an oral vowel, we are not going to the details of this matter, but observing this phenomenon we could say that a descending nasal airflow has not the same role for nasalization as an ascending nasal airflow in Brazilian Portuguese.

3. The main study: a comparison between Nasal (N) and Nasalized (n) vowels

Nasal vowels can be stressed or non-stressed and can occur in the syllable structures presented in the introduction, as in: *canto* [ˈkɜ̃ⁿtʊ] (*singing/I sing*) or *lã* [lɜ̃ⁿ] (wool). Nasalized vowels occur before full nasal consonants, in words like *cano* [ˈkɜnʊ] (*pipe*), but can also occur in words like *caneta* [kaˈnetɐ] (*pen*). The difference of nasalization between *cano* and *caneta* resides in the fact that in the second one, nasalization is not obligatory. Although it points out the importance of stress in relation to vowel nasalization in Brazilian Portuguese, this study is not going to examine in detail this aspect, but it will focus on the so called nasalized stressed vowels in order to see if it differs from the nasal vowels aerodynamically and in terms of duration.

3.1. Methodology

3.1.1. Speaker and corpus

Five Brazilian speakers, two female and three male, produced disyllabic words and nonce words (Tables 1 and 2, details in Appendix 1) in the carrier sentence "Eu digo ____claramente" (I say ___clearly). Each form was repeated four times and recorded in an EVA2 station (Teston, 1996) with simultaneous audio signal acquisition. Syllabic structures containing nasal vowels were V^nCV_o, $CV^nC_oV_o$, and those containing the so called nasalized vowels were V_nNV and C_oV_nNV (V_n = nasalized vowel and N = nasal consonant). Two nasal/nasalized vowels, one high [ĩ] and one low [ɜ̃], were chosen among five nasal vowels in Brazilian Portuguese to be investigated[2]. For both groups, the initial consonant was /p/, /k/ or null context. These initial contexts, or left contexts followed by target vowels will be treated in section 3.4.

Table 1:First group. Nasal vowels (NV)

pampa	pimpa
campa	quimpa
ampa	impa

Table 2: Second group. Nasalized vowels (nV)

pama	pima
cama	quima
ama	ima

3.1.2. Data acquisition

Nasal airflow was acquired with rubber tubes vertically adjusted below the subjects' nostrils. Oral airflow was acquired with an airtight flexible silicone mask placed around the subjects' mouth. Subjects read the carrier phrases from a computer screen in a standing position.

3.1.3. Data Analysis and measures

Airflow data, oral and nasal, were analyzed in Phonedit (Ghio, no date). Nasal airflow was measured following acoustic boundaries and observing the threshold located at the oral airflow curve very near zero ($0.015dm^3/s$) at the end of the nasal vowel. This oral airflow curve decay indicated labial closure and allowed a more reliable boundary between the nasal vowel and its coda[3]. For nasalized

[2] We assume these vowels to be representative of low and high vowels in Brazilian Portuguese.

[3]Accounts of the nasal coda in the literature show great variability in its duration due to boundary fuzziness (Seara, 2000; Sousa, 1994).

vowels, only acoustic boundaries sufficed, since both the nasal vowel and the nasal consonant waveform pattern are very different.

Aerodynamic measures were made in order to get maximum values of nasal airflow in 50 millisecond windows for nasal vowel (nasal vowel, excluding nasal coda) and nasalized vowel. The first window was aligned with the vowel first pulse, and thus, we normally obtained three windows for the low vowel and, in some cases, two for the high vowel. At each window, we searched for the maximum nasal airflow value. For instances, we could have three maximum average values for the low nasal vowel, all subjects together: 0.007 dm^3/s in the initial window, 0.019 dm^3/s in the middle window and 0.031 dm^3/s in the final window.

However, only the maximum value of the last window was selected for comparison for the following reason: although the initial and, in some cases, the middle portion of the vowel possess very low nasal airflow, there is evidence of nasality produced from the vowel onset. Such evidence is based on spectral analysis, on fiberscopic data of velum movement, and articulatory data which shows that the velum target is attained during the vocalic gesture, and not after it (respectively: Medeiros, 2007; Lovatto, 2007; Oliveira e Teixeira, 2007). Following this reasoning, it is well known that speech parameters are not linear or isochronous (Amelot, 2004; Delvaux, 2003), so acoustic and articulatory data show that nasal airflow comes later. In this sense, we were led to consider not the average nasal airflow through the vowel, but its maximum value as a more plausible parameter for the vowel nasality.

Duration measurements were taken using Praat 5.1.20. Vocalic pulses, first to the last, were taken as vowel boundaries. As there was no oral airflow curve aligned with the Praat acoustic features, we decided to measure the nasal vowel from its very first pulse to the last pulse of the nasal murmur. Besides vowel length, two sequences were measured. For nasal vowel plus /p/ sequence (NV + /p/), silence to burst were taken as consonantal boundaries; and for nasalized vowels plus /m/ (nV+/m/), the nasal murmur, was observed. Length of these sequences was considered valuable for providing cues of temporal organization.

3.2. Aerodynamical results

As expected, based on visual inspection of curves, the nasalized vowel, as well as the nasal vowel, showed ascending mean values of maximum nasal airflow (Max NAF), as can be seen in figures 1 and 2. Table 3 below shows each of these maximum nasal airflows, and, as raw data, they were not treated statistically. This is coherent with findings about the nasal vowel in Brazilian Portuguese, such as those related to velum movement (Clumeck, 1976; Lovatto, 2008). However, few authors dealing with vowel nasality and its variability in Brazilian Portuguese would mention the tongue body role in nasalization. Our present data show that the nasal high vowels start more nasalized in terms of airflow than the low nasal vowels, and this is probably facilitated by an elevation of its dorsum, besides the normal front of the tongue high position. Higher F2 for nasal high vowels compared to their oral counterparts were found in Medeiros (2007) and is in line with the claim of a higher dorsal position as a specific nasal vowel articulatory movement.

Table 3: Maximum nasal airflow of low and high vowels.

	Max NAF at each window		
	Initial	middle	final
Low NV	0.007dm3/s	0.019dm3/s	0.031 dm3/s
High NV	0.035dm3/s	0.058dm3/s	0.063 dm3/s
Low n V	0.005 dm3/s	0.010 dm3/s	0.018 dm3/s
High n V	0.021 dm3/s	0.033 dm3/s	0.031 dm3/s

Comparing the final maximum nasal airflow of each target vowel, a Mann-Whitney u-test showed a significant difference between nasal and nasalized vowels, both low and high vowels (Table 4). Low nasal vowel showed a greater maximum nasal airflow than the low nasalized vowel maximum airflow. The same happened with high vowels.

Table 4: Maximum nasal airflow at the final portion of low and high vowels.

	Max NAF		
	NV	nV	S
Low	31 dm3/s	18dm3/s	.001
High	63 dm3/s	35dm3/s	0

Vis-à-vis the generativist explanation, according to which there are only nasalized vowels in Brazilian Portuguese, these results indicate that despite similarities, nasal vowels are different from nasalized vowels in terms of nasal airflow which is an important cue of nasality, though not isochronous to velum movement. The nasal and nasalized vowel airflow behavior must also be understood in the light of durational results which give us insights about how the interplay between articulatory and aeordynamic facts work.

3.3. Duration results

Average length values showed that nasal vowels are longer than nasalized vowels (Mann-Whitney u-test, p-value = 0) for both low vowels (188 ms > 147 ms) and high vowels (164 ms >121 ms), if the coda length is not excluded (Table 5). However, since our reasoning is that there is an overlapping between the nasal coda (44 ms) and the initial portion of /p/, a subtraction of this nasal coda length approximates nasal vowels and nasalized vowels durations (Table 6). It is evidence in favor of a vocalic node (in a sequence NV + Coda) as long as a nasalized vowel.

Tables 7 and 8 may be helpful for understanding to some extent how nasal coda is temporally organized through nasal vowel plus obstruent. Results show average length of /p/and /m/, and sequences formed by nasal vowel plus /p/ and nasalized vowel plus /m/. Both /p/ and /m/ have the equal average duration (table 6), but if we take a sequence into consideration (Table 7), the one that carries the nasal vowel (NV+/p/, e.g., *c**ampa***) will be longer than the nV (nV+/m/, e.g., *c**ama***) sequence. On these grounds, we assume, despite its obviousness, the absence of a nasal coda after nasalized vowels, which is coherent to the plateau-like pattern of nasal airflow. Most importantly, we claim that there is no full overlap between the nasal coda and the following obstruent. It is plausible to think that part of the coda does not overlap with the nasal vowel nor with the following obstruent, and this portion finds place between the vocalic and consonantal gestures. This particularity of the nasal coda can be understood in terms of a specific temporal organization and will be discussed further in this paper.

Table 5: Duration of vowels.

	NV	nV	S
Low	188 ms	147 ms	0
High	164 ms	121 ms	0

Table 6: Duration of vowels. Nasal coda excluded.

	NV	nV
Low	144 ms	147
High	120 ms	121

Table 7: Duration of consonants.

/p/	/m/	S
77 ms	76 ms	< 0.010

Table 8: Duration of sequences. Nasal coda included.

NV +/p/	nV+ /m/	S
250 ms	208 ms	< .0001

3.4. Controlled variables: left context

Data collected for this study are part of a broader study which aimed to explain possible influences of different contexts on the nasal vowel (e.g. Medeiros et al., 2008). It seemed to be the case, based on visual inspection, especially for /ɜ̃/, that nasal flow would be blocked after /p/, less blocked after /k/

and free after null context (see Tables 1 and 2 for corpus presentation). However, this has not been confirmed statistically. Present results allow us to say that left context (/p/, /k/, null) seem not to compete for nasal airflow blockage or delay (Figure 3). Nevertheless attention must be paid to the fact that some plosives (like /p/), due to their high intra-oral pressure, can delay nasal airflow (Ohala & Ohala, 1993), anticipating velum lowering (Lovatto et al. 2007) and generating suction and negative airflow (Benguerel, 1974).

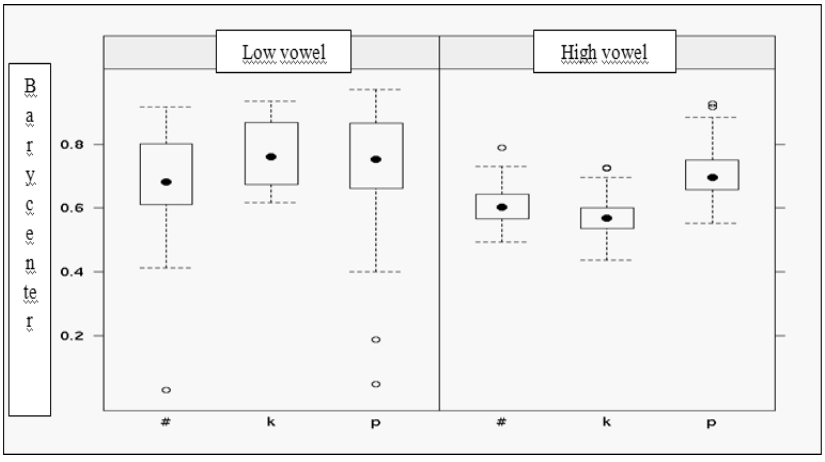

Figure 3: Box plots show nasal airflow onset throughout the vowel, which duration was normalized in a barycenter from 0 to 1 in y-axis. X- axis shows left contexts: # (null), /p/ and /k/.

The interplay between articulatory and aerodynamic movements suggested by the facts mentioned above must be considered, in relative terms, as an explanation of how nasality is installed from the vowel left border. The main point is that an early, or not too delayed nasal airflow depends more on vowel height than on the left context, as we can see in Figure 3.

4. The auxiliary study

In order to compare the acoustical duration of sequences similar to the sequences with nasal codas, two more groups of words and nonce words in Brazilian Portuguese were elaborated[4], obviously following the nasal vowels words' characteristics. Group 1 refers to the words containing nasal vowels followed by /p/, group 2 is formed by words with open first syllable plus /p/, and group 3 possess words with oral codas plus /p/ (Table 9, details in Appendix 2).

The hypothesis raised is that, if a nasal coda overlaps the following obstruent /p/, as suggested in previous work, the oral vowel plus /p/ sequence and the nasal vowel plus /p/ sequence would show the same duration.

Table 9: Three groups of words and nonce words containing comparable sequences

Group 1		Group 2		Group 3	
p**amp**a	p**imp**a	p**ap**a	p**ip**a	p**asp**a	p**isp**a
c**amp**a	qu**imp**a	c**ap**a	qu**ip**a	c**asp**a	qu**isp**a
ampa	**imp**a	**ap**a	**ip**a	a**sp**a	**isp**a

[4]A control group, possessing /s/ in onset position was investigated in order to resolve any doubt related to supposition on different lengths for different word positions of a segment. See Appendix 2.

To avoid doubts related to a possible compensatory shortening of segments implied in the coda sequence, another sequence was requested: one that would contain an oral coda (group 3 in Table 9). If this sequence showed to be equal in length compared to the other sequences under investigation, the hypothesis would not be taken into account. It is well known that addition of segments in one sequence may cause shortening of some or all the segments involved (Fowler, 1981), in such a way that units like syllables or words do not have to drastically change their durations.

4.1. Method and Measures

In a recording session with Soundforge and a Shure PG27LC, four Brazilian subjects repeated 18 target words and non-words, in the carrier phrase *Digo ... todo dia (I say...everyday)*. . Words were randomly presented on a computer screen. Praat 5.1.20 was used to extract durations of the following sequences: nasal vowel followed by /p/ (NV +/p/), oral vowel followed by /p/ (OV+/p/), and oral vowel followed by oral coda (OV+OCd+/p/).

4.2. Results

In this auxiliary study, a GLMM indicated no difference between the length of sequences constituted by NV + /p/ and OV + /p/ ($p > 0.10$), for low vowels (Table 10). An analogous result was obtained for high vowels (Table 11). However a OV+OCd+/p/ sequence, as the one in *caspa*, is longer than the nasal vowel + /p/ sequence, as we can see in the table 10, which displays average duration values in milliseconds.

Table 10**:** Duration of sequences containing a low vowel

NV +/p/	OV+ /p/	OV+Ocd+/p/
265 ms =	249 ms <	348 ms

Table 11: Duration of sequences containing a high vowel

NV +/p/	OV+ /p/	OV+Ocd+/p/
226 ms =	254 ms <	312 ms

To some extent, results support the hypothesis raised. At least, as it is in the case of high vowel sequence, the oral coda sequence is 68 milliseconds longer than the nasal coda sequence. In the case of the low vowel, the difference is 99 milliseconds. Additional data and results provide us a better analysis: /p/ in open syllable sequence is longer than /p/ in the other sequences indicating shortening of this consonant after coda (Tables 12 and 13). Thus it seems that this shortening is not directly related to overlapping, and greatest length of the oral coda sequence could be attributed to the /s/ duration that is shorter compared to /s/ in onset position (Table 14), but is longer than a nasal coda (see Table 6).

Table 12: Durations of /p/ in sequences containing a low vowel

NV +/p/	OV+Ocd+/p/	OV+/p/
87 ms =	95 ms <	117 ms

Table 13: Durations of /p/ in sequences containing a high vowel

NV +/p/	OV+Ocd+/p/	OV+/p/
92 ms =	96 ms <	131 ms

We would rather reason on the fact that this /p/ shortening may be a temporal organization of heterosyllabic gestures in Brazilian Portuguese that would rather lessen the weak syllable length than shortening segments on the strong one. Stressed open syllables in Brazilian Portuguese would require a greater time span in the word, since stress in Brazilian Portuguese is directly related to duration, whereas unstressed syllables would undergo reduction. It seems to be the case in our corpus, since it is formed by disyllable with trochaic pattern that would have a long first syllable and a short final syllable: if a segment – a coda – is added at the end of the first syllable, the following consonant becomes shorter, allowing even more space to the first syllable, but preserving the word size[5].

However, overlapping is not discarded, since the nasal vowel sequence shows to be statistically equal to the open syllable sequence; indicating that the nasal coda has a different temporal organization from the oral coda in Brazilian Portuguese that will be further discussed in the next section.

Table 14: Durations of /s/ in different positions.

onset	coda	S
152 ms	103 ms	0.02

5. Discussion

A general idea of our findings can be viewed in the three items listed below:

1. A nasal vowel is different from a nasalized vowel.
2. A nasal coda seems to play an important role in nasal vowel nasalization.
3. A nasal coda has a specific temporal organization.

Item 1 is summarized in tables 4 and 6 that present aerodynamical and durational results related to the investigated vowels in this study. Despite presenting the same duration as claimed in section 3.3, nasal and nasalized vowels are different in terms of nasal airflow. Thus, it becomes clear that in the same amount of time, a nasal vowel seeks for greater nasality than nasalized vowels. We suggest it is not a simple phonetic difference, but indicates phonological status of the nasal vowel, since speakers accomplish different gestural coordinations to different articulatory gestures (nasal versus nasalized vowel). Taking Goldstein and Fowler's (2003) proposal of language form preservation, there is no reason to reject the differences raised by our data. The language form preservation is the capacity speakers have to provide information about phonological units in real speech or "communicative exchange." In other words, neither phonological units are confined to mental structures, nor are acoustic and articulatory phenomena confined to physical structures, so the latter can reveal our knowledge about language.

To advocate in favor of item 2, we bring evidence, based on the comparison between the length of the sequences: that the nasal coda possess its own space and is not completely overlapped either with the vowel or with the following consonant. The sequence NV + /p/ in a word like *campa* is not the same, in durational terms, as found in the sequence nV + /m/ in a word like *cama* (results in Table 8). Moreover, we had already demonstrated, in a previous study, that a nasal airflow peak was consistently present after labial closure and lay in the temporal domain of the nasal coda. These findings have to be analyzed in conjunction with another one: the growing nasal airflow (Table 3). If nasal vowels in Brazilian Portuguese were merely a result of the total loss of the nasal consonant, a nasal murmur, aligned to a nasal peak (30 ms average after labial closure), and a difference in duration between two similar nasalized vowels would not be as clearly uncovered as it was in our data.

We then assume that the nasal coda is the outcome of a specific articulatory movement attributed to nasal vowels in Brazilian Portuguese that gradually generates nasality. Inevitably, as the nasal vowel attains its maximum of nasality at the end, an oral cavity closure would deviate yet more air through the nasal cavity. However, this alone does not explain nasal coda and could sound a mechanical

[5]A discussion about the rhythmic issue that emerges around the units size of Brazilian Portuguese (the word, the syllable, or else) is not the purpose of this paper, and for this reason will not be developed.

explanation. We propose a linguistic explanation that views the nasal vowel as an articulatory gesture that orchestrates velum and tongue movements in such a way that vowel quality is preserved in order to provide oral-nasal distinction through growing nasality. As it was said in section 3.2, dorsal tongue position seems to be a main fact of nasal vowel articulation that would facilitate nasalization. Nevertheless it can not be considered a present finding, but solely a cue to be pursued in future studies involving articulatory data.

Item 3 is grounded on findings of the auxiliary study whose results indicated that the nasal coda has a specific temporal organization in comparison to an oral coda in an inter-syllabic sequence. Compared to the oral coda, the nasal coda does not elongate the sequence observed. We propose that such an organization is due to the following facts: (a) a final syllable gesture shortening, understood as final reduction (Browman and Goldstein, 1995); (b) initial consonant shortening in the syllable that follows the coda; (c) a competition of two gestures, having a common articulator, for the same time interval, or blending (Vayra et al., 1999). Shortening of /p/ may be a language-specific temporal aspect, and blending may indicate a more detailed language-specific coordination between gestures: in the case of nasal coda, the jaw is the common articulator that serves both to the coda and to the next consonant closure. In this blending, it seems that the nasal coda requires only a little portion of this interval of time. In addition, the velic gesture, sequential to the vocalic gesture, preserves a partial overlapping and is responsible for the similarity in length found between distinctly structured sequences (open syllable versus closed nasal syllable).

6. Conclusion

Aerodynamic and durational data provided results that helped uncover systematical differences between nasal and nasalized vowels and led us to argue in favor of a phonological status to the nasal vowel in Brazilian Portuguese which is most frequently considered to exist as a surface form. The auxiliary study results impelled us to explain how nasal coda organized itself as part of a complex gesture – the nasal vowel – and in terms of timing.

Our findings are consistent with recent findings on vowel nasality in Portuguese that, nevertheless, offer a different approach as the nasal coda emergence (or restauration) found in high nasal vowels followed by word initial oral vowel (Shosted, 2006). What Shosted called *nasal coda emergence* (NCE), would rather be interpreted in the present study as the coordination of articulatory gestures specially attuned to accomplish vowel nasality in Brazilian Portuguese. In relation to European Portuguese (EP), an important contribution to the characterization of nasal segments in the framework of Articulatory Phonology can be found in Oliveira e Teixeira (2007). The authors reveal intergestural coordination between velum and lips and conclude that there is synchrony between these gestures in onset position, but they are sequential in coda position. Tongue gesture is not taken into account in their analysis, which favors the V + N (oral vowel plus nasal consonant) theory to explain vowel nasality.

The articulatory coordination issue (vowel height included) and gradual nasality issue are always present in experimental studies about nasal vowel in other Romance varieties. A long and gradual nasality before fricative contexts, that would mean nasal consonant weakening, can be found in Northern Italian, whereas Central Italian would not nasalize its vowels in the same extent (Busà, 2007). In European Spanish the velo-pharyngeal opening starts in relation to the nasal consonant gesture and is not aligned to the vowel gesture; as a consequence, nasalization occurs at the very end of the vowel (Solé, 1995). Low and mid low nasal vowels in French would show carryover nasalization: despite the fact that these vowels are strongly nasalized, preceding oral consonants would not be nasalized (Delvaux et al., 2008).

The nasal vowel timing issue, or simply when nasality occurs in the vowel seems to be a common issue among Romance varieties. However, related to Brazilian Portuguese, it remains to be explained how nasal vowels coordinate articulatory movements with nasal codas, a matter that is latent in this study and should be further investigated.

Appendices

Appendix 1

Utterance	Transcription	Gloss
Nasal vowels		
pampa	ˈpɜ̃ⁿpɐ	treeless plain in South America
pimpa	ˈpĩⁿpɐ	to flaunt
campa	ˈkɜ̃ⁿpɐ	gravestone
quimpa	ˈkĩⁿpɐ	non word
ampa	ˈɜ̃ⁿpɐ	non word
impa	ĩⁿpɐ	non word
Nasalized vowels		
pama	ˈpɜmɐ	indigenous tribe
pima	ˈpimɐ	non word
cama	ˈkɜmɐ	bed
quima	ˈkimɐ	non word
ama	ˈɜmɐ	to love 3rd person
ima	ˈimɐ	non word

Appendix 2

	Transcription	Gloss
Open codas		
papa	ˈpapɐ	Pope or mush
pipa	ˈpipɐ	kite or barrel
capa	ˈkapɐ	something to cover, a raincoat
quipa	ˈkipɐ	non word
apa	ˈapɐ	non word
ipa	ˈipɐ	non word
Oral codas		
paspa	ˈpaspɐ	non word
pispa	ˈpispɐ	non word
caspa	ˈkaspɐ	scurf
quispa	ˈkispɐ	non word
aspa	ˈaspɐ	vane
ispa	ˈispɐ	non word
Control group		
passa	ˈpasɐ	to pass, 3rd person
piça	ˈpisɐ	non word
caça	ˈkasɐ	hunt, to hunt 3rd person
quiça	ˈkisɐ	no word
assa	ˈasɐ	to roast 3rd person
iça	ˈisɐ	no word

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