

# Speech rate and rhythmic variation in Brazilian Portuguese

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## Abstract

This paper discusses new inventive methodologies for the classification of speech rhythms. Moreover, it sheds new light in the search for isochrony in speech by showing that fast rates exacerbates the timing characteristics of rhythms, i.e., syllable- and/or stress-timing properties are more easily perceived at these rates. This finding is supported by an acoustic experiment which showed that the standard deviation of VV duration and/or SG duration is smaller at fast rates. In addition, this work reveal that the decrease of standard deviation of SG and/or VV duration is influenced by many factors such as dialect, gender, and sentence structure. This article, therefore, calls attention to another condition that need to be controlled in the study of speech rhythm: the rhythm variability across dialects.

**Index Terms:** speech rhythm, speech rate, rhythm typology, isochrony, rhythmic variation

## 1. Introduction

Lloyd James [15, p. 25] was one of the first to perceive rhythmic differences between languages. Through a military metaphor, he stated that some languages resemble the rhythm of a morse-code (e.g. English), and other languages resemble the rhythm of a machine-gun (e.g. Spanish). Based on this assumption, Pike [22, p. 35] stated that languages are categorized either as syllable-timed or stress-timed. The first type of language is characterized by a regular succession of syllables (machine-gun rhythm), whereas the latter is characterized by a regular succession of stresses (morse-code rhythm). Even though Pike introduced the idea of isochrony in speech rhythm, he said that a language may deviate from its main rhythmic characteristic in some speech contexts. Despite considering English as a stress-timed language, Pike [22, p. 71] described that this language may present syllable-timing characteristics in some speech styles and certain stretches of singing. An up-to-date example of rhythmic variation according to different speech styles will be given further on. Up to this moment, the notion of rhythmic isochrony was, therefore, considered variable. Nevertheless, Abercrombie did not followed Pike's statements and proposed a more radical version of rhythmic tendencies in languages. According to Abercrombie [2, p. 97], "as far as is known, every language in the world is spoken with one kind of rhythm or the other". As a result, from that moment on, the search for strict isochrony at the production level began to be pursued in order to classify the rhythm of languages.

Pike and Abercrombie cite English, Russian, and Swedish as examples of stress-timed languages, and French, Spanish, and Yoruba as examples of syllable-timed languages. Nonetheless, subsequent works never found strict isochrony for either stress-timed or syllable-timed languages (see [23], for Spanish; [26], for English and French; [30], for French; [12], for Swedish, among other language data). As data on speech production has failed to proved the notion of rhythmic isochrony, some scientists tried to explain the sensation of isochrony according to qualitative (cf. [11]) and perceptual notions (cf. [14, 7, 30]). Dauer's view of isochrony has been proven to be innocuous. For example, according to Dauer's parameters for rhythmic typology, Brazilian Portuguese (henceforth BP) should be considered a stress-timed language. Yet, as will be shown afterwards, Brazilian Portuguese rhythm varies according to different speech styles. On the other hand, the isochronic sensation at the perceptual level may be conceived as a general tendency of rhythmic units (see [13]), and as such sheds no light on the linguistic question on how to categorize and differentiate linguistic rhythms. In spite of some researchers have abandoned the

search for isochrony at the production level, some others have recently devised ingenious quantitative methods to explain and classify the rhythm of languages [12, 24, 21, 5].

Port et al. [24] suggest that regularity in speech production can be seen through an experiment called speech cycling task (henceforth SCT). With SCT they showed evidence of a speech underlying dynamics in Japanese morae and in inter-stress intervals in English. Based on Stetson's experiments [28], this task consists of continuous repetitions of phrases in synchrony with an external auditory stimulus like a metronome. Classé [9] and Cummins [10], among others, showed that in interconnected phrases, as in SCT, speech occurs with a fairly regular rhythm. Port et al, state that, if English is rhythmic at the stressed syllable level, there must be an underlying metrics that coordinates inter-stress periods (similar to musical notes' beats) with another higher period (similar to musical measures) like the period of the whole sentence. The relation between inter-stress intervals with phrase period would act as an attractor in speech.

In SCT, researchers expected speakers to produce quotients in phase angles  $1/2$ ,  $1/3$ ,  $2/3$  in relation to the whole phrase, as in music, in which musical notes occur in harmonic fractions of the measure. As in simple measures, the whole measure is 1, in the  $4/4$  measure, the third note begins in the phase angle  $1/2$  (0.5), in the  $3/4$  measure, the third note begins in  $2/3$  (0.666...), and so on. Harmonic relations like these are expected to occur in speech. Stimuli consisted of repetitions of the tokens *take* and *cards* produced consecutively with different spacings. The interval between pulses (based on the *p-center* literature, see [6, 27]), of two consecutive *take* was fixed in 1.5 seconds, corresponding to a complete cycle. The phase angle of *cards* varied from 0.3 from 0.65. Although many rhythmic patterns have been stimulated, speakers converged to certain phase attractors ( $2/4$ ,  $3/4$ ,  $4/4$ ), which were around harmonics defined by the repetition of the whole sentence.

Port et al.'s hypothesis to explain this rhythmical phenomenon is the existence of an adaptive oscillator (cf. [17]), which is synchronized with the beats of individual morae and/or inter-stress intervals. These two coupled oscillators (the acoustic stimulus and the cognitive oscillator) would cause the average of the phrase duration to be perceived as isochronous. Nevertheless, the SCT experiment needs to be tested in other languages. Also, the speech rate effect on rhythm requires further investigation. It may be the case that the attractors be the same across languages and, therefore, SCT may not be able to distinguish rhythmic characteristics of languages. On the other hand, O'Dell and Nieminen's works (cf. [21]), as well as Barbosa's works (cf. [3,4,5]), both of which share some of Port and colleagues' ideas, seem to be good models for deriving rhythm typologies of the world's languages.

In addition to these, Eriksson [12] proposed that the rhythm of languages are best described using the simple linear function

$$I = a + bn \quad (1)$$

in which  $I$  is the stress group duration (inter-stress interval in his terminology), and  $n$  is the number of syllables in the stress group. Traditionally considered stress-timed (e.g. English, Thai) and syllable-timed languages (Spanish, Greek, Italian) are easily described through this function. Based on Dauer's data [11], Eriksson observed that the rhythm of these languages are differentiated by the constant  $a$ . This constant is around 100 ms for syllable-timed languages and around 200 ms for stress-timed languages. Hence, the traditional rhythmical dichotomy is reduced to a one-variable scale.

O'Dell and Nieminen [21] improved Eriksson's proposal for analyzing speech rhythms by using a mathematical technique known as Averaged Phase Difference (APD) theory. This theory was used to derive qualitative information about a model of coupled oscillators composed by syllable and stress group oscillators. According to the researchers, the "relative strength" ( $r$ ) of the oscillators is estimated by using the formula:

$$r = a/b \quad (2)$$

in which  $a$  and  $b$  are derived from equation (1). As a result, stress-timed languages would have a greater influence of the stress group oscillator ( $r > 1$ ), and syllable-timed languages would have a greater influence of the syllable oscillator ( $r \leq 1$ ). However, the scientists advised that we should be cautious in using the relative coupling strength as a measure of rhythmic structure, since it may exhibit great variation as a function of speech styles and dialects. Barbosa [3] argued that we also need to consider speech rate as an important parameter in rhythm typology, as it speeds up (or slows down) the syllabic oscillator and, accordingly, modifies the coupling strength ( $r$ ) parameter. These questions will be discussed next.

## 2. Speech rhythm variation in BP

Despite Major [16] having analyzed BP as a stress-timed language, other acoustic and phonological analyses of BP rhythm question Major's analysis. In fact, most of Brazilian linguists who work on the subject have concluded that BP is a mixture type of rhythm, i.e., it encompasses syllable-timing properties as well as stress-timing properties. These findings are in accordance with Roach [25], who asserted that no language is "totally syllable-timed or totally stress-timed – all languages display both sorts of timing" (p. 78).

Moraes and Leite [20] observe this rhythm variability in BP data. On the one hand, the mean syllable duration in stress groups from 4 to 8 syllables was statistically non-significant, what is an evidence of syllable-timing in BP. On the other hand, the mean duration of a 8-syllable stress group was statistically non-significant compared to a 9-syllable stress group, what is an evidence of stress-timing in BP.

Cagliari and Abaurre [8] have also found both timing characteristics in BP. Dispersion measurements of stress groups (small dispersion is an evidence of a stress-timed language) from 10 native speakers of distinct Brazilian geographical regions revealed a crescendo from syllable-timing to stress-timing. Thus, this paper calls attention to another condition that need to be controlled in the study of speech rhythm: the rhythm variability across dialects.

Abaurre-Gnerre [1], based on phonological evidence, affirmed that BP exhibits processes of syllable-timed languages such as epenthesis. Also, the linguist considers that Bahia (from Bahia state) and Rio Grande do Sul (from Rio Grande do Sul state) dialects sound more syllable-timed than other dialects. In addition, she suggests a correlation between slow rate (or formal style) and syllable-timing, as well as a correlation between fast rate (or casual style) and stress-timing. All these questions are addressed below.

Using a coupled oscillators approach to rhythm typology, Barbosa [3] analyzes rhythmic variation as a function of different speech styles and rates. In this article, 36 sentences were read by one speaker at three distinct speech rates (slow, normal, and fast). The following parameters were varied in the corpus: (i) word position in the sentence; (ii) syntactic structure; (iii) number of syllable-sized segments in the stress group. It is worth remembering the role of the vowel onset as a place of perceptual salience (cf. p-center literature). For this reason, the stress groups were computed from the beginning of the first unstressed vowel-to-vowel (henceforth VV) unit following a stressed VV to the next stressed VV unit. For example, the bold letters in /a.'ka.za.da.'a.na/ constitute a stress group. Stress groups are considered to be right-headed in BP (see Barbosa's discussion in [3]).

As in [21], BP rhythm in this study was measured from linear regression and coupling strength factors. The results show that BP is a stress-timed (close to British English) or a syllable-timed (close to European Spanish) language depending on specific speech situations, as follows: a) the greater the number of VVs per stress group, the greater the

occurrence of stress-timing; b) speech rhythm varies from syllable to stress timing according to different speakers and syntactic structures; c) speech rhythm varies as function of different speech rates. See also [5] for new findings on the question of rhythm typology.

Barbosa's results reveal that stress-timing may be present at slow and also at fast rates. This is counter-evidence to Abaurre-Gnerre's statement [1] that stress-timing is expected to be found at fast rates, and syllable-timing is expected to occur at slow rates. Of course, syllable-timing may occur at very slow rates due to the even repetition of syllables at this condition. Nonetheless, there is no easy relationship between speech rate and speech timing. As Barbosa [3] shows, speech rate increase is not directly correlated to stress-timing increase. Although there is such a correlation from slow (or normal) to fast rates, we observe a change from stress-timing to syllable-timing from slow to normal rates. In spite of this, the data shows that the highest coefficients of coupling strength always occurred at fast rates. Furthermore, in a comparison of 11 languages, the only example of BP as a stress-timed language is found at the fastest rate. Hence, Barbosa's data suggests that extreme fast rates may indeed be associated with stress-timing properties. Besides, we will next describe some experiments with BP data that sheds new light upon the classification of speech rhythms.

## 3. Isochronic tendencies in BP

Meireles' research has shown how speech rate modifies speech rhythm [18, 19]. The speech rate influence on speech rhythmical reorganizations can be explained by the Dynamical Speech Rhythm model [4, 5]. The results of these studies corroborate the thesis that speech rate increase modifies, dynamically, the speech rhythm at the sentence and the lexical levels. Moreover, as will be described next, this research contributes to the search for isochronic tendencies in speech.

Specifically, Meireles' results [19] have shown that the standard deviation of VV duration as well as stress group (henceforth SG) duration is smaller at faster rates. Consequently, both stress group and VV duration tend to be constant with speech rate increase. Thus, speech rate increase exacerbates the mixture character of BP rhythm, i.e., it presents tendencies to syllable as to stress-timed rhythm. What rhythmic pattern will be manifested will depend on the coupling strength ( $c$ ) between the syllable and the stress group oscillators. As seen before,  $c$  is also influenced by factors such as dialects, speech styles, and speech rates.

Based on these previous results, we questioned whether this standard deviation decrease is a general phenomenon in speech rhythm, which can be found in different speakers and dialects. Therefore, we carried out a cross-dialectal experiment to observe tendencies to speech isochrony in BP.

## 4. Cross-dialectal study on speech isochrony in BP

### 4.1. Methods

A database of 11 sentences repeated ten times (sampling rate of 22.1 kHz) was recorded by 8 native speakers of BP at three speech rates (slow, normal, and fast). These speakers are from Minas Gerais (henceforth MG) state (2 men and 2 women) and from Bahia (henceforth BA) state (2 men and 2 women). The MG speakers were born and raised in Belo Horizonte, the capital of MG. The BA speakers were born and raised in Conceição do Jacuípe, a small town in BA. These speakers are considered typical representatives of their dialects.

The recorded corpus was composed by the following sentences: 1. Há três tipos de abóbora no centro de Belo Horizonte; 2. Há três tipos de abóbora nanica em Belo Horizonte; 3. A análise de tantos dados parecia certa; 4. A análise computacional parecia certa; 5. Quando sinto cócegas, logo tenho falta de ar; 6. Dei um beijo de tirar o fôlego; 7. Fôlego de atleta foi exigido do competidor; 8. Meu fósforo terminou. Me empresta o fósforo; 9. Use fósforo para acender

o fogão; 10. Como carne de boi no sábado; 11. No sábado passado comi carne de boi.

The distinct speech rates for the sentences were obtained according to the following instructions and order: (1) normal: speak at a comfortable way; (2) slow: speak as slowly as you can, whilst preserving the prosodic structure of the sentences; (3) speak as fast as you can without introducing distortions in your speech.

## 4.2. Procedures

Semi-automatic procedures were used to observe different rhythmic structures with speech rate increase. First, VV units were labeled in Praat. Then, a Praat script (SGDetector) [19] was run, resulting in information, such as: (i) moment-to-moment VV duration; (ii) SG duration; and (iii) VV units per SG. Finally, in case of wrong attribution of phrasal stresses, we listened to the original recordings, so as to manually mark phrasal prominences.

## 4.3. Hypotheses

The hypotheses to be investigated, which are related to speech isochrony, are:

1. Standard deviation is generally smaller at fast rates, resulting in a greater sensation of isochronism at such rates;
2. The stress group duration tends to be constant with speech rate increase;
3. Speech rate increase exacerbates the mixture character of Brazilian Portuguese rhythm, i.e., tendencies to syllable as to stress-timed rhythm.
4. The decrease of standard deviation of SG and/or VV duration is influenced by different dialects and genders.

## 4.4. Results

As speech rate increase is a necessary condition to observe standard deviation (henceforth SD) decrease of VV duration and/or SG duration, one-way ANOVAs with speech rate (syllables/second) as a function of rate (slow, normal, fast) were run. The results have shown that all sentences have reached statistical significance. So, we assured the analyses were not influenced by the non-statistical significance of rates. Nonetheless, for the BA dialect, we had to discard all slow rates. These speakers did not produce the slow rate as instructed. All six BA speakers (we included 2 extra ones) introduced pauses in between the words. An informal perceptual test of the data revealed a very syllable-timed rhythm in this sort of speech style, what is in agreement with a previous analysis of this dialect by [1]. That is why we considered only two rates (normal and fast) when using data from BA dialect.

In order to test the hypotheses, this experiment investigated the following combination of factors: (i) speech rate as a function of the dialects; (ii) standard deviation (VV and/or SG duration) in milliseconds as a function of rate, dialect, gender, and speaker. Combinatorial analyses were also run with these factors.

### 4.4.1. Interdialectal durational differences

It is generally known that southwestern Brazilians (MG is a southwestern state) believe they speak faster than northeastern Brazilians (BA is a northeastern state). Because of this, we ran ANOVAs to investigate this impressionistic sensation of speech rate difference. In fact, a one-way ANOVA with VV duration as a function of dialect has supported this rate impression ( $F(1,700) = 4.7331, p < .03$ ). VV duration mean and standard deviation are as follows: a) MG: 163 (32); b) BA: 168 (28). Nevertheless, we need to be cautious to state that, categorically, MG speakers speak faster than BA speakers. A factorial ANOVA with VV duration as a function of rate and dialect was only marginally significant ( $F(1,698) = 3.6440, p < .056$ ). This result is explained by a Scheffé post-hoc test, which shows that BA normal rate is statistically equal to MG normal rate. The only difference was between BA fast rate and MG fast rate ( $p < 10^{-5}$ ). VV duration mean and standard deviation are as follows: a) BA normal rate: 185 (25); b) MG normal rate: 184 (25); c) BA

fast rate: 150 (17); MG fast rate (142, 24). Thereby, MG speakers were the fastest only at the fast rate.

### 4.4.2. Standard deviation of VV duration

For all speakers, all sentences revealed a decreasing pattern of the standard deviation of VV duration with speech rate increase. Moreover, 61 sentences (out of 88, 11 sentences x 8 speakers) reached statistical significance. Yet, there seems to be differences related to dialect, gender or speaker. From the 27 sentences with no statistical significance, only 5 were from the MG dialect. Therefore, we ran several ANOVAs to investigate this question.

First, a one-way ANOVA with VV standard deviation as a function of dialect was run. The results showed a dialect-effect on VV SD ( $F(1,700) = 6.5189, p < .01$ ). The dialect means are: a) MG: 65; b) BA: 60. Then, a one-way ANOVA with VV standard deviation as a function of gender was run. The results present differences related to gender ( $F(1,700) = 5.2727, p < .02$ ) as follows: a) female (F): 65; b) male (M): 60. Finally, a one-way ANOVA as a function of speaker was run. It was also found a speaker-effect on VV standard deviation ( $F(7,694) = 6.3562, p < 10^{-5}$ ). Furthermore, in order to investigate possible interactions between dialect and gender, we ran a factorial ANOVA with VV standard deviation as a function of these two factors. The results showed no statistical significance. Yet, a Scheffé post-hoc test revealed gender differences in the MG dialect, but not in the BA dialect. The dialect means are: a) MG standard deviation (M, F): 181, 168 ( $p < .049$ ); b) BA standard deviation (M, F): 180, 173.

### 4.4.3. Standard deviation of SG duration

Differently from the standard deviation of VV duration, we were not able to calculate the standard deviation of SG duration for all sentences of the speakers. Three of the speakers produced only 1 SG for some sentences at the fast rate (BM: sentence 3; LM: sentences 4 and 10; JE: sentence 6). Therefore, only the remaining sentences were analyzed, which resulted in: (1) decreasing pattern from slow to fast rate; (2) increasing pattern from slow to fast rate. Regarding the second pattern, due to space limitations, refer back to [18], which explains this fact from the variability of the standard deviation of VV/SG intra rates ( $DVV/SGir$ ). Then, our discussion will be focused on the first pattern, which is related with tendencies to isochrony in speech rhythm.

All speakers produced sentences with a standard deviation decrease of SG from slow to fast rate, but with different percentages. RM (MG, M), for example, produced 80% of the sentences with this pattern, while RO (BA, M) and BM (MG, F) produced only 33.3% of the sentences with this pattern. Hence, we questioned whether factors such as dialect, gender, speaker, and sentence structure would influence this decreasing pattern. To verify this matter, several ANOVAs were run.

Separate one-way ANOVAs has shown significant differences for SG standard deviation as a function of gender ( $F(1,688) = 3.9817, p < .046$ , male mean = 251, female mean = 278), speaker ( $F(7,682) = 2.1779, p < .034$ ) and sentence structure ( $F(10,679) = 21.141, p < 10^{-4}$ ). No significance was found for SG SD as a function of dialect. Nevertheless, a factorial ANOVA with SG SD as a function of rate and dialect showed a significant result ( $F(1,682) = 17.439, p < .00003$ ). We will comment this finding on the discussion.

### 4.4.4. Constant SG duration

One-way ANOVAs with SG duration as a function of rate (normal and fast) corroborate the hypothesis that SG duration is expected to be constant with speech rate increase. 60 sentences (out of 88 sentences, 11 sentences x 8 speakers) are statistically non-significant. This effect is explained by the fact that rhythmical reorganizations make VV units smaller, but with a greater number of VV/SG, yielding a statistically constant SG duration. The other 22 sentences that reached statistical significance may be explained by the argument presented in [18, 19].

## 5. Discussion

Barbosa's works on rhythm typology [3, 4, 5] demonstrate that we should be cautious about the *ceteris paribus* condition. Many factors need to be controlled in speech rhythm classification, as follows: (i) speech rate; (ii) stress group size; (iii) stress group units: VVs or syllables; (iv) stress group boundaries: left-headed or right-headed; (v) linear regression without means; (vi) dialects; (vii) speech styles.

Our results support the necessity to pay attention to this linguistic conditions when classifying speech rhythms, since rhythm is affected by many factors at the same time. Yet, we have showed here that speech rate plays an important role in this perspective. The novelty of our approach in the search for isochronic tendencies in speech is to show that fast rates exacerbates the timing characteristics of rhythms, i.e., syllable- and/or stress-timed characteristics are more easily perceived at these rates. This fact is supported by a general decrease of standard deviation of VV duration as well as SG duration with speech rate increase.

In addition, a comparison of standard deviations of these durational units gives additional base for rhythm typology, as follows: a) syllable-timed languages are expected to have smaller standard deviation of VV duration, as well as higher standard deviation of SG duration; b) stress-timed languages are expected to have greater standard deviation of VV duration, as well as smaller standard deviation of SG duration. Nonetheless, according to the discussion presented in this paper, it is more precise to say that languages are more syllable-timed in certain speech situations and more stress-timed in others. As an example, we will compare some of our data based on this parameter.

The data suggests that the MG dialect is more stress-timed than the BA dialect. Not only the BA dialect has smaller variability of VV duration, but also the standard deviation of SG duration is greater at the fast rate. This evidence was found by running a factorial ANOVA with SG SD as a function of rate and dialect ( $F(1, 682) = 17.439, p < .00003$ ). Using this statistical analysis, we observed that the SG SD decreases with rate increase for the MG dialect and increases with speech rate for the BA dialect.

Moreover, our findings suggest that the male speech tends to be more stress-timed than the female speech. On the one hand, a factorial ANOVA showed smaller variability of VV duration for the female speech (see section 4.4.2). On the other hand, the SG SD exhibits a smaller variability of SG duration for the male speech at the fast rate. This finding may be associated with the BP tendency of male speakers speak faster than female speakers (see [18], chapter 9). As we suggested before, the fastest rates may be associated with stress-timing.

## 6. Conclusions

The acoustic study described here corroborated previous results on the question of standard deviation decrease of durational units with speech rate increase [18, 19]. The main results of this study are: (i) the standard deviation of VV duration and/or SG duration is smaller at fast rates; (ii) the stress group duration and/or the VV duration tend to be constant with speech rate increase; (iii) the decrease of standard deviation of SG and/or VV duration is influenced by many factors such as dialect, gender, and sentence structure; (iv) Brazilian Portuguese rhythm varies between stress-timing and syllable-timing according to different speech styles.

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