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Statistical descriptors in the characterization of some Brazilian Portuguese fricatives: analysis of spectral moments

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ABSTRACT. In this paper, we investigated the spectral characteristics of labiodental, alveolar and postalveolar fricatives of the Brazilian Portuguese in terms of place of articulation and vowel context. We measured the spectral characteristic of fricative noise using the analysis of four spectral moments (center of gravity, standard deviation, skewness and kurtosis). Our results indicated a significant effect of place of articulation and vowel context on values of spectral moments for fricatives of Brazilian Portuguese. The results show that the fricatives were well differentiated by the center of gravity and standard deviation more than the other spectral moments, skewness and kurtosis.

Keywords: spectral characteristics, place of articulation, fricative, Brazilian portuguese.

Descritores estatísticos na caracterização das fricativas do Português Brasileiro: a análise dos momentos espectrais

RESUMO. Neste artigo, as características do espectro de frequência das fricativas labiodentais, alveolares e palatoalveolares do Português Brasileiro foram investigadas com relação ao ponto de articulação e contexto vocálico. A mensuração do espectro de frequência das fricativas foi realizada por meio da análise dos quatro momentos espectrais (centroide, variância, assimetria e curtose). Nossos resultados indicam um efeito significativo do ponto de articulação e contexto vocálico nos valores dos quatro momentos espectrais das fricativas do português Brasileiro. Os resultados indicam que os momentos espectrais centroide e variância foram mais eficazes para diferenciar as fricativas do que os outros dois momentos, assimetria e curtose.

Palavras-chave: características espectrais, ponto de articulação, fricativa, português brasileiro.

Introduction

Fricatives are sounds phonologically important to Brazilian Portuguese (hereinafter BP), occupying onset position (*f*aca, *v*aca, *s*apo, *ch*á, *j*á) and coda position (fe*s*ta, casa*s*). Fricatives are complex sounds with refined acoustic-articulatory characteristics, which provide a broad area of research. They are important to understand the underlying mechanisms in the production of speech sounds and in the knowledge of the phonological organization of languages.

Despite the increased interest to study the fricative sounds in BP, in the last few years, this class of consonants, very productive in our language, is still understudied. There are few researches dedicated to the acoustic characterization of these sounds. Most of them are studies targeting the acoustic characteristics of the BP fricatives, focusing the children's talk (acquisition of fricatives) and speech pathologies (BERTI, 2006; FREITAS, 2007; RINALDI, 2010). Exceptions are the studies of Samczuk and Gama-Rossi (2004), Haupt (2007), and Ferreira-Silva and Pacheco (2009, 2012), on the characteristics of duration and frequency of the fricative noise.

These researches do not provide enough answers to questions such as: a) what are the acoustic characteristics of fricatives produced by Brazilian adults and free of pathology?; b) what are the most effective acoustic parameters to differentiate the three places of articulation (labiodental, alveolar and postalveolar) of fricatives that comprise our phonological system?; c) can the fricative spectrum be altered due to an adjacent vowel?

Thus, our study aims at describing the characteristics of the frequency spectrum of the BP fricatives and verifying whether parameters such as places of articulation and vocalic context can interfere in their phonetic characteristics. Our hypothesis is that BP fricatives present prototypical spectra and that they can be altered due to the adjacent vowels.

Fricative sounds: acoustic-articulatory characteristic

In terms of production, the sounds of natural languages can be grouped into two major sets: those produced without obstruction – the vowels – and those with total or partial obstruction of the vocal tract – the consonants.

When a mechanism of construction is produced and it blocks the airstream inside the vocal tract, the consonants are named stop consonants. When the constriction allows the airstream to pass through the nose or the mouth, the consonants are named obstruents. (CRYSTAL, 1985).

Among the obstruent, fricatives are consonant sounds produced by a narrow constriction of the vocal tract. In this case, the production of these consonants has a noise source, resulting from air turbulence generated by the constriction of the vocal tract (KENT; READ, 1992).

Obstruent consonants are usually classified according to their voicing system and their place of articulation. Thus, the fricatives can be voiceless (with no vibration of the vocal cords) or voiced (when the vocal cords vibrate during the production of the sound) In relation to the places of articulation, BP fricatives can be labiodental, alveolar, postalveolar, velar and in some varieties also interdental, uvular and glottal (CAGLIARI, 2007). In other languages other fricatives may be found (MALMBERG, 1954; KENT; READ, 1992)

In addition to the classification, regarding the voicing and place of articulation, the fricatives can still be characterized in relation to the amount of energy concentration of the noise. Thus, a fricative can be sibilant or non-sibilant (KENT; READ, 1992). Fricatives that possess a higher concentration of noise in the high energy area of spectrum are considered sibilant, as in the case of the labiodental fricatives [f] and [v] in BP.

We can say that the pattern of energy concentration of the noise of the fricatives may vary as a function of the different places of articulation. In this way, for instance, the alveolar fricatives have their peaks of energy concentration in regions of frequency higher than the palatal fricatives. (KENT; READ, 1992; JESUS, 2001).

Brazilian portuguese fricatives

The phonological system of Portuguese from Brazil counts six oppositional fricatives in position of syllabic onset: voiceless and voiced labiodental, alveolars and postalveolar. See examples as follow. Adapted from Cagliari (2007):

a) Labiodental: /f/ : /v/ – *faca* ; *vaca*.
b) Alveolar: /s/ : /z/ – *caça; casa.*
c) Postalveolar: /ʃ / ; /ʒ / – *chá*; *já*.

As phonological variants, BP presents other fricatives:

d) Velar: [x, ɣ] – *rato*; *barriga*.
e) Uvular: [ʁ, χ] – *rato; barriga.*
f) Glottal: [h, ɦ] – *rato; barriga.*

According to Cagliari (2007), in the dialect of Rio de Janeiro and in the Northeast of Brazil it is common to find velar fricatives, while in the dialect of Minas Gerais, we can observe the use of glottal fricatives. These fricatives are in variation with a rhotic phoneme, not with other fricatives (CAGLIARI, 2007).

In coda position, the framework of the BP fricatives is reduced. According to Câmara Júnior (1970), there occurs a neutralization of the voiceless and voiced alveolar and postalveolar fricatives. So, in this syllable position, BP phonological system presents a fricative archiphoneme /S/.

Acoustic theory of speech production

The Acoustic Theory of Speech Production, also known as Source-Filter Theory, was proposed by Gunnar Fant (1970) with the main objective to relate acoustic properties of the speech sounds to their correspondent articulatory processes.

This theory proposes a simplification of the human vocal tract, which is represented by a vibrator (an elastic membrane with a narrow cut in the middle, representing the vocal folds) connected to one side of a straight tube. The vibrator is a source of acoustic energy that propagates through the tube, which acts as resonator or filter (uniform tube closed on one side and open on the other), referring to the supraglottic structures of the vocal tract (KENT; READ, 1992).

This model of uniform tube closed at one end and open at the other represents primarily, in the Fant's theory (1960), the model for the production of a vowel, corresponding to the mid central vowel, neutral, known as *schwa.* Variations in the configuration of this tube represent other vowels. The simplification of the human vocal tract for the production of vowels (uniform tube) can also be adapted for the production of fricatives. In this case, the tube is no longer straight (uniform), but it has a strong constriction (KENT; READ, 1992).

In the production of fricatives, according to Kent and Read (1992), the constriction in the vocal tract works as a nozzle. The passage of air through the constriction generates a stream that mixes with the surrounding air, producing turbulence. The turbulence is created with the generation of vortices that are produced in the flow surrounding the contraction and expansion of the conduit.

To produce these fricatives, it is necessary to fulfill two steps: 1) production of a strong constriction in some point of the vocal tract; 2) passage of air with high speed through the constriction. When the physical conditions are met, the turbulent flow is generated near the constriction (KENT; READ, 1992).

There are, at least, two acoustic sources in the production of a fricative. The first refers to the existence of a source at the articulatory obstacle, in which the sound is primarily generated in a rigid body placed perpendicularly to the flow (SHADLE, 1985; KENT; READ, 1992). In the production of voiceless palatal fricatives, the lower teeth exert the function of an additional obstacle. In the case of the voiced alveolar fricatives, the upper teeth form the additional obstacle. The source of these obstacles can be similar to a spoiler (an obstruction, as a hit in the direction of the airflow) in a conduit (KENT; READ, 1992). The second form to produce the fricatives is associated with the existence of a wall source, cases in which the sound is generated along a wall relatively rigid positioned in parallel to the flow (KENT; READ, 1992). According to Shadle (1985), the source of wall is a source distributed, in contrast to the obstacle source, in which can be modeled as a source of pressure in series located in the obstacle.

Thus, parameters such as place of constriction, length of the cavity preceding the constriction, duration and presence or not of secondary obstacles are fundamental for the characterization of fricatives (SHADLE, 1985). When the anterior cavity is very short, such as in the cases of the labiodental fricatives [f, v], their lowest resonance frequency is still very high to provide a considerable format to the noise energy. Therefore, the spectrum for these fricatives is flat or diffuse, losing prominent peaks or valleys. However, when the place of articulation moves backwards in the oral cavity, the extension of the cavity preceding the constriction increases, and their lowest resonance frequency decreases. In the case of the alveolar fricative [s], the lowest resonance frequency is around 4 kHz for a man (KENT; READ, 1992).

We can affirm that the extension of the anterior cavity and the place where the articulatory constriction occurs determine a higher or lower noise energy. The fricatives articulated in a more anterior position (lips, teeth) present lower noise energy. On the other hand, the fricatives articulated in a more posterior position (alveoli, palate) present higher noise energy. This is mainly due to the extension of the anterior cavity (SHADLE, 1985, KENT; READ, 1992).

Methodology

Corpus assembly

For this study, it has been mounted a corpus composed of disyllabic words (real and logatoms i.e., nonsense 'words', but which are in line with the language phonotaxis).

In the corpus, the onset position of the initial syllabe is occupied by a labiodental, an alveolar or by a postalveolar fricative. In the second syllable, the onset position is occupied by a voiceless bilabial stop. According to Shadle (2006), the voiceless bilabial stop has been used in acoustic analyses in order to facilitate the identification and segmentation of the segments in the acoustic signal.

The syllable nucleus is occupied by the vowels [a], [i] or [u]. The objective is to verify whether the vocalic context interferes in the characteristics of the fricatives. Following the Quantum Theory (STEVENS, 1971), the vowels [a], [i] and [u], called quantum vowels or point vowels, are produced in a point on the vocal tract in which small disturbances in the articulation produce only minimal changes in their formantic frequencies. For this reason, we opted to use only these three vowels as syllable nucleus in the corpus. See the examples presented in the Table 1.

Table 1. Examples of words that constitute the corpus.

VAPA	VIPE	VUPU
FAPA	FIPE	FUPU
SAPA	SIPE	SUPU
ZAPA	ZIPE	ZUPU
JAPA	JIPE	JUPU
CHAPA	CHIPE	CHUPU

Source: the autors

It has been decided to analyze the fricative always in stressed syllable. Thus, the syllable in which the target fricative is found is always stressed, because that is the optimum context for the present study.

The words from the corpus were inserted in the vehicle phrase "Eu digo 'palavra alvo' baixinho" (I say 'target word' in low voice), with the objective to homogenize the phonetic environment for all cases.

Speakers and acoustic recordings

Five speakers (three men and two women) natural from the city Vitória da Conquista (Bahia), Brazil, students at the university, aged between 18 and 27 years old recorded all data used in this study.

The vehicle sentences with the target fricatives were printed and presented to the speakers for the recording. They have been asked to read aloud one sentence at time and to repeat three times the reading, with normal speech rate. For the speakers reading, some distracter sentences were inserted in order to hide the objective of the investigation.

The recordings were realized in a camera with acoustic insulation, using the MBOX2 Digidesign/M-audio sound card, that runs the Protools LE audio recording software. All the recordings were performed at the Laboratory of Research in Phonetic and Phonological Studies (LAPEFF) in the State University of Southwest Bahia – UESB.

Methodology used to analyze the frequency of fricatives

The method used for the analysis of the frequency rate of fricatives was the analysis of the first four spectral moments. The analysis of the spectral moments for the acoustic characterization of the segments was initially proposed by Forrest et al. (1988) to differentiate the English stop consonants. Afterwards, Jongman et al. (2000) used the same method to characterize the English fricatives. Researchers such as Jesus (2001), Jesus and Shadle (2002), Berti (2006) and Rinaldi (2010), among others, have also used the four spectral moments as effective method to analyze the frequency of fricatives.

The analysis of the spectral moments refers to a quantitative metric based on the statistical analysis of the spectrum (FORREST et al., 1988). This procedure allowed us to calculate mean, variance, asymmetry and kurtosis of the spectrum.

According to Berti (2006), such measures incorporate both local and some general information of the spectrum. The spectral moments are obtained automatically by the PRAAT (2014) (software developed by Boersma and Weenink for acoustic analysis of speech), from the frequency spectrum of the fricative, which is given by the FFT and can be calculated at different points of the fricative noise. In the present study, the analysis of the spectral moments is processed with a window of 0.10 ms, measured at the medial portion of each fricative.

The first spectral moment – centroid ('centre of gravity') – corresponds to the mean of frequencies weighted from a set of frequencies given by the spectrum of the fricative noise. In other words, the centroid is obtained by multiplying each given value of frequency by the spectral value of each corresponding intensity, dividing the sum of these products by the sum of all values of frequency of the spectrum (BERTI, 2006).

The second spectral moment corresponds to the variance (*standard deviation*) of frequencies given by the spectrum. That is, it is a measure of the dispersion of frequencies in relation to the mean (centroid).

The third moment corresponds to the asymmetry (*Skewness)* of the frequencies given by the spectrum. The asymmetry is a measure that indicates how the frequencies of the spectrum are distributed around the mean. According to Berti (2006), a value of asymmetry equal to zero indicates that the distribution of frequencies around the mean is symmetrical. On the other hand, a positive value of asymmetry indicates that the distribution of frequencies in the spectrum has a negative slope, with concentration of energy in the low frequencies On the other hand, a negative asymmetry has positive slope, pointing to a concentration of energy in the high frequencies.

The fourth spectral moment corresponds to the kurtosis of the frequencies given by the spectrum. The kurtosis is an indicator of the peak of the frequency distribution in the spectrum. Berti (2006) affirms that a positive kurtosis indicates peaks relatively high in the spectrum. In addition, the higher the kurtosis value, the more peaks are present in the distribution of the spectrum. On the other hand, a negative kurtosis indicates that the distribution presents peaks more flattened, or a spectrum without well-defined peaks.

Statistical analysis

The values of the four spectral moments for the fricatives analyzed are catalogued and subjected to statistical analysis through the software BioEstat (AYRES et al., 2007). The objective of this analysis is to verify whether the values of the four spectral moments are different as a function of the place of articulation.

Initially, we used the Bootstrap test, which consists of removing from a small sample, larger samples with replacement, for instance, 500, 1,000, 10,000 or more (AYRES et al., 2007). This technique is also called simulation or resampling. The type of Bootstrap application used was the ANOVA (one-way) test. We adopted simulation of 10,000 replacements. With this methodological procedure, we obtained more robust probability values. We consider significant differences for p-values ≤ 0.05, and for alpha value of 0.05.

The data that presented significant values, which is, $p \leq 0.05$, were subjected to the mean separation tests of Dunn and Student-Newman-Keuls (AYRES et al., 2007). With the mean separation tests, it was possible to observe which fricatives are equal or different from each other.

Results and discussion

The results of this study show that BP fricatives tend to follow, in general, the acoustic characteristics found for fricatives of other languages.

By evaluating the centroid, we have the first spectral moment evaluated that consists of an analytical device that provides the weighted means of the noise frequencies obtained from a specific point. With the centroid, we evaluate the acoustic nature of the fricative noises what allows us to raise hypotheses about their articulatory characteristics.

The acoustic nature of the spectrum of BP fricatives can be seen in Table 1, where the mean values obtained for the first spectral moment, the centroid, and the p-values obtained from the statistical analysis are presented.

In Table 1, we observe that the labiodental, alveolar and postalveolar fricatives present values of centroid that are, for the most part, significantly different, as evidenced by the p-values. The values of the centroid of fricatives are not significant (p ≤ 0.05), only in the context of the vowel [u] for the speakers 1 and 5 (S1 and S5). In all other contexts, the values found for the comparison between fricatives are significant.

The data in Table 1 show that there is a strong tendency for the labiodental and postalveolar fricatives not being statistically different from each other. In Table 2, this condition is attested by the presence of the same letters close to the means, which reinforces the fact that the alveolar presents a general mean far superior to the other fricatives.

Table 2. Mean values of the centroid of labiodental, alveoplar and postalveolar fricatives in the context of [a], [i] and [u] for the five speakers, and respective p-values.

Individuals	Vowels	Place of articulation			*p-value*
		Labiodental	Alveolar	Palato-alveolar	
S1	[a]	5892 a(1)	7130b(2)	5294a	0.023s(3)
	[i]	4935a	7529b	4909a	0.002s
	[u]	4360	5649	4573	0.143ns(4)
S2	[a]	3538a	7946b	4619a	0.000s
	[i]	4200a	7779b	4597a	0.000s
	[u]	3848a	6914b	3996ab	0.004s
S3	[a]	5985a	9051b	4572a	0.000s
	[i]	6382a	8829b	5373a	0.011s
	[u]	6226a	7950a	5697ab	0.009s
S4	[a]	4826a	8345a	4353ab	0.000s
	[i]	5798a	8277b	5359a	0.000s
	[u]	3972a	6880b	4712ab	0.020s
S5	[a]	5032a	6305a	3348ab	0.039s
	[i]	6089a	7265a	4290ab	0.008s
	[u]	3971	5410	3437	0.111ns
General mean		5003	7417	4608	

Note: (1) Equal letters indicate that there is no significant difference between means. (2) Different letters indicate that there is no significant difference between means. (3) Values statistically significant. (4) Values statistically non-significant.

Source: the autors

We can observe in Table 1 that the alveolar fricatives present the highest centroid values. For these fricatives, the centroid values vary from 5410Hz (S5, vowel [u]) to 9051Hz (S3, vowel [a]). On the other hand, labiodental and postalveolar fricatives present centroid values that vary, respectively, from 3538Hz (S2, vowel [a]) to 6382 Hz (S3, vowel [i]) and 3348Hz (S5, vowel [a]) to 5697Hz (S3, vowel [u]). As we can see, these fricatives present similar centroid values.

Our results are in line with the results presented in the classic study of Strevens (1960) on the English fricatives. Strevens (1960) divided the fricatives into anterior, medial, and posterior as a function of characteristics of the frequency spectrum of the fricatives. According to the author, the anterior fricatives, as well as the labiodental, possess a longer spectrum with few energy peaks. According to him, the lowest frequencies of the labiodental fricatives are around 1500Hz and 1700Hz, while the highest frequencies vary between 1900Hz and 4000Hz. These fricatives, according to the author, can, occasionally, present frequencies around 5000Hz.

According to Strevens (1960) the medial fricatives, as well as the alveolar, present a lower spectrum with many regions of high frequencies of energy, if compared with the fricatives of other groups. In addition, the alveolar fricatives have their lowest frequencies in the range of 3500Hz, while the highest frequencies can reach peaks that surpass 8000Hz.

The posterior fricatives, such as the postalveolar, present a spectrum of average duration and frequencies intermediated in relation to the other two groups. The author affirms that these fricatives have their lowest frequencies around 1600Hz – 2500Hz. On the other hand, the highest frequencies can reach peaks of up to 7000Hz (STREVENS, 1960).

In relation to the vocalic context, in the Table 1 above, we observe that the fricatives present centroid values higher in the context of the vowels [a] and [i], except for the speaker 3 (S3), who presents, for the postalveolar fricative, centroid value higher in the context of the vowel [u]. In Table 1, the results demonstrate that the context of the vowel [i] promotes high centroid values. According to the Table 1, among the lowest centroid values, for the fricatives analyzed, none occurs in this vocalic context; in other words, our results show that the vowel [i] never lowers the centroid values for the fricatives analyzed.

Our results indicate that the vowel [a] favors both the lifting and the lowering of the centroid values of fricatives. Based on the Table 1, we found that the vowel [a] is responsible for 40% of the lowest values and for 46.66% of the highest values recorded for the centroid of the fricatives analyzed.

We can also observe in the Table 1 above that the vowel [u] is responsible for 60% of all lowest values recorded for the centroid of fricatives. Only 6.68% of the highest values of centroid occur in this vocalic context. It is noticed in Table 1 that the lowest values of centroid for the alveolar fricative occur in the surroundings of the vowel [u], that is, the alveolar fricative always presents lower frequency in the context of [u].

The studies of Soli (1981) and Yeni-Komshian and Soli (1981) brought important contributions to the studies on the relevance of the vocalic context to characterize the sibilant fricatives of English. The authors analyzed the spectral peaks of fricatives and the spectral characteristics of the transition between the fricative and the next vowel, through the F2. The results of the authors show that the fricative noise presented different spectral patterns, depending on the vocalic context. The frequencies of fricatives can present increase from 100Hz to 300Hz when they are before the vowel [i], when compared with the frequencies of fricatives in the environment of [u] or [a] (SOLI, 1981). According to Soli (1981), the presence of these peaks in the spectrum of the fricatives indicates that, during the last part of the fricative, the constriction starts to open, anticipating the articulation of the vowels, and, as a consequence, the resonances of the second formant are excited. Thus, according to the authors, the acoustic characteristics of the fricative formants vary as a function of the vocalic context due to differences in the preliminary co-articulation of the vowel. The results of the authors indicated that the values of F2 in the transition from vowel to fricative were higher in the context of the vowel [i] and lower in the context of the vowel [u].

For BP fricatives, in relation to the vocalic context, our results meet the results of Soli (1981) and Yeni-Komshian and Soli (1981) for English fricatives and also the results of Manrique and Massone (1981) for the Spanish of Buenos Aires, and Jesus (2001) for the European Portuguese. The last two authors affirm, similarly to Soli (1981) and Yeni-Komshian and Soli (1981), that the frequency spectrum of the fricatives is strongly influenced by the vocalic context. In their studies, these authors show that the frequencies of the fricatives tend to be higher in environment of vowel [i] and lower in environment of [u]. We can observe similarities to the results presented in Table 1, once the vowel [i] never promotes the lowering of the centroid values, but while it is in the context of vowel [u] the lowering that occurs with the lowest values of centroid.

The second spectral moment evaluated here is the variance, which indicates the dispersion of the noise frequencies around the mean. The values of variance found prove to be significant to differentiate the BP fricatives regarding the place of articulation, similarly as found for the centroid.

Table 3 presents the results obtained in the case of the variance analysis. All values of variance differentiate significantly one fricative from another. Our results indicate that the variance values for the labiodental fricatives are higher than for the alveolar and postalveolar, that is, the variance is capable of differentiating the non-sibilant fricatives (labiodental) from the sibilants (alveolar and postalveolar). These findings corroborate with the results of Jongman et al. (2000) for English fricatives. According to the authors, the variance was effective to differentiate the sibilant from the non-sibilant fricatives, since the latter presents higher values, similarly as our results, presented in Table 3.

Table 3. Mean values of variance (MHz) of the labiodental, alveolar and postalveolar fricatives in the context of [a], [i] and [u] for the five speakers, and respective p-values.

Individuals	Vowels	Place of articulation			*p-value*
		Labiodental	Alveolar	Postalveolar	
S1	[a]	2845a[1]	1801b[2]	2002ab	0.003s[3]
	[i]	2976a	1503b	1929ab	0.001s
	[u]	2880a	2421a	2242ba	0.004s
S2	[a]	2400a	1260b	1716ab	0.011s
	[i]	2560a	1390b	1739ab	0.002s
	[u]	2845a	1665b	1804b	0.000s
S3	[a]	3025a	1772b	1703b	0.001s
	[i]	2833a	1612b	1640b	0.003s
	[u]	2826a	2080b	1952b	0.019s
S4	[a]	3092a	1238b	1728ab	0.000s
	[i]	3091a	1400b	1765b	0.000s
	[u]	2402a	4154a	2295ab	0.049s
S5	[a]	3078a	2455a	1352ba	0.003s
	[i]	2678a	2455a	1780b	0.025s
	[u]	3411a	2086b	2115b	0.001s
General mean		2862.8	1952.8	1850.8	

Note: (1) Equal letters indicate that there is no significant difference between means. (2) Different letters indicate that there is no significant difference between means. (3) Values statistically significant.

Source: the autors

Regarding the vocalic context, we cannot affirm, based on the results of Table 3, which the vocalic surroundings have influenced the variance values, second spectral moment, for the fricatives analyzed.

The asymmetry is the third spectral moment analyzed. It informs on the distribution of frequencies around the mean. The results found, showed in Table 4, for the asymmetry of fricatives, do not show to be significant to differentiate the fricatives in relation to the places of articulation, regarding the two first spectral moments. In the cases of significant values, the main difference happens between the alveolar and postalveolar fricatives (Table 4).

Table 4. Mean values of asymmetry of the labiodental, alveolar and postalveolar fricatives in the context of [a], [i] and [u] for the five speakers, and respective p-values.

Individuals	Vowels	Place of articulation			*p-value*
		Labiodental	Alveolar	Postalveolar	
S1	[a]	-0.54	-0.50	0.25	0.246ns[1]
	[i]	0.23	-0.56	0.20	0.254ns
	[u]	0.34	0.36	0.33	0.200ns
S2	[a]	1.35a[2]	-0.84b[3]	1.27a	0.006s[4]
	[i]	1.00a	-0.93b	0.84a	0.004s
	[u]	1.07a	-0.00a	1.79ab	0.043s
S3	[a]	-0.42a	-1.68a	1.06ab	0.036s
	[i]	-0.54a	-1.91a	0.92ab	0.018s
	[u]	-0.58	-1.13	-0.69	0.333ns
S4	[a]	0.74	-0.35	1.15	0.200ns
	[i]	-0.38	-1.25	0.57	0.102ns
	[u]	1.20	-0.35	0.21	0.249ns
S5	[a]	-0.00a	0 a	2.30b	0.000s
	[i]	-0.57a	-0.54a	1.00b	0.001s
	[u]	0.87	3.77	2.07	0.471ns
General mean		0.25	-0.39	0.88	

Note: (1) Values statistically non-significant. (2) Equal letters indicate that there is no significant difference between means. (3) Different letters indicate that there is no significant difference between means. (4) Values statistically significant.

Source: the autors

Based on the values obtained for the asymmetry, presented in Table 5, we can affirm that the BP fricatives tend to present distribution of frequencies similarly around means. As we see in the Table 4 above, the p-values obtained with the statistical analysis show clearly that the means of the values of asymmetry for the labiodental, alveolar and postalveolar fricatives do not present significant differences in some cases.

In Table 4, the asymmetry values for the fricatives are not influenced by the vocalic context, that is, there is no significant difference in the values of asymmetry as a function of the next vowel.

The fourth and last spectral moment evaluated in this research was the kurtosis. It informs about the nature of the peaks of the fricative noise frequencies. The results of the kurtosis analysis are presented in Table 5.

The results found for the kurtosis of the fricatives, as well as for the asymmetry, are not significant to differentiate these consonants regarding the place of articulation, since the statistical analysis does not show significant differences between the kurtosis means of the three fricatives analyzed.

Despite verifying non-significant p-values, the analysis of the means of the kurtosis values shows a systematic behavior in respect to the distribution of the peaks (Table 5).

As we observe in Table 5, the alveolar fricatives are those that present the highest kurtosis values in general. On the other hand, the labiodental fricatives are those that present the lowest kurtosis values and the postalveolar present intermediate values.

Table 5. Mean values of kurtosis of the labiodental, alveolar and postalveolar fricatives in the context of [a], [i] and [u] for the five speakers, and respective p-values.

Individuals	Vowels	Place of articulation			*p-value*
		Labiodental	Alveolar	Postalveolar	
S1	[a]	-0.63	2.98	-0.44	0.135ns[1]
	[i]	-0.75	3.09	0.26	0.235ns
	[u]	-0.37	-0.43	-1.13	0.336ns
S2	[a]	2.50	3.72	2.65	0.216ns
	[i]	0.88	4.45	1.38	0.070ns
	[u]	0.75	0.11	3.78	0.140ns
S3	[a]	-0.42a[2]	7.67b[3]	2.12ab	0.008s[4]
	[i]	0.75a	6.78b	0.68a	0.005s
	[u]	-0.15	2.35	-0.41	0.120ns
S4	[a]	3.18	2.17	0.96	0.316ns
	[i]	-0.82	5.76	0.97	0.224ns
	[u]	7.63	-0.86	-1.02	0.121ns
S5	[a]	-0.80a	0.87a	9.37ba	0.008s
	[i]	-0.38a	0.22a	3.32ba	0.028s
	[u]	-0.18	2.54	5.27	0.321ns
General mean		0.74	2.76	1.85	

Note: (1) Values statistically non-significant. (2) Equal letters indicate that there is no significant difference between the means. (3) Different letters indicate that there is no significant difference between the means. (4) Values statistically significant.

Source: the autors

According to Forrest et al. (1998), kurtosis is an indicator of the distribution of frequencies in the spectrum. Therefore, high kurtosis values indicate that there are many peaks in high frequency in the spectrum. Based on that statement, we can affirm that our results for the kurtosis of the fricatives are in accordance with the expected findings. It is expected that alveolar fricatives are those that present the highest frequencies in the spectrum, while the labiodental present lower frequencies and the postalveolar present intermediate values (STREVENS, 1960; SHADLE, 1985; KENT; READ, 1992).

Conclusion

In relation to the objectives of the present study, our research showed some characteristics of three types of BP fricatives with special reference to the nature of their noise.

Regarding the noise nature of BP fricatives investigated using the analysis of the four spectral moments, we can affirm that the first and the second spectral moments, centroid and variance, are the most important acoustic parameters to differentiate the fricatives, in relation to the place of articulation. This effectiveness is statistically confirmed, as demonstrated by the p-values.

The centroid corresponds to the calculation of the intensity of the spectral frequencies and it shows clearly that alveolar fricatives have the highest centroid values, as expected, since these fricatives have the highest energy peaks in high frequencies (KENT; READ, 1992; SHADLE, 1985; JESUS, 2001). This result is also in line with the results found by Jongman et al. (2000) for English fricatives, regarding the place of articulation. In the study of Rinaldi (2010), the centroid was also effective to determine the three places of constriction for BP fricatives.

The centroid values for the fricatives also present differences in relation to the vocalic context. As showed clearly by the data from the present research, the centroid values of the fricatives are higher when accompanied by the vowels [a] or [u]. What indicates that the fricatives present higher frequencies when followed by those vowels. On the other hand, it is in the context of the vowel [u] that occurs the majority of the lowest centroid values for the fricatives. This result corroborates the results of other researchers, such as Soli (1981) and Yeni-Komshian and Soli (1981) for English; Manrique and Massone (1981) for Spanish; and Jesus (2001) for the European Portuguese.

Regarding the second spectral moment, variance, we observe that its values are effective to differentiate the sibilant fricatives (alveolar and postalveolar) from the non-sibilants (labiodental). Our results are similarly to the results found for the English fricatives by Jongman et al. (2000). They demonstrate that the non-sibilant fricatives present variance values higher than the sibilant fricatives.

In relation to the third spectral moment, asymmetry, our results evidence that the values are not very significant to differentiate the fricatives in relation to the place of articulation. The distribution of the frequencies around the mean occurs similarly for all fricatives. The statistical analysis shows that the means of the asymmetry values for the labiodental, alveolar and postalveolar fricatives do not present differences significantly.

The results, regarding the fourth spectral moment, indicate that the kurtosis was effective to differentiate the fricatives in relation to the place of articulation. In relation to the place of articulation, our results show clearly that the alveolar fricatives present the highest kurtosis values; the labiodental fricatives present the lowest kurtosis values and the postalveolars present intermediate values. As function of the vocalic context, we cannot affirm that the vocalic surroundings interfere in the kurtosis values for the fricatives investigated.

References

AYRES, M.; AYRES, M. J.; AYRES, D. L.; SANTOS, D. A. S. **BioEstat**: aplicações estatísticas nas áreas das ciências biomédicas. Belém, 2007. (Programa de computador)

BERTI, L. C. **Aquisição incompleta do contraste entre /s/ e /ʃ/ em crianças falantes do português brasileiro**. 2006. 221f. Tese (Doutorado em Linguística)-Universidade Estadual de Campinas, Campinas, 2006.

BOERSMA, P.; WEENINK, D. **Praat**: doing phonetics by computer. Version 5.3.8.2. (Computer program). Disponível em: <http://www.praat.org/>. Acesso em: 26 jul. 2014.

CAGLIARI, L. C. **Elementos de fonética do português brasileiro**. São Paulo: Paulistana, 2007.

CAMARA JÚNIOR, M. **Estrutura da língua portuguesa**. 36. ed. Petrópolis: Vozes, 1970.

CRYSTAL, D. **A dictionary of linguistics and phonetics**. 2nd ed. Oxford: Blackwell. 1985.

FANT, G. **Acoustic theory of speech production**. 2. ed. Paris: Mouton, 1970.

FERREIRA-SILVA, A.; PACHECO, V. Relação entre duração segmental e percepção de fricativas surdas e sonoras. In: CONGRESSO INTERNACIONAL DA ABRALIN, 6., 2009. João Pessoa. **Anais do VI CONGRESSO INTERNACIONAL DA ABRALIN**. João Pessoa, 2009. v. 2. Disponível em: <http://www.abralin.org>. Acesso em: 27 mar. 2010.

FERREIRA-SILVA, A.; PACHECO, V. Evidências da relação entre duração segmental e percepção de fricativas surdas e sonoras em ataque silábico. **Confluência**: **Revista do Instituto de Língua Portuguesa**. v. 39-40, n. 39/40, p. 180-200, 2012.

FORREST, K.; WEISMER, G.; MILENKOVIC, P.; DOUGALL, R. N. Statistical analysis of word-initial voiceless obstruents: preliminary data. **Journal of the Acoustical Society of America**, v. 84, n. 1, p. 115-123, 1988.

FREITAS, M. C. **Aquisição das obstruintes por crianças de 5-7 anos com queixa Fonoaudiológica**. 2007. 161f. Dissertação (Mestrado em Linguística)-Universidade Estadual de Campinas, Campinas. 2007.

HAUPT, C. As fricativas [s], [z], [ʃ] e [ʒ] do Português Brasileiro. In: **Gel**: **Estudos linguísticos XXXVI** (1). Araraquara: Unesp, 2007.

JESUS, L. M. T. **Acoustic phonetics of european portuguese fricative consonants**. 2001. 249f. Tese (Doutorado em Filosofia)-University of Southampton, Southampton, 2001.

JESUS, L. M. T.; SHADLE, C. A parametric study of the spectral characteristics of European Portuguese fricatives. **Journal of Phonetics**, v. 30, n. 3, p. 437-464, 2002.

JONGMAN, A.; WAYLAND, R.; WONG, S. Acoustic characteristics of English fricatives. **Journal of the Acoustical Society of America**, v. 108, n. 3, p. 1252-1263, 2000.

KENT, R. D.; READ, C. **Acoustic analysis of speech**. Albany: Thomson Learning, 1992.

MALMBERG, B. **A fonética**: no mundo dos sons da linguagem. Lisboa: Livros do Brasil, 1954.

MANRIQUE, A. M. B.; MASSONE, M. I. Acoustic analysis and perception of Spanish fricative consonants. **Journal of the Acoustical Society of America**, v. 69, n. 4, p. 1145-1153, 1981.

RINALDI, L. M. **Procedimentos para a análise das vogais e obstruintes na fala infantil do português brasileiro**. 2010. 175f. Dissertação (Mestrado em Linguística)-Universidade Estadual de Campinas, Campinas, 2010.

SAMCZUK, I. B.; GAMA-ROSSI, A. **Descrição fonético-acústica das fricativas do português brasileiro**. São Paulo: PUC, 2004.

SHADLE, C. **The acoustics of fricative consonants**. 1985. 200f. Tese (Doutorado em Filosofia)-Massachusetts Institute of Technology Research Laboratory of Electronics, Massachusetts, 1985.

SHADLE, C. **Phonetic acoustic**. New Haven: Haskins Laboratories, 2006.

SOLI, S. D. Second formants in fricatives: Acoustic consequences of fricative– vowel coarticulation. **Journal of Acoustical Society of America**, v. 70, n. 4, p. 976-984, 1981.

STEVENS, K. N. Airflow and turbulence noise for fricative and stop consonants: static considerations. **Journal of the Acoustical Society of America**, v. 50, n. 4, p. 1.180-1.192, 1971.

STREVENS, P. Spectra of fricative noise in human speech. **Language and Speech**, v. 3, n. 1, p. 32-49, 1960.

YENI-KOMSHIAN, B.; SOLI, S. Recognition of vowels from information in fricatives: perceptual evidence of fricative–vowel coarticulation. **Journal of the Acoustical Society of America**, v. 70, n. 4, p. 966-975, 1981.

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