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Lexical reorganization in Brazilian Portuguese: an articulatory study

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Abstract

This work, which is couched in the theoretical framework of Articulatory Phonology, deals with the influence of speech rate on the change/variation from antepenultimate stress words into penultimate stress words in Brazilian Portuguese. Both acoustic and articulatory (EMMA) studies were conducted. On the acoustic side, results show different patterns of post-stressed vowel reduction according to the word type. Some words reduced their medial post-stressed vowels more than their final post-stressed vowels, and others reduced their final post-stressed vowels more than their medial post-stressed vowels. On the articulatory side, results show that the coarticulation degree of the post-stressed consonants increases with speech rate. Also, with the use of a measure called proportional consonantal interval (PCI), it was found in measurements of articulation that such measure is influenced by the word type. Three different groups of words were found according to their PCI. These results show how dynamical aspects influenced by speech rate increase are related to the lexical process of change/variation from antepenultimate stress words into penultimate ones.

Keywords

speech rate; dynamical systems; Articulatory Phonology; linguistic change; lexical variation

1 Introduction

It is generally known by linguists who study Portuguese that some Old Portuguese antepenultimate stress words have undergone change into penultimate stress words. Besides, these words can synchronically covary with each other in Modern Portuguese. For most of these words, this phenomenon is related to the linguistic process known as syncope, that is, word-internal elision(cf. Câmara-Jr., 1988, p. 220). Diachronically, a syncope of the medial post-stressed vowel in antepenultimate stress words started in Classical Latin (saeculum > saeclum; calidus > calmus; eremus > ermus) (cf. Quednau, 2002), and continued in Vulgar Latin (speculum > speclum; angulus > anglus; oculus > oclus) (cf. *Appendix Probi* citations commented in Silva-Neto, 1946, p. 140).

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Historically, there was since Classical Latin (cf. Nunes, 1969, p. 13) a gradual change from antepenultimate stress words into penultimate stress words, resulting in very rare realizations of antepenultimate stress words in Old Portuguese (derived from Vulgar Latin) (Nunes, 1973; de Vasconcelos, 1956). Besides, even these rare forms, according to Hauy (1994, p. 42), became penultimate ones in connected speech. Summing up, the use of these words gradually decreased in the following way: Classical Latin > Vulgar Latin > Old Portuguese. Nevertheless, in the fifteenth century, in which Latin culture became greatly valued, antepenultimate stress words were reintroduced into the Portuguese lexicon (cf. de Vasconcelos, 1956, p. 62), reviving the covariation between antepenultimate and penultimate stress words (e.g.: óculos vs. oclos; aurículo vs. orelha).

This lexical variation followed two distinct paths from Latin to Portuguese: a) lexicalization of the penultimate stress word, as in: speculum > speclum > espelho; calidus > calmus > calmo; apicula > apicla > abelha; b) historical variation still under way, as in: século ~ seclo (Latin: saeculum ~ saeclum); ângulo ~ anglo (Latin: angulus ~ anglus); óculos ~ oclos (Latin: oculus ~ oclus).

Analysis based upon mainstream linguistics considered that in this variation there was a suppression (cf. Amaral, 2002, p. 102), a loss (cf. Quednau, 2002, p.79) or a fall (cf. Williams, 1961, p. 66) of the medial post-stressed vowel. Due to this fact, penultimate stress words can be represented in informal texts as “abobra (for abóbora), cosca (for cócega), anális[1] (for análise)”. It is worth pointing out, however, that these authors worked with linguistic theories which favor the speaker’s linguistic intuition, not taking into consideration phonetic details in their analyses. Yet, it will be demonstrated here, within the Articulatory Phonology (henceforth AP) framework (Browman and Goldstein, 1986, 1989, 1990, 1992), that what really happens is not the “loss” of a phoneme-sized segment, but a reduction of magnitude of the gestures composing either the medial post-stressed or the final post-stressed vowel. In other words, what happens in such cases is an acoustic-articulatory reduction of gestures, which may be perceived/reinterpreted as a transitional gesture of the surrounding gestures.

Before presenting a pilot study on the acoustics of lexical variation and the findings of an articulatory study, a brief revision of how the AP framework deals with lexical variation will be shown in the next section.

2 Lexical variation in the Articulatory Phonology

In AP there is no dichotomy between phonetic and phonological level and the minimal unit of research is the articulatory gesture, defined abstractly by the task dynamics model (Kelso et al., 1986). This phonological model proposes some principles of magnitude and temporal change to account for linguistic phenomena such as coarticulation, allophonic variation and several subsegmental phenomena in language acquisition and speech pathology.

Besides, gestures have a temporal and spatial scope (cf. fig. 1), suggesting that they do not disappear (or appear) in syllabic restructurings, i.e., they are always present and the sensation of loss (or insertion) of a segment is due to: (i) a magnitude reduction (or increase) of a certain gesture (vide Albano, 2001, for a gestural explanation of the “epenthetic” vowel in Brazilian Portuguese (henceforth BP), as in “paiz” (for “paz”), caused by a constriction gesture delay in sequences of vowel followed by /s/ in word final position); (ii) an increase (or reduction) of gestural overlap, such as in the increase of gestural overlap for the word “para” (fig. 1a), which will be similar to the gestural organization in the beginning of “prata” (fig. 1b). It can be inferred from fig. 1(b) that the overlap between the tongue body and tongue tip gestures can cause a

[1]In this case there is no syncope, but apocope, which is the loss of a sound at the end of a word.

change from “para” to “pra”, which is the usual pronunciation of this preposition in many BP dialects. These changes in gestural magnitude, as will be shown here, seem to be conditioned by social, psychological, individual and phonetic factors, which can be elicited by speech rate variation. Therefore, following Byrd (2003), “the postulation of abstract, dynamically-specified, and underlying stable phonological units, constrains the possibilities for accounting for variability in word forms”.

In the next sections, it will be shown how AP deals with the variation between antepenultimate stress and penultimate stress words in BP and how it explains the change of a lexical item into another one. This is a novel approach in BP studies. As far as is known, no previous articulatory studies have been conducted with BP data. Because of this, this research intends to inaugurate a new methodological approach for analyzing BP data. In order to do so, firstly it will be presented some results of a previous acoustic study and, then, an articulatory study based on the AP framework, which can explain lexical variation in BP.

3 Previous acoustic study

Most of the researchers who have shown the influence of speech rate upon lexical realizations in BP have used qualitative analyses instead of quantitative ones (Abaurre-Gnerre, 1979, 1981; Meireles, 2001). This paper’s analyses (acoustic and articulatory) will demonstrate how AP, based upon the dynamical systems theory (Kelso, 1995; Port and van Gelder, 1995), efficiently explains the speech rate influence upon a classical process of variation and change in Portuguese: variation/change of antepenultimate stress words into penultimate ones. As seen in the introduction, this process began in the change from Classical Latin to Vulgar Latin and from this to Portuguese (e.g. “apicula > apicla > abelha”; “teneru > tenru > tenro”) and continues until today’s lexical variations (e.g. “córrego ~ corgo”; “fósforo ~ fosfro”; “música ~ musca”).

In order to show this speech rate influence upon lexical processes, Meireles and Barbosa (submitted) have carried out an acoustic study. In this study, two male and two female Brazilian speakers from the Mineiro dialect (from Minas Gerais state) and two male and two female Brazilian speakers from the Paulista dialect (from São Paulo state), aged between 20 and 30 years, with no apparent phonatory, neurological or mental problems, read the words “abóbora, análise, cócega, fôlego, fósforo, and sábado” in a sound-treated room. These words were inserted in the carrier sentence: “Digo _ _ _ _ _ baixinho” ((I) say _ _ _ _ _ quietly) and recorded at three distinct speech rates. To obtain these three distinct speech rates, the subject was asked to read the sentences according to the following instructions and order: (1) normal: speak in a comfortable way; (2) slow: speak as slowly as you can preserving the sentence’s intelligibility and without introducing pauses between words; (3) fast: speak as fast as you can without introducing distortions in speech. Some additional utterances were also given as prompts to the subjects exemplifying each one of the intended speech rates. Also, before the recording session, the subjects practiced the elicitation of different speech rates until they were comfortable with the task.

Acoustic analyses were conducted through normalization of syllable-sized durations by means of z-score computing, according to Barbosa’s guidelines (Barbosa, 2006). Results have shown inter-speaker ($F(7,40) = 27.3$, $p < 10^{-5}$), inter-dialect ($F(1,70) = 25.3$, $p < 10^{-5}$, with Mineiro speakers on average faster than Paulista ones), and inter-gender ($F(1,142) = 6.8$, $p < 0.01$, with male speakers faster than female ones, result already found in American English by Byrd, 1994, p. 43) differences. It was also found that faster speakers produced more penultimate stress words than slower ones. Two other main results could explain this historical lexical change: 1) distinct reductions according to medial vowel resistance to reduction; 2) a tendency to reducing more extremely as speech rate increases.

Regarding the first main result, it has been studied if the medial post-stressed vowel reduces more than the final post-stressed one, for all words in the corpus, which could explain why in this historical lexical process there is, most of the times, a perception of "loss" of the medial post-stressed vowel. Nevertheless, a one-way ANOVA did not reveal any differences between the duration of the medial post-stressed (henceforth MPS) and final post-stressed (hence-forth FPS) vowels, all words, speakers and rates considered. Thus, no general pattern of reduction was found. However, separate ANOVAs per class of word revealed two different patterns of reduction: 1) MPS vowel reduces more than the FPS one in the words abóbora, cócega, and fósforo ($F(2,1106)=516.92$, $p < 10^{-4}$); 2) FPS vowel reduces more than the MPS one in the words análise, fôlego, and sábado ($F(2,1055)=672,69$, $p < 10^{-4}$). Interestingly, such results could explain why "abóbora, cócega, fósforo" covary with the syncopated forms "abobra, cosca, fosfro", and why "análise" covary with "anális/análiz" in BP.

As regards the second main result, dynamical aspects of the variation between antepenultimate stress and penultimate stress words were revealed. In order to do so, a Friedman non-parametric ANOVA was run taking as dependent variable the duration decreasing rate of the vowels in different stress conditions as a function of rate, all speakers and words considered. Duration decreasing rate measures how each vowel in different stress conditions percentually decreases from normal (N) to fast (F) rates, through the following equation: (F-N)/N.100%. Results have shown a significant difference between MPS vowel and FPS one ($p < 0.014$, effective $\alpha = 0.017$), as shown by the percentual decreasing means of the vowels in bold (MPS, FPS): abób**o**r**a** (54,22), anál**i**s**e** (48,38), cóc**e**g**a** (39,13), fôl**e**g**o** (2,7), fósf**o**r**o** (5,2), and sáb**a**d**o** (10,9). These results also show a differentiation in the reduction degrees of the MPS vowel, since "fôlego, sábado" were the words which less reduced their MPS vowels. This result corroborates the previous one revealing two statistically distinct groups according to: 1) reduction of the MPS vowel: abóbora, cócega, and fósforo; 2) reduction of the FPS vowel: análise, fôlego, and sábado. Moreover, it has also been shown how dynamical aspects influenced by speech rate increase could be related to the lexical process of variation from antepenultimate stress words into penultimate ones.

Meireles and Barbosa (submitted) have speculated how gestures would change with speech rate increase. In this work the authors have stated that gestures do not appear (or disappear) in Portuguese phonological processes. They are always present. What really happens is a reduction of the magnitude degree of a gesture or a gestural overlap, which leads to lexical variation, and that can even constitute a linguistic change in a future time. In order to experimentally evaluate these statements the following articulatory experiment was run.

4 Articulatory study

The main objective of this research was to observe the coarticulation between the MPS vowel and the surrounding consonants. In order to do so, a female native speaker of BP (30 years old) was recorded acoustically (sampling rate: 20.05 kHz) and articulatorily at USC Phonetics Laboratory. The reasons why only one speaker was used in the experiment are: a) the time consuming task of analyzing articulatory data: this point is described in the next subsection; b) the study's novelty in Brazilian Portuguese studies: there is not any previous study with articulatory data in this language, which makes the task harder to accomplish than usual. In other words, there is no previous information that could be relied on to make the articulatory analysis; c) acoustic data already measured in previous studies: despite of the unavailability of articulatory data for Brazilian Portuguese, the acoustic studies on the subject of variation/change between antepenultimate and penultimate stress words (cf. previous section) provide solid background to support the future articulatory results.

The corpus consisted of the following utterances: “a víbora, abóbora, a bêbada, abóbada”. These sentences were designed so as to have labial consonants ([v] or [b]) for the two first consonants and an alveolar consonant for the final one ([ɾ] or [d]). This articulatory pattern was chosen in order to facilitate the future analyses. As it was going to be studied the coarticulation between the MPS vowel and the surrounding consonants, the articulatory distance between the bilabial consonant and the alveolar consonant could be easily measured (see figure 2 in the next subsection). The article “a” [the] was introduced for some words, so as to have four syllables in all utterances. Besides, two more words preceded by an article were used: “o fósforo” and “o sábado”. These utterances in spite of not following this study’s articulatory pattern were chosen because of having being used in the acoustic study described in the previous section.

The subject read the utterances at three distinct speech rates in the carrier sentence “Digas _ _ _ _ _ baixinho”. Ten repetitions of each sentence (randomized within blocks) at three speech rates were recorded, resulting in a total of 180 utterances for analysis (6 sentences × 10 repetitions × 3 speech rates). As in the acoustic study described earlier, the speech rates were obtained according to the following instructions and order: (1) normal: speak in a comfortable way; (2) slow: speak as slowly as you can preserving the sentence’s meaning and without introducing pauses between words; (3) fast: speak as fast as you can without introducing distortions in speech. Some utterances were also given as prompts to the subject exemplifying each one of the intended speech rates.

4.1 Speech analysis

Before recording, the subject was informed of the rules for running an articulatory experiment. After the subject’s acceptance of the terms, she was paid for her participation, and signed an approved informed consent form explaining the purpose of the experiment. Then, she was told to read the experiment instructions and afterwards, as a short training, to read some sentences from a previous acoustic experiment at three distinct speech rates. After training, a professional dentist positioned the sensors at the places described below. As usual in EMMA data acquisition’s experiments, in a first moment, the subject felt a little uncomfortable to talking with sensors inside the mouth. Nevertheless, it is important to remark that her uncomfortableness is only related to the fact of being afraid of loosing the sensor’s placement, as reported by her. Then, she was encouraged to speak in her usual way and not to be troubled by the sensors. She was told they would not come off easily, and if they did, the dentist would be there to arrange them again. After that, she practiced some extra sentences until she felt comfortable speaking with the sensors. Finally, once she was ready for the recording session, the experiment was run. Also, no artificiality was observed in her speech during the session.

A 2-D Articulograph AG-200 (www.articulograph.de) (cf. Perkell et al., 1992, EMMA magnetometer system) was used for tracking jaw movement. The movement data was sampled at 200 Hz, head-corrected, rotated to the occlusal plane, and low-pass filtered at 25 Hz. Pellets were attached to the following articulators: tongue tip (TT), tongue body (TB), upper lips (UL), lower lips (LL), and jaw (at the lower incisors). Two other pellets were used as reference for the signal acquisition system: one at the nose bridge, and one at the center anterior surface of the maxillary incisors.

For transcription and labeling, MAVIS software (Tiede et al., 1999), modified at University of Southern California, was employed to measure the lower lip and tongue tip sensor movements in the vertical dimension (y-axis) (cf. figure 2 and figure 3). It is important to emphasize at this point that articulatory analyses are very time consuming, since the raw articulatory data obtained via EMMA have to be manually prepared so as to be used in MAVIS. It means that the 180 sentences have to be manually converted one by one, in order to be ready for analysis (see Meireles, 2007, for a detailed description). Even so, it is necessary after this process to manually adjust the articulatory parameters sentence by sentence in MAVIS, so as to begin to measure the intended articulatory distances. Recall that articulatory data are multidimensional, i.e., information are displayed in the×and y axes, as well as in a tangential axis. Besides, information about gesture's velocity and acceleration in all axes are displayed together in MAVIS.

The following articulatory parameters were marked in the signal: (i) lower lip maximum constriction (see fig. 2: 'x' is an example of such a lower lip maximum constriction): measured at y-velocity zero-crossing at maximum closing; (ii) lower lip minimum constriction (see fig. 3: the extreme right of the arrow in 'w' is an example of such a lower lip minimum constriction): measured at y-velocity zero-crossing at maximum opening; and (iii) tongue tip maximum constriction (see fig. 2: 'z' is an example of such a tongue tip maximum constriction): measured at y-velocity zero-crossing at maximum closing.

To measure the coarticulation degree in the recorded words, the articulatory distance between the post-stressed consonants (bold type) was used, namely: abó**b**o**r**a, abó**b**a**d**a, ví**b**o**r**a, bê**b**ad**a**, fós**f**o**r**o, and sá**b**a**d**o. As each one of these bold consonants were either labial or alveolar, this measure was made from zero y-velocity (LL) to zero y-velocity (TT), as shown in figure 2 below. It is shown in this figure: (i) curved lines representing the gesture's movement in the oral cavity; (ii) 'Zon' representing zero velocity onset, i.e., the moment in time where the gesture is changing direction; (iii) 'Pon' representing the gesture's peak velocity onset, i.e., the moment in time where the gesture's velocity is maximally positive; and (iv) 'Von' representing the gesture's valley velocity onset, i.e., the moment in time where the gesture's velocity is maximally negative.

The articulatory interval between the beginning and the end of the target-word was also measured, as shown in figure 3 below. As in figure 2, it is shown in figure 3: (i) curved lines representing the gesture's movement in the oral cavity; (ii) 'Zon' representing zero velocity onset; (iii) 'Pon' representing the gesture's peak velocity onset; and (iv) 'Von' representing the gesture's valley velocity onset. This word-related measure was crucial to analyze if distinct speech rates have really been pronounced by the speaker.

One can argue there is no scale information on the 'y' axis. This is due to the fact that in MAVIS this information is only displayed in another window called SPATIAL (see fig. 4). This picture represents information about the gesture displacement in millimeters on the 'x' and 'y' axes. 'x' represents the gesture's movement on the horizontal axis and 'y' represents the gesture's movement on the vertical axis. This is the scale that unfortunately is not represented in the main MAVIS window and, because of this, it is not present on figure 2 and figure 3.

A one-way ANOVA with word articulatory duration as a function of rate indicates that three distinct rates were obtained (see table 1). Each word was individually considered (e.g. word duration of "abóbora" as a function of rate). Besides, there was a gradual duration decrease with speech rate increase, statistically corroborated through a Scheffé post-hoc test. In other words, it was found a continuous duration decrease from slow to normal rates, and from normal to fast rates for all words.

Having been confirmed three distinct speech rates, an investigation of the coarticulation degree between post-stressed consonants was started. It was considered that a shorter articulatory consonantal distance would represent a greater coarticulation degree between these consonants and the related surrounded vowel. The hypothesis adopted was that such coarticulation degree gradually increases with speech rate increase. In order to verify this hypothesis, a one-way ANOVA with the articulatory duration of the consonantal interval as a function of rate was run. As before, all words were individually considered. Statistical results are represented in table 2.

Table 2 shows that there is really a coarticulation degree increase with speech rate increase in the post-stressed gestures, i.e., post-stressed consonants are closer to each other. Besides, a post-hoc Scheffé analysis reveals that, except for “fósforo”, all words behave distinctly across rates, i.e., their consonantal interval duration was smaller with speech rate increase. This coarticulation increase is reinforced taking the consonantal duration of all words together as a function of rate ($F(2,173) = 168.52$, $p < 10^{-4}$). One may argue, however, that this is an obvious result, since speech rate increase should cause a gradual gestural duration decrease. Nevertheless, table 1 and table 2 show that such decrease is not linear, word’s duration reduced differently from the consonantal interval’s duration. This result suggests that a duration differentiation in the consonantal interval of the words could be possible. In other words, their post-stressed consonantal interval duration could be different according to the word internal structure. Recall that in Brazilian Portuguese not all antepenultimate stress words covary with penultimate stress ones. This variation depends on the word internal structure. To verify this question, a one-way ANOVA with duration of the consonantal interval as a function of the individual words was run, all rates considered. Yet, statistical results did not show any differentiation.

In order to look for articulatory differences related to certain consonantal intervals and word structure, which could shed new light on the covariation between antepenultimate and penultimate stress words in Brazilian Portuguese, a new measure called proportional consonantal interval was investigated. This interval shows how consonants percentually decrease within words as a function of speech rate increase and is measured through the following formula: $PCI = CI/WD$, in which PCI refers to the proportional consonantal interval, CI to the consonantal interval, and WD to the word duration. For instance, if a CI duration is 195.5 ms and a WD is 431 ms, PCI is 45%, i.e., this interval extends over 45% of the total word duration.

The experimental hypothesis was that the PCI reduces (extends over a short part of the word) with speech rate increase. To investigate this hypothesis, a Kruskal-Wallis ANOVA with PCI as a function of rate was run, all words individually considered. Results are displayed in table 3 below.

Table 3 reveals that, proportionally to the word reduction, there was no speech rate effect upon PCI for most of the words (four out of six). Even for the words with rate effect (“abóbora” and “fósforo”), there was no distinction among all rates. Multiple (post-hoc) comparisons of average ranks for each pair of groups (corrected for the number of comparisons) have shown that (i) the fast rate in “abóbora” was equal to the normal and slow rates ($F = (S \& N)$), but the slow rate was different from the normal rate ($S \neq N$); (ii) the slow rate in “fósforo” was equal to the normal and fast rates ($S = (N \& F)$), but the fast rate was different from the normal rate ($F \neq N$). It means no clear PCI pattern can be predicted with speech rate increase. Besides, a Kruskal-Wallis ANOVA of the PCI as a function of rate, all words considered, showed no statistical significance of the PCI with speech rate increase. This data reminds us of Tuller and Kelso’s study (Tuller and Kelso, 1984), in which, searching for linguistic invariance, it was found that the relative intersegmental temporal organization is maintained when the suprasegmental structure is varied. The same seems to be the case here, since, even though it has been found that the duration of the consonantal interval decreases with speech rate increase, this interval was constant regarding the total word duration (PCI). In other words, PCI has proportionally reduced as a function of the target-word duration decrease.

As no general influence of speech rate upon PCI was found, it has been investigated whether there was influence of the word type on PCI. In order to do so, a Kruskal-Wallis ANOVA with PCI as a function of the word type was run, all rates considered. Results show that the word factor is relevant for the PCI attribution ($H(5,N=176) = 104.6431$, $p < 10^{-3}$). Besides, multiple (post-hoc) comparisons of average ranks for each pair of groups (corrected for the number of comparisons) divided the words into three distinct groups. Table 4 shows these groups with its PCI's mean and standard deviation, as follows: a) group 1: víbora; b) group 2: bêbada, abóbora, fósforo, and sábado; and c) group 3: abóbada. Recall that a higher PCI implies that the CI is less vulnerable to speech rate variation, i.e., it presents less coarticulation. Thus, the words in group 1 would be produced with less coarticulation than the ones in groups 2 and 3, consecutively. This result partly explains why in casual speech there is not a lexical form like "vibra" (for "víbora") and, on the other side, there are lexical forms such as "abobra", "fosfro", and "sabo" (for "sábado"). Nevertheless, these results are not clear to explain why "abóbada" is the word with the smallest PCI. If, on one side, this small value can be explained by the greater compression of the consonant [d] in relation to [ɾ], on the other side, in casual speech there is no penultimate stress form for "abóbada". Therefore, results suggest that there must other factors acting in the variation from antepenultimate stress into penultimate stress words (such as lexical frequency, for example), since exclusively articulatory data were not capable of completely explaining the lexical variation found in our corpus.

5 Discussion

The results of this paper, through the observation of the increase in coarticulation with speech rate, present acoustic and articulatory evidence to explain the variation from antepenultimate stress words to penultimate stress words in Brazilian Portuguese. These results show that phonetic details are extremely important if we want to correctly interpret linguistic data on lexical variation. The novelty of our approach is to make use of the AP framework for analyzing Portuguese data on linguistic variation. To the best of our knowledge, linguists who study lexical change/variation in this language have always used assumptions based on mainstream linguistics (although with criticism) and, because of that, do not pay close attention to phonetic details in their analysis. On the other side, the use of AP assumptions would greatly contribute to the study of linguistic change/variation, since it incorporates articulatory-phonetic information on a phonological theory of language, breaking up the traditional necessary division between phonetic and phonological data. Thus, such a new approach has been shown useful in sociophonetics issues and has been used in the study of lexical variation in some languages (see for instance Browman and Goldstein, 1990, who introduces the question; McMahon, 2000, who criticizes mainstream linguistics and suggests the incorporation of AP in Lexical Phonology; and Bradley, 2004, who applies AP to the study of Spanish Phonology). Likewise, the application of AP to dialectal variation in Portuguese (and other languages as well) seems to be a profitable area for linguistic studies. Our results also support the idea of language as part of a dynamical system (cf. Elman, 1995; Kelso et al., 1986; Meireles, 2007). In the program of research of the dynamical systems, language's underlying representations emerge from the systemic tendency of non-equilibrium open systems to form stable patterns. In other words, grammar emerges from the brain's physical components (see Elman, 1995, for a neural network demonstration of this process). Therefore, in this linguistic approach both phonetic and phonological aspects of language are interrelated and interdependent. Besides, time is elegantly described at the phonological (abstract) level and no *ad hoc* rules are necessary.

The question of the relevance of time in linguistic studies was demonstrated here through the covariation between antepenultimate and penultimate stress words in BP. Results have shown that gestures' durational characteristics are extremely important for a perceptual interpretation of antepenultimate stress words as penultimate ones. For example, a short [o] in "abóbora" [abɔboɾɐ] at fast rates may result in the perception of this word as a penultimate stress one. Recall that in AP gestures do not disappear (or appear) in linguistic representations. They are always present in linguistic forms, but in a reduced form. Thereby, we should be careful in analyzing antepenultimate stress words as penultimate stress ones without any acoustic or articulatory measurements to corroborate our statements, as has been made in the literature (see for example Amaral, 2002, who have used a qualitative analysis to evaluate the status of antepenultimate stress words as penultimate ones). In this specific case, the lack of quantitative analysis may lead to wrong interpretation of the data.

Obviously, there are also lexical forms that are clearly perceptually penultimate stress words, as the words "sabo" (for "sábado"), "estombo" (for "estômago"), and "meco" (for "médico"). Nevertheless, such extreme transformations of the pattern lexical item are socially or regionally marked. They occur either in low class or in rural communities in Brazil and, in our point of view, they are lexicalized as such in these dialects. On the other side, there are words that covary for all Brazilian Portuguese dialects, such as "abóbora" ~ "abóbra", and "fósforo" ~ "fósfro". In these cases quantitative analysis should be made in order to evaluate the lexical status of these words as antepenultimate or penultimate stress ones. It is worth remembering that, as shown here, speech rate seems to have a crucial effect on this lexical categorization.

Because this study describes the consequences of speech rate increase at the word level, the results benefit areas in speech technology directly concerned with speech variability. These include speech synthesis systems for which phonetic variability is not directly considered by pre-recorded material; possibly for helping to deal with pronunciation dictionaries and language models in automatic speech recognition systems. Moreover, once the variability of BP gestures due to speech rate increase is well-known, articulatory synthesis of BP gestures could be made from this knowledge, in order to realistically represent the movement of articulatory gestures in spoken Portuguese. This is a potential topic for future research.

6 Conclusion

The results of this articulatory study suggest that speech rate increase acts to reduce the magnitude of a gesture, by increasing gestural overlap, which causes the covariation between antepenultimate and penultimate stress words in Brazilian Portuguese. Moreover, disregarding other factors, speech rate increase may lead to a linguistic change at a future time. Results also show that the coarticulation degree of the post-stressed consonants increases with speech rate increase, i.e., these consonants are closer to each other at fast rates, which may result in the perception of the in-between vowel as inexistent. Besides, it was found that a coefficient called proportional consonantal interval (PCI) is influenced by word type. Using such a measure three groups were statistically found, from lesser to greater reduction: a) group 1: víbora; b) group 2: bêbada, abóbora, fósforo, and sábado; and c) group 3: abóbada. Nevertheless, future studies are needed to explain this lexical variation in Brazilian Portuguese, since other factors, such as lexical frequency, may affect this process. This factor may explain why the word "abóbada" (greater coefficient of consonantal reduction, low frequency) does not have a contracted form in casual speech. Furthermore, the new methodological approach presented here benefits areas in speech technology directly concerned with speech variability.

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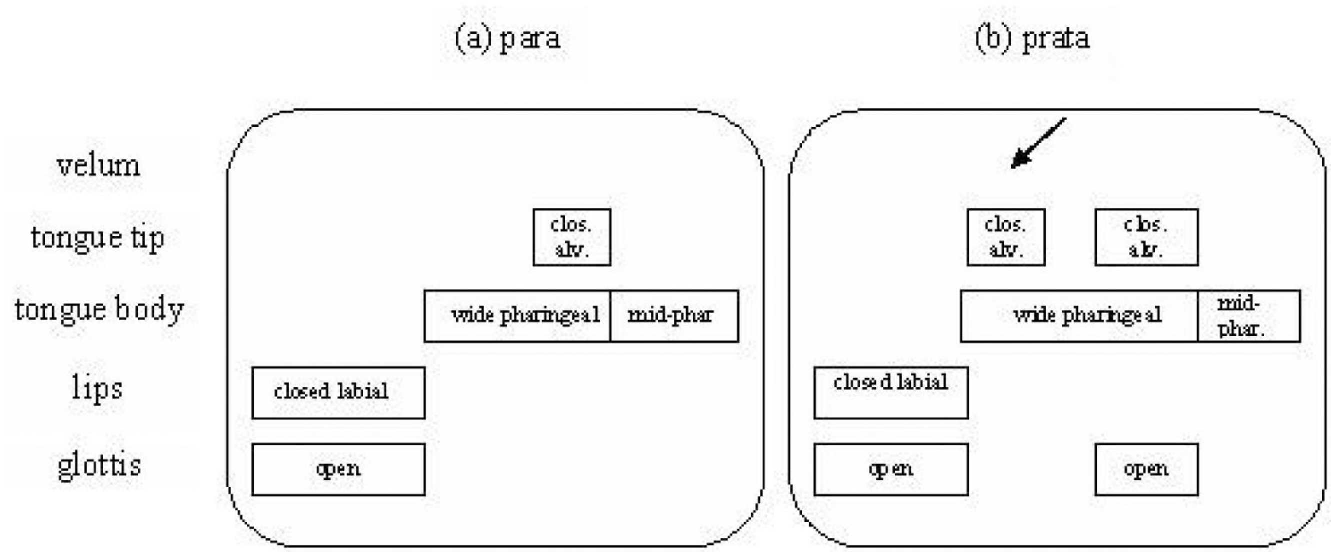

Fig. 1.

Gestural differences between the words “para” and “prata”, according to AP model. It is represented here: (a) gestural score for “para”; (b) gestural score for “prata” (see text for details).

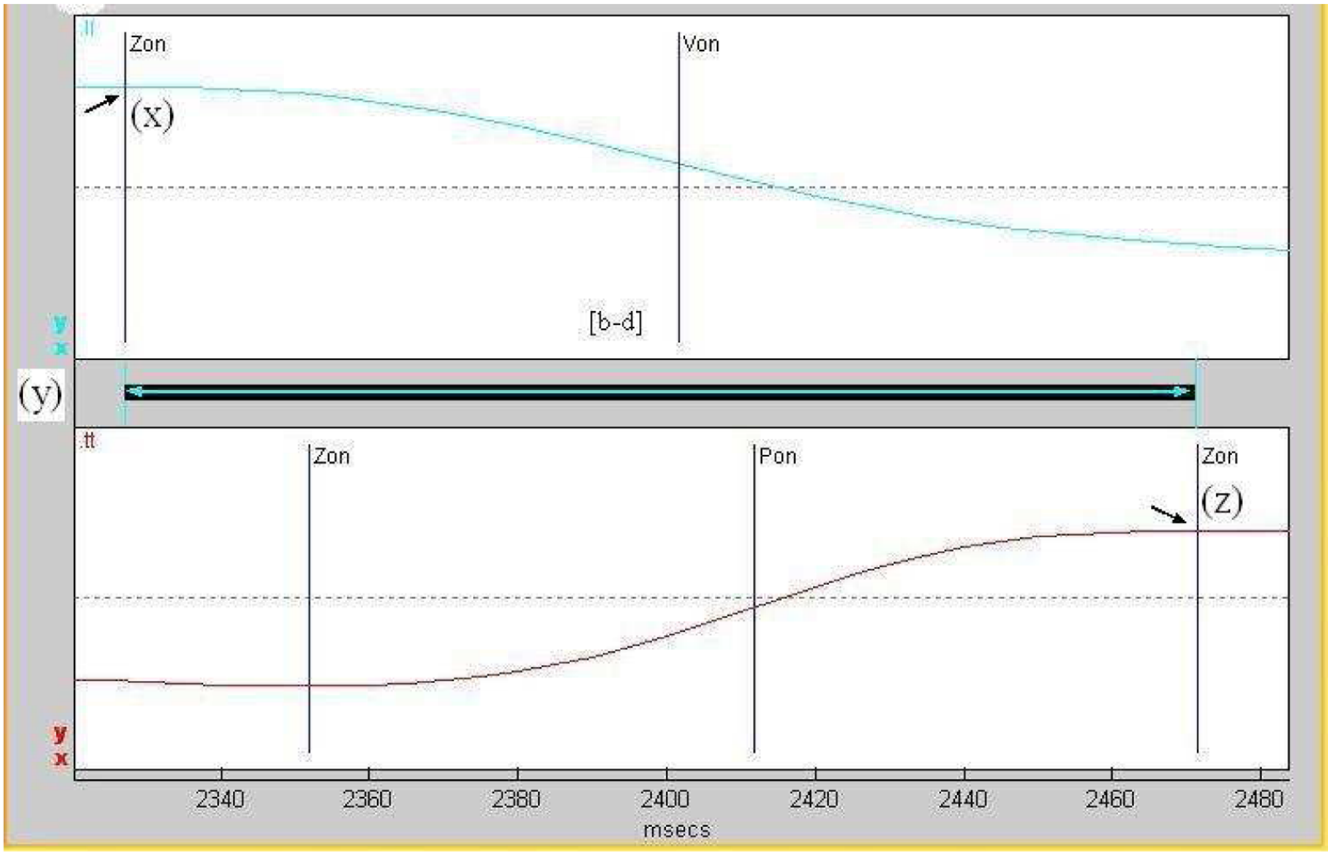

Fig. 2.
Example of the measured duration interval between post-stressed consonants. The vertical lines represent the gesture velocity displayed on the gesture displacement curve. The articulatory distance between [b] (zero velocity, y axis, lower lips, upper frame, see 'x') and [d] (zero velocity, y axis, tongue tip, lower frame, see 'z') in "bêbada" is represented by the arrow (see 'y'). The 'x' axis is displayed in milliseconds and the 'y' axis in millimeters (see additional information in the text).

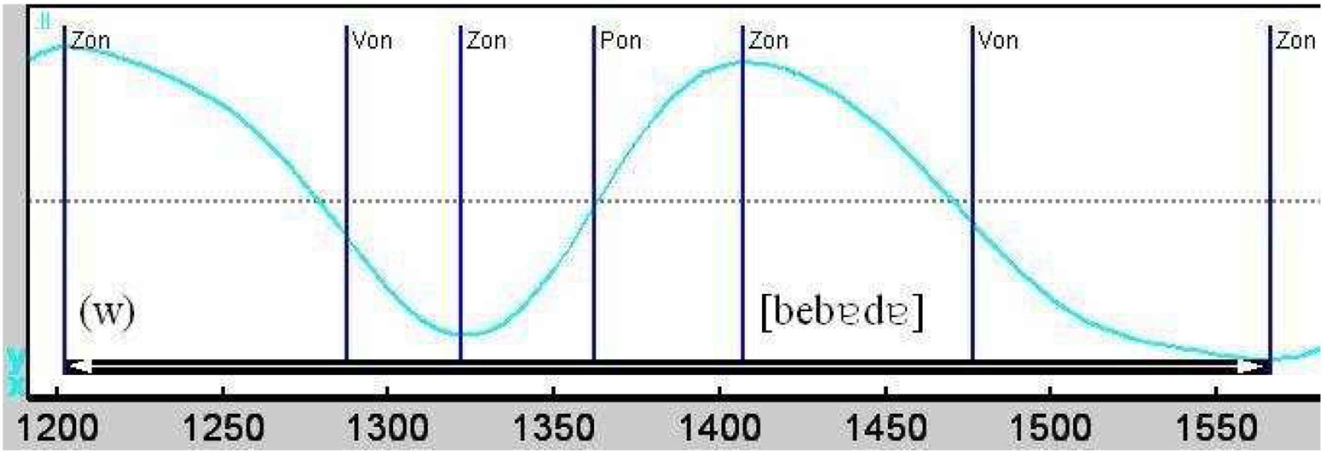

Fig. 3.
Example of the duration interval between the beginning and the end of a target-word. The vertical lines represent the gesture velocity displayed on the gesture displacement curve. The articulatory distance between [b] (zero velocity, y axis, lower lips, curved line) and the last "a" (zero velocity, y axis, lower lips, curved line) in "bêbada" is represented by the arrow (see 'w'). The 'x' axis is displayed in milliseconds and the 'y' axis in millimeters (see text for additional information).

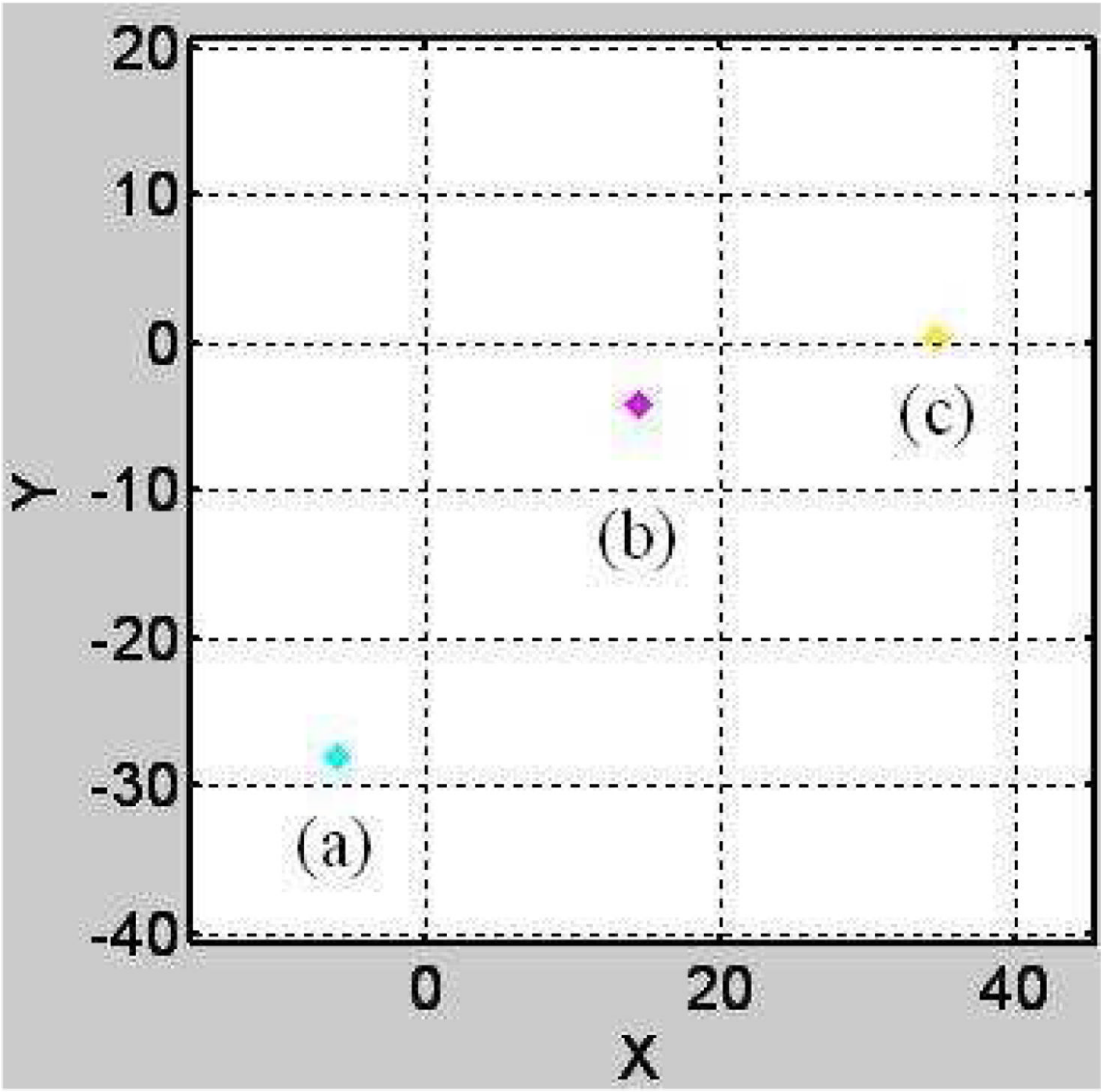

Fig. 4.
SPATIAL window in MAVIS. This is the only place where one can found information about gesture displacement. The scale is in millimeters either on the 'x' and on the 'y' axes and its values can be found using some special procedures in MAVIS. The letters represent the following gestures: (a) lower lips; (b) tongue tip; and c) tongue body.

Table 1

Statistical data for word duration as a function of rate for all words (column 1). It is displayed for all rates (columns 2, 3, and 4) the mean (μ) and standard deviation (σ) of word duration (in milliseconds) with the following pattern: μ (σ). The fourth column represents the results of a one-way ANOVA, and the fourth column represents its statistical significance ($\alpha = 0.05$).

Word	Slow	Normal	Fast	ANOVA	p <
abóbora	629 (34)	452 (25)	332 (16)	$F(2,27) = 323.39$	10^{-4}
abóbada	630 (39)	457 (18)	333 (24)	$F(2,27) = 272.64$	10^{-4}
víbora	456 (28)	346 (21)	259 (18)	$F(2,26) = 177.74$	10^{-5}
bêbada	490 (51)	344 (17)	234 (11)	$F(2,25) = 147.90$	10^{-5}
fósforo	550 (43)	400 (20)	284 (24)	$F(2,27) = 189.37$	10^{-5}
sábado	460 (37)	336 (26)	252 (36)	$F(2,26) = 85.135$	10^{-5}

Table 2

Statistical data of the duration of the consonantal interval as a function of rate for all words (column 1). It is displayed for all rates (columns 2, 3, and 4) the mean (μ) and standard deviation (σ) of the post-stressed consonantal interval (in milliseconds) with the following pattern: μ(σ). The fourth column represents the results of a one-way ANOVA, and the fourth column represents its statistical significance (α = 0.05). Finally, the last column represents the results of a Scheffé post-hoc test, which shows if the speech rates are statistically different from one rate to the next one, i.e., from slow to normal rates, and from normal to fast rates.

Word	Slow	Normal	Fast	ANOVA	p <	Scheffé
abóbora	188 (20)	149 (18)	102 (13)	$F(2,27) = 61.803$	10^{-5}	L ≠ N ≠ R
abóbada	168 (20)	122 (10)	87 (12)	$F(2,27) = 78.661$	10^{-5}	L ≠ N ≠ R
víbora	221 (19)	161 (9)	135 (13)	$F(2,26) = 75.084$	10^{-5}	L ≠ N ≠ R
bêbada	178 (21)	113 (9)	87 (14)	$F(2,25) = 86.468$	10^{-5}	L ≠ N ≠ R
fósforo	167 (29)	119 (17)	101 (13)	$F(2,27) = 26.632$	10^{-5}	L ≠ (N = R)
sábado	174 (36)	106 (6)	79 (5)	$F(2,26) = 52.209$	10^{-5}	L ≠ N ≠ R

Table 3

Kruskal-Wallis ANOVA of the PCIs as a function of rate for all words (column 1). It is displayed for all rates (columns 2, 3, and 4) the mean (μ) and standard deviation (σ) of PCIs expressed in percentage (%) with the following pattern: μ (σ). The fourth column represents the results of a Kruskal-Wallis ANOVA, and the fourth column represents its statistical significance (α = 0.05). n.s. means nonsignificant.

Word	Slow	Normal	Fast	ANOVA	p <
abóbora	30 (3)	33 (4)	31 (3)	H (2, N=30) = 6.3974	0.04
abóbada	27 (3)	27 (3)	26 (3)	n.s.	n.s.
víbora	48 (2)	47 (4)	51 (6)	n.s.	n.s.
bêbada	37 (6)	31 (2)	37 (4)	n.s.	n.s.
fósforo	30 (4)	30 (4)	36 (4)	H (2, N=30) = 8.2297	0.008
sábado	38 (7)	31 (3)	32 (5)	n.s.	n.s.

Table 4

PCIs as a function of the word type. It is displayed for all words the PCI's mean (μ) and standard deviation (σ) with the following pattern (column 2): μ (σ), all rates together. It is also represented here the word's group (column 3) found through multiple (post-hoc) comparisons of average ranks for each pair of groups (corrected for the number of comparisons).

Word	μ (σ)	Group
víbora	49 (4)	1
bêbada	36 (4)	2
abóbora	31 (4)	2
fósforo	32 (5)	2
sábado	33 (6)	2
abóbada	27 (3)	3