ON THE DURATION OF NASAL VOWELS
IN BRAZILIAN PORTUGUESE

Rui Rothe-Neves (UFMG)

Hellen Valentim (UFMG)

Introduction

In the last 25 years, the term *laboratory phonology* has become a synonym of *experimental phonology* in reference to seeking viable explanations of behavioral and organizational patterns of speech sounds by means of testing hypotheses. The introduction to the collected papers of the first conference on laboratory phonology states: "Determining the relationship between the phonological and the phonetic component demands a hybrid methodology. It requires experimental paradigms that control for details of phonological structure, and it requires observation techniques that go beyond standard field methods" (Beckman & Kingston, 1990, p. 3)[1]. Most of all, it requires a different mental setting by means of which the best explanation is never considered to be true, even when it comes from a good theory. "All we can hope for are viable *candidate* solutions which avoid certain well known flaws and which possess certain advantages". (Ohala, 1990, p. 158-159)

One of the very first attempts to apply experimental reasoning to a phonological problem in Brazilian Portuguese (henceforth BP) was the investigation of nasal vowel durations by Moraes & Wetzels (1992). The rationale was straightforward, based on phonological arguments for a distinction between contrastive and allophonic nasal vowels in BP, some examples of which can be seen in the

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1. Obviously enough, the goal of determining the relationship between the phonological and the phonetic component requires an assumption in the first place: that of independence of phonetics and phonology. In the same year the quoted passage was published, this key assumption was already pointed out and criticized on epistemological grounds by Ohala (1990).

corpus used for the present study (Table 1). Based on CV phonology, they propose that "true" nasal vowels have an extra phonological unit in the CV tier, an underlying N that is deleted after spreading [+nasal]. Their study argues for the presence of traces of that extra time unit, which should be sought in vowel duration: contrastive (or true) nasal vowels (CNV) should be longer than either allophonic nasal vowels (ANV) or their oral counterparts, whereas ANV and oral vowels should not differ significantly because both have just one time unit.

a. Oral Vowels			b. Allophonic Nasal Vowels			c. Contrastive Nasal Vowels		
caça	[ˈkasɐ]	'hunt'	*cana*	[ˈkə̃nɐ]	'cane'	*cansa*	[ˈkə̃sɐ]	's/he gets tired'
cata	[ˈkatɐ]	's/he picks something up'				*canta*	[ˈkə̃tɐ]	's/he sings'
piço	[ˈpisʊ]	'piece'	*pino*	[ˈpĩnʊ]	'pin'	*pinço*	[ˈpĩsʊ]	'I use the tweezers'
pito	[ˈpitʊ]	'cigarette'				*pinto*	[ˈpĩtʊ]	'chick'
súcia	[ˈsusiɐ]	Group of persons of bad character; 'gang'	*uno*	[ˈũnʊ]	'I unite'	*núncio*	[ˈnũsiw]	(Papal) 'Nuncio'
luto	[ˈlutʊ]	'I fight'				*unto*	[ˈũtʊ]	'I anoint'

Table 1: Words in the Corpus

In this article, twenty years after the publication of Moraes & Wetzels (1992), henceforth MW, we reexamine the details of their findings and present a critical reappraisal of the original proposal, asking whether it is still a viable candidate solution. The purpose of this article is to retest MW's hypothesis, asking how we can improve on their work without challenging the core of their theoretical interpretation. Thus, it falls within the scope of *replication*, an often neglected step in knowledge building through experimentation. In the next section, we summarize the important facts and interpretations about nasal vowels in BP. We then elaborate on some methodological issues that may hinder the generalization of MW's main finding, and connect their CV-phonological interpretation of Portuguese nasal vowels with the now more widely used moraic theory. The empirical findings we want to contribute to the topic are, first, a report of unpublished data (Valentim, 2009) whereby we tried to generalize MW's findings to other vowels. Finally, we elaborate on MW's insight and connect it with what has been dubbed *moraic primacy* (Hubbard, 1995; Ham, 1998).

Interpreting Portuguese nasal vowels

Different phonological interpretations have been proposed for Portuguese contrastive nasal vowels, an issue that is treated by more than a hundred published works (for references, see Rothe-Neves & Reis, 2012). In this section, we will be restricted to the key points. In pre-theoretical and

structuralist analyses (e.g., Sten, 1944), a system of underlying oral vowels /i e ɛ a ɔ o u/ and another of underlying nasal vowels /ĩ ẽ ã õ ũ/ was proposed. Still in structuralist terms Câmara Jr. (1953; 1970) proposed a double representation according to which nasality would spread leftwards to an underlying oral vowel from a tautosyllabic N. This N would then be deleted after [+nasal] spreading except when followed by a plosive, in which case an audible homorganic nasal consonant might be inserted. Thus, according to this double representation hypothesis, the Portuguese vowel system is to be restricted to oral vowels that become nasalized before a tautosyllabic N.

The more surface-oriented proposal of two vowel systems is unable to cope with the distributional and phonological intricacies of nasalization. On the other hand, the double representation hypothesis, which proposes that they occur in heavy syllables, accounts well for the behaviour of Portuguese nasal vowels[2]. It is also in accordance with diachronic studies on the evolution of contrastive nasal vowels as VN > ṼN > Ṽ in Romance languages (Hajek, 1997; Sampson, 1999), a pattern also found in other unrelated languages such as Tibetan (Hogan, 1994) and Urdu (Naragan & Becker, 1971). Not surprisingly, the analysis of contrastive nasal vowels as VN sequences (henceforth VN analysis for short) was already proposed in generative terms as a universal nasalization rule (Lightner, 1970) before the first generative VN analysis for Portuguese vowels (Mateus, 1975). Since then, there has been no serious repudiation of the VN analyses, the proposal simply having been reinterpreted to accompany more recent theoretical frameworks.

MW reinterpreted VN analysis in the autosegmental terms of CV phonology, whereby the nasal vowel becomes associated with a second time unit in the CV tier left by N after its deletion in the segmental tier. The association of a vowel with an extra time unit in the CV tier is the formal treatment of compensatory lengthening in CV phonology. Thus, it accounts for an important topic left unexplained by other VN analyses, the pervasive observation that nasal vowels are longer than their oral counterparts (Delattre, 1962; Delattre & Monnot, 1981; Beddor, 1993). It thus provides a phonological explanation of why in some languages nasal vowels often behave as long vowels. For instance, in Albanian Gheg nasal and long vowels never appear in unstressed position (Beci, 2006), and in Urdu, there are both long and short oral vowels, but short nasal vowels are rare (Naragan & Becker, 1971). On the other hand, it also requires that contextual or allophonic nasalization in Portuguese be explained by a different process than contrastive nasalization. Contextual nasalization affects a vowel before a heterosyllabic N, it is obligatory in stressed position or derived words (e.g. *cama* [ˈkɐ̃mɐ] 'bed', *cama+inha* [kɐ̃ ˈmĩɲɐ] 'little bed') and optional otherwise *(caminha* [kɐ̃ ˈmĩɲɐ ~ ka ˈmĩɲɐ]

's/he walks'). This process, however, does not apply across the boundaries of a phonological word (*clar[ɜ̃]+mente 'clear+ly'). For MW, contrastive and contextual nasalization are different processes: in both the vowel becomes nasalized through [+nasal] spreading from the following consonant, but only in the first does a vowel become associated to an underlying extra time unit.

A critical reappraisal

The phonetic investigation conducted by MW was thought to help determine whether CNV derives from a mono- or bimoraic representation. Two corpora (32 and 40 words) containing /a/ in contrastive nasal and in allophonic oral tokens were recorded from only two speakers of the Carioca (Rio de Janeiro) dialect. Crucial for the VN analysis was the difference between CNV and ANV, this should be significant because of the extra time slot, and the difference between ANV and oral vowels, which should not be significant. The corpora were well controlled phonetically, and an additional recording was made from an Argentinian speaker – since Spanish lacks CNV altogether. As a main result, nasal vowels were found to be 27% longer than their oral counterparts in stressed and 74% in pre-stress position. The crucial two-way distinction was observed in pre-stressed syllables only before a plosive, with CNV around 24% longer than oral vowels and 36% longer than ANV. The results seemed to be strongly conditioned by phonetic context, since no differences were found in stressed syllables before fricatives, where nasal vowels were slightly shorter than their oral counterparts, or in word-final position[3].

As said, some important methodological issues hinder the potential for generalization of MW's results. First, although the authors mention "significant" differences, no statistical tests were used, an obvious consequence of analyzing data from only two informants. Another important decision was to measure the entire rime, from onset stop release to the next onset stop closure[4]. This was in line with the theoretical proposal that the coda is filled in CNV, whereas it is not in either ANV or oral vowels. Note that this decision rests on the assumption that N is deleted after nasal spreading. But in fact, before plosives it is not always so. Along with any speaker's impression, since Cagliari (1977)

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3. Anticipating Farnetani & Recasens (1993), MW also reported an inverse relationship between vowel and stop durations. Instead of a rhythmic function keeping the V-to-V intervals relatively constant across different phonological contexts, as proposed by these authors, in MW this fact received an explanation by means of which only before stops – and not fricatives – N becomes associated with a C time slot. Interestingly enough, the nearly constant VC duration was later explored by Beddor (2009) in the context of vowel nasalization. While acknowledging this second finding as an important topic on its own, we will not pursue it further here.
4. This procedure was also used by the three other acoustic analyses we could find of BP nasal vowels (Sousa, 1994; Seara, 2000; Jesus, 2002).

there is experimental evidence of N being phonetically realized either as a nasal offglide before stops, where it agrees in place with the subsequent C (e.g. *campo* [ˈkɜ̃ᵐp ʊ] 'field'; *dente* [ˈdẽⁿtʃɪ] 'tooth'), or as an unreleased nasal closure in word-final position, where it agrees with the preceding vowel (e.g. *fim* [fĩɲ] 'end'; *som* [sõŋ] 'sound'). This fact can be accounted for from an articulatory point of view because the two articulators are not aligned in time: with velum opening superimposed in time, there is closure of the oral cavity with continuing vocal fold vibration (Albano, 1999). It seems that there is a more convincing articulatory than acoustic reason to describe murmur without formant structure outside the duration of a vowel.

Finally, among the alternative explanations that could possibly account for the results (MW, Section III), one very important articulatory explanation is lacking. Lehiste (1970) showed that intrinsic vowel duration is inversely related to vowel height, a pattern that also holds for BP (Hamel, 1983; Escudero, Boersma, Rauber & Bion, 2009). As nasal /a/ is never uttered as a low vowel in BP – it is rather [ɜ̃] or even [ɔ̃] – a possible difference in duration between oral [a] and ANV could have been compensated for by a difference in intrinsic vowel duration in the opposed direction due to a higher height. If it obviously does not obliterate the reported difference between oral vowels and CNV in MW, a "significant" difference between ANV and oral [a] would indicate a three-stage nasalization process better accounted for by the articulatory explanation (Section III, 1). Generalizing MW's conclusion thus requires one to find a difference between oral vowel and ANV *versus* CNV without significant differences between oral vowel *versus* ANV, not only with more subjects, but crucially in other vowels.

Phonological mora and phonetic timing

Perhaps the most important aspect of MW refers to the correlation between phonological time and phonetic timing. As widely known, moraic theory (Hyman, 1985; Hayes, 1989) has provided a generative-based phonological construct for the representation of time in sound structure that, contrary to other theoretical proposals, naturally accounts for onset-rime asymmetries in weight found cross-linguistically. Cohn (2003) summarizes the phonological arguments in favor of a moraic interpretation, and discusses various examples of phonetic realization of such onset-rime asymmetries. One of these examples is *moraic primacy*, introduced by Hubbard (1995). Hubbard provided examples extending evidence first presented by Port, Dalby and O'Dell (1987), which demonstrated that in Japanese words with an increasing number of moras there was an increase in duration by nearly constant increments. As Hubbard shows, the same holds for Bantu languages in which she was also able to find segmental adjustment for mora maintenance. Thus, she concludes, moraic structure is systematically although not directly reflected in phonetic duration.

Hubbard interpreted these facts in light of a theoretical proposal that incorporates a language--specific phonetic stage in the grammar, affecting utterances after the phonological component and before a universal articulatory implementation stage (Cohn, 1990). Minimum target duration is assigned at this stage to segments dominated by a mora, while the duration of other segments may be determined mostly by other factors such as place and manner features. So, in this view the duration of a segment should rather be considered as an amalgam of the time occupied by a mora (assigned at an earlier level) plus the time that varies as a function of implementation phenomena. This is consistent with previous observations dubbed by Maddieson (1984) as *closed syllable vowel shortening* (CSVS), the tendency of a vowel to be shorter in closed than in open syllables. Maddieson reviewed evidence of CSVS before singleton and geminate consonants (so the phonetic context is the same) in many languages in support of his claim that the phenomenon is universal as a phonetic marker of syllable constituency. Maddieson also discussed the case of Japanese where CSVS is not found, and explicitly dismisses it as a possible counterexample because, as a mora-timed language, segment duration is not supposed to adjust as it does in syllable-based languages.

We now come back to MW hypothesis. Bearing two morae, contrastive nasal vowels should be longer in Brazilian Portuguese than either allophonic nasal vowels or their oral conterparts. So MW hypothesis can be easily accommodated in moraic theory[5]. But directly measuring duration in different contexts, as seen from the previous discussion, may not provide good evidence to test for MW hypothesis because BP may have its segments adjusted at the implementation stage, and thus duration may reflect not just the time occupied by one or two morae. So, the question is whether there is any other research strategy to tap traces of a mora in segmental duration instead of directly comparing raw durations.

Ham (1998) compared closure duration in geminate versus singleton double consonants as a function of place of articulation in four unrelated languages. It is a common observation that closure duration decreases with a more posterior point of constriction, and Ham wanted to find whether this articulatory variation in duration could also reflect a phonological difference between geminate (one mora) and singleton double consonants (no mora). Instead of comparing raw durations, Ham measured the percentage differences in mean closure duration between stops at adjacent places of articulation. So, he estimated the percentage difference in closure duration from [p] to [t], and from [t]

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5. We are aware that, contrary to the theory, onsets were shown to affect weight-related phenomena in some languages (Topintzi, 2008), that it is not the best explanation for all observed types of compensatory lengthening (Kavistkaya, 2002), and that phonetic facts may perhaps account for differences in weight-bearers (Gordon 2002). Nonetheless, none of these presents a serious problem to apply moraic theory as a more up-to-date phonological interpretation of BP nasal vowels within the scope of MW.

to [k]. A larger percentage difference found in singletons was interpreted to mean that, as they are not assigned a mora, more variation is allowed from phonetic sources. In geminates, segmental effects on duration should be more constrained as there is a mora to be expressed in phonetic timing. In other words, percentage difference measures what is left after a mora has primarily occupied a segment's duration. It is suggested that with a mora allocated at an earlier stage, less time is left for variation due to other phonetic reasons at the implementation level. This is what Ham calls "moraic primacy" in determining duration. Ham also found evidence of moraic primacy in the tendency of voiced stops to be shorter than voiceless stops, again comparing geminate versus singleton double consonants: the percentage difference between voiceless-voiced pairs was larger in singletons than in geminates. Ham's claim is that this pattern verifies the presence of the moraic trace.

In sum, there are other, more indirect ways to look for the effects of a phonological mora in phonetic timing even if direct measures of raw durations do not allow disentangling such effects from those of an articulatory nature. If moraic primacy holds, we should expect articulatory variation to be more constrained in segments bearing two morae (as MW proposed CNV is) in contrast to segments bearing just one mora.

The present study[6]

A corpus was recorded by 15 male subjects, aged 19 to38. All subjects were born in and were lifelong residents of Belo Horizonte. None reported or presented signs of speech abnormalities. The corpus was chosen to include only real words in minimal pairs, where /a, i, u/ were inserted in an oral, ANV or CNV context, always in stressed syllables. In oral and CNV contexts, subsequent to the target vowels there was either [t] or [s]. With [a, i], voicelessness was a feature of the preceding C in all words. This pattern does not occur with the vowel [u], but was chosen to facilitate visual identification of sound boundaries. During instruction, subjects were told the dictionary meaning of low frequency words. Words were inserted in a carrier sentence and were presented three times each in random order by *CorpusViewer*®. Subjects' utterances were recorded with a Samson Q7 microphone lateral to mouth opening connected to a Fostex VF80 digital recorder inside a sound-attenuated booth at the LabFon/UFMG.

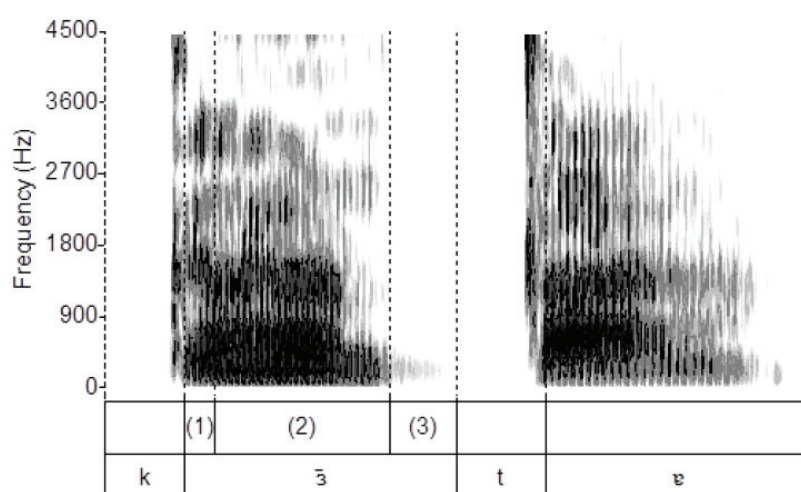6. The dissertation was approved by the local ethics committee (CAAE #330/08) and is available at http://www.letras.ufmg.br/poslin/defesas/1257M.pdf.

Figure 1: Marked points on spectrogram for duration measurements.

Duration measurements of each repetition by each subject were taken by visually inspecting the spectrogram at Praat (Boersma & Weenink, 2008). Marked points on the spectrogram are illustrated in Figure 1, in which the target vowel is further divided in its formant transition (1), stable part (2), and nasal murmur (3). For conceptual reasons, following Delattre & Monnot (1981) formant transitions at the beginning of vowels were not included because they reflect the offset from a constriction and as such they are used by speakers as a cue to consonantal place of articulation. Nasal murmur was also not included in vowel duration, because, as said, it is produced with closure of the oral cavity and no vowel is produced in such a way[7]. So, here duration was measured from the end of transition to the end of formant structure (#2 in Fig.1). This methodological choice is a natural consequence of the observation that the vowel aggregates at least part of the consonant and therefore it is longer, so only the vowel should be measured.

It is perhaps important to point out that MW inclusion of syllables in stressed and pre-stressed position provided them with a larger corpus for analysis. Including such syllables in this study would have enlarged it beyond the scope of a single article. On the other hand, as all vowels in our corpus are in stressed position, we assume that it has affected all vowels equally. Thus, while there is evidence that in BP lexical stress is manifested through duration (Moraes, 1995), it is unlikely to have been affected

7. The presence of nasal murmur was analyzed in Valentim (2009, p.60-61): it was consistently inserted before a plosive, but no speaker inserted it before a fricative. This fact undermines nasal murmur as a possible phonetic vestige of N in coda. As it crucially depends on production manner of the following consonant, nasal murmur should rather be seen as a coarticulatory consequence of mouth closing for consonant production while the velum is still open, as interpreted by Albano (1999).

by vowel quality in this study.

Data analysis was conducted in two steps. The first pertained to the following question: could MW hypothesis be verified in high vowels? Motivated by the results of the first step, the second was targeted to find evidence of moraic primacy in our data (details below). Statistical analyses were mixed--effects linear models fitted by maximum likelihood with *lme4* package in R (Bates; Maechler; Bolker, 2011; R Development Core Team, 2012). In mixed models, subjects' variances are directly modeled as random effects in conjunction with the fixed effects of the manipulated factors, which precludes any normalization procedure. These analytical techniques have become a standard in quantitative linguistic research (Baayen, Davidson & Bates, 2008; Jaeger, 2008; Quené & van den Bergh, 2004; 2008).

Could MW hypothesis be verified in high vowels?

In our study, the above-mentioned contextual differences between oral vowels, ANV and CNV made impossible an orthogonal manipulation of nasality by context. We therefore considered the whole context as a single factor with five levels:

1. Vowel followed by [s] in the next syllable, as in *caça* [ˈkasɐ] 'hunt', henceforth (_.s) for short[8];
2. Vowel followed by [t] in the next syllable, *cata* [ˈkatɐ] 's/he picks something up' (_.t);
3. Vowel followed by N in the next syllable, *cana* [ˈkɐ̃nɐ] 'cane' (_.N);
4. Vowel followed by N in coda and [s] in the next syllable, *cansa* [ˈkɐ̃sɐ] 's/he gets tired';
5. Vowel followed by N in coda and [t] in the next syllable, *canta* [ˈkɐ̃tɐ] 's/he sings'.

Context was nested within a vowel factor with three levels (a, i, u), so differences in context levels were estimated within each vowel. For the linear models, vowel duration measured in ms was the dependent variable (Subj. = 15; Obs. = 648) and context by vowels, the independent variables. Following Quené & van den Bergh (2004), the entire fixed factors structure without intercept was also entered in the random part at the subjects' level. Hence this model does not require homoschedasticity or sphericity. Results are shown in Table 2.

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8. For all words in the corpus, see Table 1.

Fixed Effects		Mean Duration (ms)	Statistics		
Vowel	Context		Estimate	Std. Error	t value
[a]	.N	130.818	131.081	7.686	17.055
	.t	130.341	-0.935	4.933	-0.190
	.s	143.286	14.138	3.903	3.623
	N.s	151.545	20.936	5.098	4.107
	N.t	151.156	20.075	5.873	3.418
[i]	.N	124.2	124.200	7.212	17.221
	.t	109.929	-14.941	5.389	-2.772
	.s	120.829	-3.303	6.928	-0.477
	N.s	154.282	28.970	5.710	5.073
	N.t	156.293	30.849	5.226	5.903
[u]	.N	175.674	177.206	8.416	21.056
	.t	121.8	-55.406	6.644	-8.339
	.s	100.489	-76.717	6.658	-11.523
	N.s	149.795	-27.296	7.688	-3.551
	N.t	192.705	14.777	8.481	1.742

Table 2: Arithmetic Mean and Fixed Effects for Vowel Duration by Context

Table 2 is to be read in the following way. The hypothesis states that ANV should be different from CNV, but not from oral vowels. Therefore [.N] was taken as the reference level. The first context for each vowel is the reference level (the first row for each vowel in Table 2): the model estimates the mean duration value for that context (column labeled "Estimate (ms)"). All other values were compared against this value. The statistically estimated durations for the whole group of subjects in [_.N] were 131 ms for [a], 124 ms for [i], and 177 ms for [u]. The column labeled "mean duration" reports the group central tendency by vowel and context estimated by a simple arithmetic mean. The column labeled "Std. Error" presents the standard error of the estimated mean from the previous column, and the rightmost column labeled "t value" presents the result of a t test against the null hypothesis that the estimate is not different from zero. In the second context for each vowel, here [_.t], what is estimated is the *difference* to the reference level. In the word CATA, [a] lasted the 131 ms of the reference level less 0.93ms, that is ~130ms. The t value in this row results from testing if this very short difference is significant considering all different contexts and the random effects at subjects' level. As the arithmetic mean is also estimation, but one that does not take into account any source of variance, and conside-

ring that the difference between arithmetic mean and mixed-effects estimates here is only up to 2 ms, in the following discussion we will refer to mixed-effects estimates.

Note that there is no information about a p value associated with the test. A major mathematical problem with mixed effects models is the calculation of the appropriate degrees of freedom (df). Nevertheless, in models with < 100 df, as the t distribution approximates the normal distribution, an adequate indication of the significance of t is provided by determining if the absolute t value exceeds its critical value for the chosen significance level. Because the hypothesis under investigation requires that duration in one context must not only be different, but also *larger* than duration in another context, a unilateral alpha level is more appropriate. As the model in Table 2 has 136 df, for α = .05 the critical value is 1.645 and for α = 0.01 it is 2.327. So, [a] is not significantly different in duration in CATA than in CANA. This replicates the finding in MW. In the next row, the duration for [a] before fricative is compared to the reference level. And so on for the subsequent CNV contexts. In Figure 2, we present the calculated mean duration values summing up the reference levels to duration differences in each context. The graph is arranged to allow for visual comparison between contexts where a stop follows (at the left) and contexts where a fricative follows (at the right) with ANV at the center.
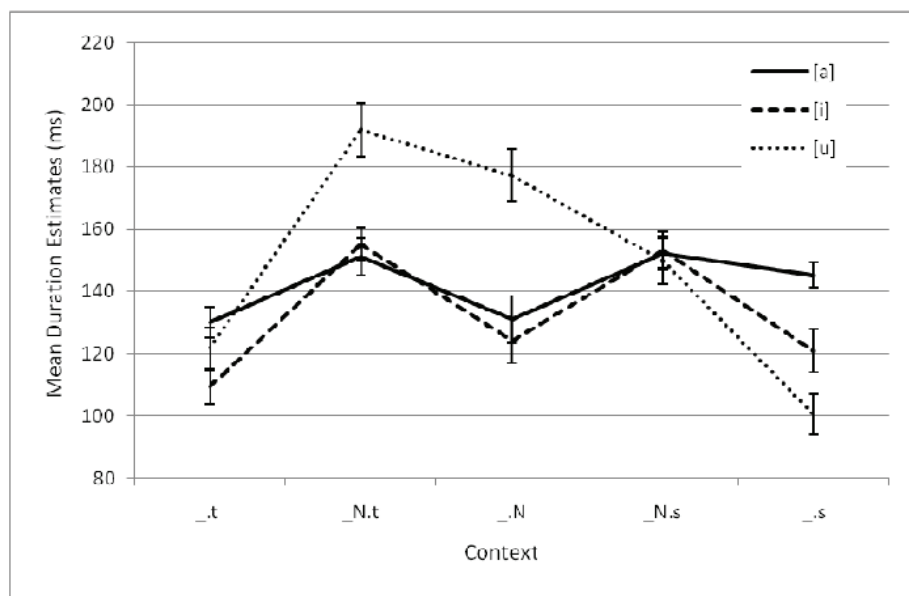

Figure 2: Mean Duration Estimates (with Std. Errors) for Vowel Duration by Context

Before we proceed with inferences about the study's hypothesis from the data, a previous question should be answered: the question about the model's fit. Two different sources of variation are

modeled jointly, that explained by fixed effects and that explained by random effects. Two strategies are typically undertaken to estimate model fit. First, we generate a *null model* by taking only the intercept as independent variable plus the random effects at the subjects' level. In this way, the mean duration value is estimated across all contexts taking into account just the variance explained by the random effects at the subjects' level. The resulting model without linguistic factors is then compared to the full model by the likelihood ratio test (for details, see Baayen, Davidson & Bates, 2008). With this we can safely conclude that the model presented in Table 2 is very well fitted (χ^2 = 844.85, df = 133, p< 2.2e-16).

The second strategy refers to the magnitude of the proportion of variance accounted for by just the *fixed* effects, what would be comparable to the explained variance by models without random effects estimated by R^2. We know this by correlating the fitted values calculated by the model with the original data. The resultant R statistic is then squared and R^2 is taken to mean the proportion of variance in the data explained by the model. Here, it is very strong (r^2_f = .89) with just 11% of all variance left unexplained. We then repeat the procedure in order to estimate how much variance is explained by the null model (r^2_0 = .367), and compare it to the previous result (r^2_0/r^2_f = .413). From this, we conclude that 100 – 41.3 = 58.7% of the variance that we can account for can be attributed to the linguistic variables of the study. We now concentrate on interpreting the results.

MW's hypothesis states that CNV should be different from ANV as well as from oral vowels, but that ANV and oral vowels should not differ. Our results support this hypothesis for [a] when followed by stops, with CNV 15% and ANV just 0.7% longer than its oral counterpart. The 15% difference between [a] and [ɜ̃] followed by tautosyllabic N is significant (t value = 3.418 is safely above the critical value of 2.327 for α = .01) and is fully integrated into the duration of the vowel for it is not due to an intruding nasal murmur[9]. Duration data for [i] before fricative are also well in accordance with MW hypothesis: ANV (124 ms) was only 2.6% longer than the oral vowel (120 ms), but significantly longer than CNV (153 ms) by 23%. The same holds for the context in which a fricative follows [a]: CNV (152 ms) was 16%, significantly longer than ANV (131 ms), but the oral vowel (145 ms) was also significantly longer than ANV by 11%. For no other vowel in no other context could MW's hypothesis be confirmed. For [i] before stops, the oral vowel (109 ms) was shorter than ANV (124 ms) by 12%, and that shorter than CNV (155ms) by 20%, both significant differences. Finally, before stops [u] showed the exact pattern described by the alternative explanation in MW, according to which, if there is an articulatory reason for a longer duration in nasal context, it should equally affect ANV and CNV. The oral [u] (122 ms) was 31%, thus significantly shorter than ANV (177 ms), but ANV was only 8% shorter

9. At this point it is perhaps useful to recall that here we take the duration between end of formant transitions and end of formant structure.

than CNV (192 ms). For [u] the context before fricative had a reduction effect in both oral (100 ms, 43%) and CNV (150 ms, 15%) as compared to ANV. Percent differences to the reference level are summarized in Figure 3.
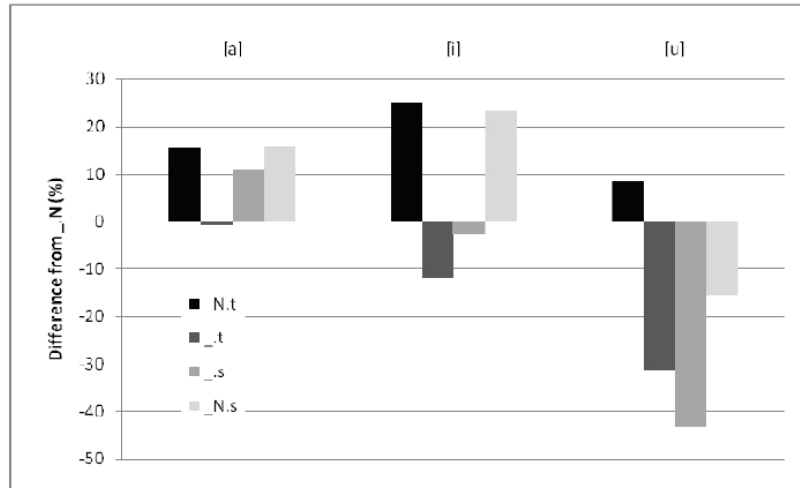

Figure 3: Vowel Mean Duration Differences to the same vowel in Context_N (Reference Level)

In sum, in our data MW's hypothesis is supported only for [a] before a stop (thus replicating the original MW study), and for [i] before a fricative. Looking at Figure 2 it seems that the lines representing each vowel invite an articulatory explanation. The lines for [a] and for [i] are not notably different, [a] being rather flatter, and the lines rise and fall in the same pattern, with [a] generally longer than [i]. This is not surprising if we consider that the tongue opens wider from consonant closure for [a] than it does for [i], but in the same direction. Even granting that the corpus was not as well controlled for [u] – the lack of an onset perhaps contributing to the longest durations in UNO and UNTO – here a longer vowel in nasal contexts could give more time for the listener to distinguish the acoustic cues damped by nasal coupling. That CNV were longer than their oral counterparts is a commonly known fact, but here the pattern of change in duration may also provide some hints onto the final question.

Is there an effect of moraic primacy?

As said, the differences between CNV and oral vowels are fully integrated into the duration of the vowel. This is consistent with either an articulatory interpretation, according to which more time is needed to open the velum which causes a nasal vowel to last longer, or a phonological interpretation – compensatory lengthening. Note however that oral [a] is longer than [i] or [u] in both contexts. Nasal vowels, on the other hand, do not expand beyond what appears to be a maximum duration for CNV,

here, ~150 ms (Table 3). That is, if there is variation due to articulatory reasons, this variation is no longer present in CNV. This is the pattern we would expect if moraic primacy holds. Recall that moraic primacy suggests that a mora occupies time at the phonological level and when a segment bears two morae there is not much room left, thus constraining articulatory variation at the level of phonetic implementation. Consistent with MW's hypothesis, bearing one mora, oral and allophonic nasal vowels should vary more as a function of articulatory factors than contrastive nasal vowels, which bear two morae.

		Duration (ms)		Δ (%)
		Oral	CNV	
[_.t]	[a]	131	151	16
	[i]	110	155	42
	[u]	122	192	58
[_.s]	[a]	145	152	5
	[i]	121	153	27
	[u]	100	150	49

Table 3: Mean Estimated Duration and Difference between Oral Vowels and CNV

To test this hypothesis we take advantage of the fact that, all other things being equal, a vowel tends to be longer when preceding a fricative consonant than when preceding a stop consonant[10]. As here we have registered oral vowel and CNV durations in similar voiceless contexts before either a stop or a fricative, we are in a position to recast MW's hypotheses according to moraic primacy in the following way. Coarticulatory variation of a vowel before stop/fricative consonant is unconstrained in oral context, whereas it is constrained in CNV context because of the two morae that leave a shorter span for variation in phonetic implementation. Accordingly, we would expect vowel duration before stop/fricative consonant to be more varied in oral than in CNV context. This should be proportionally true for [a] and [i] even though duration of [a] has been shown to vary less than that of [i] in different contexts. Because there are more articulatory differences related to [u], we will restrict the test to [i-a].

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10. Various authors since House (1961) reported and interpreted that fact. See review, references and investigation into Spanish vowels in Mendoza et al. (2003).

Context			Statistics				
Vowel	Nasality	Subs C	Estimate		Std. Error	t value	pMCMC
a	Oral	s	144.864	--	6.5965	21.961	0.0001
i			-23.088	121.776	3.7474	-6.161	0.0001
a	CNV		7.061	151.925	3.6768	1.920	0.0664
i			31.375	153.151	3.8212	8.211	0.0001
a	Oral	t	-14.597	130.267	3.6768	-3.970	0.0002
i			-12.535	109.241	3.7454	-3.347	0.0014
a	CNV		-0.769	151.156	3.6109	-0.213	0.8608
i			1.877	155.028	3.8146	0.492	0.6382

Table 4: Fixed effects for Vowel Durations before Stop/Consonant in Oral versus CNV

The mixed-effects model was fit to the recorded data removing all ANV (context _.N) and vowel [u]. This resulted in 338 tokens by 15 subjects. As the crucial test involves comparing duration before different consonants in oral versus nasal context for [a] and [i], the dependent variable in the model was vowel duration and the independent variables were "subsequent consonant" (s *versus* t) nested within "nasality" (oral *versus* nasal), and all this nested within "vowel" (a *versus* i)[11]. Intercept is also included to illuminate the difference between [a] and [i]. Results appear in Table 4. Compared to the null model, the analysis was well fitted (χ^2 = 210.52, df = 7, p<2.2e-16). Before interpreting the results, a technical note is necessary. The significance of comparisons in this case cannot be accessed directly from the absolute t values because this model only has df = 7. A Markov Chain Monte Carlo (MCMC) simulation was used to calculate p values associated to t tests with `pvals.fnc` function in `languageR` package in R (Baayen, 2008). Results appear in the appropriate column in Table 4.

Well in accordance with the moraic primacy hypothesis, in oral [a] the difference in vowel duration before [s] (145 ms) and [t] (130 ms) amounts to 11.2%, far above the 0.5% difference obtained in the comparison to CNV: [a] before [s] (152 ms) and [t] (151 ms). As predicted, the first difference was statistically significant (t = -3.97, p<0.001), but not the second (t = -0.213, p = 0.86). For [i], the results were similar: duration varied 11.4% when measured before [s] (122 ms) and [t] (109 ms) in oral context (t = -.347, p<0.01), 1.2 % before [s] (153 ms) and [t] (155ms) in CNV (t = 0.492, p<0.64). These results also replicated previous findings related to vowel duration. First, they reflect the fact that vowels before [s] are longer than before [t]. Second, there was substantial variability in subjects' productions as demonstrated in the variance at the subjects' level (σ = 549.07) and in the prediction of the fitted va-

11. Mixed effects models have no trouble comparing nested models (see Quené & van den Bergh, 2008 for details).

lues by the null model through intercept only ($r^2_0 = 0.518$). Nevertheless, the effects of moraic primacy in phonetic timing found in BP nasal vowels are very robust as the model's results correlate almost 75% with the original data ($r^2_f = 0.749$). Removing the large variance attributed to the subjects, we conclude that the contexts used as linguistic variables in this model could explain more than 50% of the overall variance.

Conclusion

After a long text, it is perhaps useful to summarize our enterprise from the beginning. This study aimed at retesting MW's hypothesis, asking how we can improve on their work without challenging the core of their theoretical interpretation. The hypothesis was that contrastive (or true) nasal vowels (CNV) should be longer than either allophonic nasal vowels (ANV) or their oral counterparts, whereas ANV and oral vowels should not differ significantly because both have just one time unit. It is worth recalling that MW original results could not support that hypothesis in all investigated contexts: it was only demonstrated in the context before a stop. As MW only investigated words with [a] as a target vowel as recorded by two subjects, for twenty years the question remained open as to the extent to which their results depend on their methodology. We then retested MW hypothesis in high vowels with more subjects, and replicated the original finding for [a] before a stop in support of the hypothesis. It was also the case for [i] in context (_.s), but our data did not support their hypothesis elsewhere.

We have now good reasons to conclude that WM original results were genuine, not due to methodological issues. In other words, nasal vowel duration does not directly reflect an extra mora. In the second part of our study, MW hypothesis was recast in terms of moraic primacy and a more indirect comparison was pursued. The investigation concentrated on how vowel duration varied in a context preceding [s] or [t], and whether that variation would be constrained in case of a nasal vowel. In this case, the results are more favorable to a phonological constraint on phonetic implementation. That is, although the direct manifestation of phonetic timing in vowel duration seems to be strongly influenced by the articulatory characteristics of vowels and contexts, the effect of moraic primacy is also quite clear, as of two morae constraining coarticulatory variation in vowel duration.

It seems that our results extend MW's original reasoning although not in the same direction. We fully agree with Hubbard (1995) that duration is as easy to measure as it is hard to interpret. Phonetic reality is not always phonologically obvious, as every field linguist can testify. In this case, the hypothesis of vowel duration as a direct consequence of phonological structure relay perhaps too heavily on the *ceteris paribus* condition. As we could see, all other things are not being equal even in a controlled laboratory environment. The remaining question is whether there are still unknown phonetic phenomena that could help to explain this pattern of results.

Aknowledgements

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RESUMO: Este estudo visou reavaliar os achados de Moraes & Wetzels (1992) sobre a duração de vogais nasais distintivas do PB ao ampliar as vogais e os contextos estudados. Segundo a hipótese, uma maior duração da vogal nasal é uma manifestação, no nível da implementação fonética, de uma representação bimoraica e por isso a vogal nasal resultaria mais longa do que as vogais orais e mesmo do que as vogais nasais alofônicas, cuja representação é monomoraica. Foram registradas três repetições de 15 palavras representando cinco contextos diferentes por sujeitos falantes do dialeto de Belo Horizonte. A análise por modelos de efeitos mistos mostrou que a hipótese se verifica apenas para vogais [a] seguida de plosiva e [i] seguida de fricativa. A hipótese foi reformulada nos termos da "primazia moraica" (*moraic primacy*): os falantes mostram maior variação se comparados seu tempo de articulação de segmentos diferentes quando tais segmentos são ocupados por apenas uma mora. Analisaram-se então a variação na duração das vogais [a, i] orais e nasais em contexto seguido por plosiva ou fricativa. Embora vogais sejam mais longas antes de fricativa do que de plosiva, esta diferença aqui só foi atestada nas vogais orais, o que é condizente com a hipótese de que duas moras ocupam mais tempo fonológico restringindo a variação coarticulatória durante a implementação fonética.

PALAVRAS-CHAVE: nasalidade vocálica; Português Brasileiro; fonética; fonologia experimental; linguística.

SUMMARY: This study aims to reassess the findings of Moraes & Wetzels (1992) on the duration of distinctive nasal vowels of BP by including more vowels and contexts. According to the hypothesis, a longer duration of nasal vowel is a manifestation, at the level of phonetic implementation, of an underlying bimoraic representation which cause nasal vowels to be longer than oral vowels and also longer than allophonic nasal vowels, whose representation is monomoraic. We recorded three repetitions of 15 words representing five different contexts by subjects of the Belo Horizonte dialect. Analysis by mixed effects models showed that the hypothesis is only borne out in the behavior of [a] before plosive and [i] before fricative. The hypothesis was then recast in terms of *moraic primacy*: speakers show greater variation in their time of articulation in different segments when such segments are occupied by just one mora. We analyzed the variation in vowel duration for oral and nasal [a, i] when followed by plosive or fricative. Although vowels are longer before plosives than fricatives, this difference was here only attested in oral vowels. This is consistent with the hypothesis that two morae use up more phonological time, thus constraining coarticulatory variation in phonetic timing.

KEYWORDS: nasal vowels; Brazilian Portuguese; phonetics; experimental phonology; linguistics.