Secondary stress, intensity and fundamental frequency in Brazilian Portuguese

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Abstract

This paper investigates whether values of acoustical correlates of pretonic syllables adjacent to the one(s) perceived as bearing secondary stress could predict such perception in Brazilian Portuguese (BP) data. In order to pursue this goal, a comparison is made between pretonic syllables perceived as bearing secondary stress and those perceived as not bearing it. According to the results, obtained by application of statistical analyses, it is possible to claim that variation in intensity and in F_0 in syllables perceived as bearing secondary stress, as well as in adjacent syllables, can be taken as a robust correlate for data perception regarding secondary stress placement in BP. Variation in intensity and in F_0 in syllables perceived as bearing secondary stress and variation in intensity and in F_0 in the other adjacent pretonic syllables seem to be complementary information for the perception of secondary stresses by BP speakers. The results point to relevant questions for further work concerning the rhythmic and intonational organization of Brazilian Portuguese.

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1. Introduction

Primary and secondary stresses define prominent syllables which play an important role in the construction of language rhythmic units.

According to Hulst (1997), primary and secondary stresses must be analysed differently: primary stress is part of the lexical information of the word and secondary stress is assigned post-lexically. While there is a natural relationship between secondary stress and rhythm, primary stress is assigned locally, in the lexicon, and is not determined by rhythm (although it plays an important role in rhythmic organization, since primary and secondary stresses interact in speech).[1] Primary stress is categorical and cannot vary across speakers and language varieties, since its position is lexically fixed and affects the meaning of words, as illustrated by the examples of Portuguese in (1):

(1)	a. (*eu/ele/ela*) *sa**BI**a*	b. *sabi**Á***	c. ***SÁ**bia*[2]
	"(I/he/she) knew"	"type of Brazilian bird"	"wise$_{\text{(fem. gender)}}$"

On the other hand, secondary stress is variable; its attribution is not categorical, but associated with the rhythmic structure of languages. For instance, different secondary stress implementations are possible in a word as *paralelepípedo* "parallelepiped; paving stone" in Portuguese, but these variations do not affect the meaning of the word:

(2) a. PAraLEle**PÍ**pedo[3] b. PAralele**PÍ**pedo c. paraLEle**PÍ**pedo

According to phonological analyses presented in works as Collischonn (1993, 1994), Abaurre & Galves (1998), Frota & Vigário (2000) and Sandalo, Abaurre, Mandel & Galves (2006), Brazilian Portuguese (henceforth, BP) favours the construction of binary rhythmic units in the implementation of secondary stresses.

Acoustically-based works (e.g. Gama Rossi, 1998; Arantes & Barbosa, 2002, 2008; Moraes, 2003; Arantes, 2010) have studied duration, fundamental frequency (F_0), intensity, spectral emphasis and formant structure in search of robust evidences for the binary rhythmic pattern proposed in phonological analyses of the secondary stress assignment in BP.

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[1] For other authors, working within the framework of Metrical Phonology, the primary stress in BP is assigned by a rule in one of the strata of the lexical component (cf. Bisol, 1992, 2000; Massini-Cagliari, 1995; Lee, 1994; Wetzels, 1997).

[2] The syllables with capital and bold letters correspond to the syllables bearing the primary stress.

[3] The syllables with capital letters correspond to the syllables bearing secondary stress.

Such works have focused exclusively on the phonetic realization of syllables perceived as bearing secondary stress, and, based on experimental data consisting of isolated sentences, the authors claim that no robust acoustical correlate(s) can be associated to secondary stresses perceived by BP speakers.

However, given the suprasegmental nature of secondary stress, our hypothesis is that its acoustical correlates can be found predominantly in pretonic syllables adjacent to the one(s) that is(are) linguistically (e.g. rhythmically) assigned as bearer(s) of secondary stress within the prosodic word (PWd).[4]

Taking into account our hypothesis, this paper aims to investigate whether there is a dependence relationship, in the statistical sense, between the acoustical correlate values of the syllable(s) perceived as bearing secondary stress(es) and the acoustical correlate values of adjacent pretonic syllables in the PWd domain, based on data from BP. Therefore, our goal is to investigate whether the acoustical correlate values of pretonic syllables adjacent to the one(s) bearing secondary stress could be taken as predictive values with respect to the values of these last syllables.[5] In order to pursue this goal, a comparison is made between pretonic syllables perceived as bearing secondary stress and those perceived as not bearing it. The acoustical correlates specifically investigated in this paper are intensity and fundamental frequency (F_0).[6]

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[4] For "adjacent syllables" we understand all syllables that precede a syllable identified as a potential bearer of secondary stress, that are not themselves bearers of secondary stress. For instance, in (2)a., we look for acoustical evidence of the secondary stress perceived in the syllables *PA* and *LE*, by analysing the adjacent syllables *ra* and *le*.

[5] It is out of the scope of this paper to investigate the impact of secondary stress subtypes (emphatic, lexical or rhythmic) on the confirmation of our hypothesis. Therefore, we do not discriminate subtypes of secondary stresses in the extraction of acoustical correlates values. In future work, however, it might be interesting to take into account these subtypes in a systematic way, given that they might have some impact on the results obtained so far. Emphatic stress, for instance, might occur systematically in prosodic word initial position.

[6] Other possible acoustical correlates of secondary stress are duration and formant configuration. As to formant configuration, it would be necessary to design a specific experiment to control different vowel qualities, given that vowel quality affects formant configuration. With relation to duration, previous work on BP (cf. Gama Rossi, 1998; Arantes & Barbosa, 2002; Arantes, 2010) have shown that duration is not a robust acoustical correlate for secondary stress, for what can be observed is an increase in duration starting in the beginning of the word in syllables perceived as bearing secondary stress and continuing until the implementation of the main stress of the stress group. On the other hand, duration has been identified as a robust correlate of primary stress in BP (cf. Moraes, 1984; Massini-Cagliari, 1991).

The paper is organized as follows: in section two, we present our data and the adopted methodology of linguistic and statistical analyses; in section three, we present the results of the extraction of intensity and F_0 values from the syllables perceived as bearing secondary stress by BP native speakers and from the other pretonic syllables, as well as the results of the statistical modelling of these two types of values, in order to confirm or discard our hypothesis; and in section four, we present our conclusions.

2. Speech material and methods

2.1. Speech material

The speech material used in this research is composed of digital recordings of readings of a chronicle, called *Complicabilizando*, published in a weekly Brazilian magazine (Ricardo Freire, *Xongas*. *Época*. Edition 275, 25/08/2003) by 5 BP native speakers, namely: ACS – speaker (1); CTY – speaker (2); FMD – speaker (3); LM – speaker (4); and PA – speaker (5). The BP informants all come from the state of São Paulo, and are speakers of the so-called "paulista dialect" from the interior of the state. They are all from the same age group and educational background (university students).

2.2. Methods

The methodology used in this work includes the following steps: (i) presentation of the speech material to BP native speakers for perceptual identification of secondary stress occurrences; (ii) analysis of the acoustical signal, in terms of intensity and F_0 of syllabic nuclei preceding the stressed syllable of PWds identified as bearing of secondary stresses by BP speakers; and (iii) application of statistical analyses to the data.

The auditory perception of secondary stress occurrences was conducted by two native speakers of the paulista dialect of BP (namely, AP and JRM, linguistic students specifically trained on the identification of secondary stress perception, who share the same age group and educational background with the 5 speakers). These two judges worked together in the identification of secondary stresses and, as a result, only one transcription was produced for each reading event. In cases of disagreement about the occurrence of

One might be tempted to apply to duration values the same statistical analysis used here for F_0 and intensity. Results thus obtained might the interesting for the discussion concerning the rhythmic on characterization of Brazilian Portuguese as stress-timed, syllable-timed or moraic. We cannot do that, however, because the analytical tools employed in this work were devised to approach prosodic phenomena independent of segmental properties. In the case of duration, it is well known that different vowel qualities, e.g., have different intrinsic duration which would pose a problem for the normalization techniques used here.

secondary stress, the judges decided on the existence or not of secondary stress after discussing their perception of the specific token. The acoustical analyses consisted of the extraction of intensity and F_0 values of syllabic nuclei preceding the syllable bearing lexical stress of PWds. For this task, we used the speech analysis software *Praat*.[7] The intensity and F_0 values were always extracted from the more stable part of pretonic vowels, e.g., from the medial part of vowels, as illustrated in Figure 1., in which the cursor marks the approximated intensity and F_0 values of the medial part of the vowel "i" in the syllable "dis" of the prosodic word *em disponibilizar* "to make available".[8]

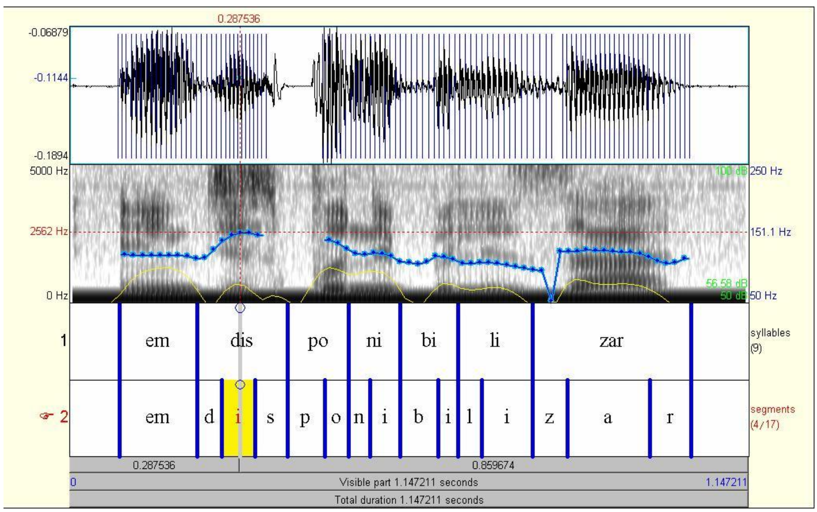


Figure 1. F_0 contour (top line) and intensity (bottom line) of the PWd *em DISponibili**ZAR*** ("make available"), produced by a BP speaker (PA).

[7] Boersma, P. & Weenink, D. (2009). *Praat: doing phonetics by computer* (Version 5.1.15) [Computer Program]. Retrieved August 30, 2009, from: http//: www.praat.org/.

[8] It might be interesting, for linguistic purposes, to organize the data according to different criteria which would focus on the number of pretonic syllables of the words. That would have allowed us to answer relevant questions like: (i) do pretonic syllables that are more distant from primary stress have F_0 and intensity mean values significantly different from pretonic syllables that are closer to primary stress?; (ii) do pretonic syllables in initial prosodic word position have F_0 and intensity mean values significantly different from non initial pretonic syllable mean values for the same parameters? We have not organized our data in such a way however, because the statistical analysis necessary to approach these questions would require a significantly greater corpus than the one utilized here.

3. Results and analysis

3.1. Secondary stress occurrences in BP data and extraction of intensity and F_0 values

The PWds perceived as bearing secondary stresses by BP speakers totalized 200: 33 PWds produced by speaker (1), 53 PWds produced by speaker (2), 54 PWds produced by speaker (3), 29 PWds produced by speaker (4) and 31 PWds produced by speaker (5). These PWds containing from 2 pretonic syllables (ex.: *impleMENto* "(I) implement") to 7 pretonic syllables (ex.: *desincompatibiliZAR "to make incompatible"*).

The intensity and F_0 values were extracted from a total of 892 pretonic syllables of these 200 PWds: 35 pretonic syllables bearing secondary stresses and 119 non-prominent pretonic syllables produced by speaker (1), 69 pretonic syllables bearing secondary stresses and 140 non-prominent pretonic syllables produced by speaker (2), 80 pretonic syllables bearing secondary stresses and 141 non-prominent pretonic syllables produced by speaker (3), 29 pretonic syllables bearing secondary stresses and 123 non-prominent pretonic syllables produced by speaker (4) and 31 pretonic syllables bearing secondary stresses and 125 non-prominent pretonic syllables produced by speaker (5).

3.2. The statistical modelling

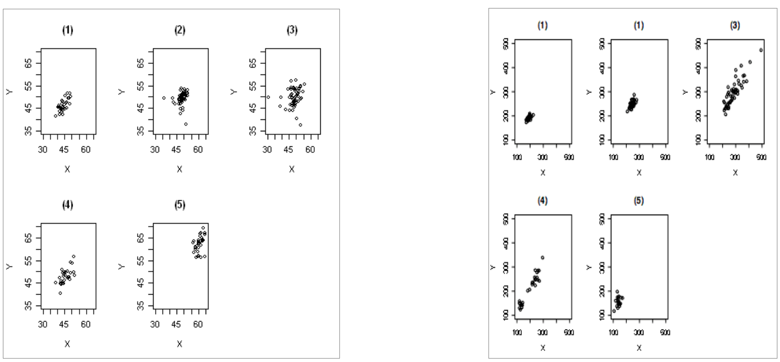
3.2.1. Data pre-processing

The values obtained from the extraction of intensity and F_0 measurements were submitted to the calculation of means. In each one of the PWds, this operation was applied to intensity and F_0 values of each type of pretonic syllables: the ones perceived as bearing secondary stresses and the other pretonic syllables. For instance, in the word *deSINcomPAtiBIliZAR*,[9] the F_0 mean values for the pretonic syllables perceived as bearing secondary stresses will be: $\frac{F0(S2) + F0(S4) + F0(S6)}{3}$ and the F_0 mean values for the other pretonic syllables will be: $\frac{F0(S1) + F0(S3) + F0(S5) + F0(S7)}{4}$, where S1 = "de"; S2 = "SIN"; S3 = "com"; S4 = PA; S5 = "ti"; S6 = "BI"; S7 = "li" and F0 (Si) is the fundamental frequency value of syllable "Si". The same procedure was adopted to analyze intensity.[10]

[9] See footnotes 2 and 3.

[10] In cases in which only one secondary stress was perceived in the PWd, it was considered the intensity or F_0 absolute value of the nucleus of the syllable perceived as bearing it.

Therefore, we obtained two groups of results for each speaker: (i) the mean intensity or the mean F_0 observed in the syllables perceived as bearing secondary stresses (see Figure 2. (a) and (b)); and (ii) the mean intensity or the mean F_0 observed in the other pretonic syllables (see Figure 2. (a) and (b)). In Figure 2.: (i) (1) corresponds to the speaker (1), ACS, (2) corresponds to the speaker (2), CTY, (3) corresponds to the speaker (3), FMD, (4) corresponds to the speaker (4), LM, and (5) corresponds to the speaker (5), PA; (ii) in the axis Y, we have the mean intensity values (measured in decibels (dB)) – see (a) – or the mean fundamental frequency (F_0) values (measured in Hertz (Hz)) – see (b) – of the nuclei of syllables perceived as bearing secondary stress; (iii) in axis X, we have the mean intensity values – see (a) – or the mean fundamental frequency (F_0) values – see (b) – of the nuclei of the other pretonic syllables; and (iv) the points correspond to each PWd perceived as bearing secondary stresses.



(a) (b)

Figure 2. (a) Mean intensity of pretonic syllables perceived as bearing secondary stress (axis Y) and mean intensity of other pretonic syllables (axis X). (b) Mean F_0 of pretonic syllables perceived as bearing secondary stress (axis Y) and mean F_0 of other pretonic syllables (axis X).

Our goal is to eliminate the "speaker effect" which is evident from the plots in Figure 2. The speaker effect is extracted in order to reveal the real process that we need to investigate.[11]

We extract the effect of the speaker using a random effect model (cf. Fernandes-Svartman, Abaurre & González-López, 2008), assuming fixed effects (see Chambers, 1992 for a complete explanation of the model and R-

[11] "Real process" refers to the results of normalized F_0 and intensity values, namely, values obtained without individual variation and recording noise.

-project environment at http://stat.ethz.ch/R-manual/R-patched/library/stats/ html/lm.html for a computational implementation and technical details). This model is presented in (1). Note that the random effect model is the simplest in the statistical sense if the objective is the standardization assuming one effect by speaker (this means 5 effects – see the complete explanation (iv) below) and one global effect (external effects – see the complete explanation (v) below)[12].

(1) $$W^{l}_{ij(i)} = W0^{l} + L^{l}_{i} + e^{l}_{ij(i)},\ j(i) = 1,\ldots, J(i),$$

In (1):

(i) "l" represents the variable type: Y – nuclei intensity or nuclei F_0 of the pretonic syllables perceived as bearing secondary stresses; X – nuclei intensity or nuclei F_0 of the other pretonic syllables. If l =1, then, $W^{l}_{ij(i)} = X$, if l = 2, then, $W^{l}_{ij(i)} = Y$.

(ii) "i" represents the speaker. i = 1 denotes the ACS speaker; i = 2 denotes the CTY speaker; i = 3 denotes the FMD speaker; i = 4 denotes the LM speaker and i = 5 denotes the PA speaker.

(iii) "J(i)" represents the total of PWds produced by the "i" speaker, in which were perceived the secondary stress. J(1) = 33, J(2) = 53, J(3) = 54, J(4) = 29 and J(5) = 31.

(iv) "L^{l}_{i}" represents the speaker influence (or fixed effect). For example: the speaker gender, the type of production (emphatic or neutral productions), etc.

(v) "$W0^{l}$" is the independent global effect. It is dependent of external effects that produce some influence on the measures (for example: the quality of recording processes and the semiautomatic process of the extraction of intensity and F_0 values).

12 In order to normalize across speaker effects it is possible to use some linguistic standard techniques, such as in the case of the fundamental frequency used to convert from Hz to ERB scale, as noted by one of the anonymous reviewers of a previous version of this paper. The statistical technique of standardization employed in this paper aims to offer the same methodology for the standardization of different acoustical parameters modelled here: fundamental frequency and intensity.

(vi) "$e^{1}_{ij(i)}$" represents the goal random process. For example, if $e^{1}_{ij(i)}$, 1 = 2, it represents the random intensity (or the random F_0) process of the pretonic syllables perceived as bearing secondary stress of the "i" speaker.

The real process is our goal because it is the process that could be obtained without the influence of the speaker and without the influence of conditions or quality of recording; consequently, it could be considered a good representation of the phenomenon (intensity or fundamental frequency).

This model assumes that $W0^l$ and L^{1}_{i} are fixed effects and could be estimated. Thus, we can concentrate the study on the relation between $e^{1}_{ij(i)}$ and $e^{2}_{ij(i)}$, where the goal processes are estimated as being $e^{l}_{ij(i)} = W^{l}_{ij(i)} - W0^{l} - L^{l}_{i}$. $W^{l}_{ij(i)}$ is the observed value (intensity or fundamental frequency), $W0^l$ is estimated and L^{1}_{i} is also estimated.

The next table shows the estimated global effects:

Table 1. Global intensity and F_0 values.

	Intensity	**F_0**
$W0^1$	60.67 dB	136.260 Hz
$W0^2$	62.28 dB	150.962 Hz

In both cases what we have is that the estimated global effects on pretonic syllables perceived as bearing secondary stress are bigger than the estimated global effect on the other pretonic syllables, i.e., the mean values of intensity and fundamental frequency are bigger under the presence of secondary stress. In order to show the influence of the global values in the goal processes we define RTX= $e^{1}_{ij(i)} + W0^{1}$ and RTY= $e^{2}_{ij(i)} + W0^{2}$.

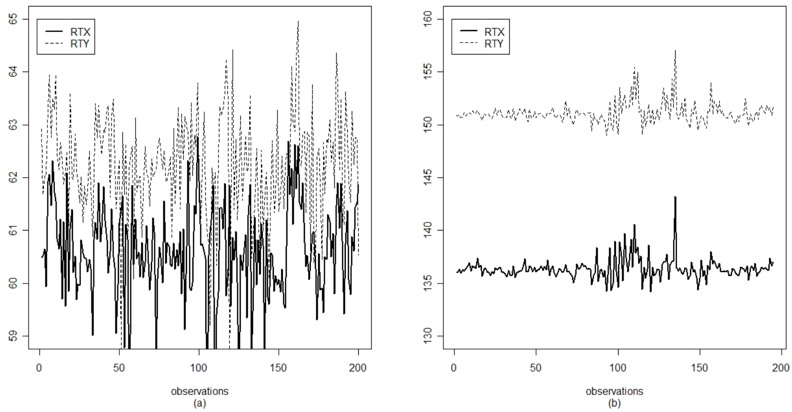


Figure 3. (a) Mean residual intensity of pretonic syllables perceived as bearing secondary stress (dotted line – RTY process) and mean residual intensity of other pretonic syllables (full line – RTX process). (b) Mean residual F_0 of pretonic syllables perceived as bearing secondary stress (in red – RTY process) and mean residual F_0 of other pretonic syllables (in blue – RTX process).

We note that when the process RTX (or the equivalent process $e^1_{ij(i)}$) shows a decreasing (or increasing) tendency, then the process RTY (or the equivalent process $e^2_{ij(i)}$) shows the same behaviour; this allowed us to enquire about the capacity of prediction that the process $e^1_{ij(i)}$ has in order to know or predict the process $e^2_{ij(i)}$. To investigate the statistical relationship between the goal processes $e^1_{ij(i)}$ and $e^2_{ij(i)}$, we use copula models, since copula quantifies the dependence. Furthermore, in our hypothesis, the hearer perception is considered as a discrete response, i.e., the hearer may verify or not the secondary stress occurrence. However, the possible acoustical correlates related to this perception may have a discrete or continuous nature. In our case, this hypothesis will be evaluated through continuous random variables, e.g., intensity and F_0. This choice attributes to the copula model the adequate profile to check the hypothesis, modelling the dependence between the continuous random variables. So, no discretization of the variables is necessary for this approach, since the copula model takes their nature into consideration. In addition, it is possible that the discretization of original measures implies important information loss. If the variables had a discrete nature, other approaches, as ANOVA, discrete copula, etc., could be considered.

3.2.2. Dependence modelling

The copula model is a way to represent the multivariate dependence between random variables, see Rifo & González-López (2012). In general lines, the dependence between random variables could be established using the marginal distribution and the joint dependence (or copula). In particular, the copula does not look at the marginal distribution, but it looks at the joint dependence and exposes the dependence quantified by a mathematical model. If we have the random vector (Z_1,Z_2) with paired observations (z_{11},z_{21}), $(z_{12},z_{22}),\ldots(z_{1n},z_{2n})$, the copula C is the joint cumulative distribution of the ranks of the observations (u_{11},u_{21}), $(u_{12},u_{22}),\ldots(u_{1n},u_{2n})$. This means that the copula fits the dependence between the observations corrected by its order, related to the marginal sample. This kind of model has two extremal situations (when we restrict the attention to positive dependence): on the one hand, the model $C(u_1,u_2)=u_1*u_2$ means that the random variables Z_1 and Z_2 are independent (Tau-Kendall measure equals to 0), on the other hand, we can find the perfect dependence quantified by the copula $C(u_1,u_2)=\min\{u_1,u_2\}$ that happens when one random variable is a perfect predictor of the other random variable (Tau-Kendall measure equal to 1). As an illustration, we show the next picture with simulations of two situations.

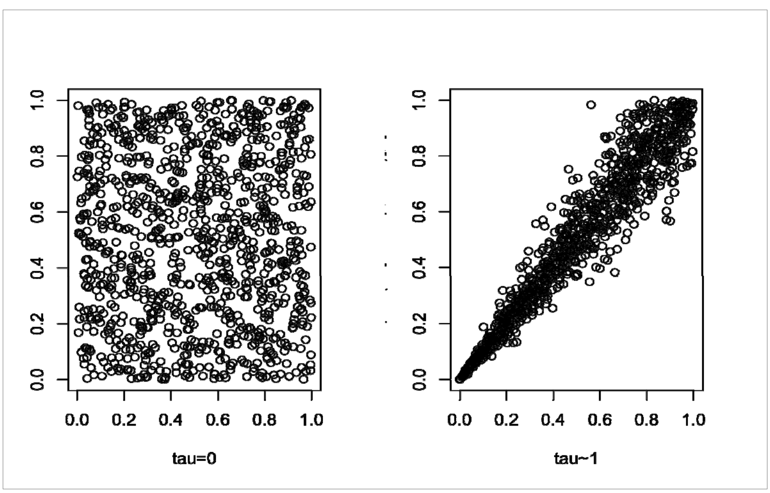


Figure 4. tau=0: simulation of independent data; tau~1:
simulation of a perfectly dependent data.

We show first the plots of the $e^1_{ij(i)}$ ranks versus $e^2_{ij(i)}$ ranks for each case (intensity and fundamental frequency).

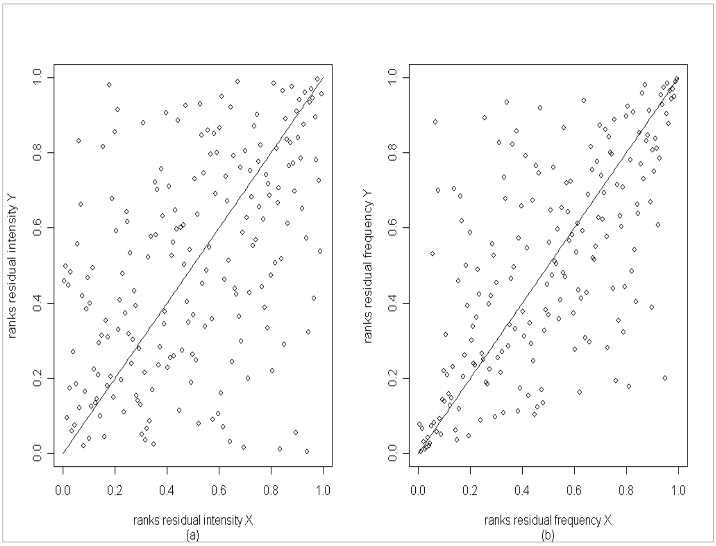
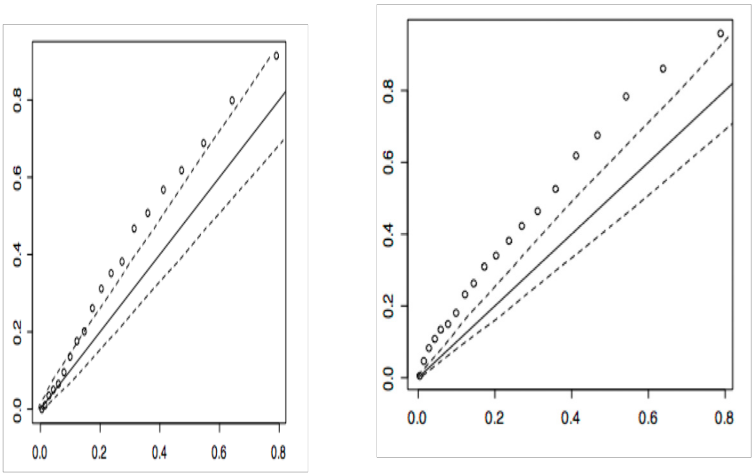


Figure 5. Dependence modelling between X and Y processes relative to (a) $e^1_{ij(i)}$ ranks intensity versus $e^2_{ij(i)}$ ranks intensity, (b) $e^1_{ij(i)}$ ranks F_0 versus $e^2_{ij(i)}$ ranks F_0.

In both cases ((a) and (b) from Figure 5.), we test whether the variables are independent. We use a new test appropriated for copula model, developed recently in Bianchi (2008). The results are presented on the next plots (Figure 6.) and they show that the supposition of independence is rejected.

Since we note that the processes $e^1_{ij(i)}$ and $e^2_{ij(i)}$ for intensity and F_0 values are not independent, we fit the Gumbel, Frank and Clayton copula models to identify the type of dependence. Using the maximum likelihood method to measure the adequacy of the models it was possible to detect the best one among the previous options. The next plots are related to the selection. We use the tests from Bianchi (2008) to verify if the best model (indicated by the maximum likelihood method) is rejected or not, and we show that at level 95% the selected model (in each case) was not rejected.



(a) (b)

Figure 6. Comparative test *Tau*-plots using a 95% confidence level. (a) Dependence between intensities fitted by Independence copula. (b) Dependence between fundamental frequencies fitted by Independence copula.

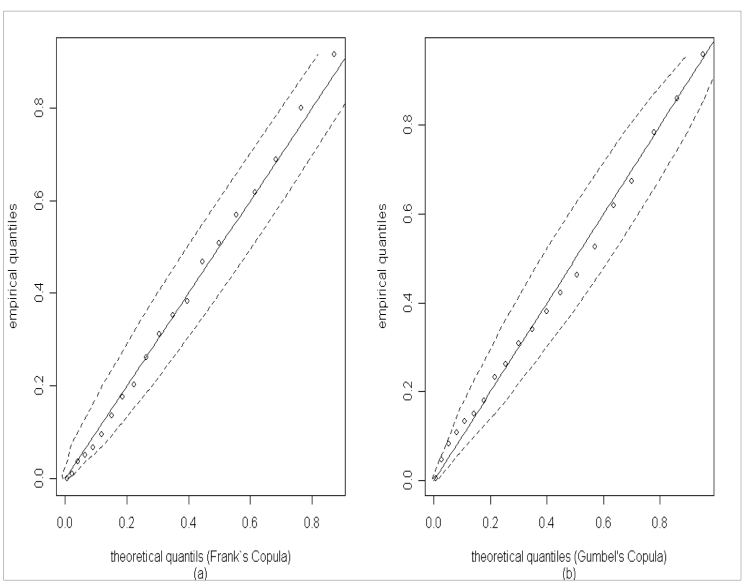


Figure 7. Comparative test *Tau*-plots using a 95% confidence level. (a) Dependence between intensities fitted by Frank copula. (b) Dependence between fundamental frequencies fitted by Gumbel copula.

In the intensity case, the best model selected by the method was the Frank model with tau=0.314 (see Figure 7. (a)). On the other hand, in the F_0 case, the best model selected by the method was the Gumbel model with tau=0.498 (see Figure 7. (b)). In both cases the tau measure reveals a positive association between the processes, as expected. Therefore, it is possible to claim effectively that the variation in intensity and in F_0 in syllables perceived as bearing secondary stress, as well as in adjacent syllables, can be taken as a robust correlate for data perception regarding secondary stress placement in BP.

The models show that the relationship is not corresponding with the extremal cases of dependence (independence and perfect dependence). This means that the random variables are not equal in the probabilistic sense or that some aspects (part of the information) of the $e^2_{ij(i)}$ process may not be predicted by the $e^1_{ij(i)}$ process.

4. Conclusions

In this paper we confirm our initial hypothesis that secondary stress acoustical correlates can be found predominantly in pretonic syllables adjacent to the one(s) perceived as bearer(s) of this type of stress within the PWd.

According to our results obtained by the application of the copula statistic model, it is possible to claim effectively that the variation in intensity and in F_0 in syllables perceived as bearing secondary stress, as well as in adjacent syllables, can be taken as a robust correlate for data perception regarding secondary stress placement in BP. The variation in intensity and in F_0 in syllables perceived as bearing secondary stress and in the other adjacent pretonic syllables are complementary information for the perception of secondary stresses by BP speakers.

The results presented here raise relevant questions concerning the rhythmic and intonational organization of Brazilian Portuguese that shall be undertaken in future work. The first of these questions refers to possible implications of our results for the characterization of BP as a language that has a binary rhythm. The results point to a regular alternation involving prominent and non prominent syllables, but further research is needed in order to exclude a possible positional effect (beginning of a prosodic word) on secondary stress placement.

The second question refers to the implications of the results for the characterization of BP intonational structure. The analysis presented in this paper was based, among other things, on the extraction of F_0 values, but no intonational analysis of the data was conducted. Since it is well known that a correlation exist between F_0 rising and occurrence of an H tone, we can hypothesize that H tones occurring in pretonic syllables might be associated to secondary stress perception, as has already been pointed out in Tenani (2002), Fernandes (2007), Fernandes-Svartman (2009), Vigário & Fernandes-Svartman (2010), among others.

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