On the correlates of rhythmic distinctions:
the European/Brazilian Portuguese case

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Abstract

Although European and Brazilian Portuguese have long been considered to belong to different rhythmic types, no clear support for this distinction has been given. In agreement with recent proposals for other languages, this paper presents an account of Portuguese rhythm based on acoustic measures of consonantal and vocalic intervals, and explores the relation between these measures and the phonological properties specific to the European and Brazilian varieties (EP and BP). The approach followed is both successful in providing evidence for the rhythmic distinction between the two varieties and in relating it to the traditional rhythm typology. Overall, the results show that EP and BP have clearly distinct mixed rhythms: stress- and syllable-timing characterise EP, whereas syllable and mora-timing characterise BP. The data further suggest that mixed rhythm is not equivalent to intermediate rhythm, thus supporting the notion of rhythmic classes against the scattering of languages along a rhythmic continuum.

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1. Introduction

In the prosodic literature on Portuguese, a rhythmic distinction is frequently noted to set apart the European and Brazilian varieties: the former has been considered a *stress-timed* language, whereas the latter has been reported to have *mixed* patterns of the syllable and stress-timed type. Although this distinction has been around in the literature at least since the early eighties (Abaurre 1981, Parkinson 1988, Brandão de Carvalho 1989), no clear support for it, experimental or other, has been given. Work on the rhythm of European Portuguese has been scarce - researchers have mainly concentrated their interest on (primary) word stress -, and comparative studies were, to our knowledge, inexistent. The present paper addresses the issue of rhythm type in European and Brazilian Portuguese (hereafter EP and BP, respectively). It has two conjoint goals: (i) to contribute to a better understanding of the rhythmic difference between EP and BP by establishing (some of) the physical correlates of the distinction intuitively asserted in the literature; (ii) to add to the understanding of the basis of rhythmic distinctions across languages.

Portuguese data are of interest to the understanding of linguistic rhythm and to the recently revived debate around the notion of rhythm classes (Nespor 1990, Auer 1991, Ramus et al. 1999, Grabe & Low 2000) for three main reasons. Firstly, EP is the only Romance language that has long been classified as stress-timed, both by native and non-native researchers (e.g. Parkinson 1988). Secondly, rhythmically mixed languages have been considered to be the critical examples in favour of a rhythmic continuum rather than the clustering of languages in rhythm classes (Dauer

1987, Nespor 1990, Auer 1991, Dimitrova 1997, Grabe and Low 2000), and BP has been claimed to be such a language. Thirdly, EP and BP offer a particularly suitable case to examine rhythmic differences, as sentences with exactly the same words and structure can be used as materials. Resorting to the song metaphor, European and Brazilian speakers may sing the same lyrics each of them using a different music.

The account of rhythm offered in the present paper is largely based on Ramus et al.'s (1999) acoustic measures of consonantal and vocalic intervals, which have succeeded in relating speech signal properties with traditional rhythmic types. To the procedure developed in Ramus et al., two innovations have been added: (i) normalised measures of the variability of intervals were introduced; (ii) the intonational phrase has been assumed to be the domain of rhythm and thus all calculations were performed within I-phrases. The procedure followed is described in section 3.

It will be shown in section 4 that this approach is both successful in capturing the rhythmic distinction between EP and BP and in relating it to the rhythm typology established in Ramus et al. (1999) on the basis of data from 8 other languages. Further, the results support the notion of rhythm classes, while allowing for the existence of different types of mixed languages such as EP and BP. Crucially, the data show that the mixed status is given by the coexistence of two acoustic parameters each of them setting a language in a different class, rather than by the gradient positioning of a language between the extremes of a variation continuum defined by a given parameter. Finally, a deep look will be given to the relation between the acoustic measures and the phonological properties of EP and BP. Ramus et al (1999) propose that the physical parameters reflect linguistic properties that influence rhythm, such as those suggested in Dauer (1983, 1987) and Nespor (1990), among others. Along the same lines, a suggestion is made regarding how the native speakers of a mixed language like EP or BP may infer the phonological properties of their language from the divergent cues present in the speech signal. These issues are discussed in section 5.

The following section lays out the different views on rhythm present in the literature and reviews the work on the rhythm of BP and EP.

2. Background

2.1. Rhythm: the traditional view

It has been traditionally believed that languages fall into one of three rhythmic groupings (Lloyd James 1940, Pike 1945, Abercrombie 1967, among many others): languages in which the timing regularity is based on syllables, such as most Romance languages, are syllable-timed; languages in which the timing regularity is based on interstress intervals, like Germanic languages, are stress-timed; and languages in which the timing regularity is based on morae, such as Japanese, are mora-timed. Closely related to the traditional view of rhythmic classes is the idea of isochrony. It is claimed that the different rhythms are respectively based on the isochrony of syllables, interstress intervals, and morae.

Unsurprisingly, the few impressionistic comments on the rhythm of EP found in the literature are couched within the traditional view. These comments unanimously classify EP as stress-timed. Cruz-Ferreira (1983) observes that the Lisbon dialect is stress-timed, and in Mateus et al. (1989) this classification is extended to most dialects. In Brandão de Carvalho (1989) and Abaurre (1981) (the latter a native speaker of BP), the rhythm of EP is approximated to that of English, a typical stress-timed language.

The picture of the rhythm of BP drawn in the literature is more complex, but nevertheless coherent. Intuitive assertions classify BP as being on the side of syllable-timed languages (Brandão de Carvalho 1989, who approximates it to French), or as having both syllable and stress-timed rhythms (Cagliari 1981). Classifications based on experimental data restate the mixed nature of BP rhythm (Major 1981, Cagliari & Abaurre 1986, Simões 1991, Massini-Cagliari 1992). The rhythm of BP has apparently never been claimed to be stress-timed, contrary to EP rhythm, but BP is not considered to be a typical syllable-timed language either. Before reviewing the acoustic evidence that arguably indicates the mixed or undefined rhythm of BP, a word on the quest for acoustic parameters that set the various rhythm classes apart is required.

It is well-known that the physical basis of rhythmic type differences has been difficult to ascertain. There have been numerous phonetic studies devoted to this problem, but they have failed to confirm the rhythmic distinctions (e.g. Wenk and Wioland 1982, Manrique and Signorini 1983, Dauer 1983). In particular, no evidence was found for the isochronous units on which the different rhythms would be based. To point out an illustrative example, Dauer (1983) shows that both in stress-timed English and Thai and in syllable-timed Spanish, Italian and Greek the duration of interstress intervals is proportional to the number of syllables in the interval and thus interstress intervals are no more constant in stress-timed than in syllable-timed languages. The phonetic research on BP rhythm mentioned above was set out to prove the hypothesis of isochronous units. It is therefore not surprising that its results have also been inconclusive. Like for other languages, it was not possible to decide whether BP is stress or syllable-timed on the basis of the duration of interstress intervals (Major 1981, Massini-Cagliari 1992), the relation between number of syllables and interstress interval duration (Cagliari & Abaurre 1986), or measures that take p-centers into account (Simões 1991). In our view, the acoustic data reported in previous work on BP does not support the mixed rhythmic status of this language, but is rather and instance of the general failure of phonetic research to confirm the isochrony theory.

2.2. Rhythm: a new approach

The lack of acoustic evidence for distinct isochronous units in speech led to a new approach to linguistic rhythm. In this approach, the rhythmic distinctions among languages are seen as the result of the presence/absence of specific phonological and phonetic properties in a particular linguistic system (Dasher and Bolinger 1982, Dauer 1983, 1987, Nespor 1990). Among such properties, syllable structure variety and complexity, vowel reduction and the correlates of stress have been first pinpointed as crucial in Dauer (1983).

Regarding syllable structure, the stress-timed / syllable-timed dichotomy is correlated with a greater variety of syllable types of different complexity in the former group against a limited number of syllable types together with phonological processes that simplify syllable structure (e.g. cluster simplification, ephenthesis) in the latter group. As to vowel reduction, in stress-timed languages unstressed vowels tend to have a reduced vowel system and be phonetically shorter or even absent, whereas in syllable-timed languages unstressed vowels are usually not centralised nor consistently shorter. With regard to the correlates of stress, stress-timed languages show a clear lengthening effect and stressed syllables are the turning points for intonation; by contrast, in syllable-timed languages less or no effect on length is present, and intonation and stress are usually more independent. It is the coexistence of a set of these properties in a given language that may promote the perception of stressed syllables in relation to other syllables - yielding stress-timing -, or make all syllables equally salient - yielding syllable-timing.[1]

A problematic consequence of this approach to rhythm is the shift from a model where languages are clustered in distinct classes into a model where languages are scattered along the rhythm dimension. According to Dauer (1987), a language is *more* or *less* stress-timed - and thus less or more syllable-timed - as a function of the number of properties that promote stress-timing it displays. Consequently, mixed languages, defined as those that occupy an intermediate position on a scale of rhythm, are allowed and expected in this system. This has been shown in Nespor (1990), on the basis of languages like Polish and Catalan. Dimitrova (1997) makes a similar argument for Bulgarian. Since Major's (1981) paper, BP has been cited as another potential intermediate language between stress and syllable-timing (Dauer 1987, Nespor 1990). However, the experimental evidence reported by Major, which is based on the (non)isochronous duration of interstress intervals, has to be interpreted with caution, as already noted in section 2.1 above, and some of the phonological evidence he presents, such as monophthongization, may be seen as a tendency towards the simplification of syllable structure. In Dauer's terms, this would add to the syllable-timing properties of the language, rather than indicate a change towards stress-timing as suggested in the paper.

The scattering of languages along a rhythmic continuum does not seem to offer an explanation for the facts of perception. Several studies on language discrimination have shown that rhythmic distinctions play an important role in the perception of speech (Mehler et al. 1988, den Os 1988, Nazzi et al. 1998, Ramus and Mehler 1999, among others). In particular, this line of research has shown that both adults and newborns, when exposed to filtered speech that preserves prosodic cues, are able to discriminate between languages belonging to different rhythm classes, but not between those of the same class. These findings strongly suggest that the properties behind the rhythmic distinctions are somehow encoded in the speech signal.

2.3. The correlates of rhythm: Ramus, Nespor and Mehler 1999

In recent work by Ramus, Nespor and Mehler, a set of simple measures of the duration of consonantal and vocalic intervals in a sentence (where an interval of each type comprises one or more units of type C or V - see section 3.2) has been shown to capture the rhythmic distinctions traditionally claimed in the literature. These measures are the proportion of vocalic intervals within the sentence (%V), and the variability of vocalic and consonantal intervals within the sentence, expressed by means of a standard deviation measure (respectively, ΔV and ΔC). The examination of data from 8 different languages shows that the acoustic measures proposed correlate well with the standard rhythm classes, thus indicating that there is acoustic evidence for rhythmic type differences in the speech signal. Besides this major finding, Ramus et al. also show that the acoustic measures can be interpreted as the reflection of the phonological properties that have been proposed to influence the perception of rhythm, namely syllable structure and vowel reduction.

Differences in syllable structure are reflected both in ΔC and %V in the following way. The greater variety of syllable types of different complexity that characterises stress-timing yields (i) syllables containing more consonants and (ii) consonantal intervals of variable duration. As a result, in stress-timed languages there is (i) a greater consonant/vowel ratio expressed in a lower %V, and (ii) a higher ΔC. The third acoustic parameter - ΔV - is related to vowel reduction, as reduced unstressed vowels contribute to increase the variability of vocalic intervals. However, ΔV is also influenced by a number of other properties whose relation to rhythm is not clear, such as the presence/absence of vowel lengthening processes and intrinsic vowel duration differences.

In the light of Ramus et al.'s (1999) findings, a number of predictions can be made concerning the rhythmic distinction between EP and BP.

EP and BP show important differences with regard to the properties described as relevant to rhythm, since their presence/absence or incidence goes in opposite directions in the two languages (on this topic, see the discussion in section 5.1 below). In EP unstressed vowels have a reduced vowel system, and some of them (i.e. [ɨ , u]) may be absent from the phonetic string (Morais Barbosa 1965, Mateus and Delgado Martins 1982). By contrast, BP is characterised by little vowel reduction, and unlike in EP there is no centralisation to [ɨ] and no generalised centralisation to [ɐ] (Câmara 1970). If in EP unstressed vowels may delete and give rise to sequences of consonants, BP is characterised instead by phenomena that contribute to syllable simplification, such as epenthesis (Silva Neto 1970, Câmara 1972). In EP the contrast between stressed and unstressed syllables is stronger than in BP (Câmara 1972); further, the stressed syllables constitute the major turning points in the intonation contour in EP, whereas intonation and stress are more independent in BP (Frota and

Vigário 2000). All these properties converge to place EP on the stress-timing side, and BP on the syllable-timing side of rhythm typology. According to these properties, the acoustic measures are predicted to express the rhythmic difference between EP and BP as stated in (1).

(1)	EP (*more* stress-timed)		BP (*more* syllable-timed)
	ΔC	>	ΔC
	%V	<	%V
	ΔV	>	ΔV

The facts of vowel reduction deserve a further comment. At least in the EP/BP case, this property should not be solely related to the ΔV parameter, as suggested in Ramus et al. (1999). As unstressed vowels are reduced and phonetically shorter, this property also contributes to the lower %V that characterises stress-timing. In addition, some reduced vowels may be deleted, and this should contribute again to a lower %V and to a higher ΔC as well: the absence of reduced vowels yields sequences with a variable number of consonants, which in turn should be signalled by the variable duration of consonantal intervals. An illustrative example of the possibility of reduced vowel deletion in EP is provided in Figure 1.

FIGURE 1

Ramus et al.'s (1999) implementation of the new approach to rhythm described in section 2.2 above allows us to make explicit predictions such as those in (1). However, as the authors note, the issue of mixed languages remains largely unsettled. From the data reported, it is not clear whether 'intermediate' languages such as Polish or Catalan should be regarded (i) as not belonging to any rhythm class, (ii) as pertaining to a different category (Polish?), or (iii) as members of one of the traditional classes (Catalan?). The investigation of additional languages is required before any conclusion may be reached.

In the remainder of this paper, the predictions in (1) are tested with the aim of contributing to a better understanding of the rhythmic difference between EP and BP. It is also hoped that the results of this study may clarify the status of mixed languages in the typology of rhythm.

3. Methods

3.1. Materials

The experimental materials consist of a selection of sentences from 3 corpora: MAVig, a European Portuguese corpus collected and analysed by the second author in a former work, with the purpose of establishing the prosodic and intonational structure of the data observed (Vigário 1998); 20F, a comparative EP/BP corpus developed by the authors together with Charlotte Galves within the Project *Rhythmic Patterns, Parameter Setting, and Language Change* (Fapesp, Brazil)[2]; and Rm, a comparative EP/BP corpus composed of the Portuguese translation of the multi-language corpus used in Ramus et al. (1999). All sentences are short, simple declaratives read as news sentences in a soundproof booth by female native speakers of EP and BP. The speakers represent the variety spoken in Lisbon and S.Paulo, respectively for EP and BP, by educated people between their early 20s and early 30s. For the purposes of the present research, these two varieties *stand for* EP and BP. Additionally, we take our speakers as representative of EP and BP in the sense that the properties described in section 2.3 and further discussed in section 5.1, whose presence/absence or incidence sets the two languages apart, neatly characterise their speech (see examples in Fig.1 above and (2)-(3) below).

Table I presents the relevant information on each of the corpora and the sentences selected for acoustic analysis.

TABLE I

Besides the Rm corpus, which matches perfectly the number of syllables per sentence in the materials used in Ramus et al., the other sentences chosen are similar in length and type. Moreover, the amount of data obtained per language is also comparable: the 20F and Rm corpora, which include both EP and BP tokens, totalise 30 sentences per language and over 650 intervals measured in each language, contra 20 sentences and more than 600 intervals measured per language in Ramus et al. (1999). Maximal comparability between the materials of EP and BP and those of the other languages to which the same acoustic measures have been applied was thus ensured. As to the materials of EP and BP, they represent the ideal case, because sentences with the same words and structure can be used to examine differences in rhythm. This is illustrated in (2) (stressed syllables are indicated in boldface).

(2) A des**ci**da das **ta**xas de **ju**ro **foi mui**to elogi**a**da (18 syllables)
the fall of-the rate of interest was very appreciated
‘The fall in the interest rate was much appreciated’
EP: [ɐdʃidɐdɐʃtaʃɐʒdʒuɾufojmũȷ̃teluʒjadɐ]
BP: [adesidadastaʃaʒdʒiʒuɾufojmũȷ̃tʷeloʒjada]

3.2. Procedure

The speakers were instructed to read each sentence silently, and then read it aloud as naturally as possible. All sentences were read at least twice and the best rendition, that is the most natural sounding one, was chosen for analysis.

The recordings of the MAVig corpus were made on tape and later digitised at 16 kHz, using the Sensimetrics Speech Station package for speech analysis. Digitised versions of the sentences from the two other corpora were provided by Ricardo Figueiredo from Unicamp, S.Paulo. These have also been segmented and measured with the help of the Speech Station software.

The sentences were segmented and labelled by the second author.[3] All the consonantal and vocalic intervals were identified and marked as precisely as possible. Zoomed waveforms and spectrograms, together with auditory cues, have been used to determine the boundaries between segments. In general, standard criteria of segmentation were followed (see Peterson and Lehiste 1960, and Lehiste 1970:chap.2). A clarification remark is needed, though, concerning the sequence stop-vowel: the voice onset time was not included in the duration of the vowel, which starts at the onset of voicing. The same criterion was applied in Ramus et al. (1999) (Ramus, p.c.).[4] Further, we have followed the definition of consonantal and vocalic intervals and the treatment of glides given in Ramus et al. work. A vocalic interval consists of one or more vowels and is thus located between the onset and offset of the vocalic stretch; likewise, a consonantal interval contains one or more consonants and is located between the onset and offset of the consonantal stretch. As to glides, these were included in the vocalic interval if part of a falling dithgthong, and in the consonantal interval if part of a rising dithgthong. This option is consistent with phonetic evidence in favour of including post-vocalic glides in the syllabic nucleus, whereas pre-vocalic glides belong to the syllable onset (Andrade and Viana 1994, Mateus and Andrade 2000). To exemplify, the phrase *muito elogiada* presented in (2) above was divided into the following intervals in EP: [m] [ũȷ̃] [t] [e] [l] [u] [ʒj] [a] [d] [ɐ].

3.3. Measurements

The duration of the consonantal and vocalic intervals in each sentence was measured. Based on these measurements, the 3 acoustic parameters proposed in Ramus et al. (1999), and already described in section 2.3., were calculated for each sentence: (i) %V, the total duration of vocalic intervals in a sentence divided by the duration of that sentence (x 100); (ii) ΔV, the standard deviation of the duration of vocalic intervals within a sentence; and (iii) ΔC, the standard deviation of the duration of consonantal intervals within a sentence.

3.3.1. The domain of rhythm

Although we have been referring to the sentence as the domain of our calculations, care was taken to choose only sentences that were prosodically phrased into *one* intonational phrase. So, in the present data, sentence and intonational phrase match. This option is consistent with the assumption that the I-phrase is the domain of rhythm, which has been supported by a number of arguments such as the following: the remedies to arrhythmic configurations (i.e. lapses and clashes) generally apply within the I-phrase and not across I-phrases (Peperkamp 1992, Nespor 1999); similarly, weight effects on word order are operative within I-phrases, but not across them (Guasti and Nespor 1999, Frota and Vigário 1999). In addition, this restriction allows us to control for phrasing variation due to speech rate: a speech string phrased into one I-phrase at a normal speech rate is usually divided into several I-phrases at slower rates (Nespor and Vogel 1986, Frota 2000 for EP).

Intonational phrasing was identified on the basis of the different sources of evidence for the I-domain in EP described in Frota (2000), of which the three most important for the present purposes were: the locus of pause insertion, preboundary lengthening and tonal marking at the right I-edge, and the domain of the tune. According to our observations, similar criteria can be applied to BP (Frota and Vigário 2000).

3.3.2. Normalisation

Two normalised measures of the variability of intervals were also calculated, in addition to the parameters proposed in Ramus et al. (1999). These measures are motivated in the following paragraphs.

In our data, sentence duration is significantly longer in BP than in EP, as illustrated in Figure 2. The difference is systematic across sentences in both the 20F and Rm corpora.

FIGURE 2

This absence of a match in average sentence duration across languages may have an effect on the results of the acoustic parameters based on absolute measurements, that is ΔC and ΔV. It was shown in Grabe and Low (2000) that longer durations may lead to a variability increase both within and across languages. This effect is replicated in our data, as can be seen in Figure 3.

FIGURE 3

Some form of normalisation is thus required to compensate for the consistent duracional difference between EP and BP. The new measures should also keep the sentence, or rather the I-phrase, as the domain over which they are calculated, and be sensitive enough to local changes in duration within that domain that may contribute to rhythmic distinctions.[5] For these reasons, we have chosen to measure the variability of interval duration relative to sentence duration, in a way similar to the measurement of %V. First, the space occupied by each interval within a sentence is calculated by dividing the interval duration by the sentence duration (x 100). Then, the variability of consonantal and vocalic intervals is given by the standard deviations of the space occupied by each type of intervals per sentence, noted respectively as Δ%C and Δ%V.

The different results provided by the absolute and normalised measures are illustrated in Figure 4. It can be seen that the longer duration that characterises BP may lead to higher ΔC values than in EP (Figure 4a). Once the variability values are normalised, the trend is reversed: EP shows higher Δ%C values than BP (Figure 4b).

FIGURE 4

In the following sections, the results of both the absolute and normalised variability measures are presented and discussed: the latter will be crucially used to compare EP with BP; we are, however, compelled to use the former in the comparison of EP and BP with the other languages studied in Ramus et al. (1999).

4. Results

Table II presents the results of the five measurements obtained averaged across all EP and BP sentences in each of the corpora analysed. Total results for each language are also given.

TABLE II

4.1. Within languages

The data of each language per se were tested for significant differences due to the speaker and corpus factors. In all the analyses performed, the results that yield $p \leq .01$ are considered statistically significant.

A MANOVA was run with *speaker* as a factor and %V, Δ%V and Δ%C as dependent variables. The values for each of the corpora were analysed separately. In each corpus, the variable *speaker* had two levels (speaker 1 and speaker 2). The results show no effect of speaker either in EP or BP [EP: corpus MaVig - for %V, $F(1,18)=0.69$, $p > .30$; for Δ%V, $F(1,18)=0.00$, $p > .90$; for Δ%C, $F(1,18)=5.73$, $p > .02$; corpus Rm - for %V, $F(1,8)=1.33$, $p > .20$; for Δ%V, $F(1,8)=0.05$, $p > .80$; for Δ%C, $F(1,8)=0.19$, $p > .50$. BP: corpus Rm - for %V, $F(1,8)=0.00$, $p > .90$; for Δ%V, $F(1,8)=0.08$, $p > .70$; for Δ%C, $F(1,8)=0.68$, $p > .30$].

The two languages, however, pattern differently as far as the effect of *corpus* is concerned. This variable has two levels in BP (20F and Rm) and three in EP (Mavig, 20F and Rm). The results of a MANOVA for each language with *corpus* as a factor revealed significant differences only in EP [EP: for %V, $F(2,47)=5.36$, $p < .0008$; for Δ%V, $F(2,47)=22.42$, $p < .0001$; for Δ%C, $F(2,47)=4.37$, $p > .01$; BP: for

%V, F(1,28)=2.76, $p > .10$; for Δ%V, F(1,28)=0.42, $p > .50$; for Δ%C, F(1,28)=1.09, $p > .30$]. Post hoc comparisons of means between groups (Scheffé) showed that the vocalic measurements differ significantly between all the three EP corpora.

BP is thus characterised by a stable behaviour across different corpora, whereas in EP this factor introduces important differences in the measurements obtained, particularly with regard to the vocalic intervals. We will return to this point further below.

4.2. EP versus BP

Figures 5 and 6 show the results of %V, Δ%C and Δ%V by sentence in the two comparative EP/BP corpora observed. It is clear that %V and Δ%C are the parameters that best differentiate the two languages. The distinguishing role played by these parameters is confirmed by the statistical results.

FIGURE 5

FIGURE 6

A MANOVA with *language* as a factor and %V, Δ%V and Δ%C as variables was computed. There was a significant effect of *language* for both %V and Δ%C [%V: F(1,78)=38.20, $p < .0000$; Δ%C: F(1,78)=26.71, $p < .0000$]. By contrast, no significant effect was found for Δ%V [F(1,78)=4.73, $p > .03$].

If these results are checked against the predictions made in (1) above, it can be seen that not all the parameters pattern as expected. The variability of consonantal intervals (Δ%C) behaves as predicted: it distinguishes EP from BP and the difference goes in the expected direction (EP>BP). The same holds for the proportion of vocalic intervals (%V: EP<BP). As regards these two parameters, EP is clearly *more* stress-timed than BP (and conversely BP is more syllable-timed than EP). The variability of vocalic intervals, however, does not set EP and BP apart. Unexpectedly, the two languages show similar Δ%V values.

Further examination of the variability data was carried out. Figure 7 shows that EP is consistently characterised by higher consonantal variability than BP. In addition, and unlike in BP, there is strong variation in the vocalic variability values within EP. These results confirm our previous observations.

FIGURE 7

An additional pattern that differentiates the two languages comes out clearly in Figure 7: in EP, Δ%C is consistently higher than Δ%V; in BP, the reverse occurs. Consonantal interval variability is thus an outstanding property of EP, whereas vocalic interval variability characterises BP. While the relation between the two types of variability distinguishes the two languages, its connection with the stress/syllable-timing distinction is not immediately clear as EP was expected to show *both* higher values of Δ%C and Δ%V than BP. We will offer an interpretation for this unexpected result in the discussion section.

In summary, the proportion of vocalic intervals (%V) together with the variability of consonantal intervals (Δ%C) provide the best characterisation of the rhythmic distinction between EP and BP. This result is consistent with the findings in Ramus et al. (1999), which also highlight vocalic space (%V) and consonantal variability (ΔC) as the parameters that fit best with the rhythm class typology.

4.3. EP and BP versus other languages

In Figures 8 and 9, the data from EP and BP are compared with the data reported in Ramus et al. (1999) for 8 other languages. The distribution of languages over the %V,ΔC plane, given in Figure 8, shows that EP clusters with stress-timed languages in the ΔC dimension *and* with syllable-timed languages in the %V dimension. As to BP, it is located very far from EP: BP is close to syllable-timed languages in the ΔC dimension *and* to mora-timed languages in the %V dimension.

FIGURE 8

The integration of EP and BP in the traditional rhythm classes was tested through an ANOVA for each of the ΔC and %V parameters, with *rhythm class* as a factor. For ΔC, EP was classified as stress-timed together with English, Dutch and Polish, and BP as syllable-timed together with Italian, Spanish, Catalan and French. For %V, EP was classified as syllable-timed together with the other Romance languages, and BP as mora-timed like Japanese. A significant effect was found for both parameters [ΔC: $F(2,7)=45.47$, $p < .0001$; %V: $F(2,7)=41.24$, $p < .0001$]. Post hoc tests (Scheffé) showed that each rhythm class differs significantly from all others, except in the syllable- vs. stress-timed case for %V, which is nearly significant [for ΔC, $p < .004$ in all cases; for %V, $p < .0008$ for syllable- vs. mora-timed and stress- vs. mora-timed, and $p < .02$ for syllable- vs. stress-timed]. By contrast, the inclusion of EP in the stress-timed group and of BP in the syllable-timed group for *both* parameters yields a non-significant result for %V and has a drastic effect on the %V differences among all rhythm classes [F(2,7)=2.34, $p > .10$; Post hoc tests: $p > .10$ in all cases].

It is thus clear that vocalic space and consonantal interval variability support the traditional stress-, syllable-, and mora-timed classes. This result corroborates the findings reported in Ramus et al. (1999). On the other hand, the same two parameters support the view that both EP and BP are rhythmically mixed languages, as each parameter locates them in a different (but adjacent) rhythm class.

FIGURE 9

The distribution of languages over the ΔC,ΔV plane, given in Figure 9, is not so well correlated with the traditional rhythm classes. Again, this result confirms the observations in Ramus et al. (1999). In addition to Polish, which was found in that previous study to deviate from stress-timed languages with regard to ΔV, BP is also found to deviate from syllable-timed languages in the ΔV dimension. As to EP, it clusters with English and Dutch for both consonantal and vocalic interval variability.

To summarise, the data show that the rhythm of EP and BP is clearly distinct, although the two languages have mixed rhythms: EP shows simultaneously syllable-timing (%V) and stress-timing (ΔC and ΔV) properties, whereas BP shows simultaneously syllable-timing (ΔC) and mora-timing (%V) properties. Vocalic space and consonantal interval variability seem to support both the notion of rhythm classes and the existence of mixed rhythms. The contribution of vocalic interval variability to rhythm is less clear from the data.

5. Discussion

5.1. EP and BP: the acoustic measures and their relation to phonological properties

It was mentioned earlier (section 2.3) that EP and BP are characterised by specific phonological and phonetic properties that place them on different sides of the stress-/syllable-timing distinction. In Ramus et al. (1999), it is proposed that the acoustic measures correlated with rhythmic distinctions are reflections of such properties. Based on this proposal, we have predicted how the acoustic measures should signal the disparate properties of EP and BP and thus the rhythmic difference between the two languages (see (1) above). In this section we will explore the relation between the *phonological* properties of EP and BP and the *acoustic* results just reported.

EP and BP were shown to differ significantly with regard to vocalic space (%V) and consonantal interval variability (Δ%C), as predicted in (1). Ramus et al. (1999) have argued that both parameters can be related to differences in syllable structure. In section 2.3, we have proposed that in the EP/BP case they should also reflect the vowel reduction facts. Although syllable types and syllable complexity are similar in EP and BP (Parkinson 1988, Mateus and Andrade 2000), several phenomena push the two languages in opposite directions, making their phonetics very different: in EP, reduced vowels may frequently delete yielding consonant clusters; by contrast, in BP vowel epenthesis breaks consonant clusters and there is a tendency for coda loss. These differences are illustrated in (3) below (see also the example in Figure 1).

(3)	EP		BP	
	ob**e**d**e**cer	mal	o**bj**ectivo	ma**l**
	[obd´seɾ]	[mał]	[obiʒɛ´tʃivu]	[maw]
	‘to obey’	‘badly’	‘goal’	‘badly’

As a result, sequences of consonants of variable duration are promoted in EP, but not in BP, while the space occupied by vowels decreases in the former language and increases in the latter.

The properties of vowel reduction in EP and BP further contribute to the difference in vocalic space. In both languages, there is a stressed vowel system with 7 oral vowels. In EP, the stressed vowel system is reduced to 4 vowels in unstressed position ([i, ɨ, ɐ, u]). BP, however, is characterised by less reduction, with a 5-vowel system in pre-tonic position ([i, e, a, o, u]) and a 4-vowel system in post-tonic position ([i, e, a, u]), both including mid vowels and excluding the centralised [ɨ] and [ɐ] that characterise EP (Câmara 1970, Mateus and Andrade 2000). As the vowels in reduced systems are generally known to be phonetically shorter (Delgado Martins 1975 and Andrade 1984 for EP; Morais 1992 and Barbosa 1996 for BP), these differences add to the lower vowel space in EP than in BP.

The acoustic parameters %V and Δ%C can be thus directly related to the contrasting properties of EP and BP. The same cannot apparently be said of Δ%V. Based on the same vowel reduction properties just described, a greater variability of vocalic intervals would be expected in EP due to the stronger contrast between stressed and unstressed vowels and the occurrence of centralised vowels. However, the results are contrary to expectations: vocalic interval variability does not distinguish EP from BP. An equally so far obscure result is the strong variation among the values of vocalic interval variability across the various corpora that only characterises EP. We believe that the two results may be related and are partially explained by vowel reduction.

$\Delta\%V$ variability across different corpora in EP can be interpreted as a reflex of the two possible outcomes of vowel reduction in this language: either reduced vowels are shorter and thus add to vocalic interval variability, or reduced vowels ([ɨ, u] in particular) are deleted and thus do not add to vocalic interval variability. The second outcome offers a good reason for a globally lower vocalic variability in EP relative to BP than it was expected. However, the high value of vocalic variability in BP also requires an explanation, as the limited vowel reduction present in this language does not seem a reason enough.

Ramus et al. (1999) have observed that vocalic interval variability is a composite parameter in which combined effects of different phonological and phonetic factors may be reflected. Vowel reduction, phonologically distinctive vowel length, intrinsic vowel duration, and vowel lengthening phenomena (e.g. ϕ-final lengthening) are among those factors. The question is whether BP shows several of these factors, which are crucially absent in EP, thus increasing the variability of vocalic intervals in the former language. It seems that there are at least two factors that may contribute to such an effect: intrinsic vowel duration and contextual prosodic lengthening.

The data on vowel duration reported in Delgado Martins (1973, 1975) for EP and Barbosa (1996) for BP support an effect of the intrinsic duration of vowels in the vocalic variability results. Based on these data, we have calculated the V/V ratios for each language (Table III).

TABLE III

In BP, the differences in intrinsic duration among stressed vowels tend to be more extreme than in EP. Likewise, glides are much shorter than their fully vocalic counterparts in BP, and nasal vowels are also much longer than their oral counterparts. By contrast, this is not apparently the case in EP.

Phonological-phrase related lengthening may further add to vocalic variability in BP, unlike in EP. The phonological phrase (ϕ) seems to play an important role in the intonation structure of BP: every ϕ-head is signalled by a pitch accent and a ϕ-final edge tone is common. In EP, the phonological phrase plays no such role (ϕ-heads are not usually accented and ϕ-edge tones are extremely rare), and there is no ϕ-related lengthening in the language (Frota 2000, Frota and Vigário 2000). As pitch changes, both accentual and edge related, and lengthening phenomena often go hand in hand (Wenk and Wioland 1982 for French, Beckman et al. 1992 and Turk and Sawusch 1997 for English, Frota 2000 for EP), it is plausible that ϕ-related lengthening constitutes an additional source of vocalic variability in BP.

The fact that vocalic interval variability reflects different properties in different languages, which may converge on a similar result like in EP and BP, makes the interpretation of this parameter much more difficult. Furthermore, some of the properties that vocalic variability signals have been related to languages characterised by different rhythms (e.g. intrinsic duration differences in English, Dutch, French and BP, ϕ-final lengthening in Italian, contrastive vowel length in Japanese - cf. Ghini 1993, Ramus et al. 1999).[6] It is thus clear that the status of the vocalic variability parameter as a correlate of rhythmic distinctions has to be tackled with caution until more is known about the different properties it may reflect in particular languages.

5.2. On the status of mixed languages in the typology of rhythm

The rhythm of EP and BP has long been claimed to be different, although no phonetic evidence was given in support of that claim. In this paper, we have provided acoustic evidence for a clear rhythmic distinction between EP and BP. However, the contours of this distinction do not fully corroborate the intuitive classifications present in the literature, according to which EP has stress-timed rhythm and BP syllable-timed rhythm or a mixture of stress- and syllable-timing. Our results show that both EP and BP have mixed rhythms: consonantal interval variability locates EP in the stress-timed class, and vocalic space places it in the syllable-timed class; BP, by contrast, joins syllable-timed languages with regard to consonantal interval variability, and mora-timed languages as for vocalic space. The distinct mixed rhythmic properties of EP and BP make them good cases to assess the status of mixed languages in the typology of rhythm.

The distribution of EP and BP over the %V,ΔC plane, given in Figure 8, shows that they are *mixed* languages, but not *intermediate* languages. Languages with mixed rhythmic properties have been regarded in the literature as intermediate between stress-, syllable-, and mora-timed languages (Dauer 1987, Nespor 1990, Auer 1991). This intermediate position of mixed languages has been the crucial argument in favour of a rhythmic continuum rather than clear-cut rhythm classes. EP and BP, however, do not occupy such intermediate positions. The difference between the expected intermediate positions for stress-/syllable-timed EP and syllable-/mora-timed BP and their actual location in the rhythmic chart is given in Figure 10.

FIGURE 10

The present data thus support the view that a mixed language is cued by (at least) two acoustic parameters each of them setting the language in a different class, rather than by its gradient positioning between the extremes of a variation continuum defined by a given parameter. As a consequence, the notion of rhythm classes is strengthened. Studies on more languages are required in order to assess the generality of this finding.

Another outcome of the distribution of EP and BP over the %V,ΔC plane concerns the relation between the acoustic parameters at stake. It is obvious from Figures 8 and 10 that %V and ΔC are negatively correlated. This correlation is what one should expect on the basis of the syllable structure properties reflected by these parameters (Ramus et al. 1999). If the distribution of languages over the %V,ΔC plane were exhausted by such a near-perfect correlation, it would be fair to assume that only one of the parameters was enough to account for rhythmic differences across languages, the other being redundant. The data of EP and BP, however, show that this assumption is wrong. %V and ΔC are to some extent independent parameters that may point to conflicting classifications of the languages they characterise. This strongly suggests that (at least) the two parameters are needed for an account of the rhythmic patterns of language.

Taking into consideration the literature on BP, the finding that BP rhythm mixes syllable-timing with mora-timing may come as a surprise. What explains BP’s location near mora-timed languages? Following the same line of reasoning that underlies our approach to the study of rhythm, the physical parameters must signal linguistic properties that push BP into mora-timing. In fact, there are at least three of such properties described in the literature, but previously unrelated to the mora-timing characteristic of BP.

Although the syllable structure of BP is similar to that of syllable-timed languages in general, there is a tendency for coda loss expressed in the weakening and vocalising of syllable-final / r l /, and the deletion of word-final / r s / (Silva Neto 1977, Brandão de Carvalho 1989, Parkinson 1988).[7] This tendency, together with the breaking of medial clusters by vowel ephenthesis (see the examples in (3) above), results in a generalisation of the simple CV syllable type and brings BP close to the languages with a syllable complexity intermediate between syllable- and mora-timed languages (Marked II languages in the typology of Levelt & Van de Vijver 1998). Secondly, BP shows intonational properties reminiscent of languages like Japanese and Korean. In particular, both the presence and placement of certain tonal events is dependent on the number of syllables available in the string, and independent of stress (Pierrehumbert and Beckman 1988 show that the number of morae plays a role in Tokyo Japanese intonational structure, and Jun 1996 demonstrates the same for syllables in Korean; for the BP facts see Frota and Vigário 2000). The third piece we would like to adduce is the presence of moraic and tonal systems both in the native languages of Brazil and in the languages taken to Brazil by black African slaves (namely of Yoruba and Bantu origin).[8] Although the influence of these languages on BP is a matter of dispute (e.g. Câmara 1972), several native languages have survived to present days, like Gavião, a moraic language with lexical tone, General Kadiwéu, a moraic language, and Noble Kadiwéu, a pitch accent language (Moore 1999, Sândalo 1997), and varieties of the creolized Portuguese spoken by African Brazilians are still reported to exist (Crystal 1987). It is thus conceivable that these languages may have played a role in pushing BP away from syllable-timing. This idea finds further support in the results of a recent study on the rhythmic properties of Afro-Brazilian Portuguese (Cruz 2000), that uses the %V and ΔC parameters proposed in Ramus et al. (1999). Cruz’ finding that Afro-Brazilian Portuguese has mora-timing properties in the %V dimension stands as an additional piece of evidence in favour of the tendency to mora-timing in some BP varieties. Equally relevant is Cruz’ conclusion that the prosody of Afro-Brazilian Portuguese argues for a Bantu substratum in BP.[9]

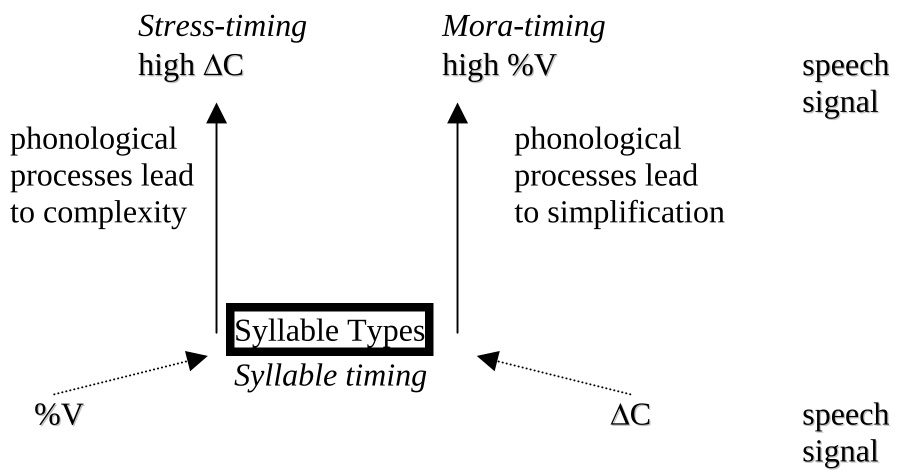
Like the rhythmically mixed status of BP, the mixed rhythm of EP can also be motivated on the basis of the phonological and phonetic properties of the language. The acoustic parameters show that EP displays both syllable- and stress-timing properties. The syllable types of EP are similar to those found in syllable-timed languages (CV, CVC, V(C), CCV(C)) and their relative frequency is also comparable, as shown in Table IV.

TABLE IV

However, as described earlier in this paper, the effacement of reduced vowels may lead to frequent and variably long consonant clusters (of more than 5 consonants like in *desprevenir* [dʃprv´niɾ] ‘to neglect’). The presence of frequent consonant clusters of variable length has always been associated to stress-timing. The acoustic parameter %V can thus be interpreted as cueing the former property, while ΔC is clearly a reflection of the latter property.

Mixed languages like EP and BP raise yet a further question. The speech signal provides the native speaker with mixed cues relative to the language rhythm, and thus to the properties that determine it. How can the native speaker infer the phonological properties of his/her language on the basis of the disparate cues present in the signal? It is known that infants use rhythm to discriminate between languages (Mehler et al. 1988, Nazzi et al. 1998, among others), and it has been proposed that rhythm may help in the acquisition of certain phonological properties, such as syllable structure (Ramus et al. 1999). If both stress- and syllable-timing cues are contained in the signal, like in the EP case, how can the correlates of rhythm provide that help? We would like to suggest the following. The speech signal offers a cue to the kind of phonological processes that characterises each language and influences the phonetic string, as depicted in (4). Noticeably, it also provides a cue to the phonological syllable types of EP and BP. As both cues are available in the speech signal, they may in principle be used in the acquisition process.

(4)



A different but related issue to which the findings reported in this paper may contribute is the perceptual weighting of the different acoustic parameters. From the data reported in previous work, it was not clear how the relative importance of vocalic space and consonantal interval variability to the perception of rhythm could be tested. For the eight languages studied in Ramus et al. (1999), the two parameters converged on the same classification. That is, however, not the case for EP and BP. On the basis of the Portuguese data, the relevance of each of the two parameters may be assessed by means of discrimination experiments. If vocalic space plays the major role, then it is predicted that EP can be distinguished from a stress-timed language, but not from a syllable-timed language. If the major contribution is given by consonantal variability, the reverse is predicted. Finally, both parameters may be equally decisive to rhythm perception, in which case EP should be both distinguished from syllable- and stress-timed languages. We hope to test these predictions in future research.

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Notes

[1] It should be noticed that these timing contrasts, as they are standardly used in the literature on linguistic rhythm reviewed here, are orthogonal to the iambic/trochaic feet distinctions that characterise (word) stress patterns in metrical phonology (Hayes 1995, Goedmans et al. 1996, among others: e.g. both English and Spanish, respectively stress- and syllable-timed, are analysed as trochaic systems).

[2] Information on this project can be found at http://www.ime.usp.br/~tycho/ .

[3] A previous segmentation of the 20F corpus done by Ricardo Figueiredo was revised by the second author with some assistance from the first author to ensure the homogeneity of the criteria applied.

[4] To evaluate whether our segmentation is comparable to the one done in Ramus et al., we have segmented a sample of Ramus at al.'s sentences and crosschecked the results obtained. The variations found were not significant and thus allow a meaningful comparison of the two sets of data. The computation procedure was checked as well. We have computed the three variables on a sample of Ramus et al.'s data and obtained the same results as those reported by Ramus (p.c.).

[5] In a recent study on the acoustic correlates of rhythm, Grabe and Low 2000 apply a normalisation procedure which is very different from the one proposed here, as it measures the duration difference of two successive intervals of the same type in a text and divides it by the mean duration of that pair. On the one hand, this procedure is strictly local and reminiscent of former phonetic research in which the duration of interstress intervals or syllables was compared. On the other hand, this procedure is unbound in the sense that successive intervals are compared across I-phrases and utterances. Further, Grabe and Low only apply the normalisation procedure to vocalic intervals, because for them this type of interval is defined as consisting of just one segment, unlike the consonantal intervals.

[6] Grabe and Low 2000 take a vocalic variability measure to be the main parameter in the search for acoustic correlates of rhythm. Besides the differences between their measure and the one proposed by Ramus et al. 1999 (see ftn 5), the continuum of acoustic variability that characterises the 18 languages they study may well be due to the entangled effects of the various factors behind vocalic variability.

[7] It should be noted that only a liquid or sibilant may follow an oral nucleus, and only a sibilant may follow a nasal nucleus.

[8] To be more specific, in many of these languages the mora is a crucial unit for prosody, as either stress and/or tone patterns or intonation depend on the parsing of the segmental string into morae.

Incidentally, the mora has been argued to play a major role in the assignment of stress in BP, as well as in other parts of BP phonology (Wetzels 1997, 2000, among others).

[9] In a study on the evolution of vowel reduction in EP, Marquilhas 2000 dates post-tonic reduction from the Middle Ages (probably the XIII century) and pre-tonic reduction from the XVI-XVII centuries. The latter is argued to have resulted from a reanalysis of an older vowel harmony process whose output had become similar to that of post-tonic reduction. According to Marquilhas, both the fact that pre-tonic vowels have not followed the same path in non-European varieties of Portuguese and the similarity between BP and Portuguese-based African Creoles in this regard are due to the importance of vowel harmony in the native African languages. This substratum effect would have blocked the reanalysis towards general vowel reduction already in process.

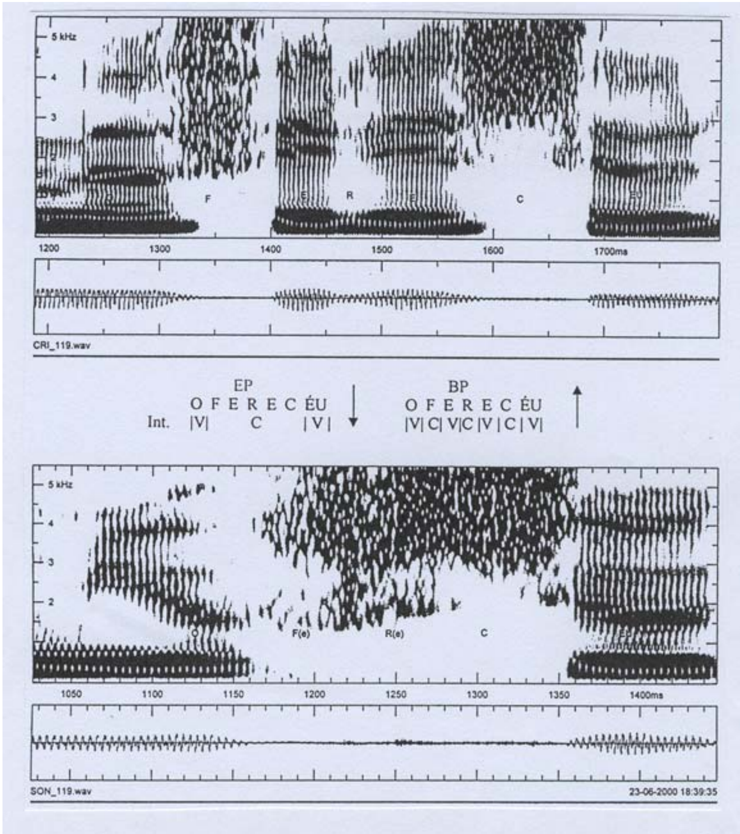


Figure 1. Spectrogram of the underlined section of the sentence *O investigador já me* <u>*ofereceu*</u> *dinheiro* (the researcher already to-me gave money) uttered by a Brazilian (upper panel) and a European (lower panel) Portuguese speaker.

Table I. The 3 corpora: the number of speakers, the number of sentences selected, the number of syllables per sentence, and the total number of intervals measured.

Corpus	Language	Speakers	nº of sentences	nº of syll. per sent.	nº of intervals
MAVig.	EP	2	20 (10x2)	13-18	532
20F	EP&BP	2 (1+1)	40 (20x2)	13-21	450 & 537
Rm	EP&BP	4 (2+2)	20 (5x4)	15-19	230 & 274

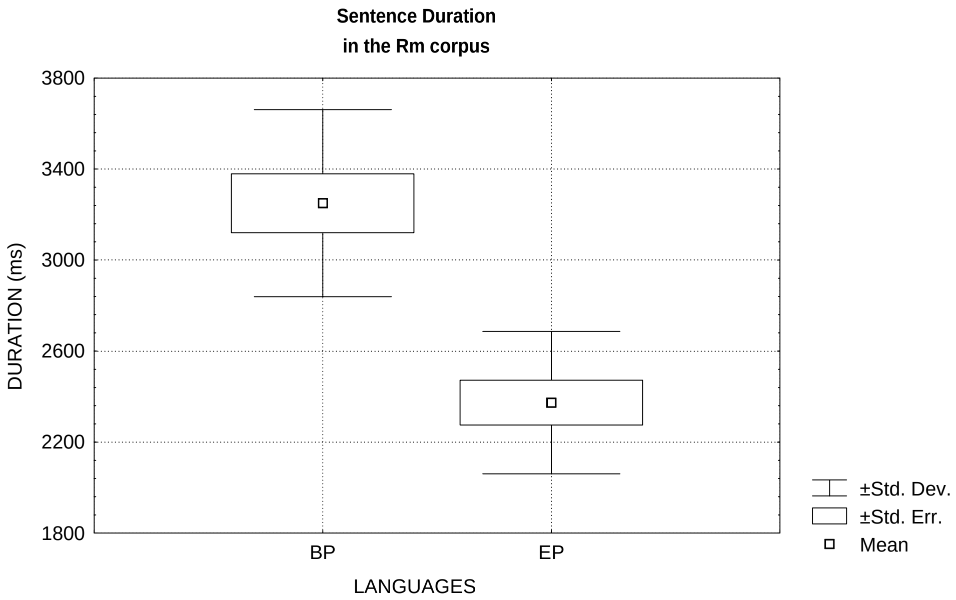


Figure 2. Boxplot for sentence duration values per language in the Rm corpus.

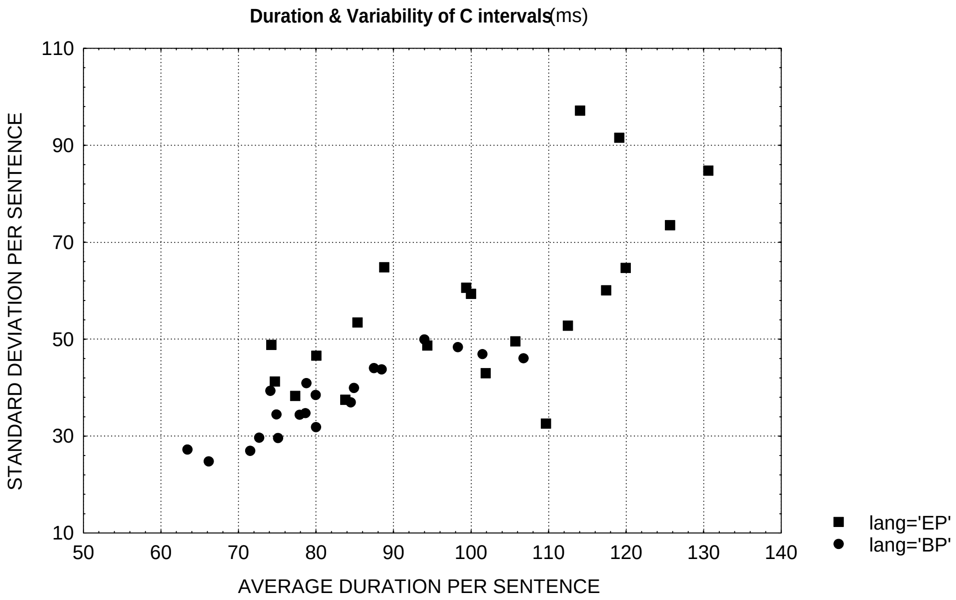
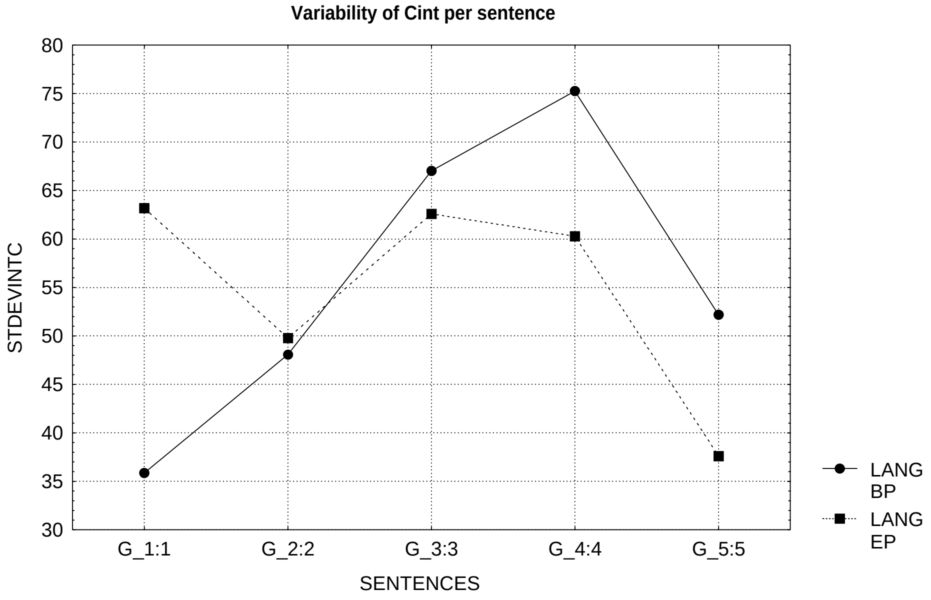


Figure 3. Standard deviation of consonantal intervals as a function of their average duration (in ms), per language. Each data point represents one sentence from the 20F corpus.

(a)



(b)

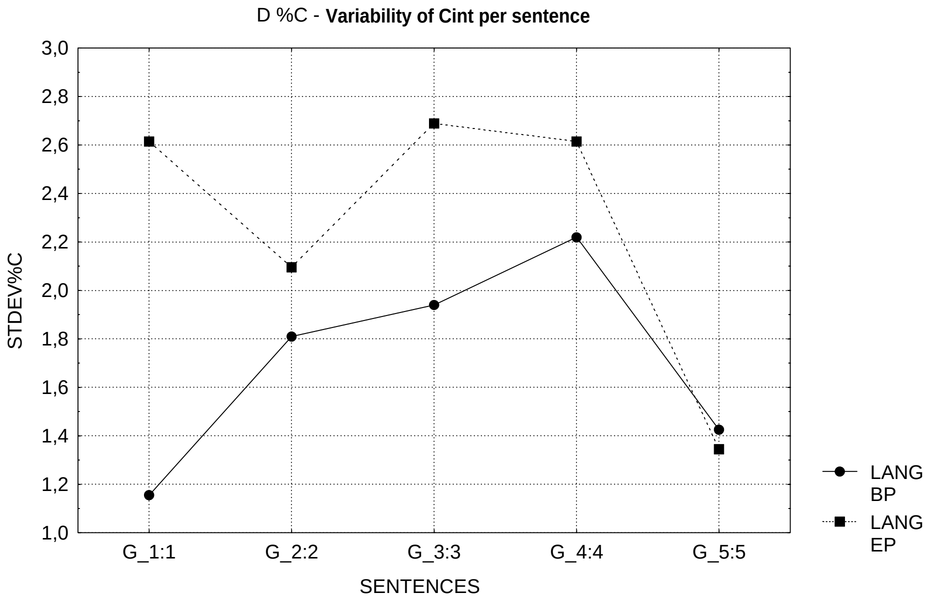


Figure 4. Variability of consonantal interval duration per language. Each data point represents one sentence from the Rm corpus. ΔC values are plotted in panel (a); Δ%C values are plotted in panel (b).

Table II. The results of the five acoustic measures averaged by corpus and language, and their respective standard deviations.

Language		N	%V	Δ%C	Δ%V	ΔC	ΔV
EP	MAVig	20	48.8(3.89)	2.1(0.42)	1.2(0.23)	51.8(11.12)	28.2(5.22)
	20F	20	49.4(3.93)	2.8(1.03)	2.5(0.89)	57.5(17.9)	49.9(13.0)
	Rm	10	43.8(6.94)	2.3(0.74)	1.9(0.45)	54.7(13.37)	44.8(7.65)
	Total	50	48.0(5.04)	2.4(0.83)	1.8(0.84)	54.6(14.55)	40.2(14.10)
BP	20F	20	56.8(4.84)	1.5(0.35)	2.2(0.68)	37.4(7.60)	52.1(14.96)
	Rm	10	53.2(6.90)	1.7(0.49)	2.3(0.62)	55.7(18.20)	74.2(14.81)
	Total	30	55.6(5.75)	1.6(0.40)	2.2(0.66)	43.5(14.73)	59.5(18.09)

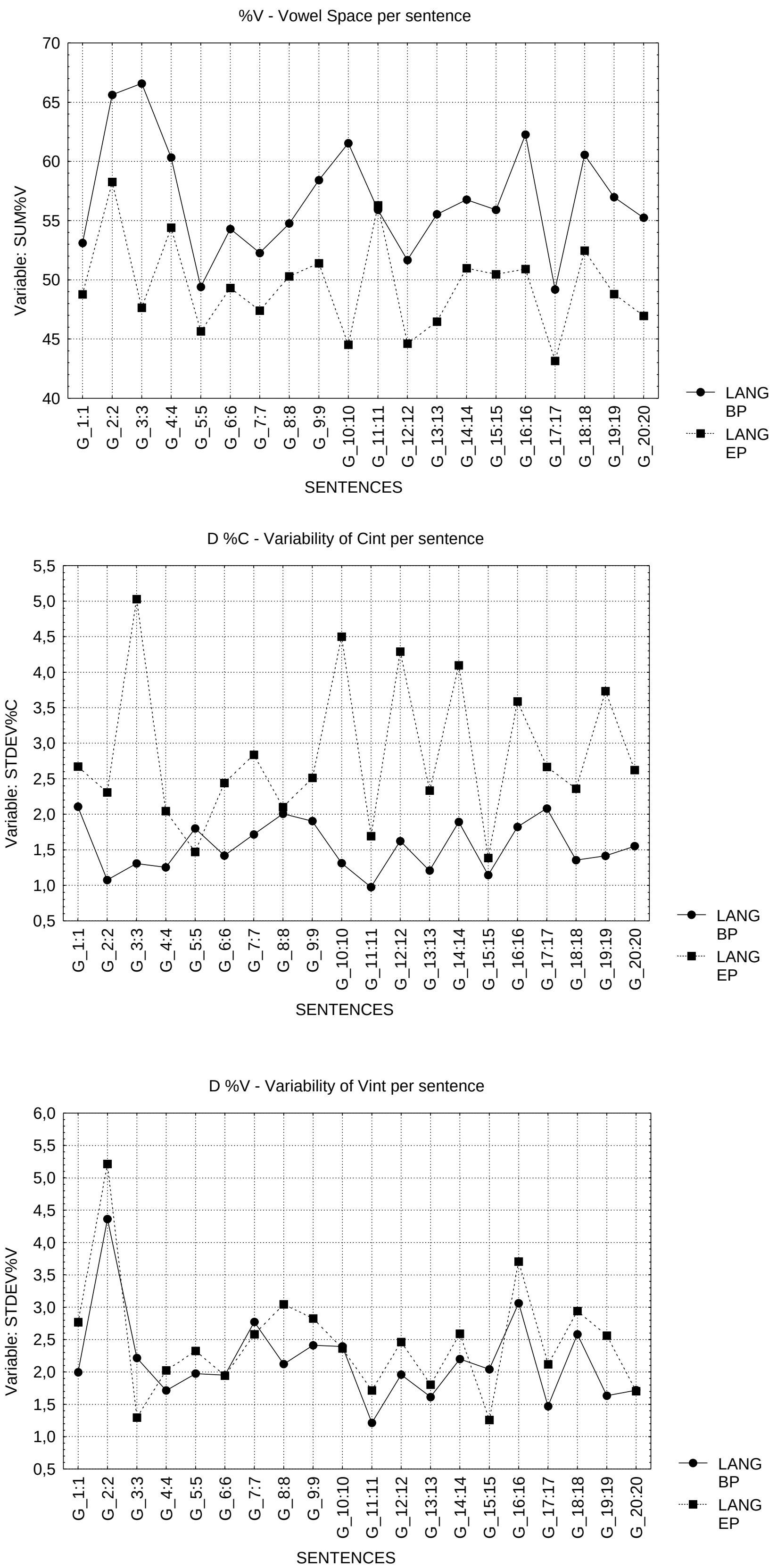


Figure 5. Vowel space (%V), variability of consonantal intervals (Δ%C) and of vocalic intervals (Δ%V) in the 20F corpus. Each data point represents one sentence per language.

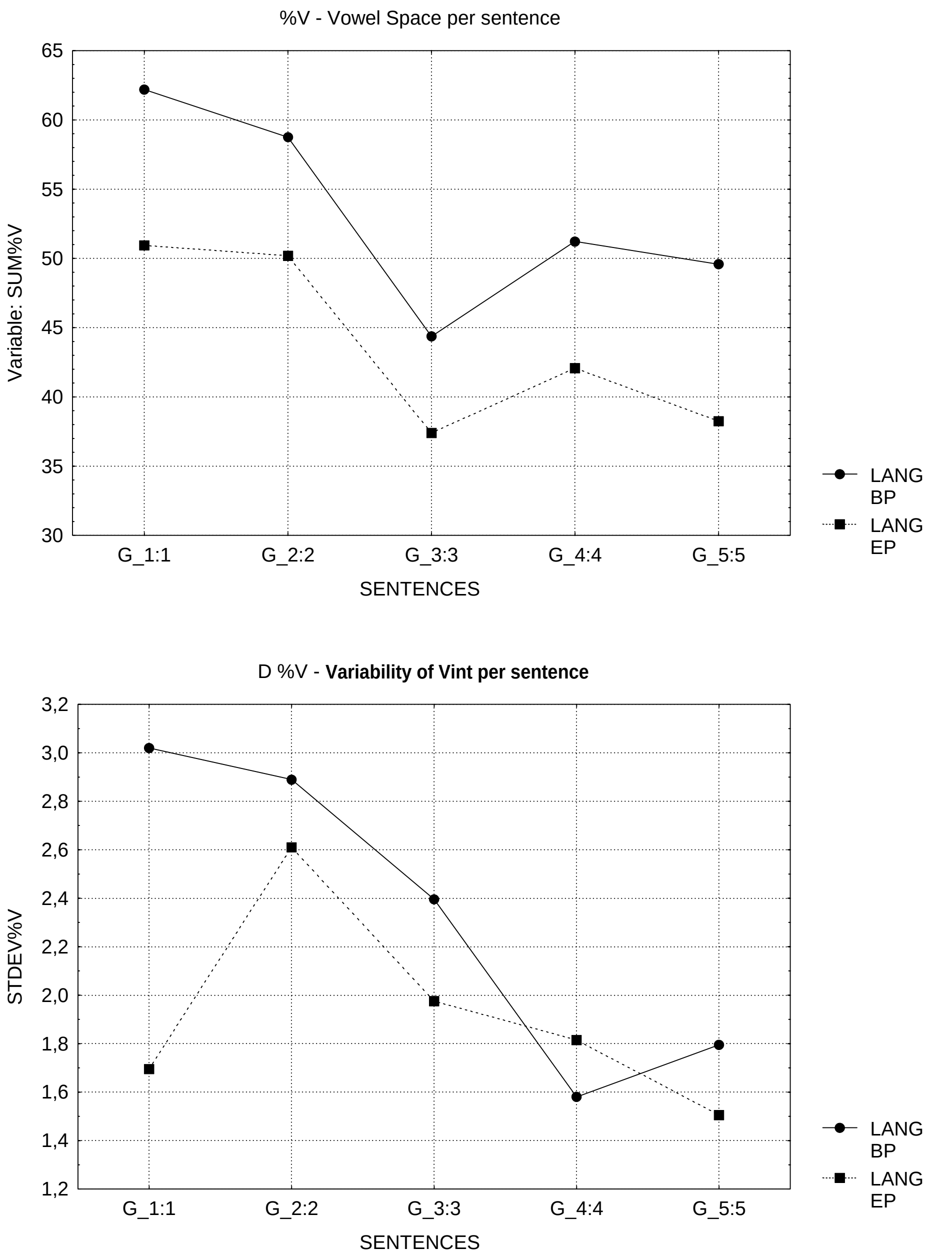


Figure 6. Vowel space (%V) and variability of vocalic intervals (Δ%V) in the Rm corpus. Each data point represents the average value for one sentence per language. (The consonantal variability values were already plotted in Figure 4b.)

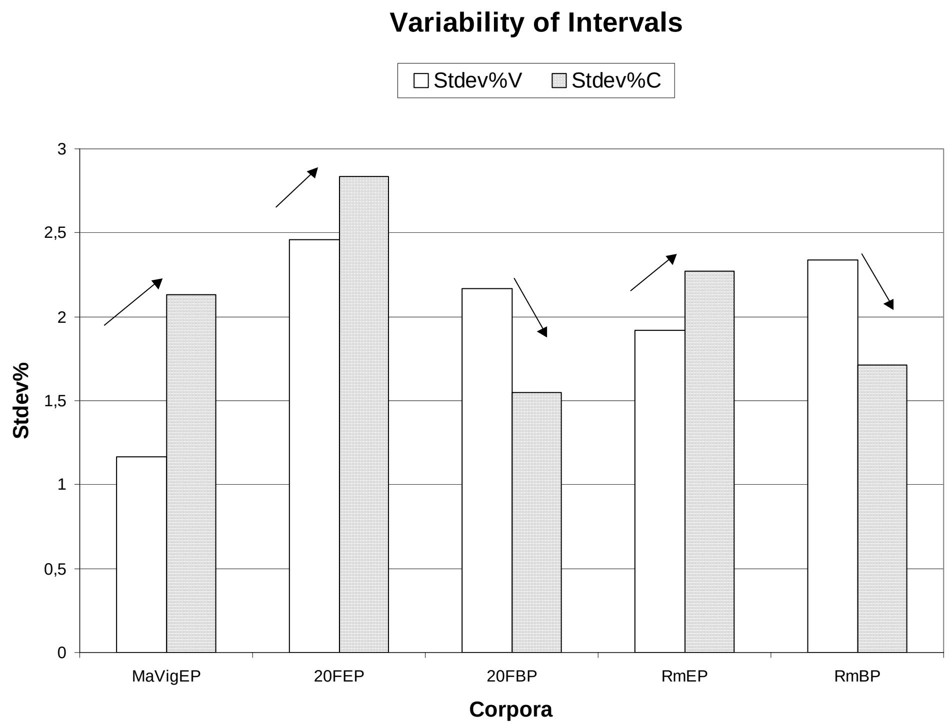


Figure 7. Variability of intervals. Δ%V and Δ%C averaged by corpus and language.

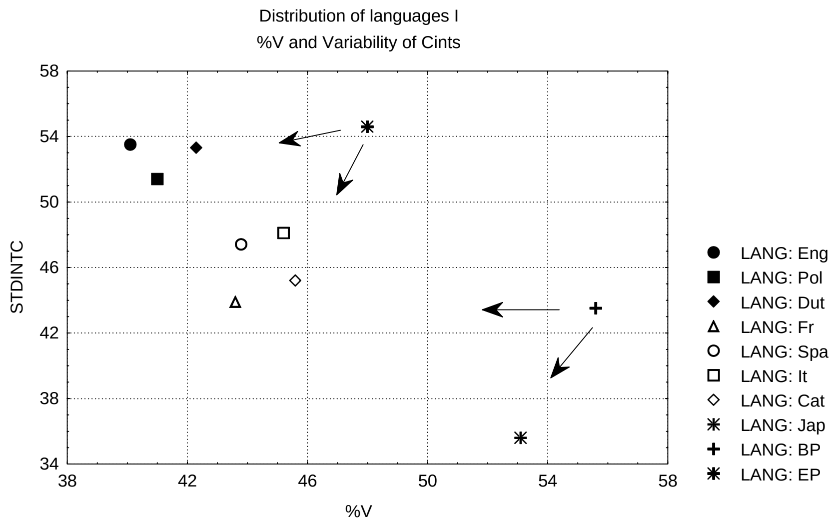


Figure 8. Distribution of languages over the %V,Δ plane. Values averaged by language. Data for the 8 other languages from Ramus et al. (1999).

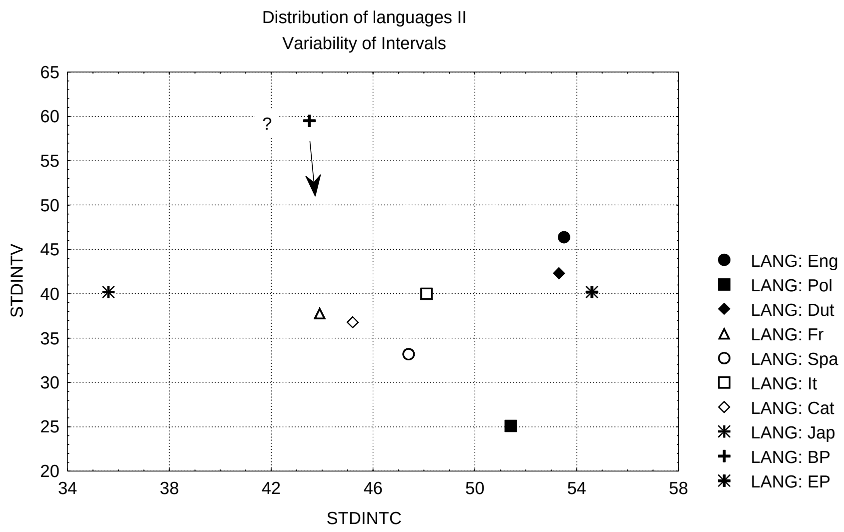


Figure 9. Distribution of languages over the ΔC,ΔV plane. Values averaged by language. Data for the 8 other languages from Ramus et al. (1999).

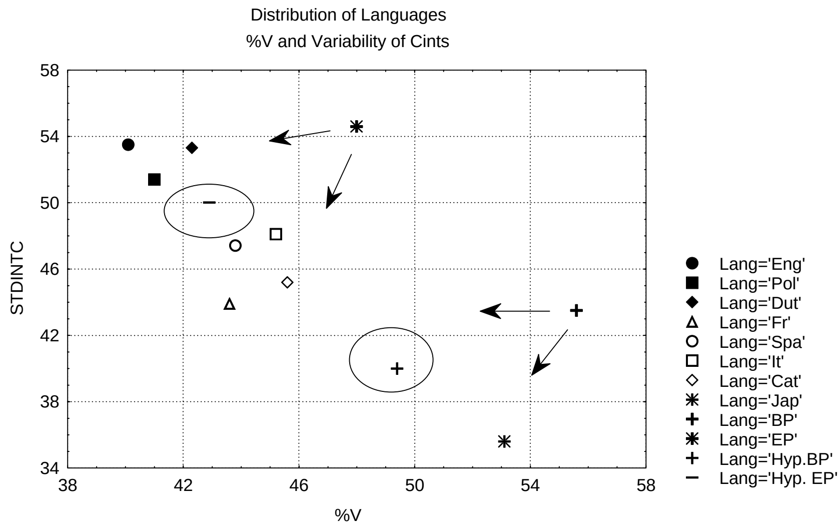


Figure 10. Distribution of languages over the %V,Δ plane, including hypothetical intermediate positions for stress-/syllable-timed EP and syllable-/mora-timed BP (within circles).

Table III. Vowel/vowel ratios, glide/vowel ratios and oral/nasal vowel ratios based on data reported in Barbosa (1996) for BP and Delgado Martins (1973, 1975) for EP.

Ratios	BP	EP
stressed		
i : e	0.85	0.90
i : ɛ	0.83	0.76
e : ɛ	0.97	0.85
u : o	0.79	0.87
u : ɔ	0.73	0.82
o : ɔ	0.92	0.94
unstressed and stressed		
a/ɐ : a	0.67	0.79
glides		
j : i	0.63	1.15
w : u	0.72	0.77
nasals		
ɐ : ɐ̃	0.64	0.93
e : ẽ	0.81	1.03
i : ĩ	0.69	0.78
o : õ	0.73	1.57
u : ũ	0.62	1.06

Table IV. Most frequent syllable types and percentage of closed syllables in EP (Vigário and Falé 1994, Andrade and Viana 1994), Italian (Nespor 1990), Spanish (Manrique and Signorini 1983, Dauer 1983), French (Wenk and Wioland 1982, Dauer 1983), Dutch (Levelt and Van de Vijver 1998), and English (Dauer 1983).

Syllable Types	EP	Italian	Spanish	French	Dutch	English
CV	59%	60%	56%	56%	43%	34%
closed syllables	19%	----	30%	26%	48%	56%