Acoustic Phonetics of European Portuguese Fricative Consonants

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Technical Report

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July 2000

Abstract

The study of Portuguese fricatives is a complex problem, which has not been explored fully. As part of a larger study of the acoustic properties of Portuguese fricatives, a corpus based on 154 Portuguese words containing the fricatives /f, v, s, z, ʃ, ʒ/ in combination with the non-nasal vowels /i, ɨ, e, ɛ, ɐ, a, ɔ, o, u/ has been recorded. A nonsense word corpus was also devised consisting of /pVCV/ sequences. Sustained Portuguese fricative consonants were also recorded. Both the acoustic speech signal and the laryngograph signal were recorded in a sound treated booth. Observation of laryngograph and acoustic signals of Portuguese words has revealed that there is a large number of devoiced examples. Averaged power spectra were computed for all fricatives. For the nonsense word corpus, ensemble averaging based on one DFT computed at the same event in each of nine tokens was used. For all other corpora, time averaging of DFTs computed from nine 10 ms windows was used. Substantial differences are found between spectra of voiced and unvoiced, same-place fricatives. Other comparisons of effort level in sustained fricatives to position in the word add to a knowledge of the interaction of voice and frication source in Portuguese.

The multiple comparisons possible in such a study, across speakers, corpora, place, vowel context, syllable stress, location within fricative, etc., demanded a systematic approach, since our interest is primarily in the production mechanisms of the fricatives and the language-specific variation of these mechanisms. We sought a way of parameterizing the fricatives that makes use of our knowledge of the underlying aeroacoustics. The parameters spectral slope, frequency of maximum amplitude, and dynamic amplitude, were developed to characterize fricative spectra, and applied to corpora. The parameters behaved as predicted for changes in effort level, voicing, and location within the fricative. Some combinations were also useful for separating the fricatives by place or by sibilance.

The work presented in this Thesis, is a systematic study of European Portuguese fricatives in a range of contexts, with temporal and spectral analysis. Our long-range goal is synthesis of Portuguese fricatives.

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Chapter 1

Research Overview

1.1 Introduction

The research presented in this thesis aims to investigate the acoustic features and articulatory configurations which characterize the production of fricative consonants. Fricatives are a particularly complex class of speech sounds because their production mechanisms are not yet fully understood. This work will be combining different data into sequences of acoustic, aerodynamic and articulatory events. We will be focusing on the analysis of frication in the Portuguese language, and plan to use the accumulated knowledge to design a new production model that will accommodate particular characteristics of Portuguese fricatives. Portuguese is an important European language, spoken by over 180 million people worldwide. Because Portuguese fricatives have not been fully explored, we have devised a large study of their acoustic properties.

When a vowel is being uttered, the vocal tract is relatively unconstricted ($\sim$1 cm^2 at most constricted region) and the vocal folds vibrate periodically, causing the volume of air flowing through the glottis to fluctuate periodically as well. Fricative consonants are produced when the vocal tract is constricted ($\sim$0.1 cm^2 at most constricted region) somewhere along its length, enough to produce turbulence noise when air is forced through the constriction. The place of constriction affects the tract resonances (filter properties), but also affects the shape of the tract downstream of the constriction and thus the source properties: where the turbulent jet will impinge on tract walls, gen-

erating more noise, and the particular spectral characteristics of that noise.

It is known from studies of jet noise and mechanical models (Goldstein 1976) that when a particular configuration is held constant, and only the air velocity is increased, the turbulent noise increases, and increases more at higher frequencies. Though it is not easy to control nor measure parameters so precisely in the vocal tract, the same phenomenon appears to occur for fricatives.

The acoustic mechanism for production of fricatives is thus not as well understood as for vowels because:

1. turbulence noise defies an analytic formulation, requiring empirical studies;
2. turbulence noise sources are much more sensitive to changes in the surrounding geometry than are acoustic resonances (Shadle 1991);
3. given the small constriction dimensions and the dependence of all aeroacoustic sources on flow velocities, it is much more difficult and more important to get sufficiently accurate vocal tract *shape* and simultaneous *aerodynamic* and *acoustic* data for fricative configurations.

These difficulties have been reflected in the relatively poor quality of fricative and affricate synthesis. Nevertheless, our understanding of fricative production has been improved by the use of existing expertise in the production of speech corpora, the extraction of magnetic resonance imaging (MRI) data (Narayanan et al. 1995; Shadle et al. 1996), acoustic analysis methods (fricative aeroacoustics) (Shadle and Scully 1995), and the incorporation of three dimensional vocal tract data in speech synthesis (Davies et al. 1993).

The study of relations between articulatory, acoustic and perceptual cues (Hoole et al. 1989; Nguyen and Hoole 1993; Nguyen et al. 1994; Stevens 1997) provides crucial information for the articulatory synthesis of fricative consonants (Scully 1979; Scully and Allwood 1985; Scully et al. 1992). More specific studies of the articulation of fricatives include the palatographic experiments of Fletcher (1989) and Fletcher and Newman (1991), the extensive studies of tongue shapes by Stone et al. (1992) and Stone and Lundberg (1996), and the MRI and electropalatography experiments of Narayanan (1995) and Narayanan et al. (1995). The study of the nature of the interaction between acoustic sources and vocal tract shapes for constricted

consonantal configurations (Stevens 1987; Stevens 1991; Badin 1991; Badin et al. 1994; Shadle 1995), and the study of mechanical models by Shadle (1985, 1990, 1991), has supplied important data to drive various parametric multi-tube acoustic models (Vescovi and Castelli 1995; Narayanan and Alwan 1996; Liu and Lacroix 1997; Riegelsberger 1997).

Further research is needed to determine specific acoustic, aerodynamic and articulatory attributes of fricatives. Analysis methods such as time averaging and ensemble averaging (Shadle, Dobelke, and Scully 1992; Shadle, Moulinier, Dobelke, and Scully 1992; Shadle, Mair, and Carter 1996), and studies that establish cavity affiliation (Shadle et al. 1991) and the effect of vowel context on the acoustic characteristics of fricatives (Shadle et al. 1995), have identified some parameters that might be useful for the analysis of Portuguese fricative consonants. Researchers have used spectral moments and locus equations on fricatives (Forrest et al. 1988; Jongman and Sereno 1995; Jongman et al. 1998) without much success, although such techniques work well on stops (Forrest et al. 1988). A different parameter set, based more on our understanding of the acoustic mechanisms of fricative production, was developed and tested against our large corpus of fricatives (see Chapter 6). An initial study, based on an existing English and French fricative corpus, suggested some fruitful directions to pursue (Shadle and Mair 1996).

1.2 Analysis of Portuguese Fricatives

There have been many studies of the phonetics and phonology of Portuguese. These have shown some interesting features of Portuguese; it is unusually rich in instances of vowel reduction, consonant clusters, and fricatization of plosives (Viana 1984).

The study of Portuguese fricative consonants constitutes a challenging and complex research area, which is yet to be explored in its full depth. This is in part due to the lack of specific speech corpora that reflect the variety of phonetic contexts in which these speech sounds occur and the large number of variations in fluent Portuguese speech.

One of the first specific studies of Portuguese fricatives was that of Lacerda and Rogers (1939), which consisted of the analysis of aerodynamic and acoustic readings using very primitive methods. Johns (1972) observed, from

a study of slips of the tongue, that because of the difficulty of motor coordination during the production of unvoiced Portuguese fricatives, place of articulation was often incorrectly executed. A study by Martins (1975) produced a rank order of average duration and "intensity" of Portuguese fricatives. Unfortunately, the methodology used to measure amplitude is rather outdated and averaging of results inappropriate.

Lacerda's (1982) paper on Portuguese voiceless fricatives describes the use of perceptual experiments to identify the acoustic features of /f, s, ʃ/. /f/ has a flat spectrum and low intensity level; /s/ has a broad-band spectral peak between 4.1 kHz and 5.7 kHz, and high intensity level; the energy in the high frequency bands (around 6 kHz) is perceptually important for /s/; /ʃ/ has a high intensity level and an important broad-band spectral peak between 2.7 kHz and 3.5 kHz.

The acoustic and aerodynamic study of Portuguese consonant clusters of Andrade (1982, 1995) included an analysis of /asV/ sequences, where V was one of the vowels /i̞, e̞, u/. Results showed that the duration of the frication period is longer when the fricative is followed by /i̞/, due to the fact that this vowel is weakened (or even not produced) in final position.

Viana's (1984) study of Portuguese plosives also includes the analysis of fricative spectra. Results showed that fricative consonants have longer average duration than the neighboring vowels, and that in final position, they have lower average energy than in initial position. /f/ showed the weakest spectra.

Martins et al. (1995) observed that when the vowel /V_1/ in a /V_1ʃV_2/ sequence is weakened (or not produced), its formant structure is somewhat "transferred" to the following fricative /ʃ/, allowing the listener still to perceive the vocalic segment.

Portuguese is unusually rich in instances of vowel reduction, consonant clusters, and fricatization of plosives (Viana 1984). Further regional variations (Cunha and Cintra 1992) result in some instances of substitution of fricative /ʃ/ by affricate /ʧ/ in the north of Portugal, and various occurrences of phonemic variation, e.g. [s̪] as produced in Viseu (Mateus 1996). These all contribute to make the study of Portuguese fricatives a complex problem.

In this thesis, a corpus of Portuguese fricatives, was recorded in controlled and more natural speech contexts, and was analysed. The results of this analysis were first compared between four Portuguese speakers, and in the

future will be compared with other languages (English, French, German, ...). Results of the analysis can also be used in the future to model and synthesize the fricatives, and compared to current formant (Wilde 1995) and articulatory synthesis (Narayanan and Alwan 1996; Riegelsberger 1997).

1.3 Thesis Overview

In this study we focus on the analysis of frication in Portuguese, by combining analysis of fricative-rich Portuguese words and sentences with techniques developed in previous work using more controlled nonsense utterances. The corpus is described in Chapter 2. The segmentation and annotation of the recorded material is described in Chapter 3. A detailed description of time and frequency domain analysis methods is also included in Chapter 3. The first results of this analysis are presented in Chapters 4 and 5, including an inventory of all cases of devoicing. Chapter 6 describes the parameterisation of the fricative spectra, done both to aid within- and across-speaker comparisons, and as a first step towards modelling and synthesis of the fricatives. Conclusions and a plan for future work are presented in Chapter 7.

Chapter 2

Design and Recording of a Corpus of Portuguese Fricatives

2.1 Introduction

A speech corpus has been designed for standard European Portuguese. The phonetic and phonological evidence underlying the design of the corpus are described in the sections that follow. The complete corpus is described in Appendices A and B.

2.2 Design

During the design phase of the corpus, we tried to define a large number of phonetic contexts using both real Portuguese words and nonsense words. This will allow us to study the most relevant phoneme variants, and fully describe the spectral and articulatory characteristics of Portuguese fricative consonants.

To produce examples that would be possible words in Portuguese, the nonsense words all followed these language-specific phonological rules (Mateus 1975):

1. any of the vowels /i, e, ɛ, ɐ, a, ɔ, o, u, ĩ, ẽ, ɐ̃, õ, ũ/ can occur in the tonic syllable;
2. any of the vowels /i, ɨ, e, ɛ, ɐ, a, ɔ, o, u, ĩ, ẽ, ɐ̃, õ, ũ/ can occur before the tonic syllable;
3. only vowels /i, ɨ, ɐ, u/ can occur after the tonic syllable;
4. the vowel /i/ does not appear in final position;
5. the fricatives /f, v, s, z, ʃ, ʒ/ can all occur in initial and medial positions;
6. only /ʃ/ can occur in final position (see page 16 in Mateus, 1975).

In addition to these constraints and to facilitate comparisons, the corpora were designed to be compatible where possible with the fricative corpora recorded of English, American, French and German subjects (Shadle 1992; Shadle and Carter 1993).

2.2.1 Corpus 1: Sustained Fricatives

We recorded a set of VCV sequences, where V belongs to the reduced set of Portuguese vowels /ɨ, ɐ, u/, and C is one of the Portuguese fricative consonants /f, v, s, z, ʃ, ʒ/ sustained for 5 s (see Appendix B). As shown by Shadle et al. (1996), the vowel context, even for sustained examples, influences the articulatory and spectral characteristics of fricatives. Since the vocalic contexts of Corpus 1 overlap with those of Corpus 3 (set of Portuguese words), it is possible to make a comparative study between the fricatives produced within these two experimental conditions.

A separate set of Portuguese fricative consonants, sustained for 3 s, at medium, soft and loud effort levels, was also recorded. Ideally we would like the articulation to be held constant, and only the air velocity during its production to be varied. We attempt to elicit this by asking for a variation in effort level.

2.2.2 Corpus 2: Nonsense Words

A set of nonsense words (see Appendix B) was also recorded consisting of /pVCV/ sequences, where V is one of the vowels /ɨ, ɐ, u/. The set con-

sisted of all possible vowel and fricative permutations, each repeated about 12 times in one breath. The phoneme /p/ is an easily identifiable marker for segmentation and spectral analysis, and has been used in Rothenberg mask recordings by Shadle et al. (Shadle 1992; Shadle and Carter 1993) to measure the subglottal pressure and to check where the zero is in the recorded time signal (no flow velocity).

2.2.3 Corpus 3: Real Words

To have a rich variety of phonetic contexts using a reasonably small number of examples, we have selected Portuguese words where fricatives occur in contexts which provide a broad spectrum of information. This will allow us to define future strategies to expand the corpus to include relevant new contexts.

We have selected examples where the vowels in the VCV sequences are one of the Portuguese non-nasal vowels /i, ɨ, e, ɛ, ɐ, a, ɔ, o, u/. We tried to have the same vocalic context for each different fricative and selected an appropriate alternative when there was not a suitable example.

To have the widest variety of phonetic contexts using the smallest number of examples possible, we selected words that follow the pattern /FV_1FV_2/ (nearly minimal pairs):

1. "fofa" /ˈfofɐ/;
2. "viva" /ˈvivɐ/;
3. "cessa" /ˈsɛsɐ/;
4. "Zézé" /ˈzɛzɛ/;
5. "chocha" /ˈʃoʃɐ/;
6. "Gigi" /ʒiˈʒi/.

These words, shown in Table A.1 of Appendix A, have all the fricatives in initial and medial positions, and both VCV and CVC sequences. We also used a different set of words, shown in Tables A.2 to A.13, to capture examples of VCV and CVC syllables not covered by the minimal pairs.

The vowels in words with VCV sequences have been divided into three groups: /i, ɨ, e/ – group V_1; /ɛ, ɐ, a/ – group V_2; /ɔ, o, u/ – group V_3. Tables A.8 to A.13 in Appendix A list examples with nearly all Portuguese non-nasal vowels preceding each one of the fricatives, followed by one vowel from each one of the vowel groups V_1, V_2 and V_3.

We have used words of the following type to "simulate" final position contexts:

1. "chefe" /ˈʃɛfɨ/;
2. "ave" /ˈavɨ/;
3. "asse" /ˈasɨ/;
4. "doze" /ˈdozɨ/;
5. "age" /ˈaʒɨ/.

The vowel /ɨ/ is generally reduced in final position, as shown by Andrade (1994), and so the resulting allophone is not expected to influence the preceding fricative. Tables A.14 and A.15 in Appendix A show examples of Portuguese words with fricative consonants in final position.

In sum, Corpus 3 consists of 8 nearly minimal pairs, 54 words with fricatives in initial position, 69 words with fricatives in medial position, and 23 words with fricatives in final position. The carrier sentence "Diga ..., por favor." /ˈdigɐ ... pur ˈfɐvor/ was used to record the words in the corpus in a balanced phonetic context and with a neutral prosody. The examples in Tables A.1 to A.15 in Appendix A were read, within the carrier sentence, in a randomized order.

2.2.4 Corpus 4: Real Words in Connected Speech

To study the effects of co-articulation in connected speech, we have devised a set of sentences (see Appendix A) with words selected from Corpus 3. The goal was to form a phonetically rich sequence of speech sounds and still produce a meaningful paragraph.

2.3 Recording

The subjects used in this study were two male (LMTJ and CFGA) and two female (ACC and ISSS) adult Portuguese native speakers. Recordings were made in an anechoic chamber using a Bruel & Kjaer 4165 1/2 inch microphone located 1 m in front of the subject's mouth. The signal was amplified and filtered by a Bruel & Kjaer 2636 measurement amplifier, with high-pass cut-on frequency of 22 Hz and low-pass cut-off frequency of 22 kHz. A laryngograph signal (Lx) was also collected using a laryngograph processor [1]. The acoustic speech signal and Lx were recorded with a Sony TCD-D7 DAT system at 16 bits, with a sampling frequency of 48 kHz, and digitally transfered to a computer for post-processing.

2.4 Summary

In this chapter, the design of the speech corpus and the underlying phonological rules that determined the selection of Portuguese words and nonsense words were described. Details of an additional corpus of sustained fricatives and a corpus of Portuguese sentences have also been presented. This chapter also provides a description of the recording apparatus and techniques. Chapter 3 describes the segmentation and annotation, and presents the various methods used to analyse the speech corpora.

[1] Model LxProc, type PCLX produced by Laryngograph Ltd (UK).

Chapter 3

Methods for Segmentation, Annotation, and Analysis

3.1 Introduction

This chapter describes the method used to manually segment and annotate the various corpora presented previously. This is followed by a description of the acoustic signal calibration process, and extensive definition of both a manual method and an automatic method to determine if a fricative is devoiced. Finally we describe the two techniques used to average the power spectra of the fricatives: time-averaging and ensemble-averaging.

We have used methodology of previous fricative studies, begun with the EC SCIENCE "Fricative" Project, conducted by Shadle, Scully, Guérin and others at ICP, Grenoble. That study was focussed on characterizing fricatives in general. Here, we've adapted that methodology to focus on Portuguese fricatives in particular, and thus use real words and phonology of Portuguese.

3.2 Segmentation and Annotation

The data on the DAT tape were digitally transfered to `.wav` computer files, which contain the acoustic speech signal in the right channel and the laryngo-

graph signal on the left channel, recorded at 16 bit, with a sampling frequency of 48 kHz.

The time waveforms of all the corpus words were manually analysed to detect the start of the vowel-fricative transition, the start of the fricative, the end of the fricative, and the start of the fricative-vowel transition. During the vowel-fricative transition, there is a decrease in amplitude, voicing ends (for unvoiced fricatives) and frication noise starts, as shown in Figure 3.1. During the fricative-vowel transition, there is an increase in amplitude, voicing starts (for unvoiced fricatives) and frication noise ends. These events overlap in time, making the segmentation a somewhat subjective process. However, it is important to segment consistently, since the analysis methods depend on the boundaries so identified.

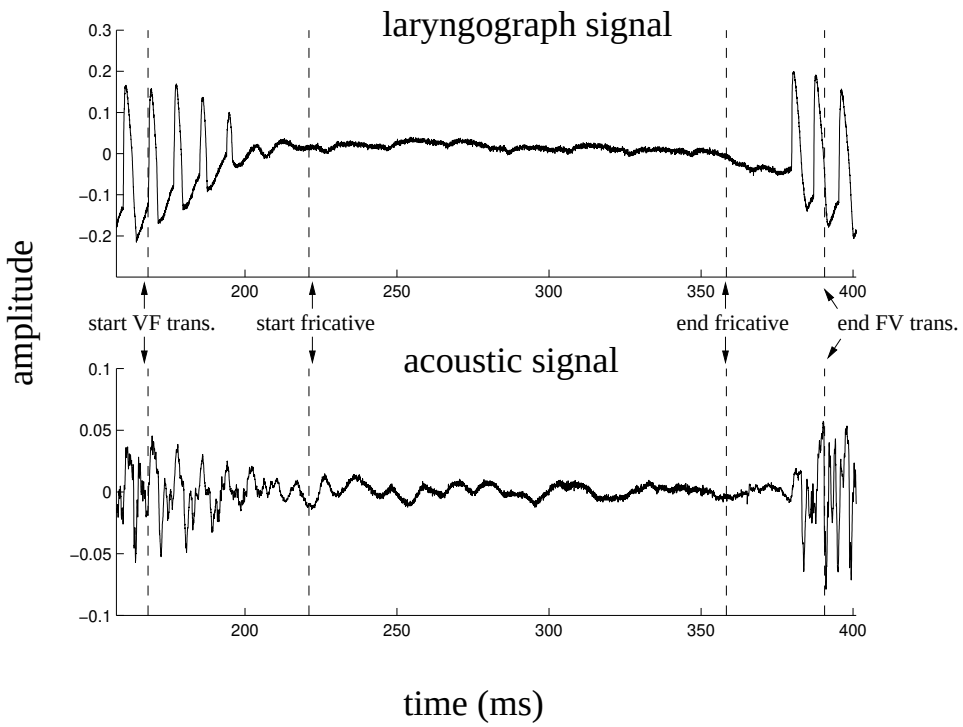


Figure 3.1: Laryngograph signal and acoustic signal of fricative /f/ in "café" /kɐˈfɛ/, showing the start of the vowel-fricative transition, the start of the fricative, the end of the fricative, and the end of the fricative-vowel transition. Corpus 3 (Speaker LMTJ).

The laryngograph signal was also used in the decision process to determine the VF and FV boundaries (see Figure 3.1). For unreduced vowels there was always significant voicing, and for the duration of most fricatives the laryn-

gograph signal changed drastically. Therefore the amplitude of the laryngograph signal is an important cue to determine the boundaries between the different phones.

The annotation files generated for Corpus 3, which have been used by various analysis programs, consist of eight sample numbers referring to the following locations within the corpus word:

1. start of first vowel-fricative transition;
2. start of first fricative;
3. end of first fricative (or start of first fricative-vowel transition);
4. end of first fricative-vowel transition;
5. start of second vowel-fricative transition;
6. start of second fricative;
7. end of second fricative (or start of second fricative-vowel transition);
8. end of second fricative-vowel transition.

For corpus words with only one fricative (e.g. "fala" /ˈfalɐ/), values 5 through 8 are set to zero.

Examples such as "este" /ˈeʃtɨ/, because we have a vowel-fricative-plosive segment, the fourth annotation value corresponds to the end of first fricative-plosive transition. When the words contain a final fricative, the fourth annotation value has the same sample value as the third, or the fourth annotation value corresponds to a marker in the "silence" that follows the fricative.

During the annotation phase of the nonsense word corpus, we have eliminated the first and the last repetitions, and a few additional repetitions (usually the last few or some "problematic" tokens), to obtain the ensemble of nine tokens (see Section 3.7.2).

We have also created a set of files containing a phonetic transcription, according to the International Phonetic Alphabet (IPA), of all the individual VCV, VCC and VCVCV transitions considered in the corpus.

3.3 Calibration

A 94 dB, 1000 Hz calibration tone produced by a Bruel & Kjaer 4620 calibrator was recorded on the same tape on which speech was recorded, with the amplification varied by a known amount, see Table 3.1.

Table 3.1: Recordings' settings.

Date	Speaker	DAT Rec. Level	Input Gain		Output Gain	
			Speech	Tone	Speech	Tone
6/11/1998	LMTJ	6	20	10	20	10
25/1/1999	LMTJ	Not registered	20	10	20	20
22/6/1999	ACC	6	20	10	20	10
19/11/1999	CFGA	3.5	20	10	30	10
19/11/1999	ISSS	5	20	10	20	10

In order to obtain an absolute spectral amplitude we will start by calculating a factor A_1 which, when added to the internal arbitrary amplitude of the recorded calibration tone, makes the sum equal to the known amplitude of the calibration tone:

$$A_1 = 94.1 - 20log(Y_{arb}(f))(dB) \tag{3.1}$$

where $Y_{arb}(f)$ is the arbitrary internal amplitude of the Fourier transform at 1 kHz of the calibration tone. We will also have to calculate a second A_2 that will be equal to the difference in amplification for the tone and speech:

$$A_2 = G_{cal} - G_{sp}(dB) \tag{3.2}$$

where G_{cal} is the gain applied when the calibration signal was recorded, and G_{sp} is the gain applied when the speech signal was recorded. Therefore the absolute spectral amplitude of the speech signal $X_{arb}(f)$ is given by

$$X_{abs} = 20log(X_{arb}(f)) + A_1 + A_2(dB) \tag{3.3}$$

The spectra shown in the sections that follow do not present an absolute amplitude. We are currently working on a method that uses the calibration signal to calculate an absolute spectral amplitude that will be referred to a 1 Hz interval and will thus allow comparison regardless of window lengths and averaging techniques.

The power spectrum (energy) of the speech signal is defined as:

$$E = \int_{-\infty}^{\infty} |x(t)|^2 dt = \int_{-\infty}^{\infty} |X(f)|^2 df \tag{3.4}$$

If we increase the number of points in $x(t)$ (i.e. the size of the window) the value of the integral (area delimited by the function) also increases. Therefore, the window length used to calculate the power spectra affects the overall amplitude. The larger the size of the window the higher is the overall amplitude.

We will be using the same window size to calculate the power spectra of ambient noise, sustained fricatives, fricatives in nonsense words and real words. We will use a larger number of windows to calculate the spectrum of a longer segment of signal (ambient noise and sustained fricatives). This allows us to compare spectral amplitudes of Corpus 1a, 1b, 2, 3 and 4, for a given recording session.

3.4 Devoicing

While segmenting, we noticed a large number of devoiced examples. To study this phenomenon further we devised a new criterion for devoicing based on both the acoustic and laryngograph signals. The signal shown in Figure 3.2 is one such case. It corresponds to a segment that starts at the onset of the VF transition, and ends at offset of the FV transition.

Smith (1997) used a criterion for devoicing in American English based on the amplitude of the electroglottograph (EGG) cycles:

> "The fricative was considered to be voiced during the portion of its duration that the amplitude of the EGG cycles exceeded one-tenth of the EGG cycle amplitude at the time of maximum energy in the preceding vowel." (page 478)

A study by Pirello et al. (1997) presents an alternative measure of voicing based on the acoustic signal:

> "An amplitude difference greater than 10 dB between the amplitude of the vowel and frication noise was classified as voiceless.

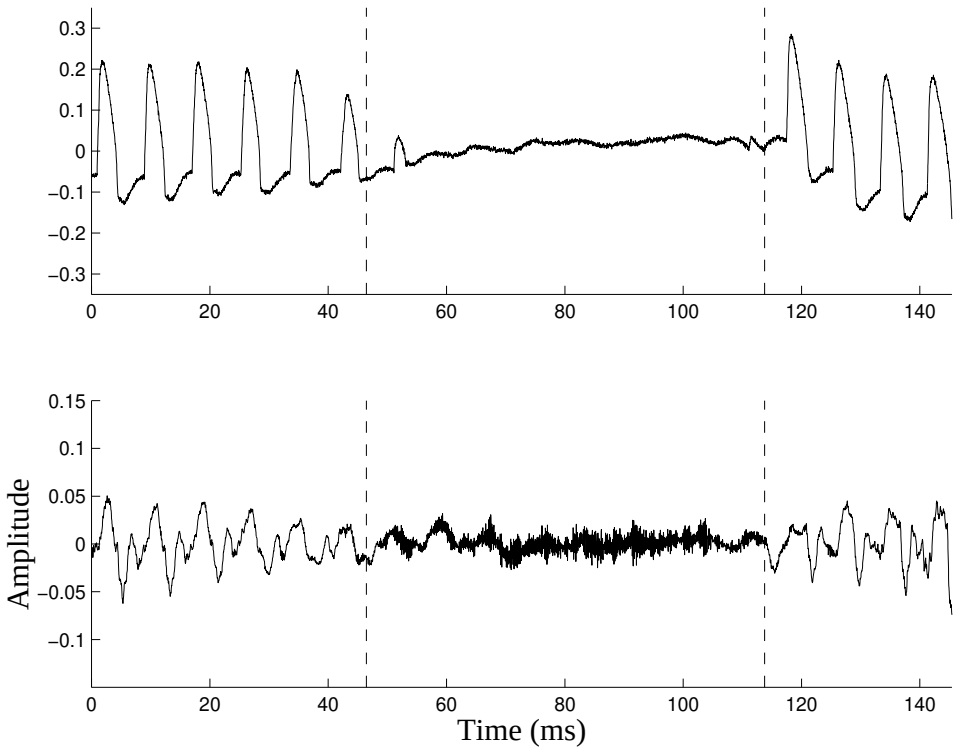


Figure 3.2: Laryngograph signal and acoustic signal of fricative /z/ in "diga zarpar" /ˈdigɐ zɐrˈpar/. The dashed lines mark the start and end of the fricative. Corpus 3 (Speaker LMTJ).

> A difference of less than or equal to 10 dB sustained over 30 ms was classified as voiced." (page 3756)

We used both the relative value of the amplitude and duration of the acoustic signal, and the amplitude of the laryngograph signal to determine if a fricative is devoiced. Devoiced is defined as no periodic structure of the laryngograph signal on the frication interval. Partially devoiced is a few steady laryngograph signal cycles during frication; voiced is steady laryngograph signal cycles throughout the whole frication, even if the amplitude is much lower than in the vowel. Voiced and devoiced fricatives can also be related to differences in their spectral shape.

In Chapter 4 we present an inventory of all cases of devoicing, a detailed analysis of the devoicing patterns found, and try to identify the causes (vowel context, word position, ...) of this phenomenon.

3.5 Automatic Criterion for Devoicing

The mean

$$\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{3.5}$$

and variance

$$\sigma^2(x) = \frac{1}{N-1}\sum_{i=1}^{N} (x_i - \overline{x})^2 \tag{3.6}$$

of the laryngograph signal were calculated during the VF transition and during the fricative. The ratio of variances of the two intervals,

$$r_{\sigma^2(x)} = \frac{\sigma_t^2(x)}{\sigma_f^2(x)}, \tag{3.7}$$

where $\sigma_t^2(x)$ is the variance of the signal during the VF transition and $\sigma_f^2(x)$ is the variance of the signal during the fricative, was used as an automatic criterion for devoicing. Obviously the ratio gets bigger if the laryngograph signal during the fricative gets really small relative to the transition – a good heuristic threshold was 15. Bigger than that, the fricative is labelled *devoiced*; less than 15, *voiced*.

The laryngograph signal presents, in some voiced fricatives examples and in most unvoiced fricatives examples, a slowly increasing or decreasing amplitude over the frication interval, which results in a large variance, and therefore a misclassification as voiced. This problem has been solved using an averaged $r_{\sigma^2(x)}$. We have computed the mean $\overline{x}$ and the variance $\sigma^2(x)$ for three consecutive equal length sections of the frication interval, calculated the average frication interval variance, and used it to compute a new ratio of variances. We have tried to use a larger number of sections over which we calculate the averaged $r_{\sigma^2(x)}$ but this does not improve significantly the efficiency of this measure of devoicing.

Fricatives classified as partially devoiced, using a manual criterion, were considered to be in the devoiced category when using the $r_{\sigma^2(x)}$ metric, i.e., when $r_{\sigma^2(x)} \geq 15$, and the fricative is manually classified as partially voiced, then the example is considered to be correctly classified.

3.6 Vowel Reduction

Another striking feature of the corpus is that of highly reduced vowels, which are often also devoiced. Figure 3.3 shows an example of a reduced /u/, and Figure 3.4 shows a reduced /ɨ/. Because there are different patterns of reduction (reduced throughout, partially reduced, ...) depending on the phonetic context, it could also be useful to define a criterion, based on amplitude and duration, for deciding if a vowel is reduced.

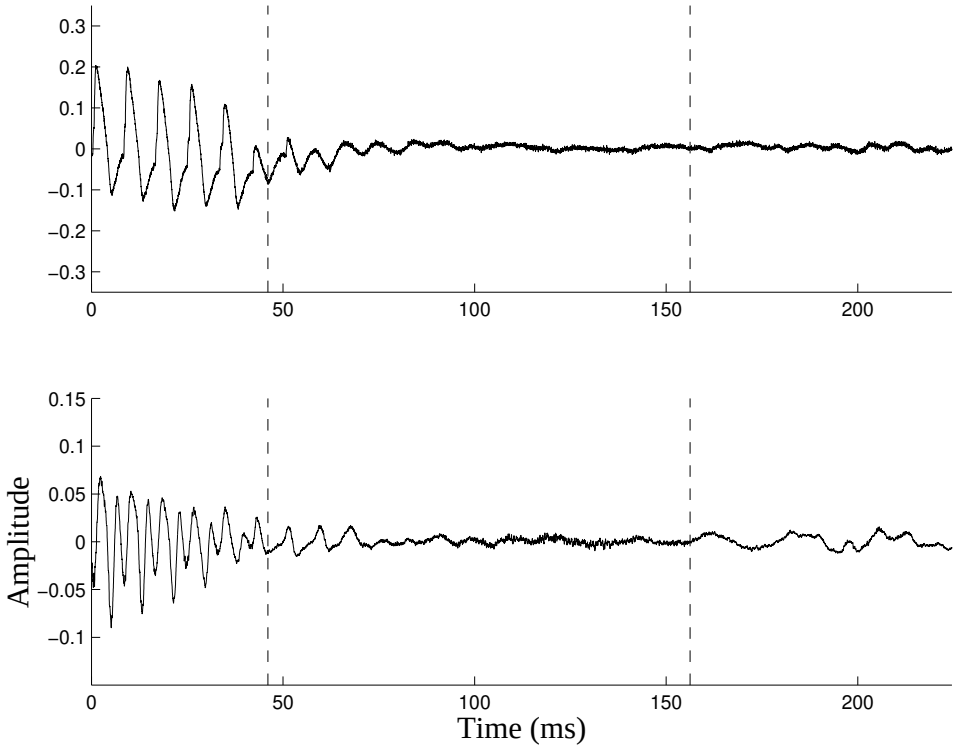


Figure 3.3: Laryngograph signal and acoustic signal of fricative /v/ and beginning of reduced /u/ in "altivo" /al'tivu/. The dashed lines mark the start and end of the fricative. Corpus 3 (Speaker LMTJ).

3.7 Spectral Analysis

This section describes the method used to compute the averaged power spectra of fricatives (see brief summary in Figure 3.5). We've used nine 10 ms

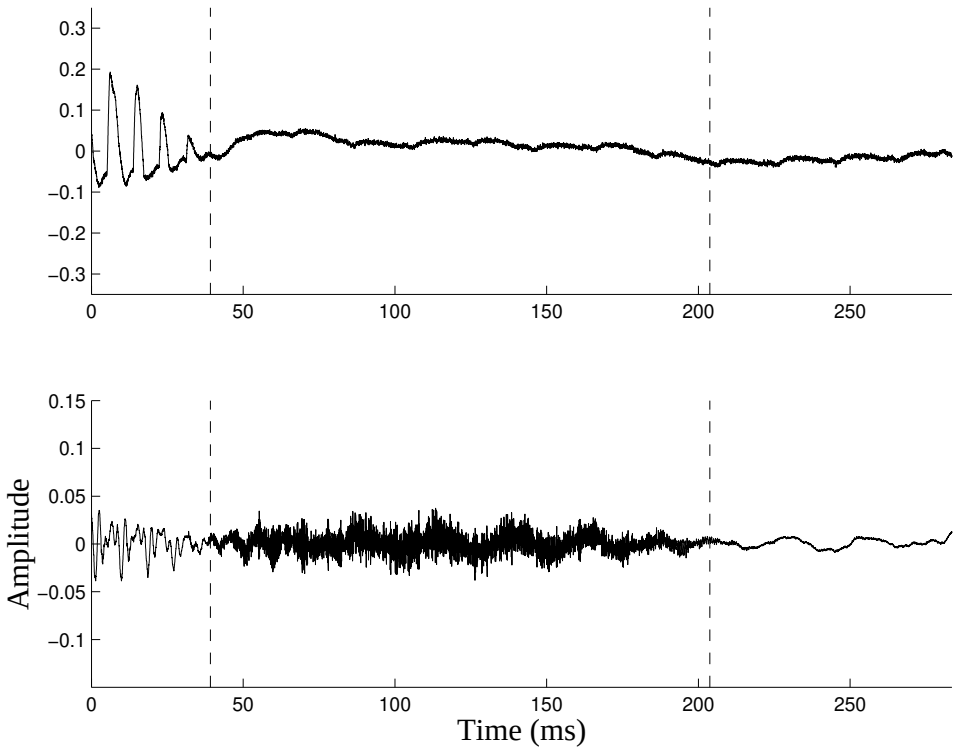


Figure 3.4: Laryngograph signal and acoustic signal of fricative /s/ and start of reduced /i̞/ in "pêssego" /ˈpesi̞gu/. The dashed lines mark the start and end of the fricative. Corpus 3 (Speaker LMTJ).

Hamming windows and time-averaging for Corpus 1a, 1b, 3 and 4. Ensemble averaging, based on one DFT computed at the same event (beginning, middle or end) in each of nine tokens of fricatives from the nonsense word corpus (Corpus 2), is also described.

3.7.1 Time-Averaged Spectra (Corpus 1a, 1b, 3 and 4)

The first phase of spectral analysis consisted of a study of the averaged DFT spectra, used to see the broad characteristics of the fricatives. The duration of the windows (10 ms) was chosen so that a reasonable number of windows could be used to cover adequately the wide range of lengths of the fricatives in the corpora (from 35 ms to 200 ms). For the shorter fricatives the windows overlap. We have used nine windows to calculate the averaged spectra, because from a careful observation of Corpus 2, we have noticed

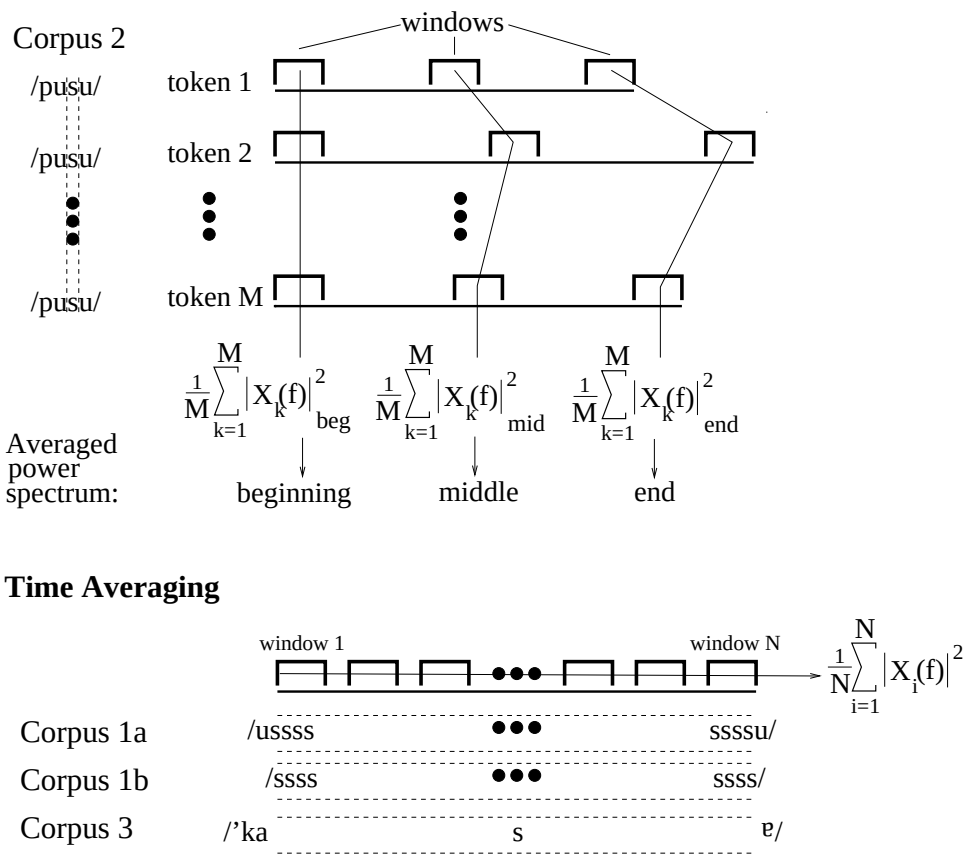


Figure 3.5: Spectral averaging.

that there are always at least nine valid repetitions of the nonsense words. This will allow us to compare the spectra of fricatives calculated from real Portuguese words (Corpus 3 and 4) with the ensemble-averaged spectra of nonsense words.

The windows' placement is related to the proportion of the distance through the fricative interval. The idea is that, regardless of the fricative length, the segments used to calculate the averaged spectra will always be placed in a time position which corresponds to the same speech event. This allows us to compare the spectra of short and long fricatives.

We have used time averaging with nine 10 ms Hamming windows, one left-aligned to the start of the fricative, one right-aligned to the end of the fricative, one centered at the middle of the fricative, and the remaining six win-

dows centered at $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{5}{8}$, $\frac{3}{4}$ and $\frac{7}{8}$ times the total length of the fricative. For the shorter fricatives, as shown in Figure 3.6, there will be considerable overlap between the windows, but for the longer fricatives, as shown in Figure 3.7, the windows are evenly spaced over the fricative.

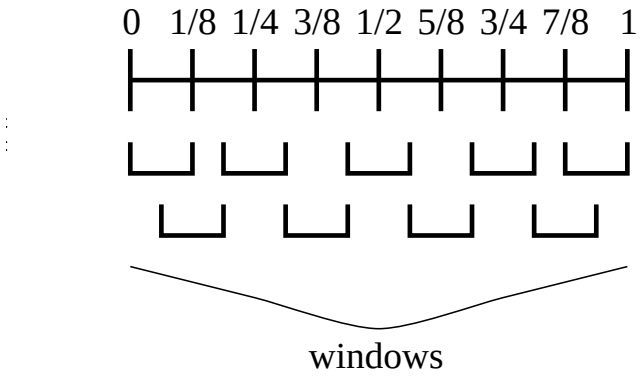


Figure 3.6: Placement of windows for the calculation of the time-averaged spectrum of a fricative (less than 81 ms).

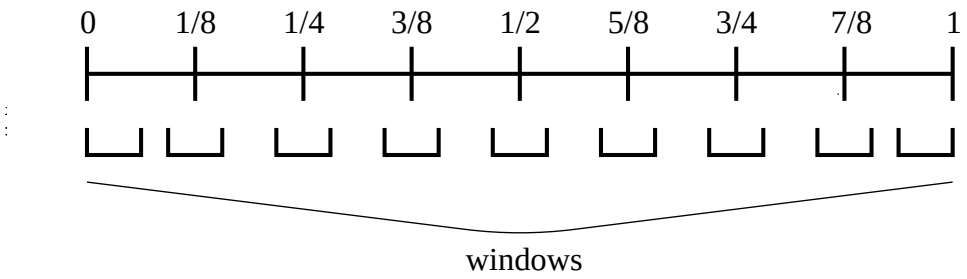


Figure 3.7: Placement of windows for the calculation of the time-averaged spectrum of a fricative (more than 81 ms).

We have also used the same time-averaging technique to calculate the spectra of sustained fricatives in Corpus 1a and Corpus 1b (one hundred, 10 ms windows); see Figures 3.8 and 3.9, respectively. This allows us to devise a comparative study of all fricatives in different phonetic contexts. For example, the spectrum of fricative /s/ in Figure 3.8 is shifted down when compared with the spectra of the same fricative shown in Figure 3.9, because of the rounded vowel /u/ context. In the future we should also consider having a neutral vowel /ə/ context for fricatives in Corpus 1b, because the speaker naturally uses some vowel before starting the production of the actual fricative.

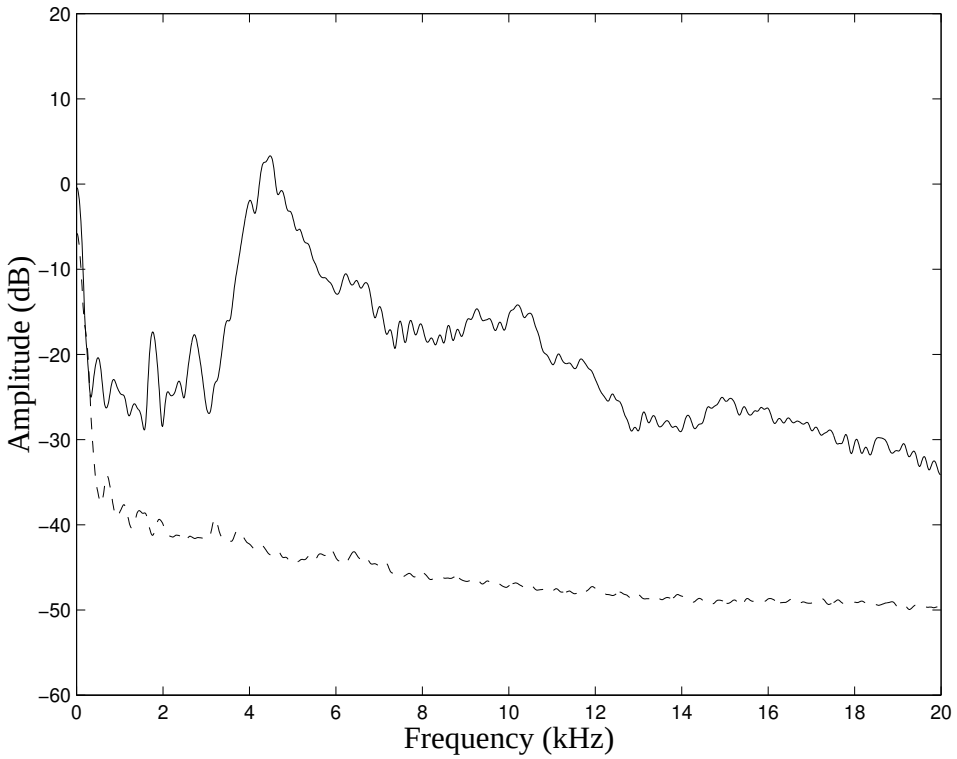


Figure 3.8: Time-averaged spectrum of sustained fricative /ussss ... u/. The dashed curve is the averaged spectrum of the room noise. Corpus 1a (Speaker LMTJ).

The time-averaged power spectrum for each fricative is given by

$$P_T(f) = \frac{1}{N} \sum_{i=1}^{N} |X_i(f)|^2 \tag{3.8}$$

where X_i is the DFT of a portion of the fricative signal, x_i, corresponding to the ith windowed segment.

An example of the time-averaged spectrum of a Portuguese fricative is presented in Figure 3.10. The spectrum is not shown above 20 kHz because human hearing does not usually go beyond that limit, and the spectrum below 20 Hz has also been filtered out, because it clearly corresponds to room noise and other external artifacts. The dashed curve in the same figure corresponds to the time average of the room noise ($N = 500$; 10 ms windows). The picture has a significant low frequency peak that corresponds to room noise. The speech signal amplitude is considerably higher than the noise

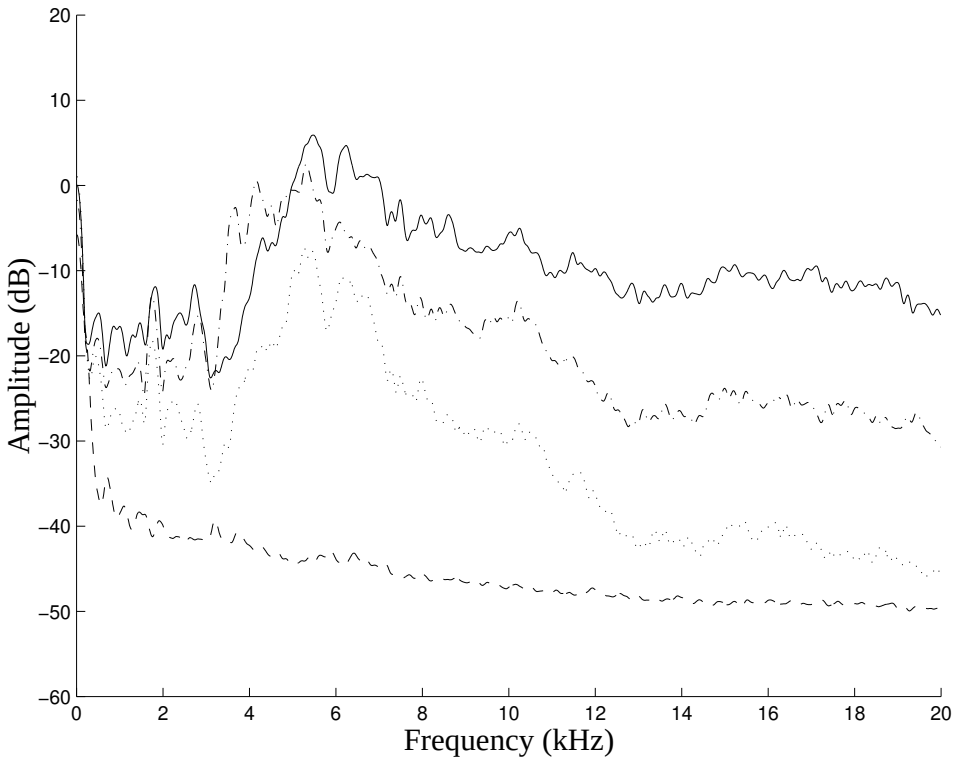


Figure 3.9: Time-averaged spectra of fricative /s/ sustained at three different effort levels: soft (dotted line), medium (dash-dotted line) and loud (solid line). The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

amplitude for most of the examples.

3.7.2 Ensemble-Averaged Spectra (Corpus 2)

Ensemble averaging, based on one DFT computed at the same event in each of nine tokens, was used. We have used 10 ms windows located relative to events within one fricative: one left-aligned to the start of the fricative, one centred at the centre of the fricative, and one right-aligned to the end of the fricative (see Figure 3.11). The ensemble-averaged power spectrum of each fricative is given by

$$P_E(f) = \frac{1}{9} \sum_{k=1}^{9} |X_k(f)|^2 \tag{3.9}$$

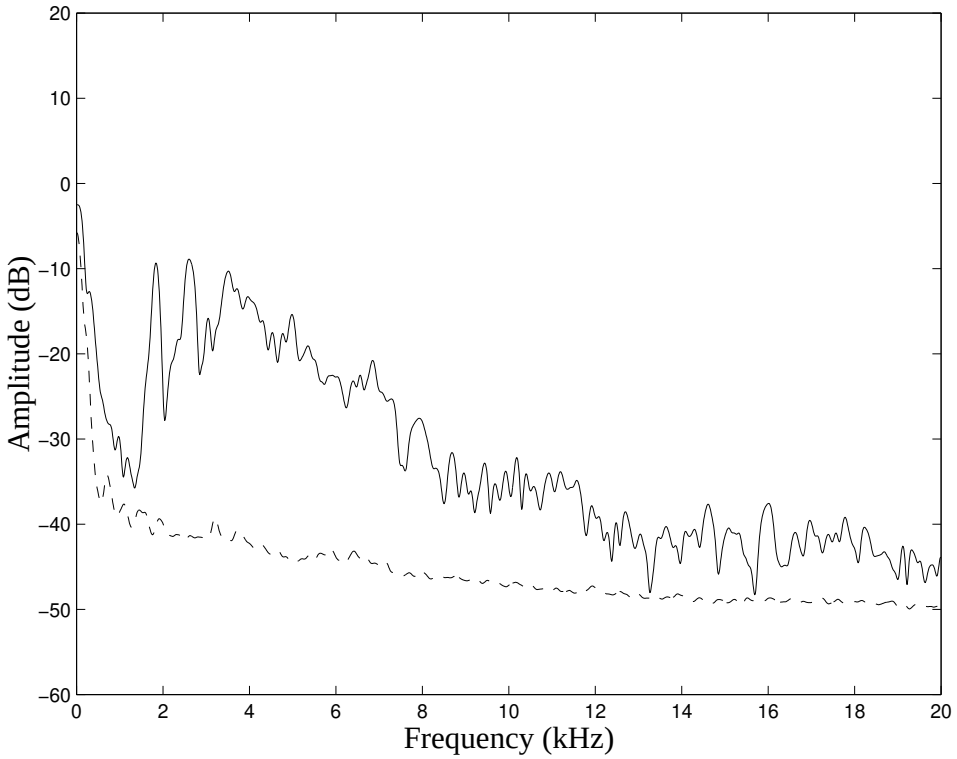


Figure 3.10: Time-averaged spectrum of fricative /ʒ/ in "jaqueta" /ʒəˈketɐ/. The dashed curve is the averaged spectrum of the room noise. Corpus 3 (Speaker LMTJ).

where X_k is the DFT of a portion of the fricative signal, x_k, corresponding to the windowed segment (at the beginning, middle or end of the fricative) of the kth token. The first and last, and any atypical tokens were eliminated to obtain the ensemble of nine tokens. Figure 3.12 shows an example of the ensemble-averaged spectra of fricative /ʒ/ in Corpus 2.

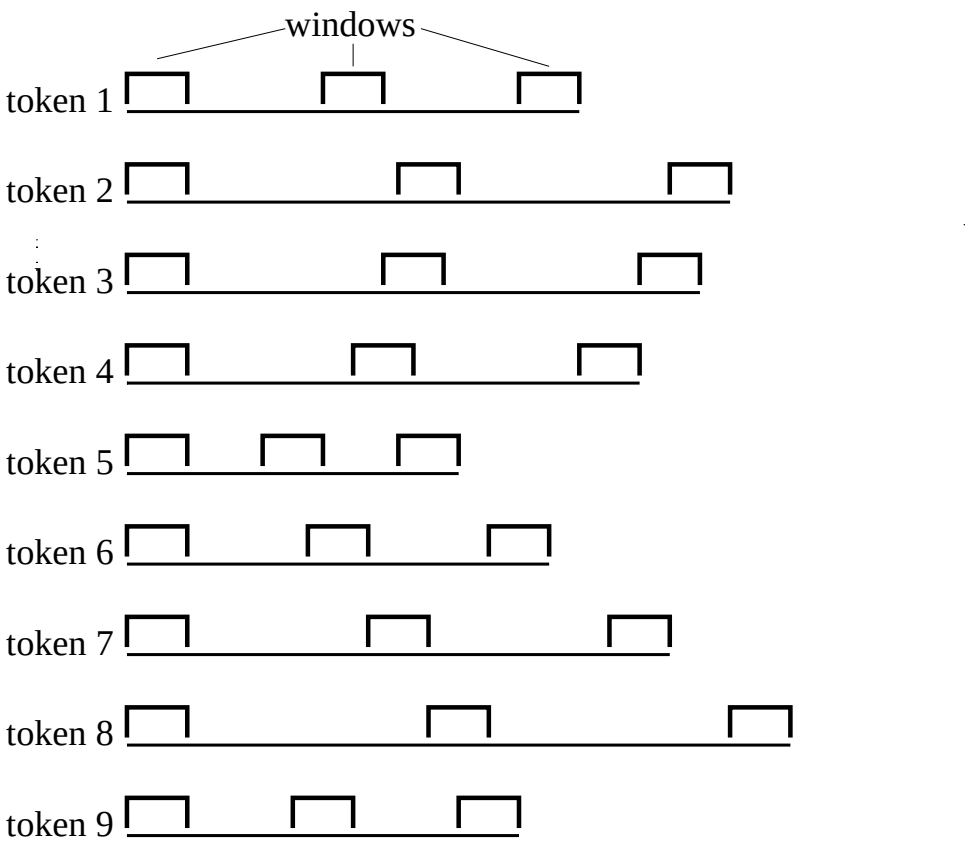


Figure 3.11: Schematic drawing of the placement of windows for the calculation of the ensemble-averaged spectra of fricative consonants, allowing for differing lengths of tokens.

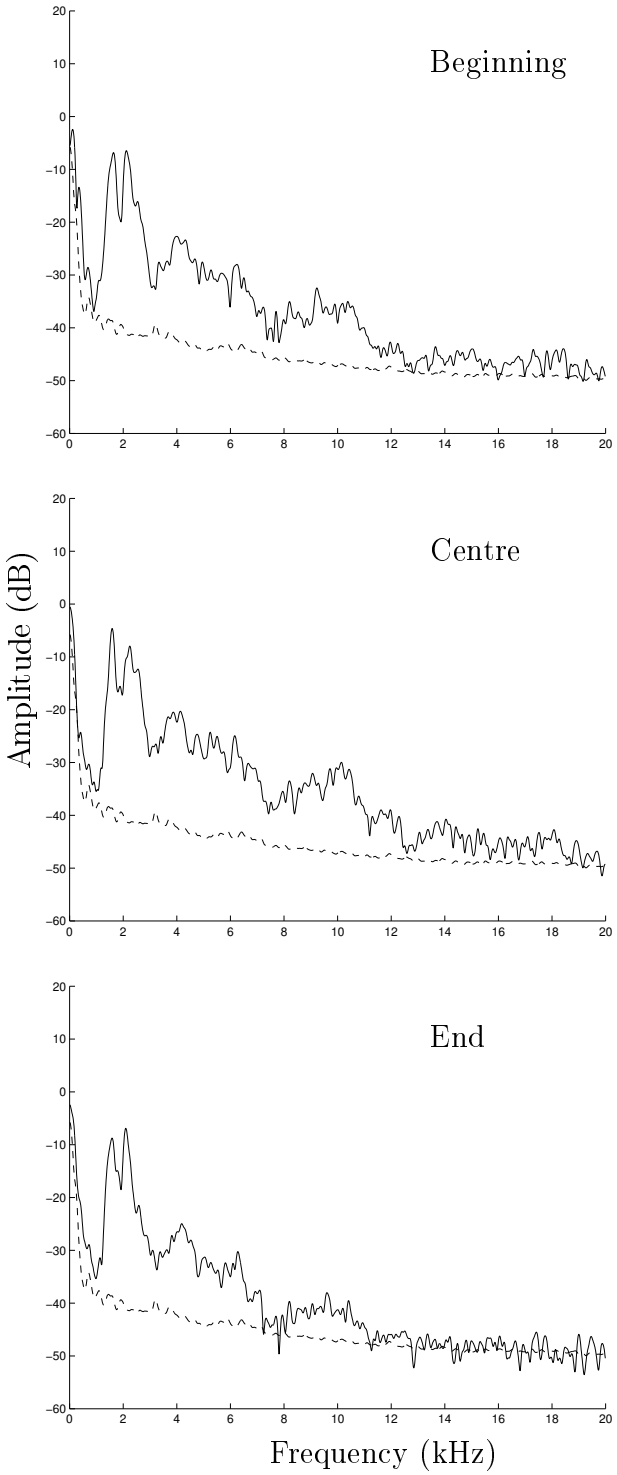


Figure 3.12: Ensemble-averaged spectra of fricative in /puˈʒu/; Top: beginning of the fricative; Middle: centre of the fricative; Bottom: end of the fricative. The dashed curve is the time-averaged spectrum of the room noise. Corpus 2 (Speaker LMTJ).

Chapter 4

Temporal Analysis

4.1 Introduction

This chapter presents a detailed discussion of the results from the temporal analysis of both the acoustic and laryngograph signals. This includes a study of devoicing in Corpus 2, 3 and 4, and a complete inventory of possible causes of this phenomenon. Two devoicing criteria (a manual criteria and a criteria based on the ratio of variances of the laryngograph signal during the VF transition and during the fricative) are used to classify the examples into two/three categories. The results of the automatic measure of devoicing are compared with the manual ones, and a consistent justification for misclassification is presented.

A duration analysis of words from Corpus 2, 3 and 4 is also presented. This consists of a study of the influence of word and sentence position, and place of articulation on the duration of the fricatives, and of the VF and FV transitions.

4.2 Devoicing

The fricatives in nonsense words from Corpus 2 were analysed with the manual criteria for devoicing. Results show a very high percentage of devoiced

examples, as can be seen in the inventory presented in Table 4.1. The partially devoiced cases of Speaker LMTJ have not been accounted for.

Table 4.1: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced, partially devoiced or voiced examples divided by the total number of examples. Corpus 2.

Speaker LMTJ			
	Devoiced	Partially Devoiced	Voiced
/v/	64/101 (63.4%)		37/101 (36.6%)
/z/	63/116 (54.3%)		53/116 (45.7%)
/ʒ/	58/124 (46.8%)		66/124 (53.2%)
All Fric.	185/341 (54.3%)		156/341 (45.8%)
Speaker CFGA			
	Devoiced	Partially Devoiced	Voiced
/v/	95/145 (65.5%)	30/145 (20.7%)	20/145 (13.8%)
/z/	79/174 (45.4%)	30/174 (17.2%)	65/174 (37.4%)
/ʒ/	124/173 (71.7%)	30/173 (17.3%)	19/173 (11%)
All Fric.	298/492 (60.6%)	90/492 (18.3%)	104/492 (21.1%)
Speaker ACC			
	Devoiced	Partially Devoiced	Voiced
/v/	32/132 (24.2%)	8/132 (6.1%)	92/132 (69.7%)
/z/	50/130 (38.5%)	21/130 (16.2%)	59/130 (45.4%)
/ʒ/	16/120 (13.3%)	26/120 (21.7%)	78/120 (65%)
All Fric.	98/382 (25.7%)	55/382 (14.4%)	229/382 (60%)
Speaker ISSS			
	Devoiced	Partially Devoiced	Voiced
/v/	60/108 (55.6%)	7/108 (6.5%)	41/108 (38%)
/z/	64/118 (54.2%)	22/118 (18.6%)	32/118 (27.1%)
/ʒ/	75/108 (69.4%)	11/108 (10.2%)	22/108 (20.4%)
All Fric.	199/334 (59.6%)	40/334 (12%)	95/334 (28.4%)

The influence of vowel context in the devoicing of Corpus 2 (Speakers LMTJ and ACC) fricatives has been analysed and the results are presented in Figures 4.1 and 4.2. The combinations of numbers on the x-axis (1-1, 1-2, ...) represent different nonsense words such as /pɨvɨ/ and /pɨvɐ/.

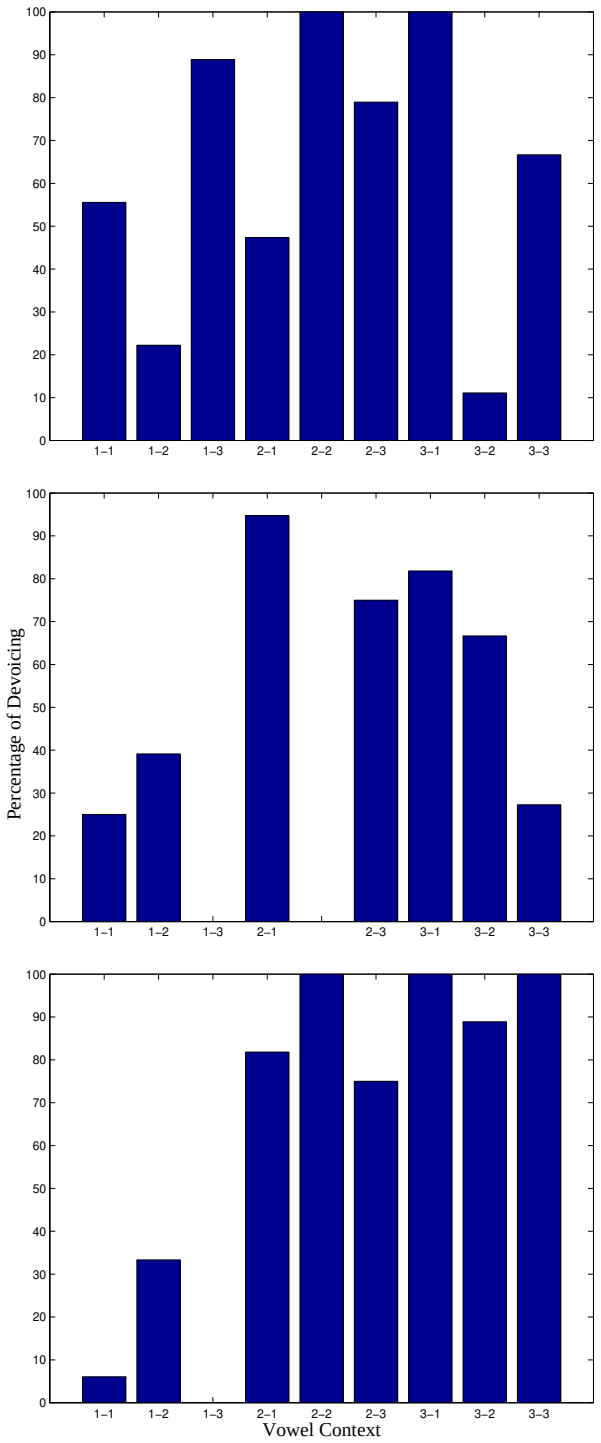


Figure 4.1: Percentage of devoiced examples of fricatives in different /pV$_1$FV$_2$/ vowel contexts: 1 – /i̞/; 2 – /e̞/; 3 – /u/. Top: fricative /v/; Midle: fricative /z/; Bottom: fricative /ʒ/. Corpus 2 (Speaker LMTJ).

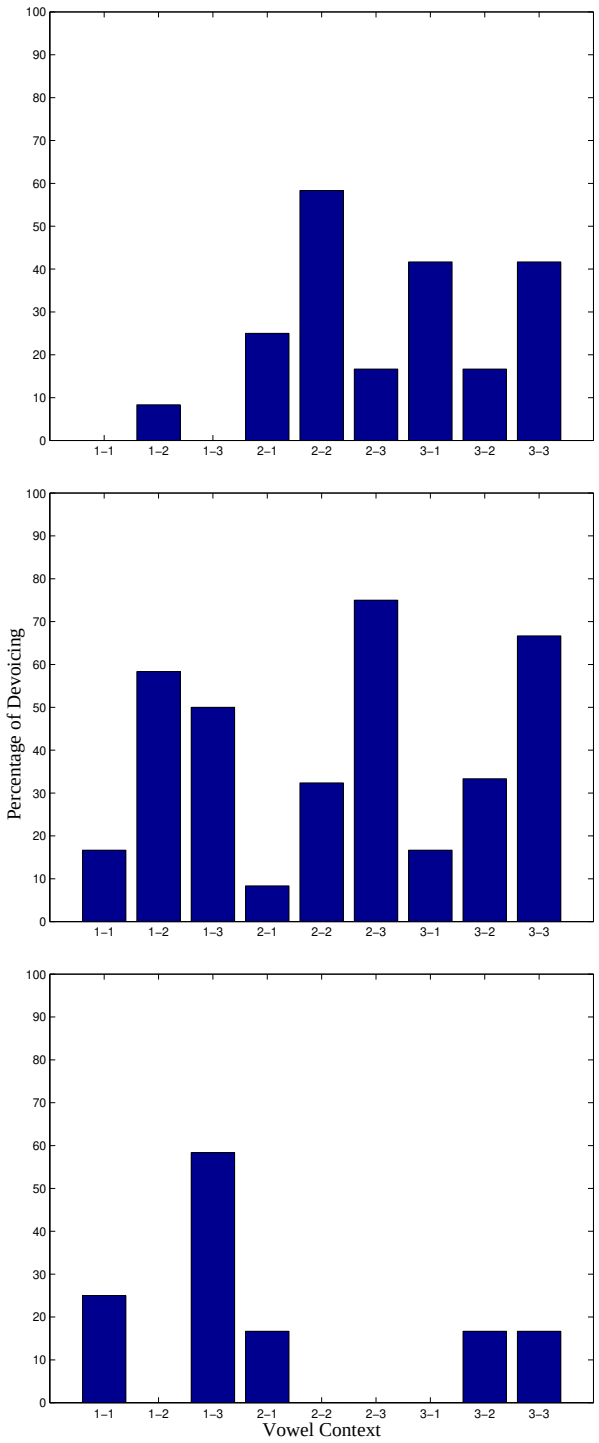


Figure 4.2: Percentage of devoiced examples of fricatives from in different /pV$_1$FV$_2$/ vowel contexts: 1 – /i̞/; 2 – /e̞/; 3 – /u/. Top: fricative /v/; Midle: fricative /z/; Bottom: fricative /ʒ/. Corpus 2 (Speaker ACC).

A detailed observation of the acoustic and laryngograph signals during the production of nonsense words by Speaker ACC has revealed that:

- Most examples of voiced fricatives present a very low laryngograph signal amplitude during the frication interval.
- For some of the nonsense words with voiceless fricatives /f,s,ʃ/, the laryngograph signal amplitude is zero during the VF transition, but the vowel is still voiced, as can be seen from the acoustic signal.
- Some vowels devoice before the start of the vowel to unvoiced fricative transition.
- The amplitude of the laryngograph signal for voiced fricatives, increases to "vowel values", before the fricative ends.

Observation of laryngograph and acoustic signals of Portuguese words in Corpus 3 (Speaker LMTJ) has revealed that: 50% (18 out of 36) of the examples of fricative /v/ were totally devoiced (see Section 3.4 for devoicing criteria); 66.7% (20 out of 30) of the examples of fricative /z/ were totally devoiced; 80% (24 out of 30) of the examples of fricative /ʒ/ were totally devoiced. Most word-final fricative examples (15 out of 17) were totally devoiced. A complete inventory of devoiced, partially devoiced and voiced examples in Corpus 3 is presented for all four speakers in Tables 4.2 to 4.5.

Table 4.2: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 3 (Speaker LMTJ).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	6/14 (42.9%)	4/14 (28.6%)	8/9 (88.9%)	18/37 (48.7%)	Devoiced
	2/14 (14.3%)	2/14 (14.3%)	0	4/37 (10.8%)	Partially Devoiced
	6/14 (42.9%)	8/14 (57.1%)	1/9 (11.1%)	15/37 (40.5%)	Voiced
/z/	5/10 (50%)	12/17 (70.6%)	3/3 (100%)	20/30 (66.7%)	Devoiced
	2/10 (20%)	2/17 (11.8%)	0	4/30 (13.3%)	Partially Devoiced
	3/10 (30%)	3/17 (17.7%)	0	6/30 (20%)	Voiced
/ʒ/	7/10 (70%)	13/15 (86.7%)	4/5 (80%)	24/30 (80%)	Devoiced
	1/10 (10%)	0	0	1/30 (3.3%)	Partially Devoiced
	2/10 (20%)	2/15 (13.3%)	1/5 (20%)	5/30 (16.7%)	Voiced
All Fric.	18/34 (52.9%)	29/46 (63%)	15/17 (88.2%)	62/97 (63.9%)	Devoiced
	5/34 (14.7%)	4/46 (8.7%)	0	9/97 (9.3%)	Partially Devoiced
	11/34 (32.4%)	13/46 (28.3%)	2/17 (11.8%)	26/97 (26.8%)	Voiced

Table 4.3: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 3 (Speaker CFGA).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	7/11 (63.6%)	8/12 (66.7%)	7/7 (100%)	22/30 (73.3%)	Devoiced
	0	2/12 (16.7%)	0	2/30 (6.7%)	Partially Devoiced
	4/11 (36.4%)	2/12 (16.7%)	0	6/30 (20%)	Voiced
/z/	8/10 (80%)	12/14 (85.7%)	2/3 (66.7%)	22/27 (81.5%)	Devoiced
	1/10 (10%)	2/14 (14.3%)	0	3/27 (11.1%)	Partially Devoiced
	1/10 (10%)	0	1/3 (33.3%)	2/27 (7.4%)	Voiced
/ʒ/	8/10 (80%)	12/13 (92.3%)	4/4 (100%)	24/27 (88.9%)	Devoiced
	1/10 (10%)	0	0	1/27 (3.7%)	Partially Devoiced
	1/10 (10%)	1/13 (7.7%)	0	2/27 (7.4%)	Voiced
All Fric.	23/31 (74.2%)	32/39 (82.1%)	13/14 (92.9%)	68/84 (81%)	Devoiced
	2/31 (6.5%)	4/39 (10.3%)	0	6/84 (7.1%)	Partially Devoiced
	6/31 (19.4%)	3/39 (7.7%)	1/14 (7.1%)	10/84 (11.9%)	Voiced

Table 4.4: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 3 (Speaker ACC).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	4/11 (36.4%)	6/12 (50%)	7/7 (100%)	17/30 (56.7%)	Devoiced
	2/11 (18.2%)	2/12 (16.7%)	0	4/30 (13.3%)	Partially Devoiced
	5/11 (45.5%)	4/12 (33.3%)	0	9/30 (30%)	Voiced
/z/	4/10 (40%)	8/12 (66.7%)	3/3 (100%)	15/25 (60%)	Devoiced
	4/10 (40%)	3/12 (25%)	0	7/25 (28%)	Partially Devoiced
	2/10 (20%)	1/12 (8.3%)	0	3/25 (12%)	Voiced
/ʒ/	9/10 (90%)	11/11 (100%)	3/4 (75%)	23/25 (92%)	Devoiced
	1/10 (10%)	0	1/4 (25%)	2/25 (8%)	Partially Devoiced
	0	0	0	0	Voiced
All Fric.	17/31 (54.8%)	25/35 (71.4%)	13/14 (92.9%)	55/80 (68.8%)	Devoiced
	7/31 (22.6%)	5/35 (14.3%)	1/14 (7.1%)	13/80 (16.3%)	Partially Devoiced
	7/31 (22.6%)	5/35 (14.3%)	0	12/80 (15%)	Voiced

Table 4.5: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 3 (Speaker ISSS).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	1/11 (9.1%)	5/12 (41.7%)	7/7 (100%)	13/30 (43.3%)	Devoiced
	4/11 (36.4%)	0	0	4/30 (13.3%)	Partially Devoiced
	6/11 (54.6%)	7/12 (58.3%)	0	13/30 (43.3%)	Voiced
/z/	8/10 (80%)	11/12 (91.7%)	3/3 (100%)	22/25 (88%)	Devoiced
	0	0	0	0	Partially Devoiced
	2/10 (20%)	1/12 (8.3%)	0	3/25 (12%)	Voiced
/ʒ/	8/10 (80%)	9/11 (81.8%)	4/4 (100%)	21/25 (84%)	Devoiced
	2/10 (20%)	1/11 (9.1%)	0	3/25 (12%)	Partially Devoiced
	0	1/11 (9.1%)	0	1/25 (4%)	Voiced
All Fric.	17/31 (54.8%)	25/35 (71.4%)	14/14 (100%)	56/80 (70%)	Devoiced
	6/31 (19.4%)	1/35 (2.9%)	0	7/80 (8.8%)	Partially Devoiced
	8/31 (25.8%)	9/35 (25.7%)	0	17/80 (21.3%)	Voiced

We have used a different carrier sentence ("Diga ..., bem dito." /ˈdigɐ ... bẽ ˈditu/) in the re-recording session of Speaker LMTJ, to test the influence of the phoneme that follows the word where the fricative is contained. Results show that the fact that we have used a voiced plosive /b/ instead of an unvoiced plosive /p/ does not necessarily imply that final /v/, /z/ and /ʒ/ are voiced.

We have also looked at a limited number of words from Corpus 3 (Speakers LMTJ and ACC) that follow the same pattern /V_1FV_2/, see Figures 4.3 and

4.4, where V_1 and V_2 are vowels which belong to one of the groups: group 1 – /i, ɨ, e/; group 2 – /ɛ, ɐ, a/; group 3 – /ɔ, o, u/.

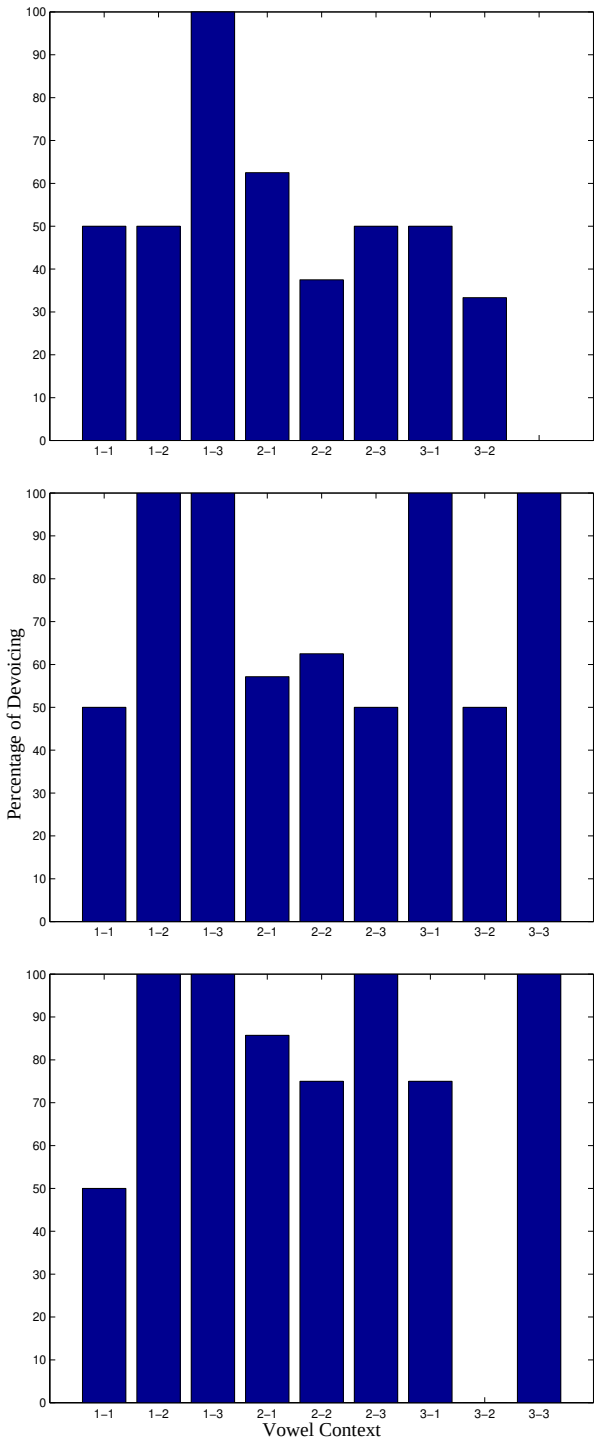


Figure 4.3: Percentage of devoiced examples of fricatives in different /V_1FV_2/ vowel contexts: 1 – /i, ɨ, e/; 2 – /ɛ, ɐ, a/; 3 – /ɔ, o, u/. Top: fricative /v/; Midle: fricative /z/; Bottom: fricative /ʒ/. Corpus 3 (Speaker LMTJ).

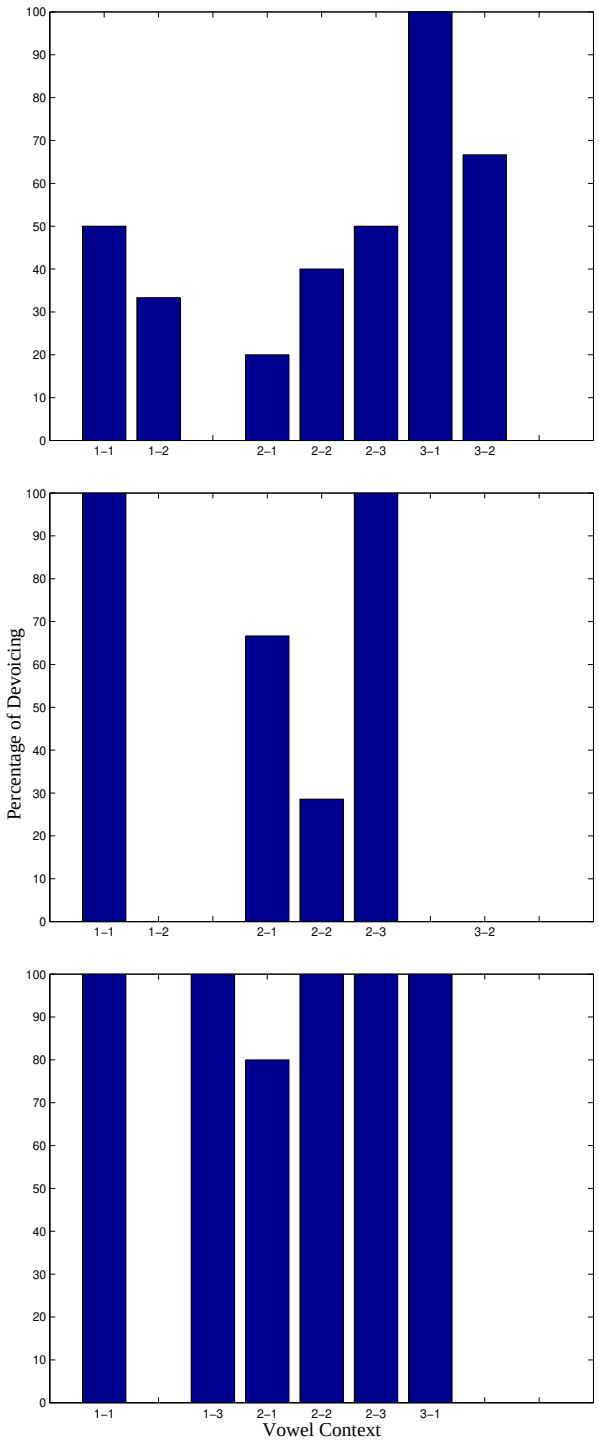


Figure 4.4: Percentage of devoiced examples of fricatives in different /V_1FV_2/ vowel contexts: 1 – /i, ɨ, e/; 2 – /ɛ, ɐ, a/; 3 – /ɔ, o, u/. Top: fricative /v/; Midle: fricative /z/; Bottom: fricative /ʒ/. Corpus 3 (Speaker ACC).

The results shown in Table 4.6 indicate that in Corpus 4 (Speaker LMTJ): 38.2% (13 out of 34) of the examples of fricative /v/ were totally devoiced; 72.7% (16 out of 22) of the examples of fricative /z/ were totally devoiced; 68.2% (15 out of 22) of the examples of fricative /ʒ/ were totally devoiced. In Tables 4.7 to 4.9 results are presented for Speakers CFGA, ACC and ISSS.

Table 4.6: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 4 (Speaker LMTJ).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	5/14 (35.7%)	7/18 (38.9%)	1/2 (50%)	13/34 (38.2%)	Devoiced
	1/14 (7.1%)	3/18 (16.7%)	0	4/34 (11.8%)	Partially Devoiced
	8/14 (57.1%)	8/18 (44.4%)	1/2 (50%)	17/34 (50%)	Voiced
/z/	5/8 (62.5%)	7/10 (70%)	4/4 (100%)	16/22 (72.7%)	Devoiced
	1/8 (12.5%)	2/10 (20%)	0	3/22 (13.6%)	Partially Devoiced
	2/8 (25%)	1/10 (10%)	0	3/22 (13.6%)	Voiced
/ʒ/	7/8 (87.5%)	5/9 (55.6%)	3/5 (60.0%)	15/22 (68.2%)	Devoiced
	1/8 (12.5%)	3/9 (33.3%)	0	4/22 (18.2%)	Partially Devoiced
	0	1/9 (11.1%)	2/5 (40%)	3/22 (13.6%)	Voiced
All Fric.	17/30 (56.7%)	19/37 (51.4%)	8/11 (72.7%)	44/78 (56.4%)	Devoiced
	3/30 (10%)	8/37 (21.6%)	0	11/78 (14.1%)	Partially Devoiced
	10/30 (33.3%)	10/37 (27%)	3/11 (27.3%)	23/78 (29.5%)	Voiced

Table 4.7: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 4 (Speaker CFGA).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	11/24 (45.8%)	9/24 (37.5%)	2/6 (33.3%)	22/54 (40.7%)	Devoiced
	4/24 (16.7%)	6/24 (25%)	3/6 (50%)	13/54 (24.1%)	Partially Devoiced
	9/24 (37.5%)	9/24 (37.5%)	1/6 (16.7%)	19/54 (35.2%)	Voiced
/z/	10/12 (83.3%)	12/16 (75%)	5/5 (100%)	27/33 (81.8%)	Devoiced
	1/12 (8.3%)	2/16 (12.5%)	0	3/33 (9.1%)	Partially Devoiced
	1/12 (8.3%)	2/16 (12.5%)	0	3/33 (9.1%)	Voiced
/ʒ/	9/12 (75%)	10/15 (66.7%)	11/12 (91.7%)	30/39 (76.9%)	Devoiced
	1/12 (8.3%)	2/15 (13.3%)	1/12 (8.3%)	4/39 (10.3%)	Partially Devoiced
	2/12 (16.7%)	3/15 (20%)	0	5/39 (12.8%)	Voiced
All Fric.	30/48 (62.5%)	31/55 (56.4%)	18/23 (78.3%)	79/126 (62.7%)	Devoiced
	6/48 (12.5%)	10/55 (18.2%)	4/23 (17.4%)	20/126 (15.9%)	Partially Devoiced
	12/48 (25%)	14/55 (25.5%)	1/23 (4.4%)	27/126 (21.4%)	Voiced

Table 4.8: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 4 (Speaker ACC).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	14/23 (60.9%)	12/26 (46.2%)	3/4 (75%)	29/53 (54.7%)	Devoiced
	1/23 (4.4%)	2/26 (7.7%)	0	3/53 (5.7%)	Partially Devoiced
	8/23 (34.8%)	12/26 (46.2%)	1/4 (25%)	21/53 (39.6%)	Voiced
/z/	10/12 (83.3%)	16/19 (84.2%)	2/2 (100%)	28/33 (84.9%)	Devoiced
	2/12 (16.7%)	0	0	2/33 (6.1%)	Partially Devoiced
	0	3/19 (15.8%)	0	3/33 (9.1%)	Voiced
/ʒ/	9/12 (75%)	13/18 (72.2%)	3/9 (33.3%)	25/39 (64.1%)	Devoiced
	3/12 (25%)	3/18 (16.7%)	3/9 (33.3%)	9/39 (23.1%)	Partially Devoiced
	0	2/18 (11.1%)	3/9 (33.3%)	5/39 (12.8%)	Voiced
All Fric.	33/47 (70.2%)	41/63 (65.1%)	8/15 (53.3%)	82/125 (65.6%)	Devoiced
	6/47 (12.8%)	15/63 (7.9%)	3/15 (20%)	14/125 (11.2%)	Partially Devoiced
	8/47 (17%)	17/63 (27%)	4/15 (26.7%)	29/125 (23.2%)	Voiced

Table 4.9: Inventory of all cases of devoicing (using a manual criterion). Values given are number of devoiced or partially devoiced examples divided by the total number of examples. Corpus 4 (Speaker ISSS).

	Word-Initial	Word-Medial	Word-Final	All Pos.	
/v/	6/16 (37.5%)	5/16 (31.3%)	2/4 (50%)	13/36 (36.1%)	Devoiced
	2/16 (12.5%)	1/16 (6.3%)	0	3/36 (8.3%)	Partially Devoiced
	8/16 (50%)	10/16 (62.5%)	2/4 (50%)	20/36 (55.6%)	Voiced
/z/	6/8 (75%)	7/12 (58.3%)	2/2 (100%)	15/22 (68.2%)	Devoiced
	1/8 (12.5%)	3/12 (25%)	0	4/22 (18.2%)	Partially Devoiced
	1/8 (12.5%)	2/12 (16.7%)	0	3/22 (13.6%)	Voiced
/ʒ/	5/8 (62.5%)	8/12 (66.7%)	6/6 (100%)	19/26 (73.1%)	Devoiced
	3/8 (37.5%)	3/12 (25%)	0	6/26 (23.1%)	Partially Devoiced
	0	1/12 (8.3%)	0	1/26 (3.9%)	Voiced
All Fric.	17/32 (53.1%)	20/40 (50%)	10/12 (83.3%)	47/84 (56%)	Devoiced
	6/32 (18.8%)	7/40 (17.5%)	0	13/84 (15.5%)	Partially Devoiced
	9/32 (28.1%)	13/40 (32.5%)	2/12 (16.7%)	24/84 (28.6%)	Voiced

The four examples of the word "dos" /ˈduʃ/ in Corpus 4 (Speaker LMTJ) have been produced in the following way: [ˈduʃ] – 8_138; [ˈduʒ d] – 8_138r; [ˈduʒ m] – 10_138; [ˈduʃ] – 10_138r. We have /ʒ/ instead of /ʃ/ in examples 8_138r and 10_138 because there is co-articulation with a voiced phoneme (/d/ and /m/) at the start of the following word.

A similar phenomenon has been observed for some examples of Corpus 4 fricatives produced by Speaker ACC. The fricative /ʃ/ in the words "mares" (/ˈmaɾɨʃ/) and "dos" (/duʃ/) when followed by a voiced phoneme is produced

as /ʒ/. This happens in examples 10_130, 10r1_130, 10r2_130, 8_138, 8r1_138 and 8r2_138, where the fricative is followed by /d/, and in examples 10_138, 10r1_138 and 10r2_138, where the fricative is followed by /m/.

Overall results from the analysis of devoicing in Corpus 2, 3 and 4, using the manual criteria, show that more than 50% of the fricatives devoice, see Figure 4.5, except for Speaker ACC who has a very low percentage of devoiced tokens in Corpus 2, as can be seen in Figure 4.6.

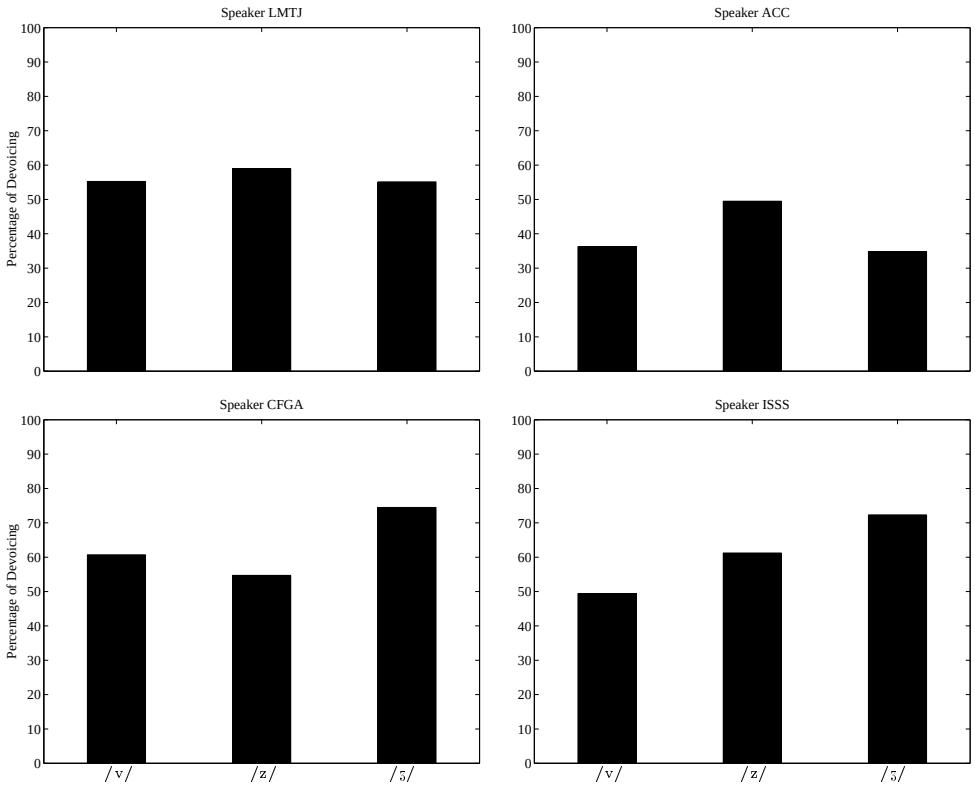


Figure 4.5: Overall devoicing. Corpus 2, 3 and 4.

Devoicing rate by Corpus, shown in Figure 4.6, differs between the three fricatives, and between Corpus 2, 3 and 4. There is no apparent pattern.

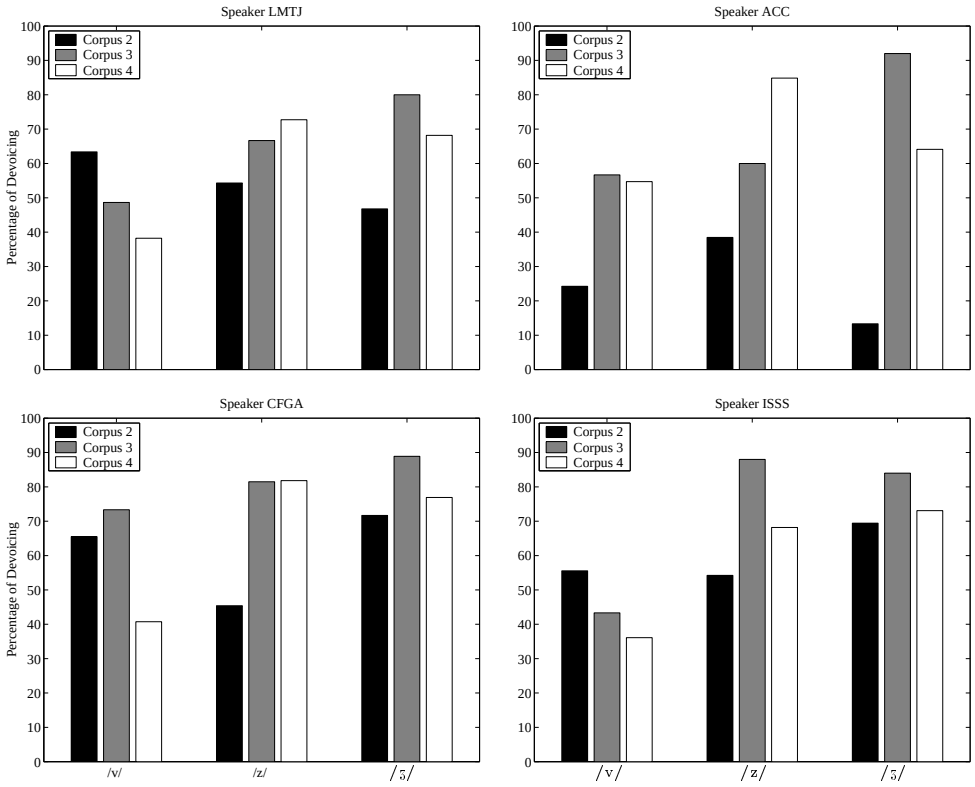


Figure 4.6: Devoicing by Corpus.

If we plot the percentage of devoicing by position in words, as shown in Figure 4.7, there's a significant increase in devoiced examples from word-initial, through word-medial to word-final positions, for Corpus 3 fricatives.

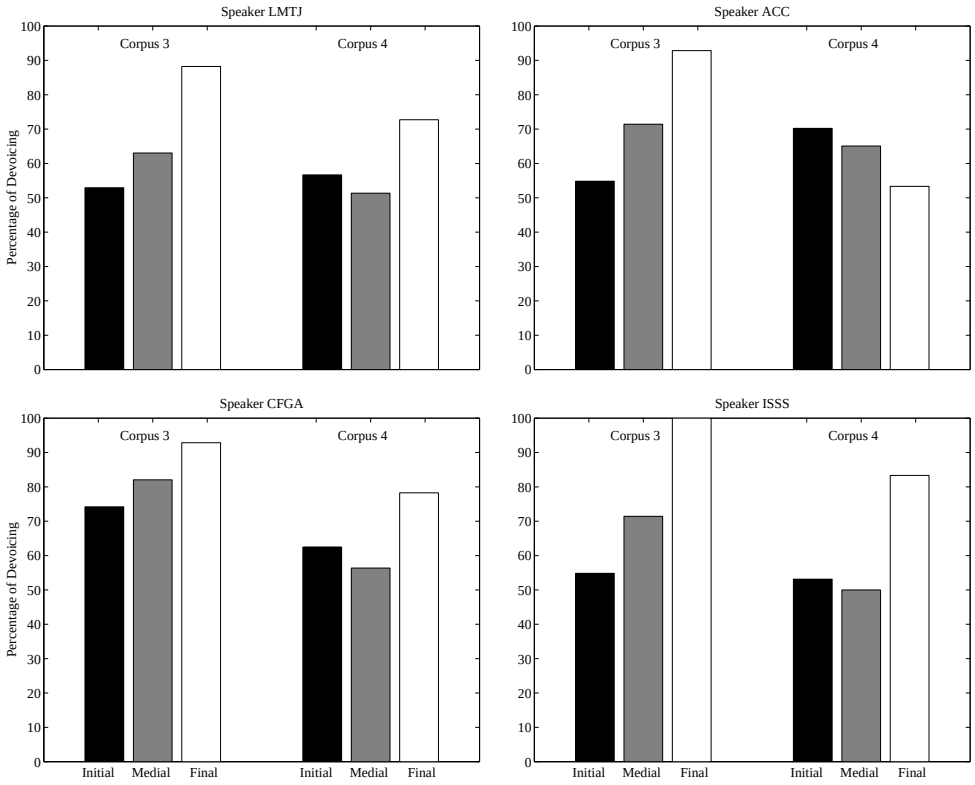


Figure 4.7: Devoicing by position in word.

4.3 Automatic Criterion for Devoicing

If classifying in Corpus 3 (Speaker LMTJ) is instead done using $r_{\sigma^2} \geq 15$ as the criterion for devoicing, results are as shown in Table 4.10. There are a few examples which are classified differently from the initial manual observation of the laryngograph signal (see Table 4.2). Still, the percentage of examples from Corpus 3 which were classified in the same category using the two methods is quite high: /v/ – 86.1% (31 out of 36), /z/ – 93.3% (28 out of 30), and /ʒ/ – 83.3% (25 out of 30). Most of the discrepancies result from cases on the partially devoiced / completely devoiced borderline, giving promise that this automatic measure can be used in the future. The r_{σ^2} metric was also successful when used for unvoiced fricatives /f, s, ʃ/. The percentage of correctly classified examples was: /f/ – 96.2% (25 out of 26); /s/ – 85.2% (23 out of 27); and /ʃ/ – 93.8% (30 out of 32).

Table 4.10: Inventory of all cases of complete devoicing (using the ratio of variances criterion). Values given are number of devoiced examples divided by the total number of examples. Corpus 3 (Speaker LMTJ).

	Word-Initial	Word-Medial	Word-Final	All Pos.
/v/	9/14 (64.3%)	8/13 (61.5%)	8/9 (88.9%)	25/36 (69.4%)
/z/	6/10 (60%)	15/17 (88.2%)	3/3 (100%)	24/30 (80%)
/ʒ/	5/10 (50%)	13/15 (86.7%)	4/5 (80%)	22/30 (73.3%)
All Fric.	20/34 (58.8%)	36/45 (80%)	15/17 (88.2%)	71/96 (74%)

Some examples (/muˈver/ – 57, /ˈzɨlar/ – 126, /ʒɨˈladu/ – 127, /ˈʒelu/ – 119, /ˈʒogu/ – 3, and /ɐˈʒudar/ – 66), which were initially classified as devoiced or partially devoiced (manual classification based on the laryngograph signal, which is listed in the column named "Devoicing" in the tables of results in Appendix D), present a few peaks in the laryngograph waveform, which contribute for a larger variance than what was initially expected. The inclusion of these peaks in the segment of speech signal which is considered to be the fricative, depends on the criteria used for segmentation. Since segmentation was mostly based on the characteristics of the acoustic signal, there were some discrepancies between the VF and FV boundaries for the acoustic signal and the laryngograph signal.

There are also some examples (/ˈvivɐ/ – 140, /ˈlɛvɐ/ – 149, /oˈvɐʎɐ/ – 136, /ɐkuˈzar/ – 146 and the second fricative in /ʒiˈʒi/ – 145) manually classified as voiced but with a ratio of variances greater than 15. Although there is voicing throughout the whole frication interval, the amplitude of the laryngograph signal during the fricative is much lower than during the VF transition.

In Corpus 3 (Speaker LMTJ) only /v/ in /dɨˈver/ and /ˈnɔvɐ/ present a laryngograph signal which does not differ significantly from the signal observed during adjacent transitions. The other examples present a "dramatic" amplitude reduction of the laryngograph signal for the duration of the voiced fricative.

Results of the analysis of Corpus 4 (Speaker LMTJ) using $r_{\sigma^2} \geq 15$ as the criterion for devoicing, shown in Table 4.11, revealed that: 29.4% (10 out of 34) of the examples of fricative /v/ were totally devoiced; 63.6% (14 out of 22) of /z/; and 50% (11 out of 22) of /ʒ/.

Table 4.11: Inventory of all cases of complete devoicing (using the ratio of variances criterion). Values given are number of devoiced examples divided by the total number of examples. Corpus 4 (Speaker LMTJ).

	Word-Initial	Word-Medial	Word-Final	All Pos.
/v/	3/14 (21.4%)	7/18 (38.9%)	0/2 (0%)	10/34 (29.4%)
/z/	3/8 (37.5%)	8/10 (80%)	3/4 (75%)	14/22 (63.6%)
/ʒ/	4/8 (50%)	4/9 (44.4%)	3/5 (60%)	11/22 (50%)
All Fric.	10/30 (33.3%)	19/37 (51.4%)	6/11 (54.6%)	35/78 (44.9%)

In Corpus 4 the ratio of variances measure does not work in examples 9_44, 9_44r and 4_2 (fricative /f/); 8_81r (fricative /v/); 11_77, 4_75r, 3_34, 3_139r, 1_49, 1_49r, 7_82r, 11_95, 11_95r, 1_56 (fricative /s/); 4_135r, 2_84r (fricative /z/); 7_65r, 4_11r, 11_51r (fricative /ʃ/); 1_79 (fricative /ʒ/). The misclassification of these examples as voiced is due to a non-existent VF transition or devoicing in the VF transition.

The amplitude of the laryngograph signal increases slowly along the frication interval (one broad peak) causing examples 9_153, 12_137 and 7_35 of fricative /s/ to be misclassified as voiced. Examples 2_92r, 3_67r, 12_102r, 11_95r, 3_45, 3_45r (fricative /v/); 9_68r, 2_84, 8_50r (fricative /z/); 1_145 (first fricative), 1_145r (second fricative), 2_119r, 6_32, 6_32r, 5_46r, 2_155 (fricative /ʒ/); were misclassified as voiced because their laryngograph waveform presents a few peaks in the frication interval.

The percentage of "correctly classified" examples from Corpus 4 was: 81% (13 out of 16) of /f/; 79% (27 out of 34) of /v/; 55% (16 out of 29) of /s/; 77% (17 out of 22) of /z/; 85% (17 out of 20) of /ʃ/; and 64% (14 out of 22) of /ʒ/. The examples were misclassified because there was no VF transition or there was devoicing during the VF transition (51% – 20 out of 39 misclassified examples), and because there were a few cycles of the laryngograph during the production of the fricative (41% – 16 out of 39 misclassified examples). The remainder of misclassified examples (8% – 3 out of 39) resulted from a broad peak in the laryngograph signal during the fricative.

4.4 Duration Analysis

There does not seem to be any particular correlation between the percentage of devoiced tokens and the average duration of the nine tokens used to ensemble average the spectra of fricatives from Corpus 2 as shown in Figure 4.8. This might be related to the fact that the probability density distribution curves of the durations of fricatives occurring in stressed and destressed syllables, and the probability density distribution curves of the durations of voiced and voiceless fricatives, overlap significantly, as shown in Figure 4.9 from a detailed study by Crystal and House (1988).

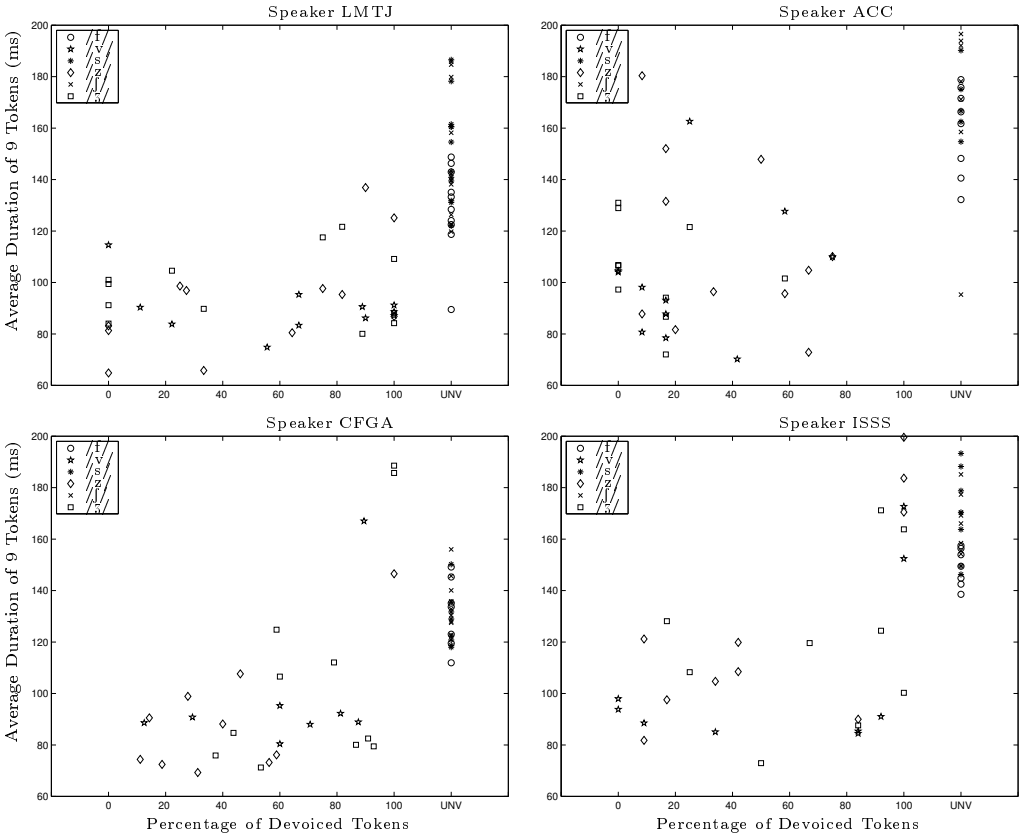


Figure 4.8: Correlation between the percentage of devoiced tokens Corpus 2. The graphs also include the duration of unvoiced (UNV) fricatives.

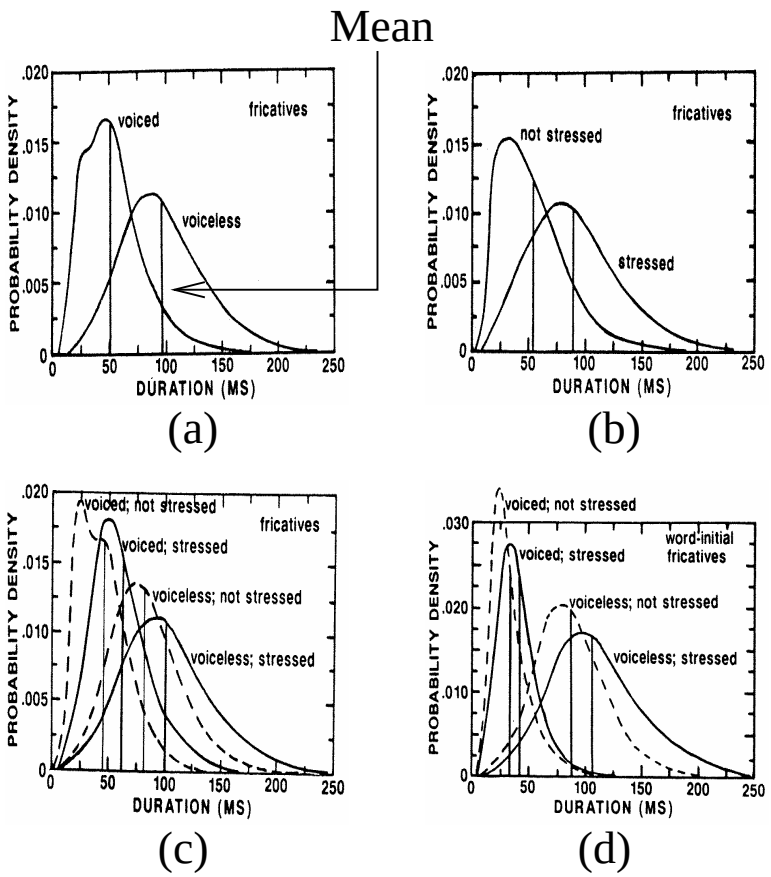


Figure 4.9: Probability density distribution curves of the durations of: (a) voiced /v,ð,z/ and voiceless /f,θ,s/ fricatives; (b) fricatives occurring in stressed and destressed syllables; (c) voiced and voiceless fricatives occurring in stressed and destressed syllables; (d) word-initial voiced and voiceless fricatives occurring in stressed and destressed syllables. From (Crystal and House 1988).

We looked at duration by fricative but wanted to make sure any differences weren't simply due to segmentation decisions. The minimum and maximum durations of the fricatives from Corpus 3 (Speaker LMTJ) are: 86 ms $\leq$ /f/ $\leq$ 182 ms (mean = 129 ms), 37 ms $\leq$ /v/ $\leq$ 135 ms (75 ms), 109 ms $\leq$ /s/ $\leq$ 220 ms (151 ms), 46 ms $\leq$ /z/ $\leq$ 117 ms (81 ms), 76 ms $\leq$ /ʃ/ $\leq$ 194 ms (132 ms), and 60 ms $\leq$ /ʒ/ $\leq$ 139 ms (93 ms). The mean duration of the unvoiced fricatives is always greater than the mean duration of the voiced fricatives. There is no significant difference by place of articulation. For fricative /s/ in initial position, as the following vowel's place of articulation moves further back, the duration of the fricative diminishes.

A complete analysis of duration in Corpus 3 is presented in Appendix D and summarized in Figures 4.10 and 4.11 for Speakers LMTJ and ACC. The mean duration of the fricative is greater than the mean duration of the VF and FV transitions. The mean duration of the VF transition is greater than the mean duration of the FV transition.

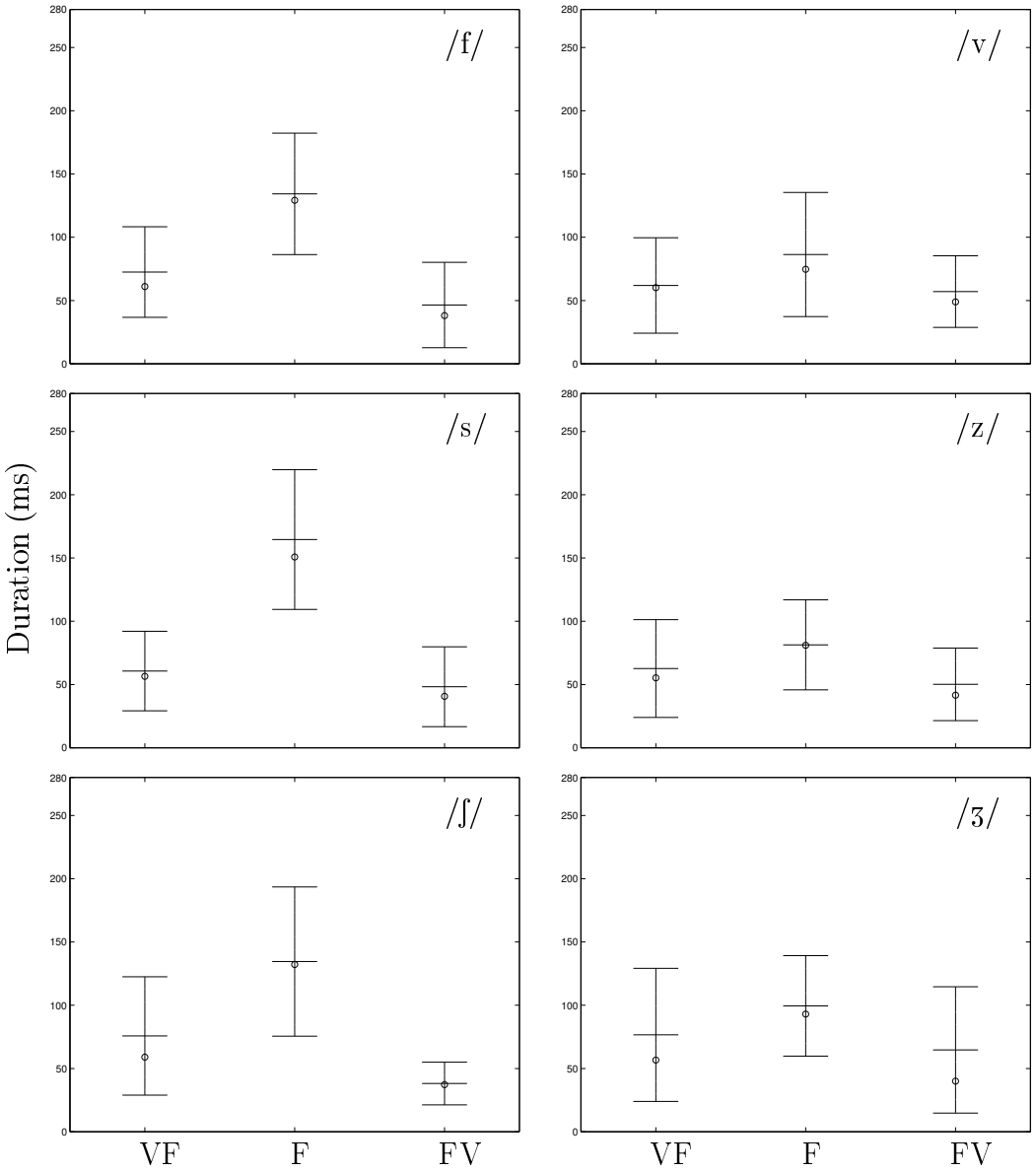


Figure 4.10: Variance of duration of fricatives /f, v, s, z, ʃ, ʒ/, and of VF and FV transitions. o is the mean. Corpus 3 (Speaker LMTJ).

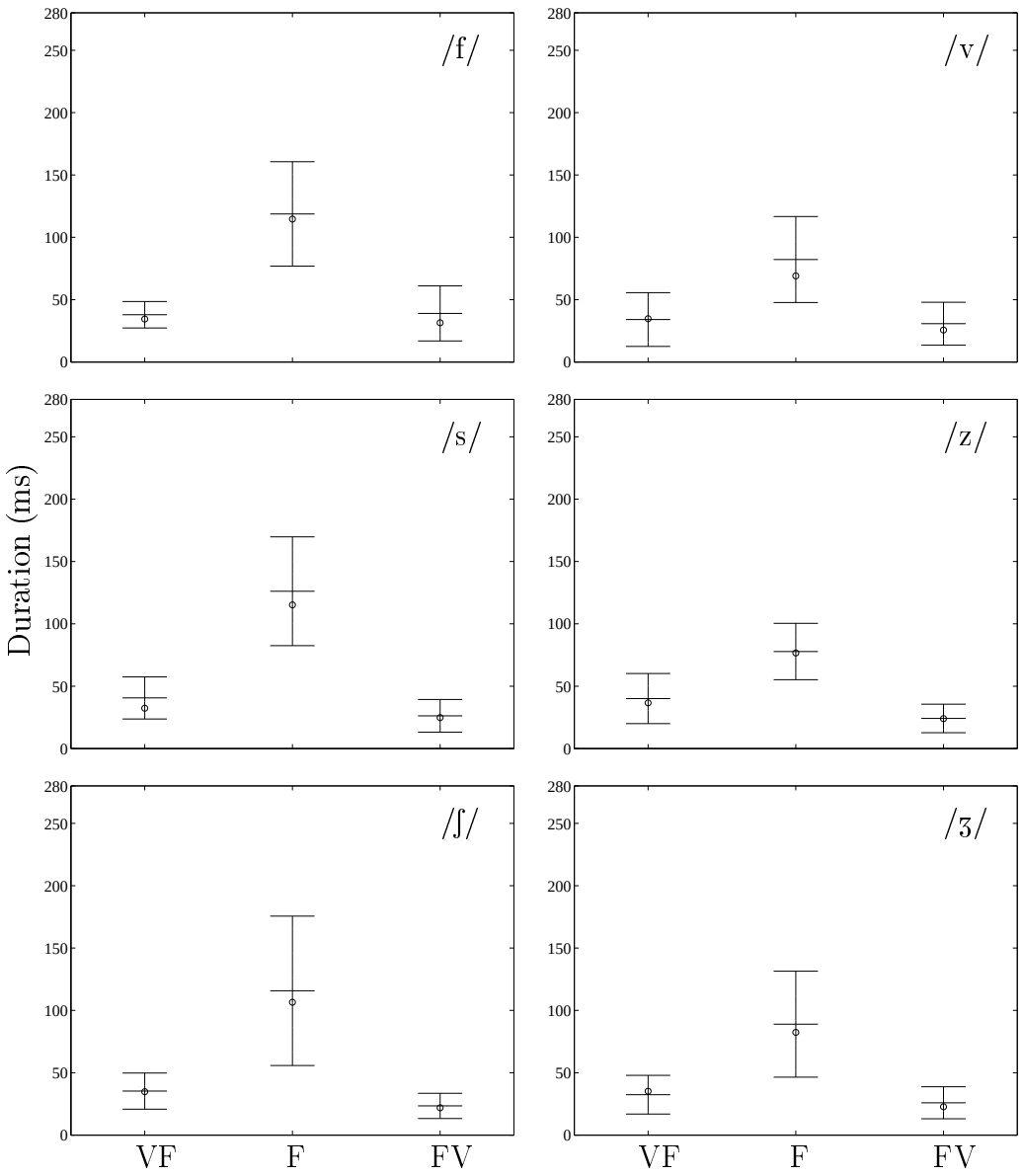


Figure 4.11: Variance of duration of fricatives /f, v, s, z, ʃ, ʒ/, and of VF and FV transitions. o is the mean. Corpus 3 (Speaker ACC).

The average duration of the VF and FV transitions of unvoiced fricatives /f, s, ʃ/ is quite similar to the average duration of the VF and FV transitions of their voiced counterparts /v, z, ʒ/. This proves that although the annotation of voiced fricatives' FV and FV transitions is much more difficult, we have managed to produce a good estimate of where the boundaries are located. So the unvoiced-voiced difference appears to be real, not just an artifact of segmentation.

Figures 4.12 and 4.13 present the average durations of the fricatives /v, z, ʒ/ from Corpus 3 (Speakers LMTJ and ACC), and relates them to devoicing. We've used the manual criteria to classify the fricatives, and considered only totally devoiced examples. When a fricative devoices its FV transition duration diminishes, and the duration of fricatives /v/ and /ʒ/ increases. The VF transition duration is fairly stable. The duration of fricative /z/ does not seem to be significantly affected by devoicing.

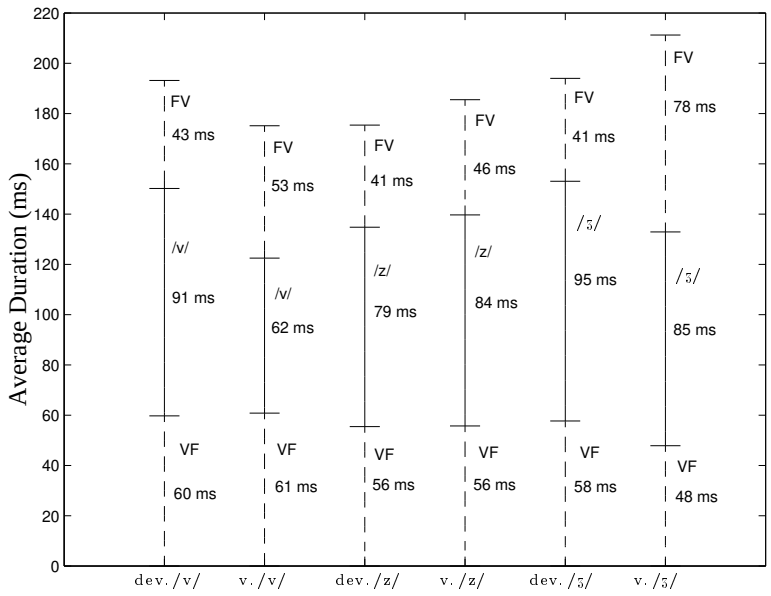


Figure 4.12: Average duration of voiced and devoiced examples of fricatives /v, z, ʒ/, and of VF and FV transitions in Corpus 3 (Speaker LMTJ).

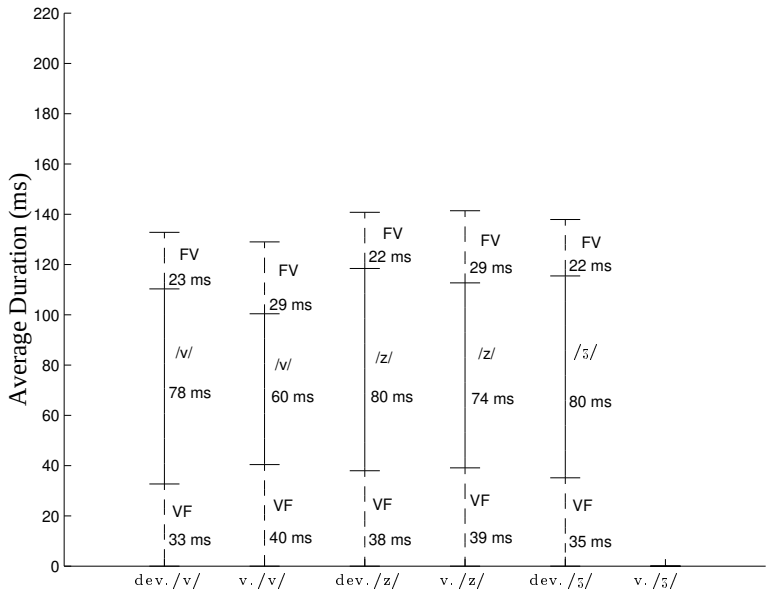


Figure 4.13: Average duration of voiced and devoiced examples of fricatives /v, z, ʒ/, and of VF and FV transitions in Corpus 3 (Speaker ACC).

A detailed time analysis of fricatives from Corpus 4 is also presented in the tables of Appendix D and summarized in Figures 4.14 and 4.15 for Speakers LMTJ and ACC. The minimum and maximum durations for Speaker LMTJ are: 85 ms $\leq$ /f/ $\leq$ 149 ms (mean = 115 ms), 41 ms $\leq$ /v/ $\leq$ 101 ms (62 ms), 95 ms $\leq$ /s/ $\leq$ 272 ms (154 ms), 49 ms $\leq$ /z/ $\leq$ 268 ms (102 ms), 40 ms $\leq$ /ʃ/ $\leq$ 186 ms (130 ms), and 48 ms $\leq$ /ʒ/ $\leq$ 156 ms (85 ms). Sentence and word final examples "doce" ['dos] – 1_56 and "doze" ['doz] – 8_132 and 8_132 have much longer fricative duration than the other examples in Corpus 4 (Speaker LMTJ). The duration of the VF transition of example 8_132 and of the FV transition of example 8_132r are also longer.

The mean duration of the VF and FV transitions are quite similar in words from the sentence corpus for Speakers LMTJ and ACC, as shown in Figures 4.14 and 4.15. This differs from the results for the word corpus (Corpus 3), where the mean durations of VF transitions are always greater than the mean durations of FV transitions. Nevertheless, the mean duration of the fricatives is still always greater than (or equal to) the duration of the VF and FV transitions.

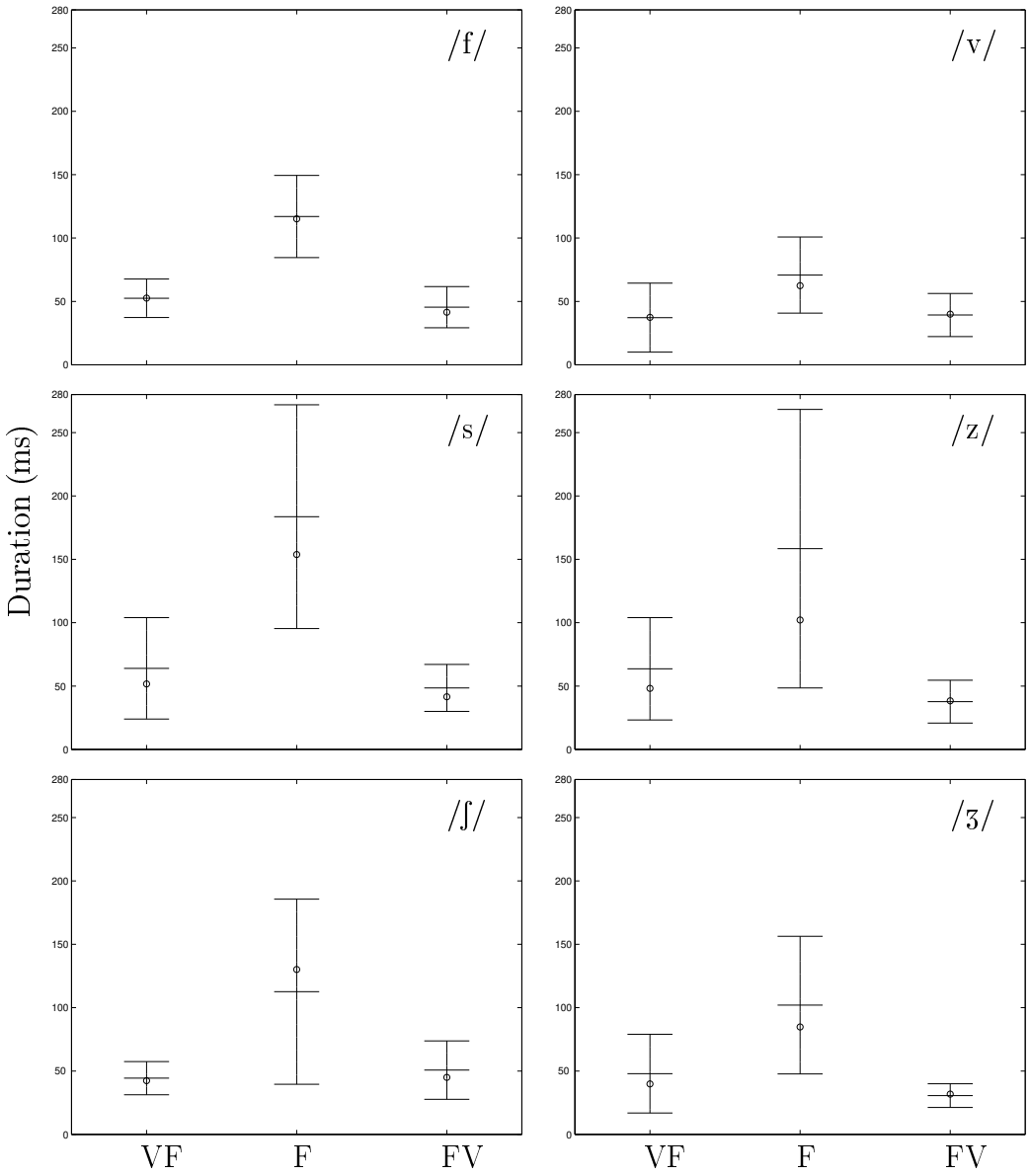


Figure 4.14: Variance of duration of fricatives /f, v, s, z, ʃ, ʒ/, and of VF and FV transitions. o is the mean. Corpus 4 (Speaker LMTJ).

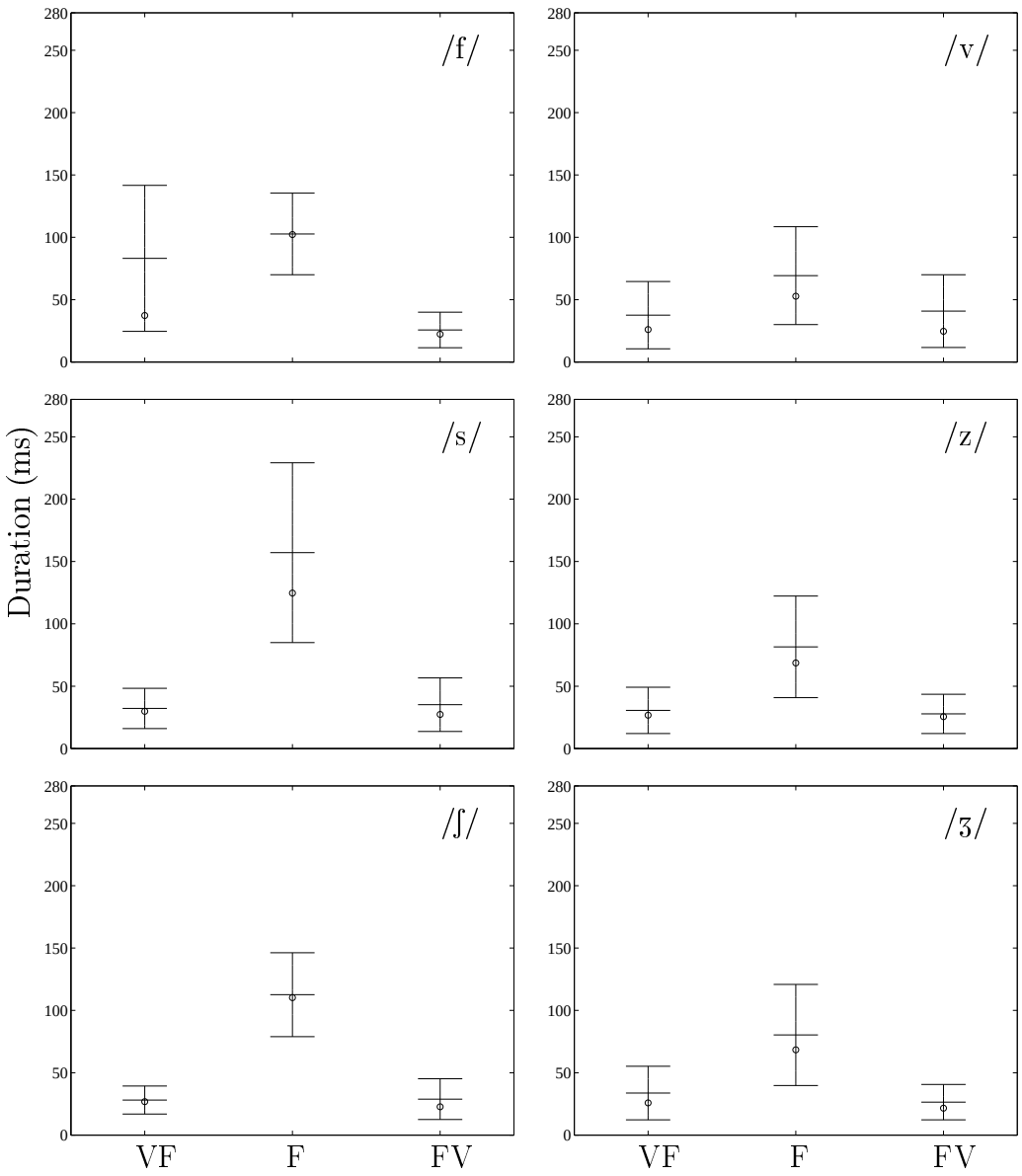


Figure 4.15: Variance of duration of fricatives /f, v, s, z, ʃ, ʒ/, and of VF and FV transitions. o is the mean. Corpus 4 (Speaker ACC).

When fricatives /v, z, ʒ/ from Corpus 4 devoice their duration increases, and the VF and FV transitions are longer, as shown in Figures 4.16 and 4.17 for Speakers LMTJ and ACC. This contradicts the result obtained for Corpus 3 where the FV transition duration diminishes when the fricative devoices. Also the variance and the mean of the VF and FV transitions is significantly smaller for Speaker ACC than for Speaker LMTJ.

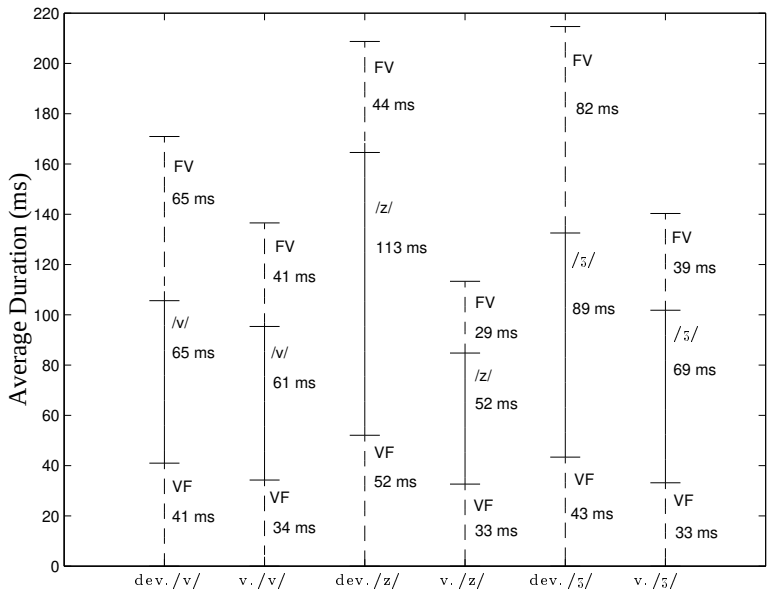


Figure 4.16: Average duration of voiced and devoiced examples of fricatives /v, z, ʒ/, and of VF and FV transitions in Corpus 4 (Speaker LMTJ).

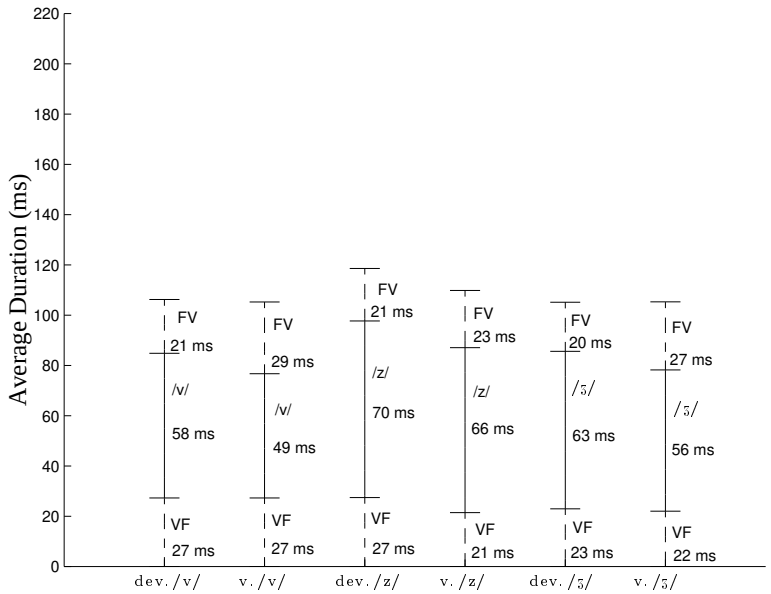


Figure 4.17: Average duration of voiced and devoiced examples of fricatives /v, z, ʒ/, and of VF and FV transitions in Corpus 4 (Speaker ACC).

Table 4.12 shows that the mean duration of the fricatives in Corpus 3 and 4 for Speaker ACC is much smaller than for Speaker LMTJ, and that the

mean duration of the fricatives produced by Speakers ACC or LMTJ in the word corpus (Corpus 3) is quite similar to the mean duration of fricatives from the sentence corpus (Corpus 4).

Table 4.12: Comparing the duration of fricatives in Corpus 3 and 4 (Speakers ACC and LMTJ).

Corpus 3						
	Speaker ACC			Speaker LMTJ		
	Min. (ms)	Mean (ms)	Max. (ms)	Min. (ms)	Mean (ms)	Max. (ms)
/f/	77	115	161	86	129	182
/v/	48	69	117	37	75	135
/s/	83	115	170	109	151	220
/z/	55	77	100	46	81	117
/ʃ/	56	107	176	76	132	194
/ʒ/	46	82	131	60	93	139
Corpus 4						
	Speaker ACC			Speaker LMTJ		
	Min. (ms)	Mean (ms)	Max. (ms)	Min. (ms)	Mean (ms)	Max. (ms)
/f/	70	102	135	85	115	149
/v/	30	53	109	41	62	101
/s/	85	125	229	95	154	272
/z/	41	69	122	49	102	268
/ʃ/	79	110	146	40	130	186
/ʒ/	40	68	121	48	85	156

Table 4.13 lists all the VF and FV transitions' durations for Corpus 3 and 4 (Speaker ACC).

Table 4.13: Comparing the duration of VF and FV transitions in Corpus 3 and 4 (Speaker ACC).

Corpus 3						
	VF			FV		
	Min. (ms)	Mean (ms)	Max. (ms)	Min. (ms)	Mean (ms)	Max. (ms)
/f/	27	34	49	17	31	61
/v/	13	35	56	14	26	48
/s/	24	32	58	13	25	39
/z/	20	37	60	13	24	36
/ʃ/	21	35	50	13	22	34
/ʒ/	17	35	48	13	23	39
Corpus 4						
	VF			FV		
	Min. (ms)	Mean (ms)	Max. (ms)	Min. (ms)	Mean (ms)	Max. (ms)
/f/	25	37	142	11	22	40
/v/	11	26	65	12	25	70
/s/	16	30	48	14	27	57
/z/	12	27	49	12	26	44
/ʃ/	17	27	39	13	23	45
/ʒ/	12	26	55	12	22	41

4.5 Discussion

Both measures of devoicing occur more often in word-final than word-initial position. Devoicing rate by fricative differs between the two measures, and between Corpus 2 and 3.

The speakers produced a large number of repeated tokens of nonsense words in one breath (more than 12 tokens). This high rate of speech could be one of the reasons why there are so many devoiced examples, a hypothesis which has been confirmed by the results of all four speakers.

There seems to be no particular vowel context that causes devoicing. Vowels from all vowel groups (/i, ɨ, e/ – group V_1; /ɛ, ɐ, a/ – group V_2; /ɔ, o, u/ – group V_3) form VCV and CV clusters where the fricative is devoiced.

Chapter 5

Spectral Analysis

5.1 Introduction

In the following sections, we present spectral analysis results for Speakers LMTJ, CFGA, ACC and ISSS. This includes a detailed discussion of the time-averaged spectra of fricatives sustained at three different effort levels (Corpus 1b), and a study of averaged power spectra of sustained (Corpus 1a) and fricatives in real words (Corpus 3 and 4). A discussion of the main spectral peaks and troughs is presented, together with some considerations on the amplitude of the spectra, and the influence of vowel context, word position and stress. Initial results of the spectral analysis of Corpus 1a, 1b, 2, and 3 for Speaker LMTJ are listed in the tables of Appendix E.

Substantial differences are found between spectra of voiced and unvoiced, same-place fricatives: not only are the voiced spectra lower in amplitude, as expected, but differences in spectral shape occur, particularly for /ʃ-ʒ/. Other comparisons of effort level in sustained fricatives to position in the word add to a knowledge of the interaction of voice and frication source in Portuguese.

Spectral peaks are due to the poles of the vocal tract frequency response. Spectral troughs are due to the zeros of the vocal tract frequency response. Moving the articulators alters the shape of the vocal tract which in turn changes its frequency response. Since spectral troughs do not show clearly in the spectra of speech (because of effects such as pole-zero cancellation,

window leakage in the averaging technique and noise floor superimposition) spectral peaks tend to be the most prominent feature in the spectra of speech. We will therefore be referring to them as one of the most important acoustic features, and considering the following three "categories of peaks" as illustrated in Figure 5.1: "Peaks", "Medium Bandwidth Peaks" and "Broad Peaks".

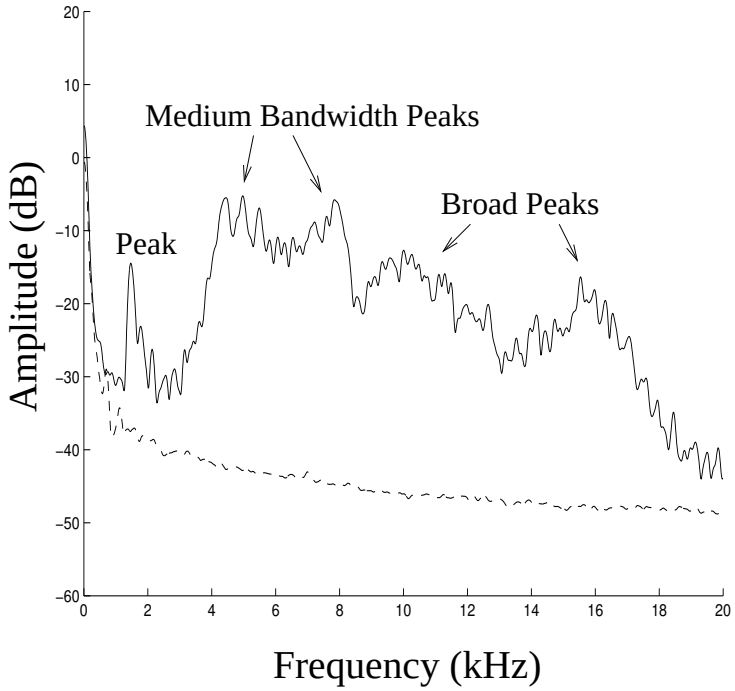


Figure 5.1: Ensemble-averaged spectra at the middle of /s/ in ['pusi]. The dashed curve is the averaged spectrum of the room noise. Corpus 2 (Speaker ACC).

5.2 Fricative /f/

5.2.1 Corpus 1a, 1b, 2, 3 and 4

5.2.1.1 Speaker LMTJ

Fricative /f/ spectral peaks at 1.4 - 1.9 kHz and 2.2 - 2.7 kHz, a trough at 3 - 3.8 kHz, another peak around 3.8 - 4.1 kHz, and broad peak around 11 kHz which is only visible for some back vowel context examples. For most examples, the amplitude of the first peak is 4 - 10 dB higher than the the amplitude of the second peak.

5.2.2 Corpus 1a

5.2.2.1 Speaker CFGA

Peaks: 1.4 - 1.5 kHz, 2.3 - 2.6 kHz, 3.5 - 3.8 kHz and 5.2 - 5.3 kHz.

Broad Peak: 8 - 9 kHz.

5.2.2.2 Speaker ACC

Peaks: 1.4 - 1.7 kHz, 2.8 - 2.9 kHz, 3.1 - 3.6 kHz and 4.7 - 5 kHz.

Broad Peak: 8 - 9.9 kHz.

5.2.2.3 Speaker ISSS

Peaks: 1.6 kHz, 2.9 - 3.1 kHz, 4.1 kHz, 5.3 kHz and 7.6 kHz.

Broad Peak: 11.2 - 13.2 kHz.

5.2.3 Corpus 1b

5.2.3.1 Speaker LMTJ

The spectrum of fricative /f/ has identical amplitude in the low frequencies for all effort levels, but differs quite significantly at higher frequencies. There is a high - frequency broad peak, see Figure 5.2.

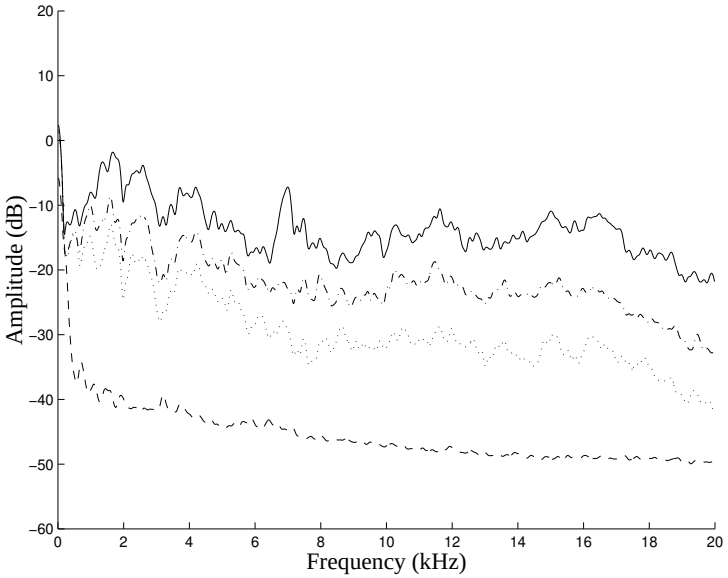


Figure 5.2: Time - averaged spectra of fricative /f/ sustained at three different effort levels: soft (dotted line), medium (dash - dotted line) and loud (solid line). The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

5.2.3.2 Speaker CFGA

Peaks: 1.2 - 1.4 kHz, 2.2 - 2.5 kHz, 3.6 - 3.8 kHz and 5.3 - 5.4 kHz.

Broad Peak: 8 - 10 kHz.

5.2.3.3 Speaker ACC

Peaks: 1.5 - 1.6 kHz, 2.7 - 2.9 kHz, 3.6 - 3.8 kHz and 4.5 - 4.7 kHz.

Broad Peak: 9.6 - 10 kHz.

The spectral amplitude is identical in the low frequencies ($\leq$ 5 kHz) for all effort levels, but differs by 10 - 15 dB at higher frequencies.

5.2.3.4 Speaker ISSS

Peaks: 1.6 - 1.8 kHz, 3 kHz, 4.1 - 4.2 kHz, 5.3 - 5.4 kHz and 7.7 - 7.9 kHz.

Broad Peaks: none.

5.2.4 Corpus 2

5.2.4.1 Speaker LMTJ

When there is no stress, or the stress is placed in the syllable containing the fricative, the amplitude at the middle and end of the fricative falls off. When we place the stress in the syllable before the fricative, the spectrum at the beginning, middle and end are quite consistent in terms of amplitude.

5.2.4.2 Speaker ACC

Peaks: 1.6 - 1.7 kHz (shifted down by 200 - 400 Hz for /u/ vowel context), 2.7 - 2.9 kHz and 3.9 - 4.6 kHz.

Broad Peak: 9 - 10 kHz (shifted down by 0.2 - 3 Hz for /u/ vowel context).

There is a 20 - 30 dB drop of amplitude on the spectra from the first peak to 20 kHz. The high frequency amplitude ($\geq$ 14 kHz) is lower for /pufu/.

5.2.5 Corpus 3

5.2.5.1 Speaker LMTJ

For word-initial /f/ the spectrum is rather flat above 6 kHz for /e, ɛ, ɐ, a, o/ vowel contexts, see Figure 5.3.

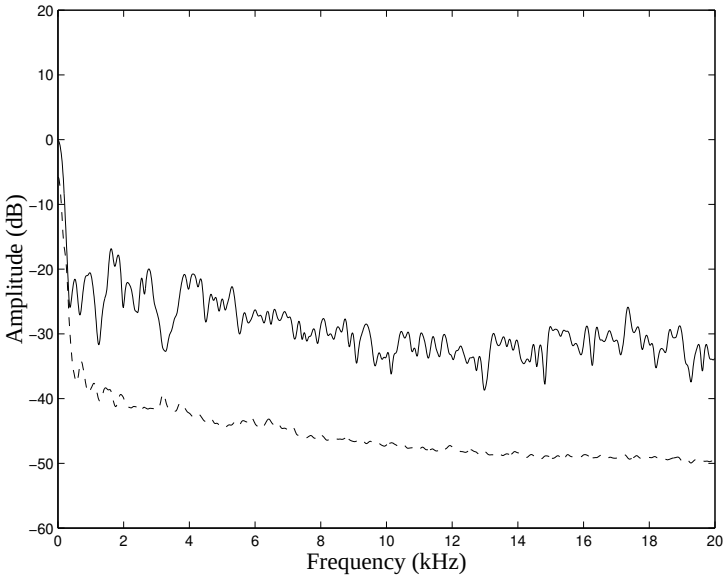


Figure 5.3: Time-averaged spectra of fricative /f/ in "febra" /ˈfebrɐ/. The dashed curve is the averaged spectrum of the room noise. Corpus 3 (Speaker LMTJ).

5.2.6 Corpus 4

5.2.6.1 Speaker LMTJ

The first peak is shifted down to 1.2-1.3 kHz for [uˈfo] and [fu] vowel contexts. When there is a trough around 1.5 kHz this peak is shifted up to 2.2-2.3 kHz (examples [ɨˈfi] and [ɛfi]).

5.2.6.2 Speaker ACC

Peaks: 1.6 - 1.9 kHz (when there is a pronounced trough preceding this peak it is shifted up to 2 - 2.1 kHz), 2.9 - 3.3 kHz and 4.4 - 5 kHz.

Broad Peak: 9.1 - 10.3 kHz (shifted down to 8.2 - 8.9 kHz when a back vowel follows the fricative).

Trough: 0.7 - 0.9 kHz (shifted up to 1 - 1.4 kHz and more pronounced for /i/ vowel context).

5.3 Fricative /v/

5.3.1 Corpus 1a, 1b, 2, 3 and 4

5.3.1.1 Speaker LMTJ

We have observed a first peak at 1.6 - 1.9 kHz. Rounding of the lips for /ɔ, o, u/ displaces this peak to a lower frequency (1 - 1.5 kHz), and the higher-frequency ($\geq$ 4 kHz) spectra is generally weaker (down by $\sim$ 10 dB) than for unrounded vowel contexts (Stevens 1998). There are also peaks around 2.4 - 2.8 kHz and 3.6 - 4.3 kHz. The overall amplitude of /v/ is 10 - 20 dB lower than for /f/ (see for example Figures 5.4 and 5.2).

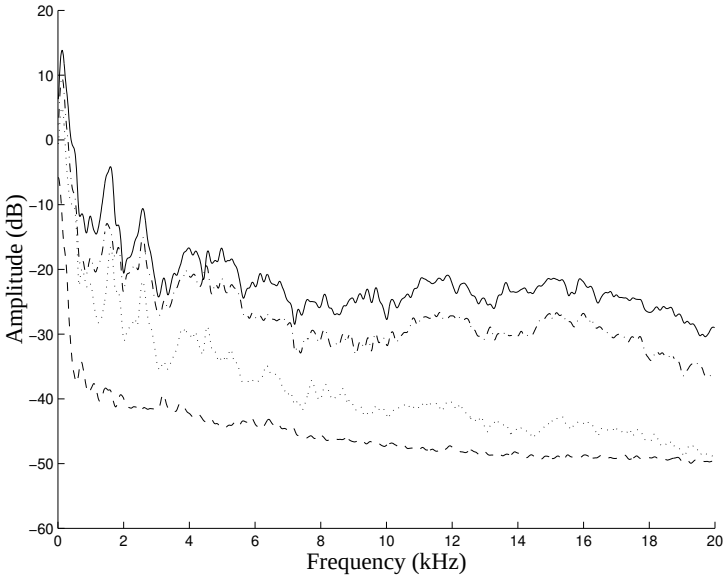


Figure 5.4: Time - averaged spectra of fricative /v/ sustained at three different effort levels: soft (dotted line), medium (dash - dotted line) and loud (solid line). The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

5.3.2 Corpus 1a

5.3.2.1 Speaker CFGA

Peaks: 1 - 1.3 kHz, 2.2 - 2.3 kHz, 3.5 - 3.8 kHz and 5.2 kHz.

Broad Peak: 8.2 - 8.3 kHz.

5.3.2.2 Speaker ACC

Peaks: 1.1 - 1.4 kHz, 2.9 - 3.3 kHz and 4.4 - 4.9 kHz.

Broad Peaks: none.

The overall amplitude of /v/ is 10 dB lower than for /f/.

5.3.2.3 Speaker ISSS

Peaks: 1.5 - 1.7 kHz, 2.9 - 3 kHz, 4.1 kHz, 5.3 kHz and 7.5 kHz.

Broad Peaks: none.

5.3.3 Corpus 1b

5.3.3.1 Speaker CFGA

Peaks: 1.2 kHz, 2.2 kHz, 3.7 - 3.9 kHz and 5.3 kHz.

Broad Peaks: none.

5.3.3.2 Speaker ACC

Peaks: 1.3 - 1.5 kHz, 2.7 - 2.8 kHz, 3.6 - 3.7 kHz and 4.5 - 4.8 kHz.

Broad Peaks: none.

The spectral amplitude is identical in the low frequencies ($\leq$ 5 kHz) for all effort levels. The amplitude difference between high and medium effort level spectra is 10 - 20 dB, and the amplitude of medium and low effort levels is identical, at higher frequencies.

5.3.3.3 Speaker ISSS

Peaks: 1.3 - 1.6 kHz, 2.9 - 3 kHz, 4.2 kHz, 5.2 kHz and 7.8 kHz.

Broad Peaks: none.

5.3.4 Corpus 2

5.3.4.1 Speaker LMTJ

As the vowel that follows the fricative is changed from /ɨ/, through /ɐ/ and to /u/, the peak around 1.2 - 1.7 kHz in the spectrum of the fricative is shifted down by 100 - 200 Hz steps. The beginning, middle and end amplitudes are always quite consistent.

5.3.4.2 Speaker ACC

Peaks: 1.4 - 1.7 kHz (shifted down by 200 - 400 Hz for /u/ vowel context), 2.5 - 2.9 kHz and 3.8 - 4.4 kHz.

Broad Peak: 9 - 9.7 kHz (shifted down by 0.5 - 2 Hz for /u/ vowel context).

The overall spectral amplitude of /v/ is 10 - 15 dB lower than for /f/.

5.3.5 Corpus 4

5.3.5.1 Speaker LMTJ

The two examples of fricative /v/ in sentence 12 have very similar spectral peak frequencies ($\sim$ 1.6 kHz, 2.5 kHz and 3.6kHz). Durations of the fricative, and VF and FV transitions are also quite similar. It seems that [ɨ've] within a word or across word boundaries (when a new word starts with /v/) have the same characteristics.

5.3.5.2 Speaker ACC

Peaks: 1.5 - 1.8 kHz (when there is a pronounced trough preceding this peak it is shifted up to 1.9 - 2 kHz), 2.8 - 3.4 kHz and 4.1 - 5 kHz.

Broad Peak: 7.9 - 10.2 kHz.

Trough: 0.8 - 1 kHz (shifted up to 1.2 - 1.5 kHz and more pronounced for /i,e/ vowel contexts).

5.4 Fricative /s/

5.4.1 Corpus 1a, 1b, 2, 3 and 4

5.4.1.1 Speaker LMTJ

Fricative /s/ has a peak around 1.5 - 2 kHz, whose amplitude is generally 5 dB higher than that of the second peak at 2.5 - 2.8 kHz. There is also a broad peak around 5 - 6 kHz for central and front vowel contexts, and around 4 - 4.5 kHz for back vowel contexts, with an overall amplitude 10 - 30 dB higher than the first two peaks, see Figure 5.5.

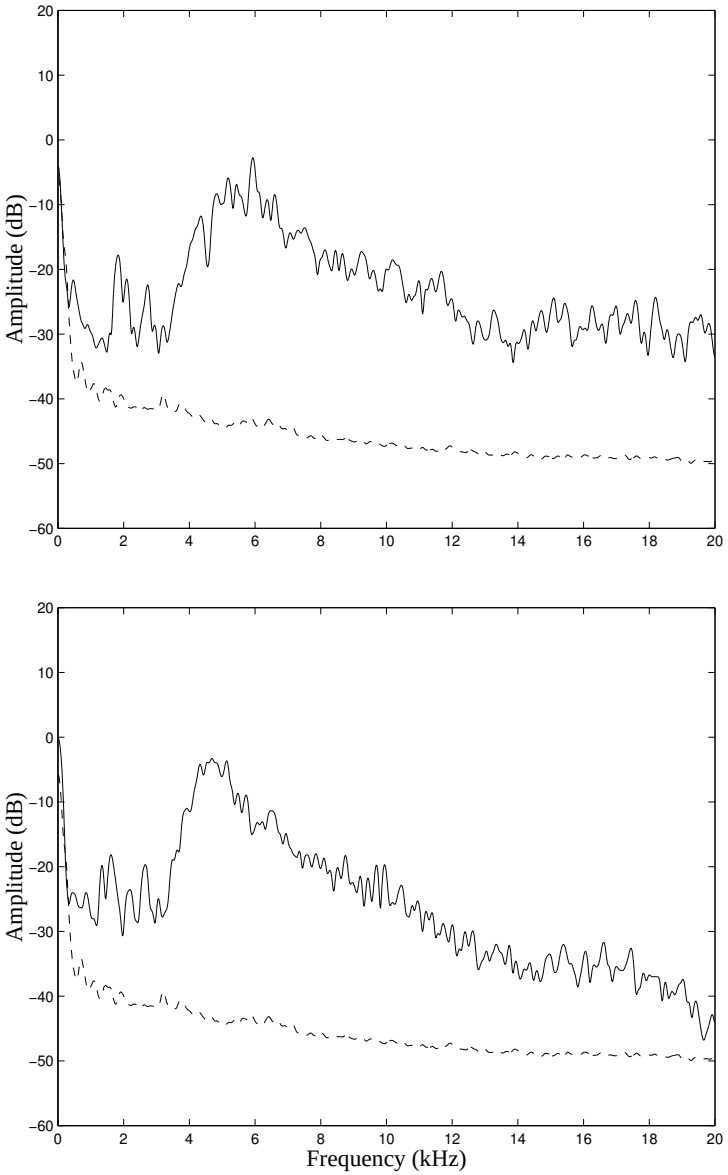


Figure 5.5: Time-averaged spectra of fricative /s/ in "sítio" /ˈsitju/ (top) and "só" /sɔ/ (bottom). The dashed curve is the averaged spectrum of the room noise. Corpus 3 (Speaker LMTJ).

5.4.2 Corpus 1a

5.4.2.1 Speaker CFGA

Peaks: 1.4 - 1.5 kHz, 2.6 - 2.8 kHz and 4 kHz.

Broad Peaks: 7.6 - 8 kHz and 12.4 - 12.8 kHz.

5.4.2.2 Speaker ACC

Peaks: 1.4 - 1.8 kHz and 4.3 - 4.9 kHz.

Broad Peaks: 7.3 - 8.9 kHz and 15 - 16 kHz.

5.4.2.3 Speaker ISSS

Peaks: 1.8 - 1.9 kHz, 2.9 - 3.1 kHz and 4.2 - 4.3 kHz.

Broad Peaks: 5.7 - 7.2 kHz and 10.8 - 11.9 kHz.

5.4.3 Corpus 1b

5.4.3.1 Speaker LMTJ

Fricative /s/ has a main spectral peak around 5 - 6 kHz and a secondary peak around 2 kHz. The amplitude difference between low and medium effort level spectra, and between medium and high effort level spectra is about 15 dB at the 5 - 6 kHz peak and about 30 dB at higher frequencies. The frequency of the broad peak for loud and soft effort levels in File N.2r1, shown in Figure 5.6, and File N.7r1 is higher (6.2 kHz and 5.5 kHz respectively) than for medium effort level (5.1 kHz and 5 kHz respectively).

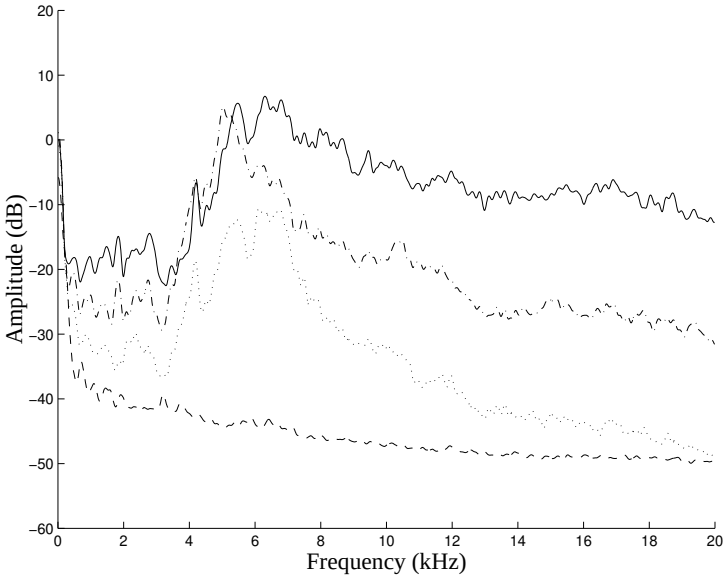


Figure 5.6: Time - averaged spectra of fricative /s/ sustained at three different effort levels: soft (dotted line), medium (dash - dotted line) and loud (solid line). The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

5.4.3.2 Speaker CFGA

Peaks: 1.4 - 1.5 kHz, 2.3 - 2.6 kHz and 4 kHz.

Broad Peak: 7.8 - 7.9 kHz.

5.4.3.3 Speaker ACC

Peak: 1.6 - 1.7 kHz.

Broad Peaks: 8 - 8.5 kHz (shifted down to 5 - 6 kHz for low effort level) and 15.2 - 15.5 kHz.

The amplitude difference between low and medium effort level spectra, and between medium and high effort level spectra, is the same at the first broad peak and at higher frequencies.

5.4.3.4 Speaker ISSS

Peaks: 1.9 kHz, 3.2 kHz and 4.3 - 4.4 kHz.

Broad Peak: 5.1 kHz (soft) to 5.7 kHz (medium and loud) – File N.7, or 5.8 kHz (soft) to 7.4 kHz (medium and loud) – File N.2.

5.4.4 Corpus 2

5.4.4.1 Speaker LMTJ

The amplitude of the spectrum at the middle of the fricative is higher than at the beginning and end, for frequencies greater than the broad peak frequency, see Figure 5.7.

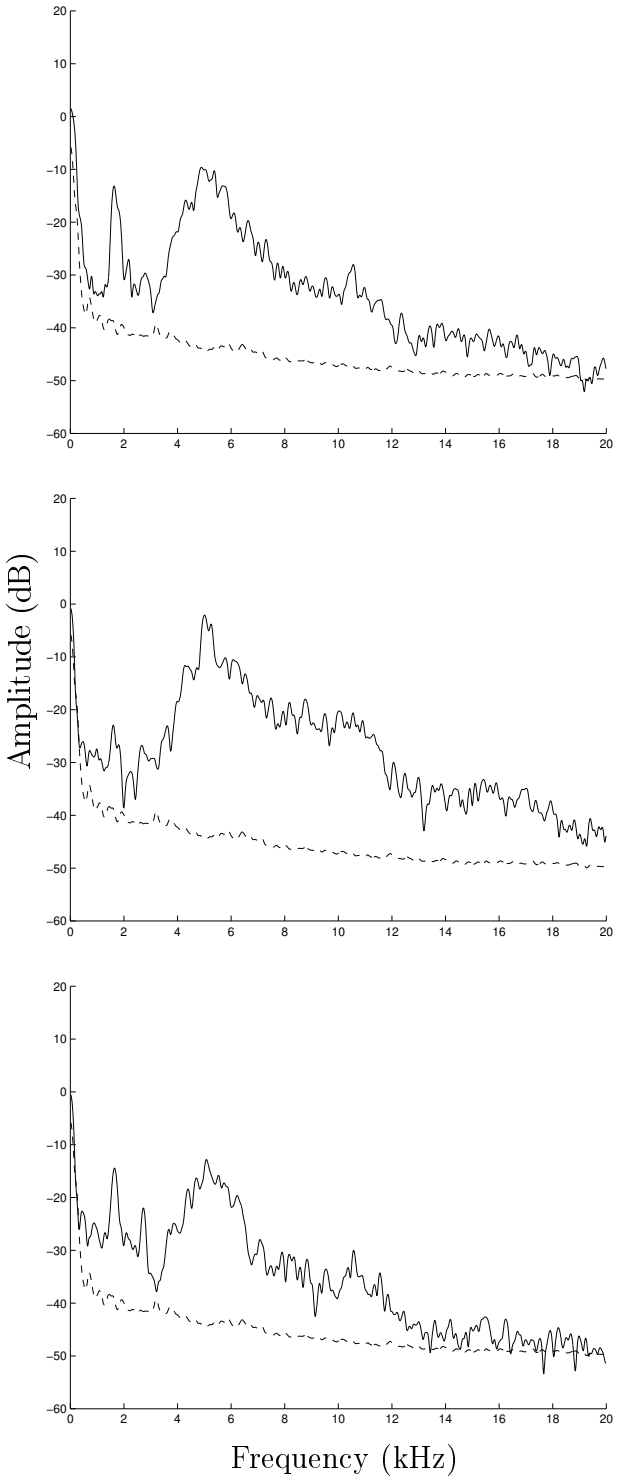


Figure 5.7: Ensemble-averaged spectra of fricative /s/ in /pɨˈsɐ/; Top: beginning of the fricative; Middle: centre of the fricative; Bottom: end of the fricative. The dashed curve is the time-averaged spectrum of the room noise. Corpus 2 (Speaker LMTJ).

5.4.4.2 Speaker ACC

Peaks: 1.4 - 1.8 kHz and 2.8 - 3 kHz.

"Medium Bandwidth Peaks" (/u/ vowel context): 4 - 5 kHz, 7.5 - 8 kHz and 9.5 - 11.5 kHz.

Broad Peak: 5.4 - 6.1 kHz (central vowels contexts) and 15.2 - 16 kHz (/u/ vowel context).

Trough: 2.5 kHz.

The overall spectral amplitude at the middle of the fricative is higher than at the beginning and end, and the overall spectral amplitude at the beginning is higher than at the end.

5.4.5 Corpus 4

5.4.5.1 Speaker LMTJ

We could observe a broad peak at 15 - 16.5 kHz for initial word position fricatives. There is a 20 - 35 dB drop in amplitude from the first broad peak (4 - 6 kHz) to the second broad peak (15 - 16.5 kHz). The two pairs of fricative /s/ in sentences 11 and 12, with the same vowel context within a word and across word boundaries, are quite similar in terms of VF, F, and FV durations, and spectral peak frequencies.

5.4.5.2 Speaker ACC

Peaks: 1.5 - 2.1 kHz and 2.8 - 3.5 kHz.

"Medium Bandwidth" Peaks (/ɔ, u/ vowel contexts): 4.3 - 5.6 kHz, 7.1 - 8.2 kHz and 10.1 - 12.1 kHz.

Broad Peaks: 5.6 - 7 kHz (front and central vowel contexts) and 14.7 - 16.2 kHz.

Trough: 2.3 - 2.6 kHz.

There are four different vowel and consonant contexts ([dˈse], [ɐˈsɛ], [aˈsa] and [ɐˈsa]) where the first broad peak (5.6 - 7 kHz) has a reduced bandwidth, see Figure 5.8 – (a), due to the presence of a "new broad peak" at 7.9 - 10 kHz, as shown in Figure 5.8 – (b).

> The most "reliable" spectral characteristics are the *two peaks* (1.5 - 2.1 kHz and 2.8 - 3.5 kHz) and the *trough* (2.3 - 2.6 kHz).

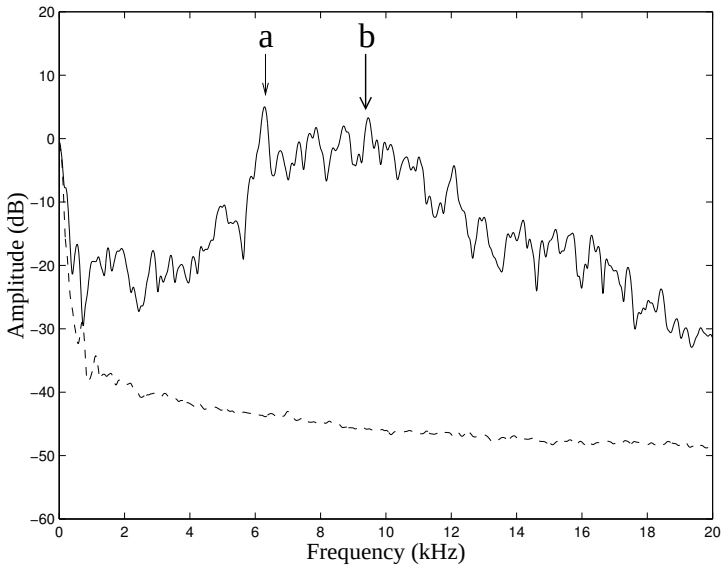


Figure 5.8: Time - averaged spectra of fricative /s/ in "sala" ([a ˈsalɐ]): (a) – Broad peak (5.6 - 7 kHz); (b) – broad peak (7.9 - 10 kHz). The dashed curve is the averaged spectrum of the room noise. Corpus 4 (Speaker ACC).

5.5 Fricative /z/

5.5.1 Corpus 1a, 1b, 2, 3 and 4

5.5.1.1 Speaker LMTJ

The spectra has peaks around 1.4 - 2 kHz and 2.5 - 3 kHz, and a broad peak at 5 - 6 kHz for central and front vowel contexts, which is shifted down to 3.8 - 4.7 kHz for back vowel contexts. The amplitude of the broad peak is 5 - 25 dB higher than the amplitude of the first two peaks.

5.5.2 Corpus 1a

5.5.2.1 Speaker CFGA

Peaks: 1.1 - 1.2 kHz, 2.3 kHz and 4 kHz.

Broad Peaks: 6.8 - 7.9 kHz and 12.7 - 13.1 kHz.

5.5.2.2 Speaker ACC

Peak: 1.1 - 1.2 kHz.

Broad Peaks: 8.1 - 8.8 kHz and 14.4 - 15.4 kHz.

Trough: 2.4 - 2.6 kHz.

5.5.2.3 Speaker ISSS

Peaks: 1.8 kHz, 3.1 - 3.2 kHz and 4.2 kHz.

Broad Peaks: 5.4 - 6.9 kHz and 10.7 - 10.8 kHz.

5.5.3 Corpus 1b

5.5.3.1 Speaker LMTJ

The peak around 2 kHz is more prominent (relative to the overall spectral amplitude) than for /s/ and it's top is not as flat as that of /s/. There is always a 10 - 30 dB drop of amplitude on the loud spectra from a 5 - 6 kHz peak to 20 kHz; there is a 20 - 40 dB amplitude difference between high and low effort levels at high frequencies, see Figure 5.9. The frequency of the broad peak for loud and soft effort levels in File N.6r2 is higher (5.9 kHz) than for medium effort level (5.2 kHz).

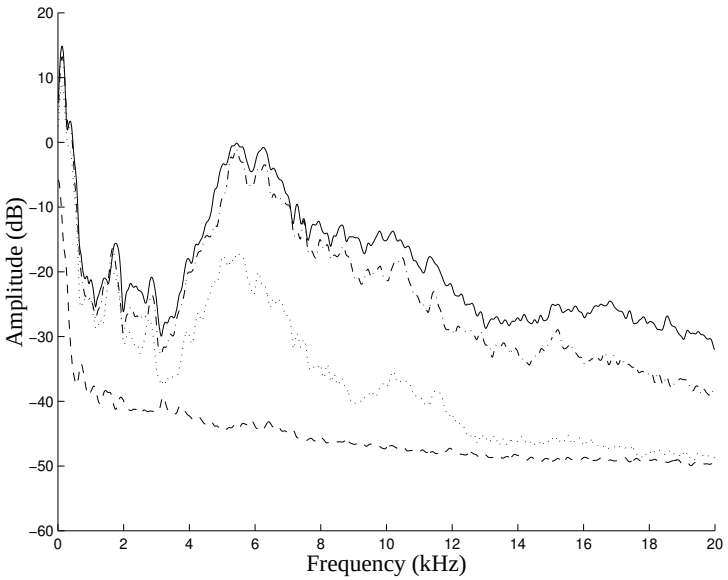


Figure 5.9: Time - averaged spectra of fricative /z/ sustained at three different effort levels: soft (dotted line), medium (dash - dotted line) and loud (solid line). The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

5.5.3.2 Speaker CFGA

Peaks: 1.1 - 1.3 kHz, 2.3 - 2.5 kHz and 4 kHz.

Broad Peaks: 7.1 - 7.9 kHz (shifted down to 6 - 6.4 kHz for soft effort level)

and 13.2 - 15.1 kHz.

5.5.3.3 Speaker ACC

Peaks: 1.2 - 1.4 kHz and 3.1 kHz.

Broad Peaks: 5 - 6 kHz and 15 kHz.

Trough: 2.3 - 2.4 kHz.

There is a 20 - 30 dB drop of amplitude on the spectra from the first broad peak to 20 kHz. The spectral amplitude is identical in the low frequencies ($\leq$ 4 kHz) for all effort levels. The amplitude difference at higher frequencies (4 to 20 kHz) varies between 5 and 20 dB.

5.5.3.4 Speaker ISSS

Peaks: 1.6 - 1.9 kHz, 3.3 kHz and 4.3 kHz.

Broad Peak: 5.3 - 5.9 kHz.

5.5.4 Corpus 2

5.5.4.1 Speaker ACC

Peaks: 1.4 - 1.8 kHz and 2.8 - 3 kHz.

"Medium Bandwidth Peaks" (/u/ vowel context): 4 - 4.8 kHz, 7.3 - 8 kHz and 9.8 - 11.8 kHz.

Broad Peaks: 5.2 - 6.1 kHz (central vowels contexts) and 15 - 15.8 kHz (/u/ vowel context).

Trough: 2.4 - 2.5 kHz.

The overall spectral amplitude for /z/ is 10 - 15 dB lower than for /s/.

5.5.5 Corpus 3

5.5.5.1 Speaker LMTJ

The broad peak in the spectra of word - initial /z/ is shifted down by 1.5 kHz in /ɔ,o/ contexts, and shifted down by 500 Hz in /u/ context, relative to the broad peak in the spectra of /z/ in /ɨ,e/ contexts, see Figure 5.10.

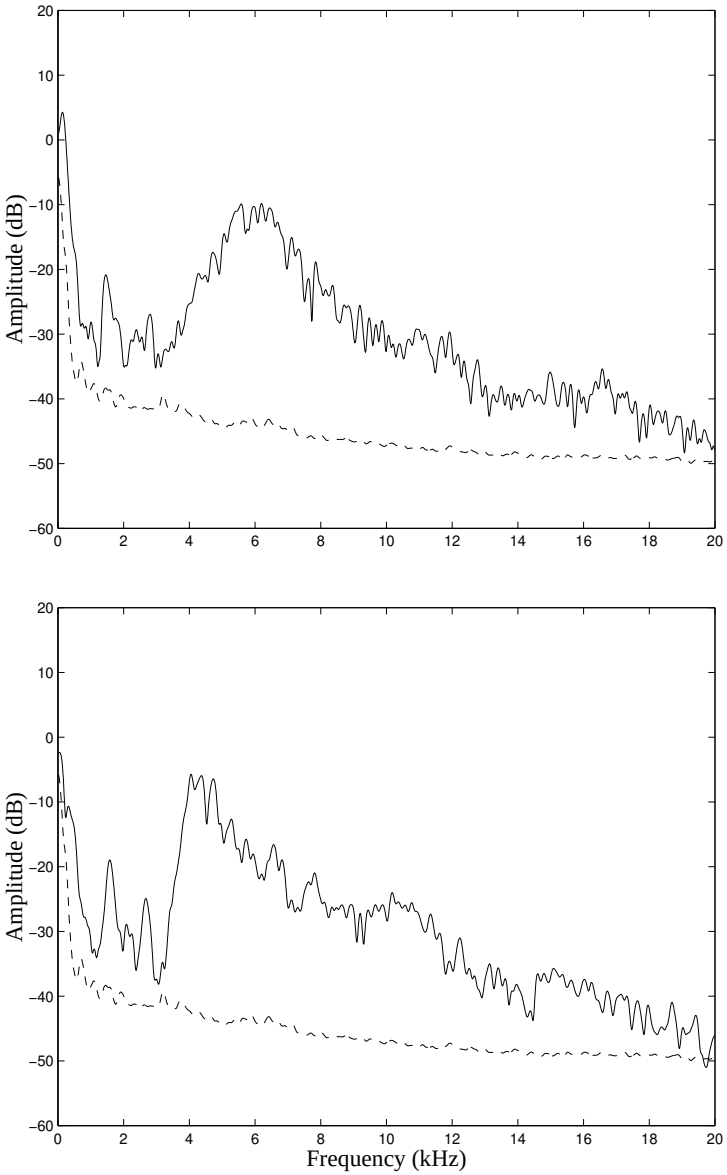


Figure 5.10: Time-averaged spectra of fricative /z/ in "zelar" /ˈzɬlar/ (top) and "zona" /ˈzonɐ/ (bottom). The dashed curve is the averaged spectrum of the room noise. Corpus 3 (Speaker LMTJ).

5.5.6 Corpus 4

5.5.6.1 Speaker LMTJ

For back vowel contexts, the difference in amplitudes between the broad peak and the first two peaks is larger. The broad peak's top is not as flat as that of central and front vowel contexts. In fact, it is most of the time sharper and narrower for back vowel contexts. The overall amplitude of /z/ is 10 - 15 dB lower than that of /s/.

5.5.6.2 Speaker ACC

Peaks: 1.5 - 2 kHz and 2.8 - 3.6 kHz.

"Medium Bandwidth" Peaks (back vowel contexts): 4.3 - 5.8 kHz, 7.4 - 8.3 kHz and 10.2 - 11.8 kHz.

Broad Peaks: 5 - 6.4 kHz (front and central vowel contexts) and 14.2 - 17 kHz.

Trough: 2.4 - 2.6 kHz.

5.6 Fricative /ʃ/

5.6.1 Corpus 1a, 1b, 2, 3 and 4

5.6.1.1 Speaker LMTJ

There is a trough at 0.6 - 1.3 kHz and a peak around 1.6 - 2 kHz. There is also a broad peak around 3 - 3.5 kHz for central and front vowel contexts, which is shifted down to 2.2 - 2.6 kHz for back vowel contexts and for [wʃɨ] in Corpus 4. Word final fricatives have weaker higher frequency ($\geq$ 7 kHz) spectra.

5.6.2 Corpus 1a

5.6.2.1 Speaker CFGA

Peak: 1.6 kHz.

Broad Peaks: 2.9 - 3 kHz (shifted down to 2.5 kHz for /u/ vowel context due to the presence of a "new broad peak" at 6.1 kHz) and 12.5 - 12.6 kHz.

5.6.2.2 Speaker ACC

Peaks: 1.4 - 1.7 kHz, 2.9 - 3.7 kHz and 4.4 - 4.8 kHz.

Broad Peaks: 6.6 - 8.7 kHz and 14.4 - 15.4 kHz.

The overall amplitude of /z/ is very similar to /s/.

5.6.2.3 Speaker ISSS

Peak: 1.9 - 2.1 kHz.

Broad Peaks: 3.4 - 3.9 kHz, 7.3 - 7.8 kHz and 14.4 - 15.4 kHz.

5.6.3 Corpus 1b

5.6.3.1 Speaker LMTJ

High effort shifts the main spectral peak of /ʃ/ to a higher frequency ($\sim$4 kHz), and the amplitude increases, see Figure 5.11. There is a fairly similar falloff at all levels and the difference between high and low effort level amplitudes at high frequencies is about 30 dB.

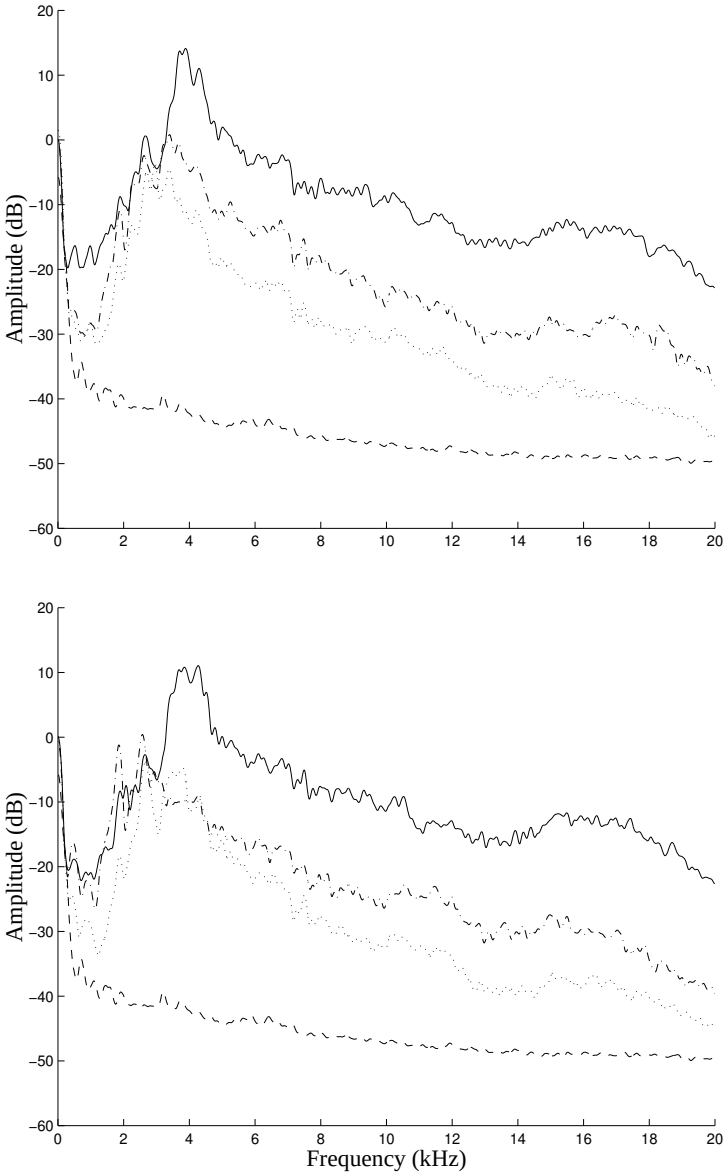


Figure 5.11: Time - averaged spectra of fricative /ʃ/ sustained at three different effort levels: soft (dotted line), medium (dash - dotted line) and loud (solid line). Top: File N.1r1; Bottom: File N.12r1. The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

5.6.3.2 Speaker CFGA

Peak: 1.6 - 1.7 kHz.

Broad Peaks: 2.7 - 2.8 kHz (soft) to 3.1 - 3.7 kHz (medium and loud) and 12.1 - 14.8 kHz.

5.6.3.3 Speaker ACC

Peak: 1.5 - 2 kHz.

Broad Peaks: 3.1 - 3.6 kHz (shifted up to 4.1 - 4.5 kHz for medium and low effort levels ← **opposite of Speaker LMTJ!**) and 14.7 - 15.3 kHz.

The amplitude difference between low and medium effort level spectra, and between medium and high effort level spectra is 5 - 20 dB. There is as 20 - 30 dB drop of amplitude on the spectra from the first broad peak to 20 kHz.

5.6.3.4 Speaker ISSS

Peak: 2 - 2.2 kHz.

Broad Peaks: 2.9 kHz (soft) to 3.6 - 4 kHz (medium and loud), and 8.4 - 8.5 kHz (soft) to 7 - 7.9 kHz (medium and loud).

5.6.4 Corpus 2

5.6.4.1 Speaker ACC

Peak: 1.6 - 1.9 kHz (shifted down to 1.4 - 1.5 kHz for ['puʃu]).

Broad Peaks: 3.5 - 4 kHz (central vowels contexts), 7.5 - 9.5 kHz (shifted down to 6 - 7 kHz for /u/ vowel context) and 14 - 16 kHz.

Trough: 0.8 - 1.3 kHz.

5.6.5 Corpus 4

5.6.5.1 Speaker LMTJ

For [aʃ] the first broad peak (3 - 3.5 kHz) is shifted back to 2.5 kHz. A second broad peak could also be observed at 15.1 - 16.9 kHz for back vowel contexts and for [wʃɨ], see Figure 5.12. There is a 25 - 40 dB drop of amplitude from the first broad peak to the second broad peak. The two examples of fricative /ʃ/ in sentence 11 are identical (time and frequency domain).

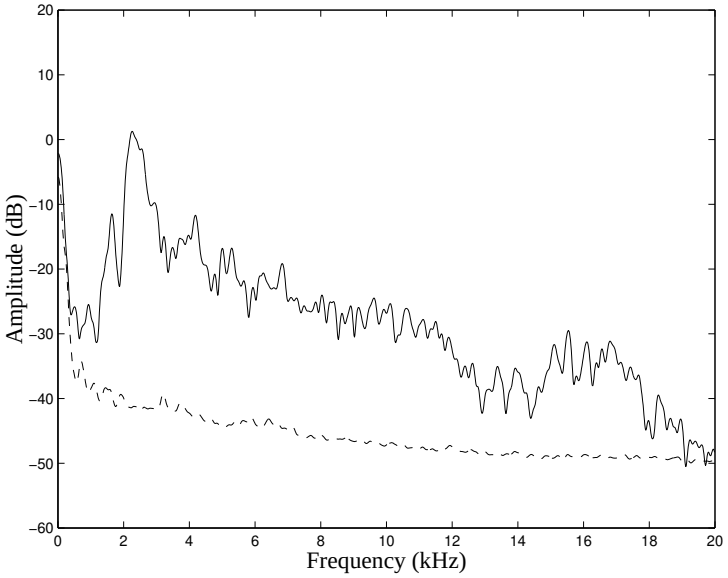


Figure 5.12: Time - averaged spectra of fricative /ʃ/ in [w ʃɨˈgar], showing a high frequency broad peak around 16 kHz. The dashed curve is the averaged spectrum of the room noise. Corpus 4 (Speaker LMTJ).

5.6.5.2 Speaker ACC

Peak: 1.7 - 2.1 kHz.

"Medium Bandwidth" Peak: 2.9 - 4.3 kHz.

Broad Peaks: 5.9 - 7.8 kHz and 13.3 - 15.9 kHz.

Trough: 0.8 - 1.2 kHz.

5.7 Fricative /ʒ/

5.7.1 Corpus 1a, 1b, 2, 3 and 4

5.7.1.1 Speaker LMTJ

There is a trough around 0.9 - 1.3 kHz and a peak at 2.5 - 3 kHz, which is shifted down to 1.5 - 2 kHz for back vowel contexts and for most /ɐ/ vowel context examples. A "medium bandwidth peak" is located around 3.3 - 3.6 kHz, and shifted back to 2.3 - 3kHz for back vowel contexts and for most /ɐ/ vowel context examples. For some vowel contexts the first two peaks have equal prominence.

5.7.2 Corpus 1a

5.7.2.1 Speaker CFGA

Peak: 1.5 - 1.6 kHz.

Broad Peaks: 2.9 kHz (shifted down to 2.6 kHz for /u/ vowel context due to the presence of a "new broad peak" at 5.2 kHz) and 10.4 - 12.8 kHz.

5.7.2.2 Speaker ACC

Peaks: 1.2 - 1.5 kHz, 3.2 - 3.4 kHz and 4.4 - 4.7 kHz.

Broad Peak: 14.1 - 15.2 kHz.

The overall amplitude of /ʒ/ is very similar to /ʃ/.

5.7.2.3 Speaker ISSS

Peak: 1.9 - 2 kHz.

Broad Peaks: 3.7 - 4.1 kHz, 7.8 kHz and 14.6 - 15.2 kHz.

5.7.3 Corpus 1b

5.7.3.1 Speaker LMTJ

The relative amplitude of the cluster of peaks (around 2, 2.5 and 3.5 kHz) in the spectra of fricative /ʒ/, shown at the top of Figure 5.13, is different from the one shown at the bottom of Figure 5.13 where the spectral shape is closer to that of /ʃ/. The overall amplitude is 20 - 30 dB lower than that of /ʃ/. Generally there is less amplitude difference at high frequencies between medium and high effort, than between low and medium effort.

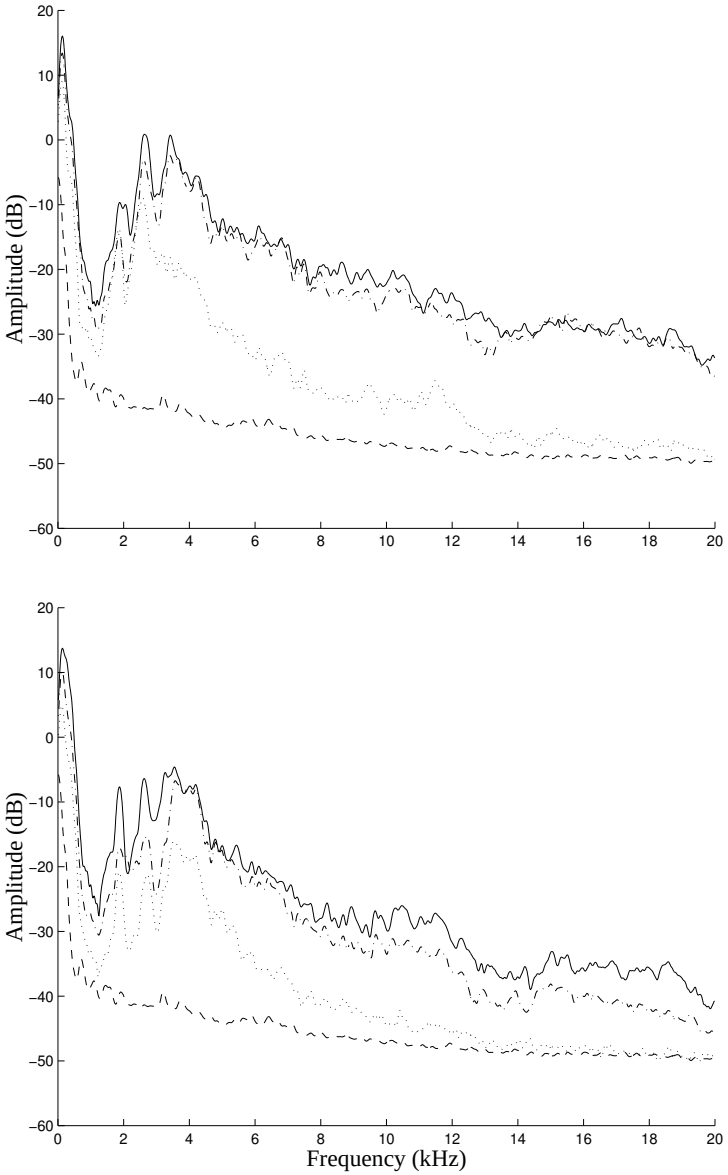


Figure 5.13: Time - averaged spectra of fricative /ʒ/ sustained at three different effort levels: soft (dotted line), medium (dash - dotted line) and loud (solid line). Top: File N.10r1; Bottom: File N.4r2. The dashed curve is the averaged spectrum of the room noise. Corpus 1b (Speaker LMTJ).

5.7.3.2 Speaker CFGA

Peak: 1.4 - 1.7 kHz.

Broad Peaks: 2.6 - 3.6 kHz and 10.1 - 12.7 kHz.

5.7.3.3 Speaker ACC

Peaks: 1.5 - 1.6 kHz, 2.7 - 3.6 kHz and 4.3 - 4.7 kHz.

Broad Peak: 15 - 15.6 kHz.

Trough: 2.1 - 2.4 kHz.

There is less amplitude difference between effort levels (5 - 10 dB) than for /ʃ/. There is a 30 dB drop of amplitude on the spectra from the peak around 4.3 - 4.7 kHz to 20 kHz.

5.7.3.4 Speaker ISSS

Peak: 1.9 - 2.1 kHz.

Broad Peaks: 3.6 - 4.1 kHz and 7.7 - 8 kHz.

5.7.4 Corpus 2

5.7.4.1 Speaker ACC

Peak: 1.5 - 1.8 kHz.

"Medium Bandwidth Peaks": 3.2 kHz (shifted down by 300 - 500 Hz for /u/ vowel context) and 4.1 - 4.7 kHz.

Broad Peak: 7.7 - 8.7 kHz (shifted down to 6 - 7 kHz for /u/ vowel context).

Trough: 0.9 - 1.1 kHz.

The overall spectral amplitude of /ʒ/ is 10 - 15 dB lower than /ʃ/.

5.7.5 Corpus 3

5.7.5.1 Speaker LMTJ

Word-initial /ʒ/ in /ɛ/ context has a peak around 4 kHz, which has a higher amplitude than the same peak in the spectra of fricative /ʒ/ in back vowel contexts.

5.7.6 Corpus 4

5.7.6.1 Speaker LMTJ

There is a 9.5 - 11.5 kHz broad peak, which is not visible for final word position fricatives. There is a 20 - 30 dB drop in amplitude from the "medium bandwidth peak" (2.3 - 3.6 kHz) to the broad peak, and the overall amplitude of /ʒ/ varies over a similar range ($\sim$ 40 dB) to that of /ʃ/.

5.7.6.2 Speaker ACC

Peak: 1.5 - 2.2 kHz.

"Medium Bandwidth" Peak: 2.4 - 4.7 kHz.

Broad Peaks: 6 - 7.6 kHz and 13.8 - 16.3 kHz.

Trough: 0.8 - 1.4 kHz.

5.8 Comparing the Overall Spectra of Speakers LMTJ and ACC

5.8.1 Corpus 1a

The peaks in the spectra of Speaker ACC are much broader and their top much flatter than for Speaker LMTJ, as can be seen in Figure 5.14. The overall amplitude of the spectra of fricatives produced by Speaker ACC is $\simeq$10 - 20 dB higher than for Speaker LMTJ. The "voice bar" (first peak in the spectra) of fricatives /v,z,ʒ/ for Speaker ACC is $\simeq$10 dB higher than for Speaker LMTJ.

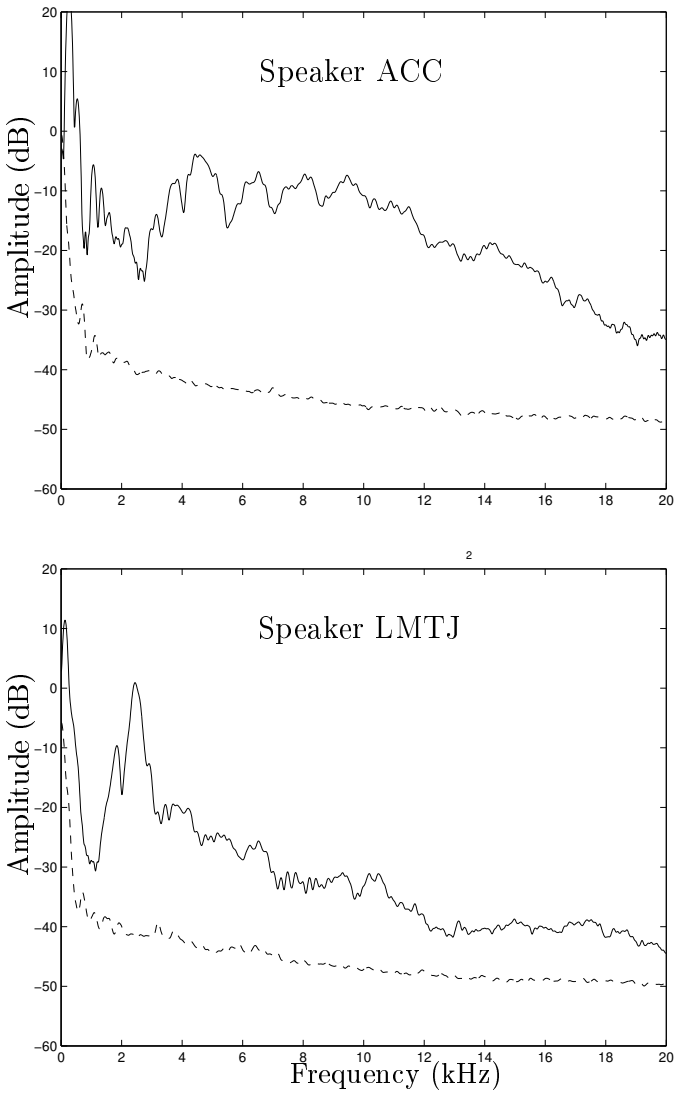


Figure 5.14: Time-averaged spectra of sustained fricative /ʒ/ in /ɐ-ʒ-...-ɐ/. The dashed curve is the averaged spectrum of the room noise.

5.9 Syllable Stress and Effort Level

We expected that effort level of sustained fricatives would correspond with stress of the syllable containing the fricative in Corpora 2 and 3, and possibly also position within the word in Corpus 3. Figures 5.15 to 5.21 contrast spectra for /ʃ/ with similar vowel context from Corpora 2 and 3 (Speaker

LMTJ).

Four of the seven such pairs-by-vowel-context showed this pattern, with the Corpus 2 spectral amplitude slightly higher than that of Corpus 3 for frequencies above 6 kHz, see Figures 5.15 to 5.18. This amplitude difference across the frequency range corresponds strongly with a difference in stress between the two fricatives. In all of these four cases, the Corpus 3 fricative was in a destressed syllable, and the Corpus 2 fricative was in a stressed syllable.

The other three such cases showed a different pattern, with the spectral amplitudes differing at the main peak but approximately equal above 3 kHz, see Figures 5.19 to 5.21. Two of these cases matched in stress (one pair, both stressed, shown in Figure 5.19; the other, both destressed, shown in Figure 5.21), the third case, shown in Figure 5.20, did not match, and the amplitude difference at the peak was the largest (stressed Corpus 2 is 15 dB above destressed Corpus 3).

The spectral shapes and amplitudes are similar to the soft effort level for all destressed /ʃ/ fricatives, and to the medium effort level for stressed /ʃ/ fricatives. No fricatives from Corpus 2 or 3 resemble their high-effort-level Corpus 1b counterparts. Some vowel context effects were noted: the main peak in Figure 5.18, for /uʃu/ context, was at a significantly lower frequency than in, e.g., /i̟ʃi/ context; this is as expected from previous work (Shadle and Scully 1995).

These points taken together (see summary in Table 5.1) give us information needed to model the fricative. They also indicate that the nonsense word corpus follows Portuguese phonological rules. Corpus 2 is better controlled and easier to analyse than Corpus 3 or 4; validating its use would give an important advantage.

Table 5.1: Spectral amplitude comparisons. Same vowel context. Spectral amplitudes $> 2\,\text{kHz}$. Speaker LMTJ.

Corpus 2 e.g. [puʃu]		Corpus 3 e.g. [kɐˈpuʃ]
	≈	3 cases, stressed
	>	4 cases, unstressed

Corpus 1a e.g. [uʃ... ʃu]		Corpus 2 and 3 e.g. [puʃu], [kɐˈpuʃ]
high effort		no equivalents in word or nonsense - word
medium	≈	all stressed
low	≈	all destressed

We have also looked at the same set of 7 examples for Speaker ACC but the overall spectral amplitude of fricatives from Corpus 2 and Corpus 3 is approximately the same.

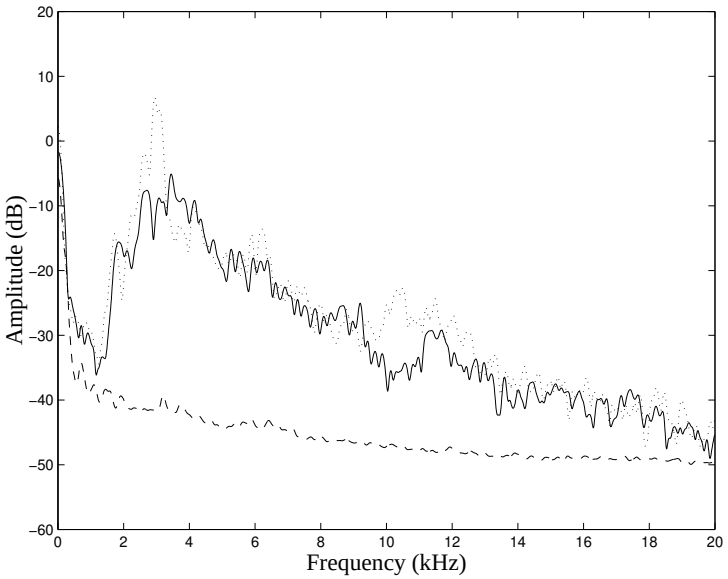


Figure 5.15: Averaged power spectra of fricative /ʃ/ in [ˈbiʃɐ] from Corpus 3 (solid line), and in [pɨˈʃɐ] from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

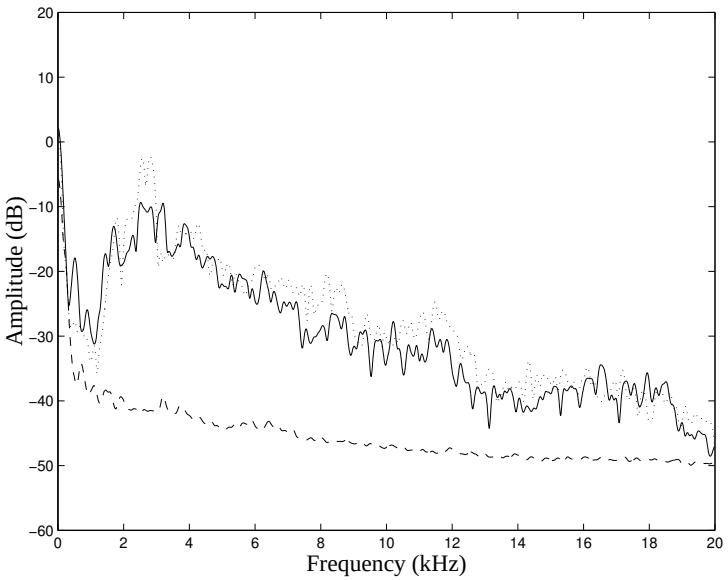


Figure 5.16: Averaged power spectra of fricative /ʃ/ in [ˈtaʃ] from Corpus 3 (solid line), and in [pɐˈʃu] from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

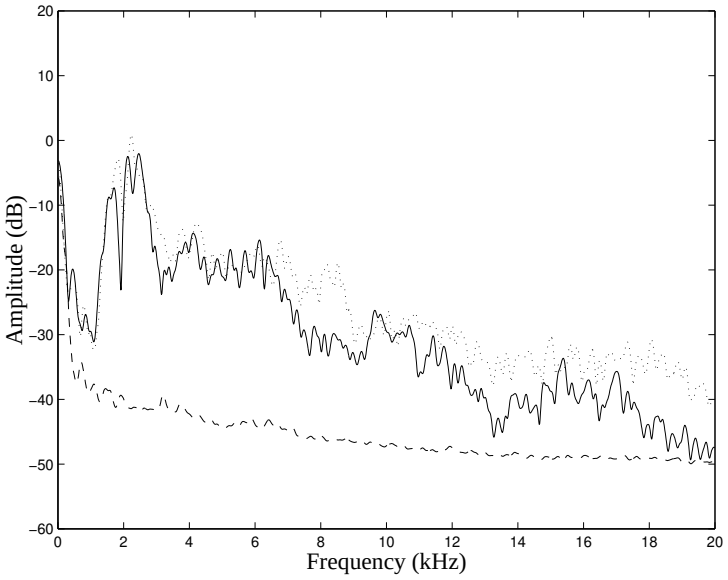


Figure 5.17: Averaged power spectra of fricative /ʃ/ in [ˈmoʃ] from Corpus 3 (solid line), and in [puʃu] (both syllables equal stress) from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

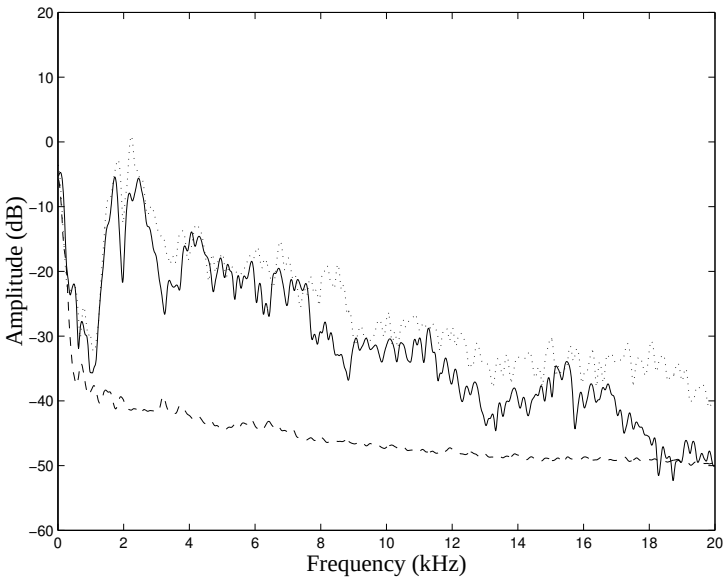


Figure 5.18: Averaged power spectra of fricative /ʃ/ in [kɐˈpuʃ] from Corpus 3 (solid line), and in [puʃu] (both syllables equal stress) from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

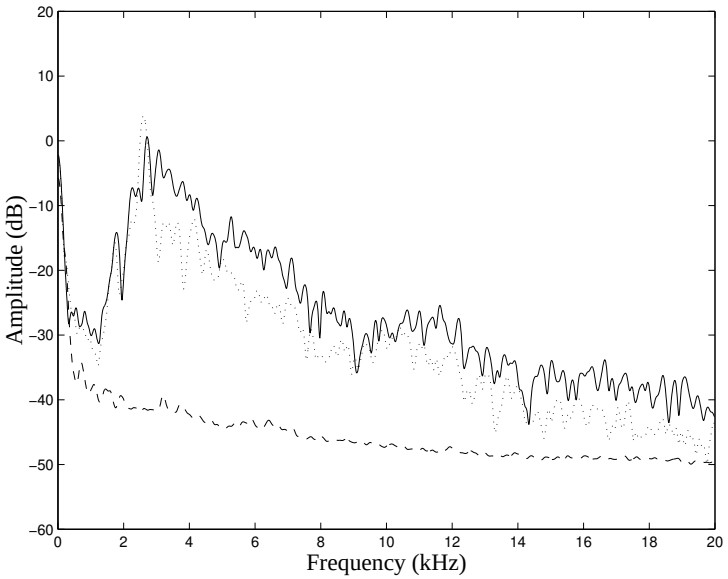


Figure 5.19: Averaged power spectra of fricative /ʃ/ in [ɐˈʃar] from Corpus 3 (solid line), and in [pɐˈʃɐ] from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

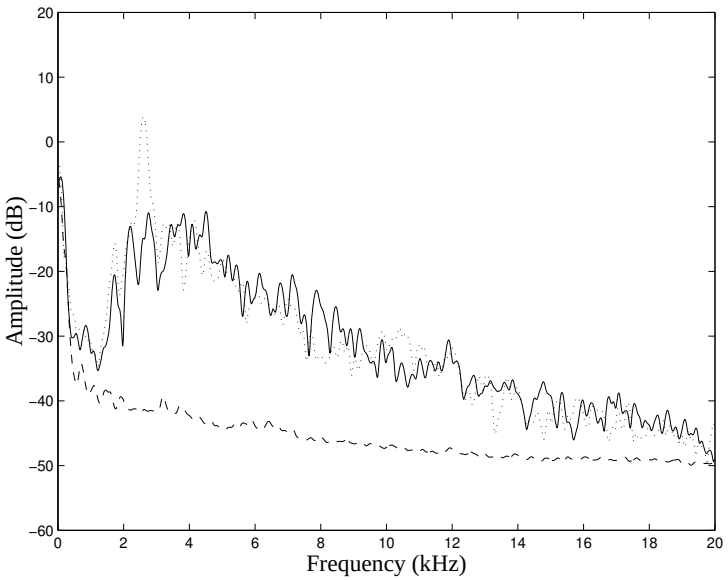


Figure 5.20: Averaged power spectra of fricative /ʃ/ in [buˈlaʃɐ] from Corpus 3 (solid line), and in [pɐˈʃɐ] from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

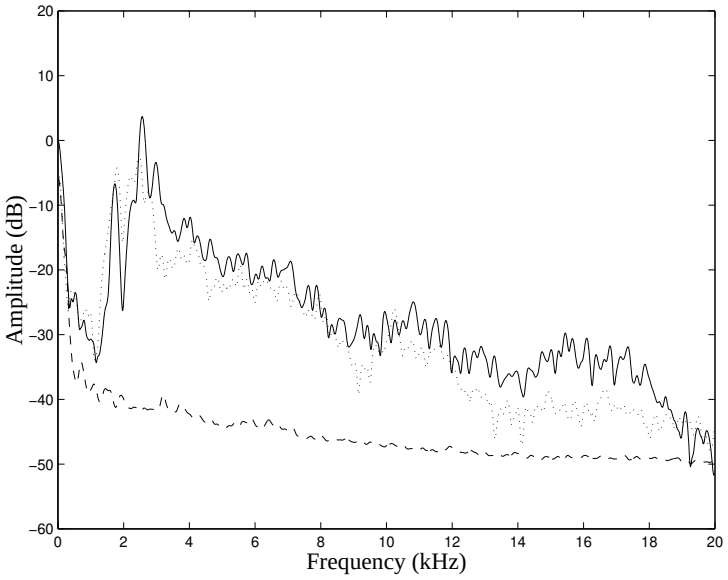


Figure 5.21: Averaged power spectra of fricative /ʃ/ in [ˈtɔʃɐ] from Corpus 3 (solid line), and in [ˈpuʃɐ] from Corpus 2 (dotted line). The dashed curve is the averaged spectrum of the room noise. Speaker LMTJ.

5.10 Discussion

The analysis of results from different corpora, shows that the peak and trough locations are quite similar. The vowel context does not seem to affect most of the peaks and troughs locations in the spectra of Portuguese fricatives.

The peak locations for the spectra of sustained fricatives are identical to those of corresponding fricatives in real words. Some of the broad peaks above 10 kHz observed in sustained fricatives are not visible in the spectra of fricatives from the word corpus.

From the analysis of the time-averaged spectra of different fricatives from Corpus 1b we have observed that the amplitude differences between the three effort levels are smallest at low frequencies. The amount of amplitude difference at high frequencies varies with the fricatives, from 10 dB for /f/ to 15 dB for /ʃ/; it tends to be smaller for the voiced fricatives, from 5 - 10 dB for /v/ to 10 dB for /ʒ/. These differences are associated with source type and strength, and are similar to results for American English and French subjects.

We have analysed the broad spectral envelope, and then refined this description to specific frequency bands which present significant differences or cues. We have also studied, the similarity of word-initial (Corpus 3) to high-effort (Corpus 1b) fricatives, word-medial to medium-effort fricatives and word-final to low-effort fricatives.

Chapter 6

Parameterising the Spectral Characteristics of Fricatives

6.1 Introduction

Fricative spectra have been parameterized in order to aid comparisons across speaker and across corpus, and to gain insight into the production mechanisms underlying the language-specific variations. The parameters, derived from previous studies, capture source-related changes for the most part as predicted; for the sustained fricative, they also separate fricatives by place.

6.2 Previous Studies Parameterising Fricatives

Automatic identification of fricatives in natural speech would be useful for speech recognition. Related applications involve detecting change in production of fricatives, e.g. after a cochlear implant, and quantifying differences in production across speakers. However all of these applications require a set of parameters to be applied to the acoustic signal or acoustic spectrum. Researchers have used spectral moments (Forrest et al. 1988) and locus equations (Sussman 1994) on fricatives without much success, although such techniques work well on stops. The parameterisation of fricatives can then have *two goals*: distinguish fricatives (e.g. speech recognition) and charac-

terize fricatives (e.g., voiced-voiceless, normal-disordered speech); and *three approaches*: locus equations, spectral moments and other time- or frequency-domain parameters.

Wilde (1995) studied acoustic cues (place and voiced/voiceless categorization) in fricative-vowel boundaries and assessed perceptual importance of various time/frequency-domain parameters via synthesis. She used nonsense words produced by 4 speakers of American English. Results showed that voiceless fricatives are more dependent on vowel context, and that voicing onset time and formant structure provide important place information. She also showed that the amplitudes of fricative noise in restricted frequency regions can distinguish sibilants from nonsibilants.

Jongman and Sereno (1995) and Jongman et al. (1998) studied spectral moments, locus equations, the spectral peak location, and noise duration and amplitude, as cues to place of articulation. The corpus consisted of nonsense words produced by 3 speakers of American English (Jongman and Sereno 1995) and 20 speakers of American English (Jongman et al. 1998). Spectral peak location and noise duration distinguished sibilants from non-sibilants; spectral peak location separated /s,z/ from /ʃ,ʒ/; the amplitude distinguished all four places of articulation. The slope of locus equations could be used to differentiate labiodental from the other three places of articulation. The first moment distinguished all places of articulation.

Sussman (1994) also used locus equations to distinguish fricatives but without much success, although this technique worked well on stops. The corpus consisted of a small number of nonsense words produced by 4 speakers of American English.

Evers et al. (1998) tried to distinguish and characterize the fricatives /s/ and /ʃ/ produced by two speakers of English, Bengali and Dutch (12 real words). They used power spectra computed from a single 40 ms window placed mid-fricative, and calculated the slopes of linear regression lines fit to spectra from 0 to 2.5 kHz (S_a) and from 2.5 kHz to 8 kHz (S_b). Their results showed that it was possible to separate /s/ from /ʃ/ by using the difference in slope below and above 2.5 kHz, i.e., $(S_a - S_b)_ʃ > (S_a - S_b)_s$. The slope difference was successful in categorizing the two sibilants within a range of 7-15 dB/kHz across the three languages. Results also showed that there is no vowel influence in the discrimination, and that there is a variation between speakers.

Forrest et al. (1988) used spectral moments to characterize normal speech with the intent of using them on disordered speech. Results showed that spectral moments worked well to classify stops but could not distinguish all fricatives. However, the authors used a very limited corpus of 5 real words produced by 10 speakers of American English.

Shadle and Mair (1996) used spectral moments, as in (Forrest et al. 1988), on a large fricative corpus recorded by one American English and one French native speaker. The moments that were the most useful for distinguishing fricatives in (Forrest et al. 1988) proved not to be, when used on multiple tokens, varying effort levels, different vowel contexts, and three different locations within a fricative. Two additional parameters, dynamic amplitude and spectral slope, were defined. These did not distinguish the fricatives completely but did vary with source location and effort level as predicted.

Parameters similar to those used in (Shadle and Mair 1996), and S_p' similar to S_a used in (Evers et al. 1998), were used in this study in order to compare fricatives across-speaker, relate the more controlled productions (sustained and nonsense words) to those of real words, and gain insight into the production mechanisms underlying the variations specific to Portuguese.

6.3 Parameterisation

The parameters used were defined first from mechanical model results (Shadle 1985) and further developed as a potential tool for classifying fricatives using real speech (Shadle and Mair 1996). They consist of measures of the dynamic range of the spectrum, and spectral slope, and are applied to the spectrum of the far-field acoustic signal.

The far-field acoustic signal is the result of the excitation of the tract transfer function by the source (for unvoiced) or sources (for voiced fricatives). The transfer function consists of poles, which are the resonances of the entire vocal tract, and zeros, which are antiresonances of the part of the tract upstream of the noise source, see Figure 6.1.

If the noise source is distributed, as in /ç/, zero frequencies will be correspondingly smeared. An intermediate source location (as for all fricatives) always produces a low-frequency zero. Poles and zeros corresponding to

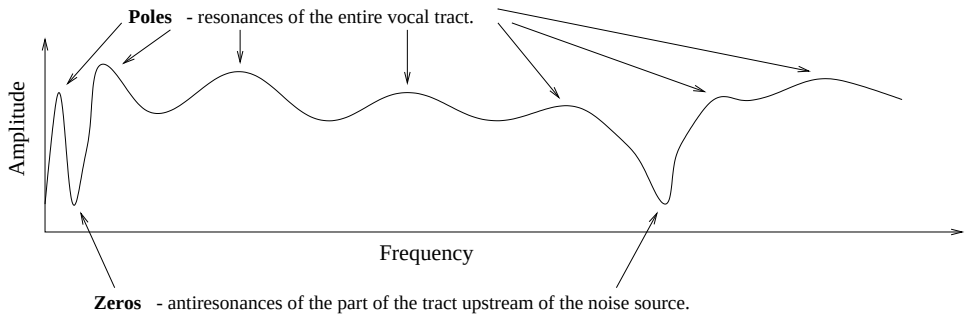


Figure 6.1: Transfer function.

back-cavity resonances tend nearly to cancel. Uncancelled poles correspond to front cavity resonances; their spectral prominence will depend on both the losses (especially radiation losses) and the noise source strength at their respective frequencies.

The noise source spectrum depends on the shape of the constriction, the tract downstream of it, and the flow velocity through it. The noise source spectrum envelope has its highest amplitude at low frequencies and falls off smoothly. If the tract geometry remains the same and flow velocity is increased, as seen in Figure 6.2, the noise spectral envelope increases in amplitude at all frequencies, *but more so at higher frequencies* (Shadle and Mair 1996). The noise source is weaker in voiced fricatives than their unvoiced counterparts.

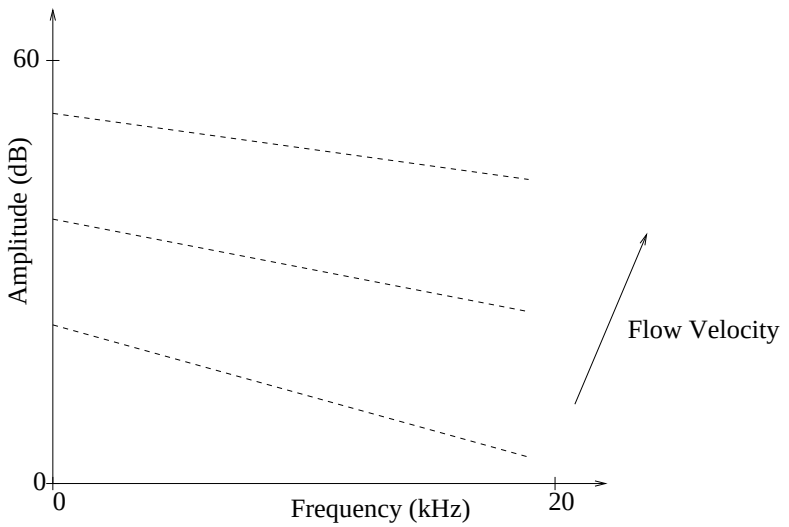


Figure 6.2: Noise source spectral envelope.

The frication source location can be constant as in most examples of /s/ and

/ʃ/, or it can be changing over time as in any fricative which is surrounded by different vowels. We will be looking at time-averaged power spectra, so the change in source location will also be "time-averaged", i.e., the change in source location is assimilated into the time-averaged spectra.

If our goal is identification of the fricative spoken regardless of its context or the way in which it was spoken, we are then interested in the transfer function, since the peak frequencies offer clues to the place, and in the source type, since that not only differentiates voiced and unvoiced versions, but, in indicating whether the source is localized or distributed, again offers clues to the place. If our goal instead is to describe the acoustic variation caused by the context or the way in which a particular fricative is spoken, we are then interested in the source spectrum, since it offers clues to the source variations across subject and corpus. In this study we are primarily interested in the latter goal.

Figure 6.3 illustrates the four parameters that we consider in this paper. F is the frequency of the spectral peak between 2 and 8 kHz having maximum amplitude, and which corresponds to the same cavity resonance for all tokens of a particular fricatives.

The dynamic amplitude, A_d, is the difference between the maximum amplitude value of the averaged power spectrum occurring between 0.5 and 20 kHz, and the minimum amplitude between 0 and 2 kHz. Two linear regression lines are fit to the spectrum; S_p' is the slope of the line fit to all the points from 500 Hz to F, and S_p is the slope of the line fit to all the points from F to 20 kHz. This frequency range allows us to capture relevant variations in the sound power (the area delimited by the acoustic spectrum) and shifts in the peaks, which was not possible in previous studies such as the measurements of spectral tilts up to 5 kHz by Badin et al. (1994).

The values of F used to calculate S_p and S_p' were the same for each place of articulation of the 6 fricatives for all speakers and corpora: $F_{/\text{f,v}/} = 5\,\text{kHz}$, $F_{/\text{s,z}/} = 6\,\text{kHz}$ and $F_{/\text{ʃ,ʒ}/} = 4\,\text{kHz}$. These frequencies are the average of the manually calculated values of all sustained tokens (Corpus 1a) of a particular place (labiodental, alveolar and postalveolar).

Given these definitions, we can make the following predictions. The parameter F should be related to place of the fricative, decreasing as place moves posteriorly. The parameter A_d should be maximized for a localized source,

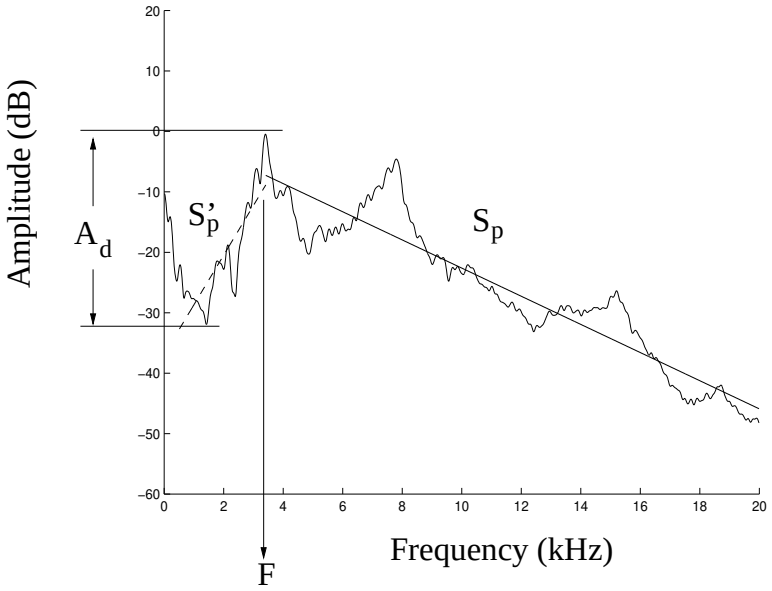


Figure 6.3: Dynamic amplitude A_d, and regression lines used to calculate low frequency (500 Hz to F kHz) slope S_p' (dashed line) and high frequency (F kHz to 20 kHz) slope S_p (solid line). Sustained fricative /ʃ/ (Corpus 1a) produced by Speaker ISSS.

and for higher source strength, as in sibilants, and unvoiced fricatives. The parameter S_p should be related to the source strength. Although the resonance peaks will affect the line fit, they should affect the fit in the same way for within-fricative comparisons. Thus, for a given fricative where transfer function will vary only slightly from token to token, S_p should increase, i.e. become less negative, as flow velocity through the constriction increases.

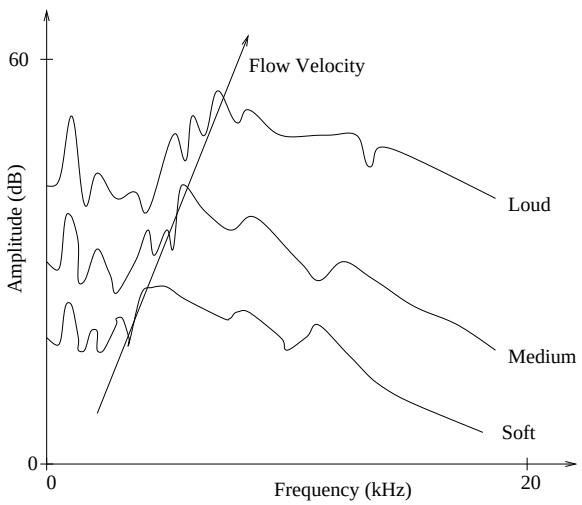


Figure 6.4: Correlation between effort level and increased flow velocity.

Effort level (see Figure 6.4) and syllable stress should be correlated with increased flow velocity; the velocity should also be at a maximum mid-fricative, when constriction area is smallest and pressure across the constriction highest. The parameter S_p' should be similar to A_d. For a fricative with a localized source and posterior place, S_p' will be the largest. Within a fricative, increased S_p' should be correlated with either more posterior place (due, for instance, to a more rounded vowel context) or greater source strength. See Table 6.1 for a summary of the predicted effects on parameters.

Table 6.1: Predicted effects on parameters.

Phonetic Class	Aeroacoustics	Predictions
Posterior place; sibilants /s,z,ʃ,ʒ/	Longer front cavity; Localized source; Higher source strength *	F lower; A_d, S_p and S'_p higher
Forward place; nonsibilants /f,v/	Distributed source; Lower source strength	F higher; A_d, S_p and S'_p lower
Unvoiced	Higher source strength *	A_d, S_p and S'_p higher
Voiced-Devoiced		
Voiced	Lower source strength	A_d, S_p and S'_p lower
Loud effort level	Higher source strength *	A_d, S_p and S'_p higher
Medium effort level		
Soft effort level		
Beginning of fricative		
Middle of fricative	Higher source strength *	A_d, S_p and S'_p higher
End of fricative		
Stressed syllable	Higher source strength *	A_d, S_p and S'_p higher
Destressed syllable		
Word position		
Rounded	Longer front cavity; Lower source strength †	F lower; A_d higher; ? S'_p and S_p lower
Unrounded		
Subject		? No effect

*A higher source strength means higher airflow for the same constriction area A_c, or a constant flow for a smaller A_c.

†The lips form a second constriction and so the one downstream in the vocal tract has lower strength (unpublished experimental results by Shadle and Bandin).

6.4 Results

6.4.1 Sustained Fricatives

Figure 6.5 shows average regression line fits (from F to 20 kHz) to the spectra of the sustained fricatives in Corpus 1b. Each graph corresponds to a single place, and shows lines for three effort levels, voiced and unvoiced. Clearly,

each place has a different "family" of nearly-parallel lines; higher effort level increases amplitude significantly and slope slightly, as predicted. The families of lines for the voiced and unvoiced fricatives always overlap, with the voiced cases mostly lower in amplitude and occupying a smaller range of amplitudes than the unvoiced cases.

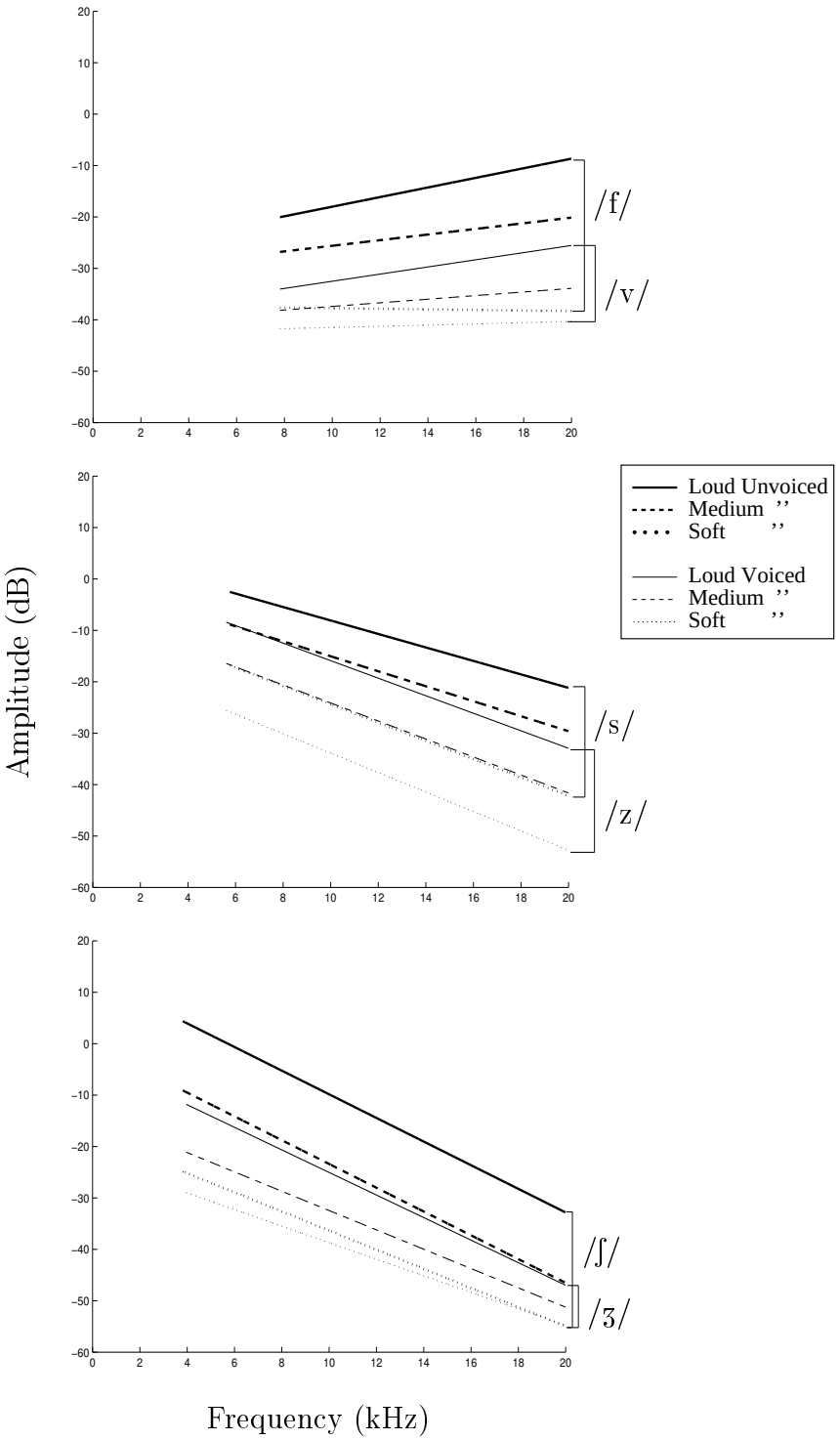


Figure 6.5: Average regression line fits (from F to 20 kHz) of sustained labiodental (top), alveolar (middle) and postalveolar (bottom) fricatives from Corpus 1b at loud, medium and soft effort levels. Speaker ISSS.

For all subjects, Corpus 1a and 1b, /s, z, ʃ, ʒ/ have a higher A_d than /f, v/, as predicted; this parameter also differentiates between voiced fricatives and their unvoiced counterparts, as can be seen in Figure 6.6.

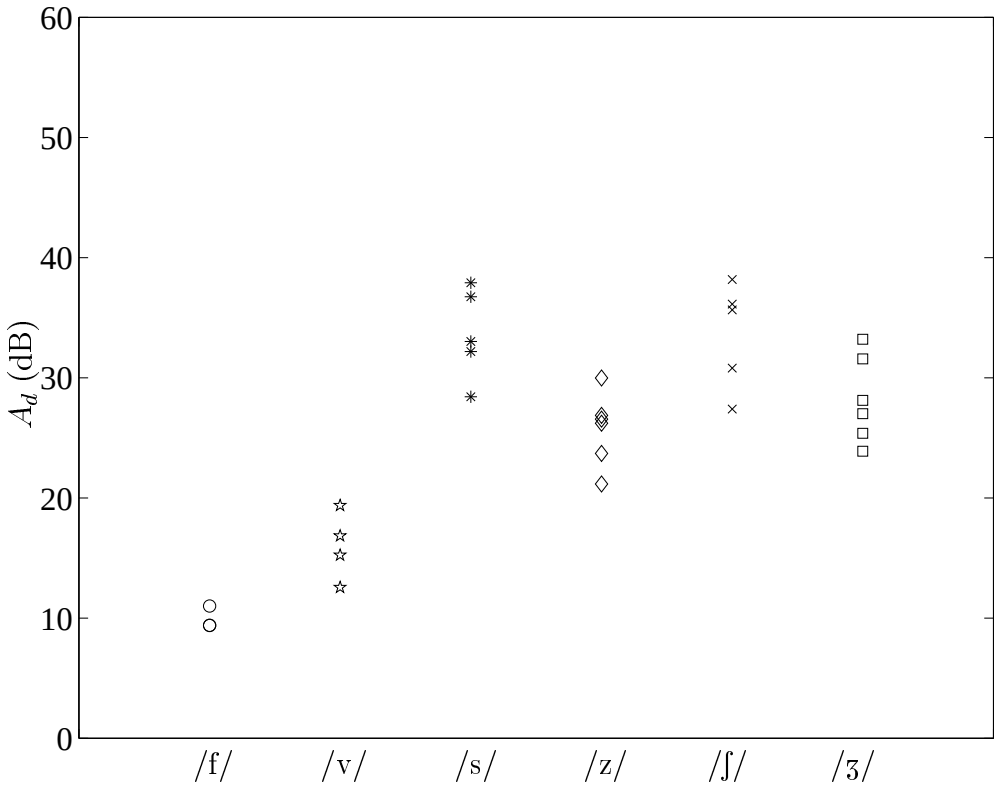


Figure 6.6: Dynamic amplitude of fricatives from Corpus 1a. Speaker LMTJ.

Figure 6.7 shows S_p vs. effort level for subject ACC. Slope generally increases with increased effort level, though this pattern is much more consistent for unvoiced fricatives. This is consistent with results in (Shadle and Mair 1996).

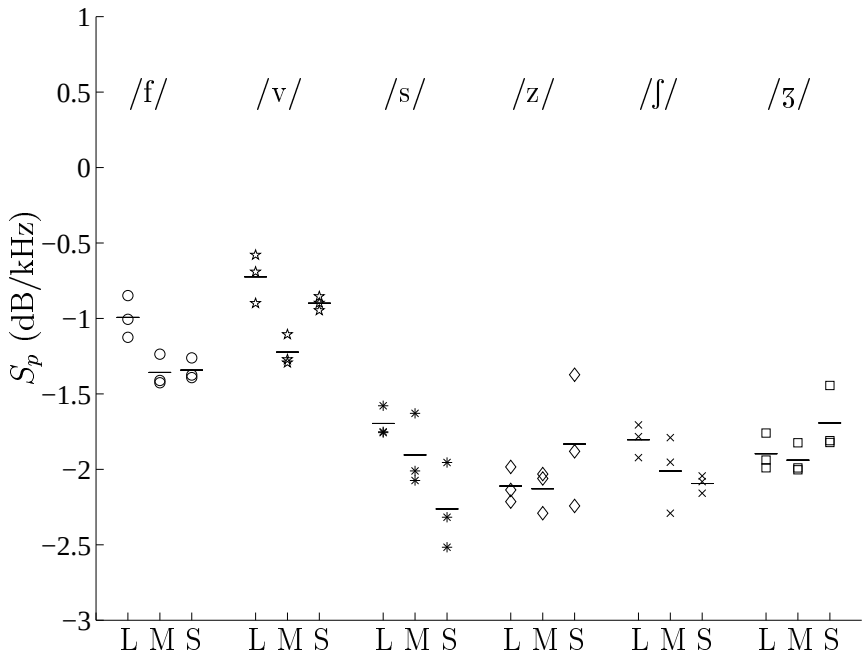


Figure 6.7: Spectral slope of sustained fricatives from Corpus 1b at Loud (L), Medium (M) and Soft (S) effort levels. The horizontal line is the average value of all the examples. Speaker ACC.

On an A_d vs. S_p plot shown in Figure 6.8 we predict that sustained fricatives will form two distinct clusters: sibilants and /f,v/. This is confirmed by the results shown in Figure 6.9 . If we use the value of F as a third dimension then on a F vs. A_d vs. S_p plot the fricatives cluster by place (labiodental, alveolar and postalveolar) as shown in Figure 6.10.

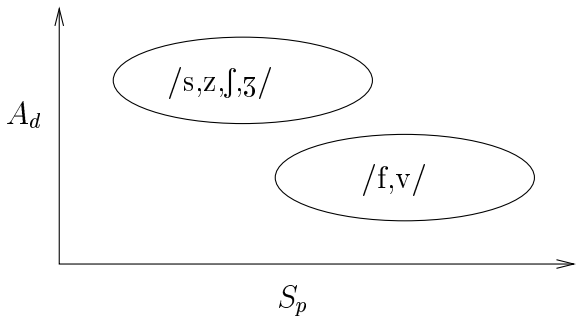


Figure 6.8: Predictions of A_d vs. S_p.

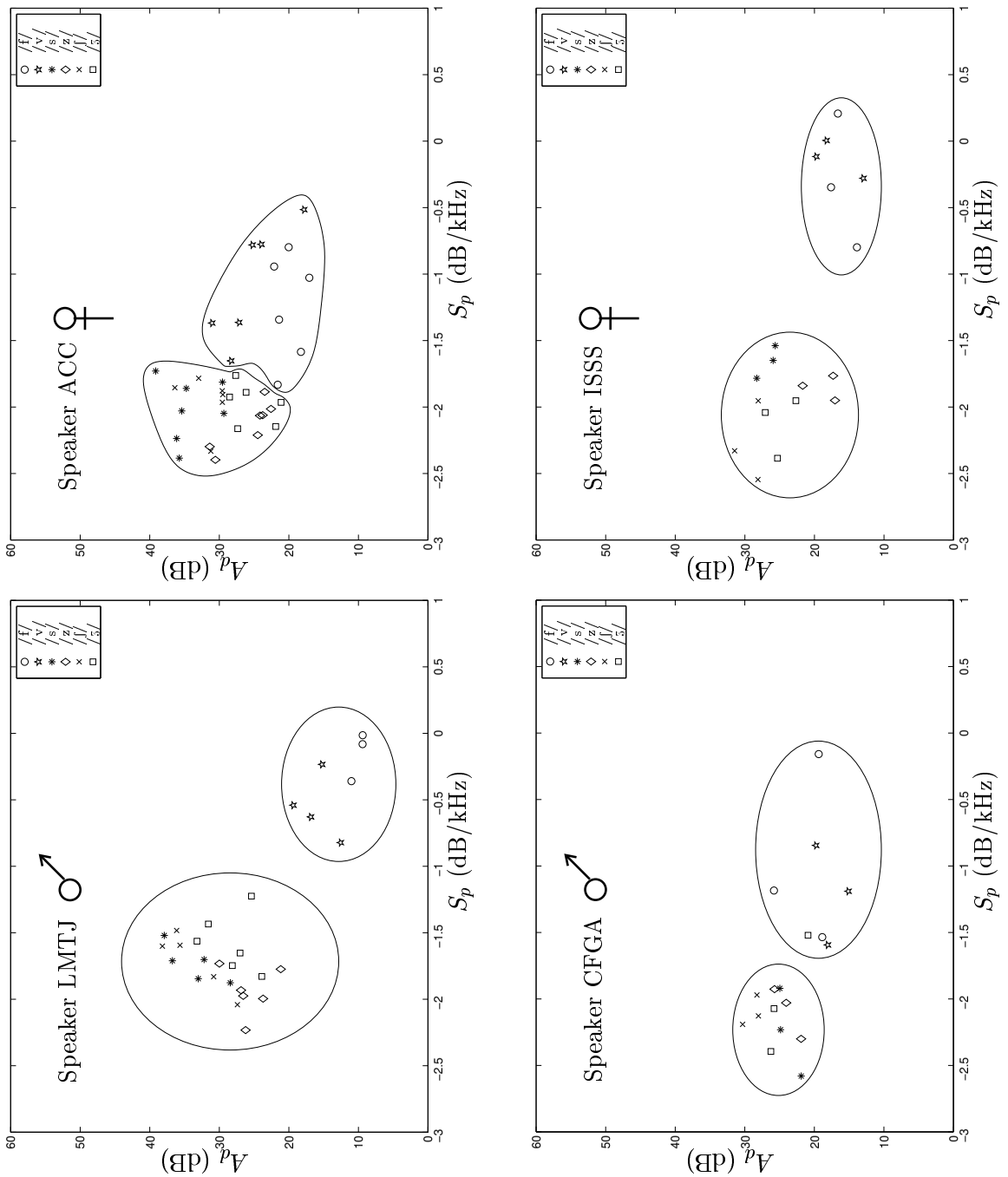


Figure 6.9: Corpus 1a (sustained fricatives), A_d vs. S_p.

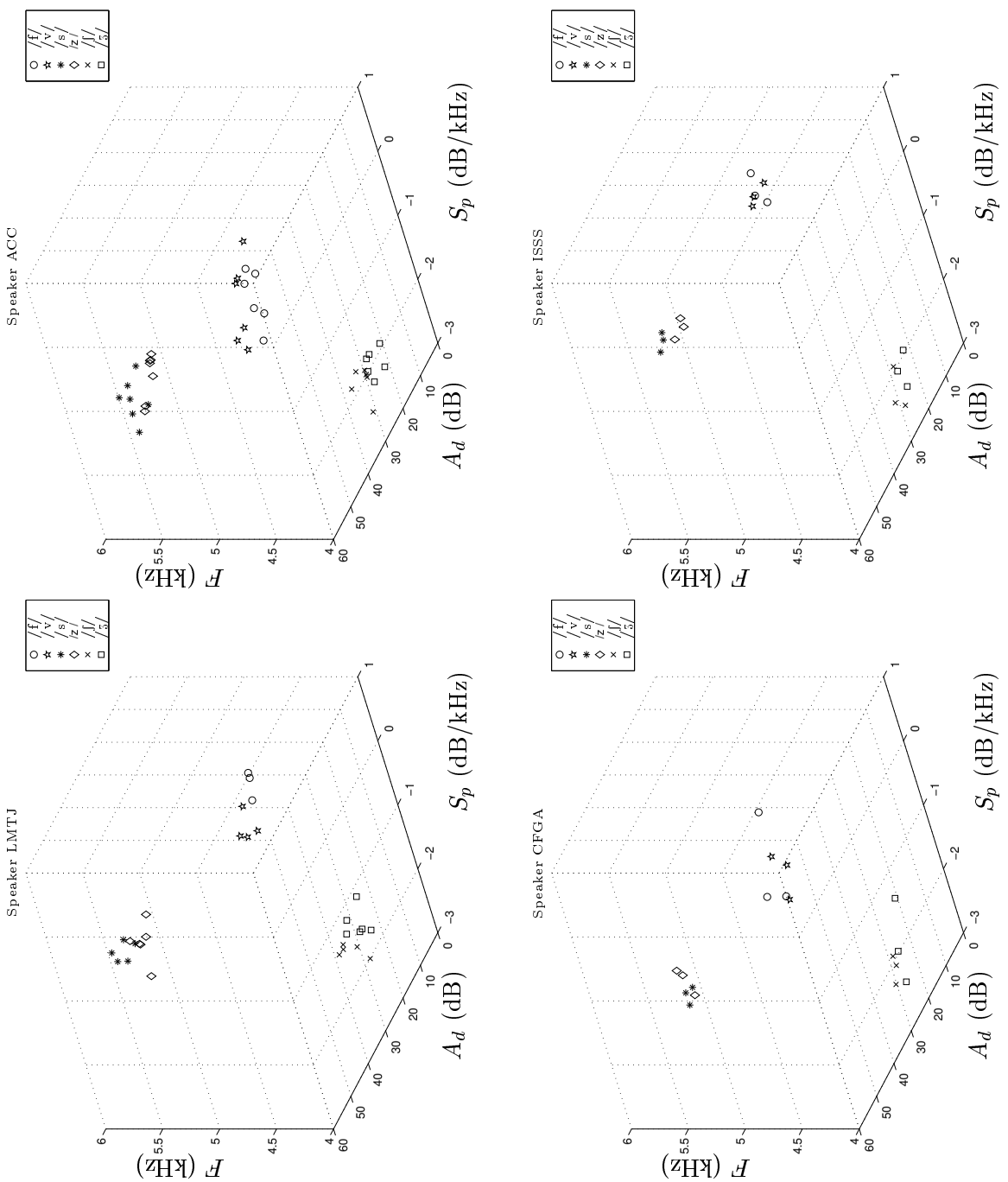


Figure 6.10: Corpus 1a (sustained fricatives), F vs. A_d vs. S_p.

We predict that on an S_p' vs. S_p plot, as the one shown in Figure 6.11, each place will cluster separately, with voiced tokens having lower S_p' but similar S_p relative to their unvoiced counterparts.

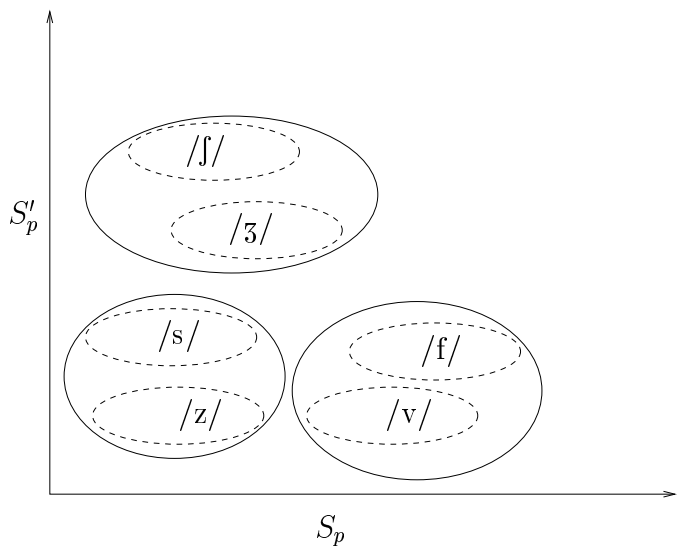


Figure 6.11: Predictions of S'_p vs. S_p.

Figure 6.12 shows S'_p vs. S_p values plotted for Corpus 1a. Results for speakers LMTJ, CFGA and ISSS, confirm the findings of Evers et al. (1998), i.e., that it is possible to separate /s/ from /ʃ/. In fact, for these subjects, fricatives /f,v/, /s,z/ and /ʃ,ʒ/ form clusters in the feature space, i.e., they are separated by place; as predicted, the voiced tokens of each had lower S'_p and similar S_p than their unvoiced correlates. For ACC the voicing relationship was maintained, but /s,z/ tokens fell inbetween the /ʃ/ and /ʒ/ tokens. If we plot a F vs. A_d vs. S_p graph the fricatives produced by all four speakers cluster by place as shown in Figure 6.13.

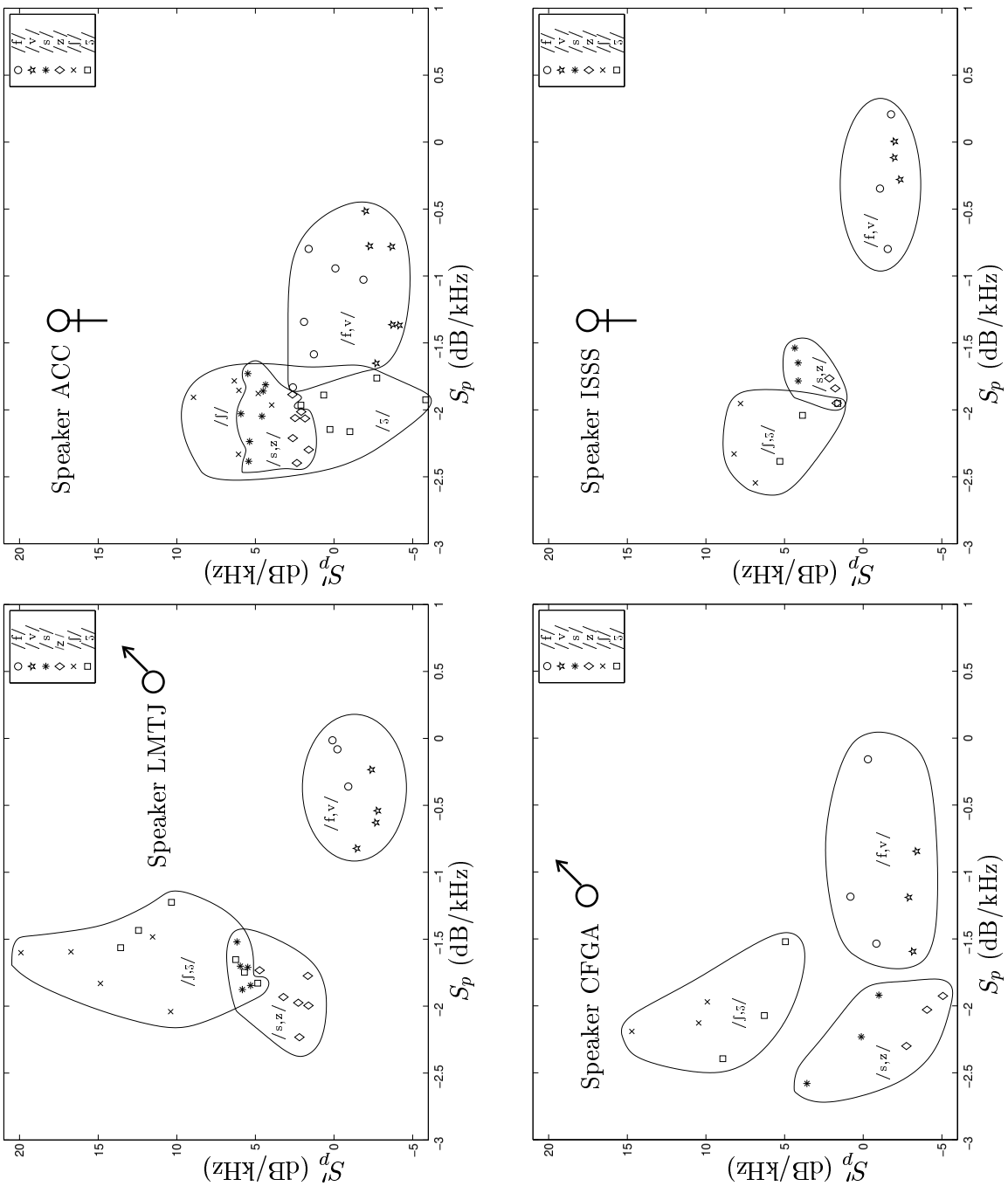


Figure 6.12: Corpus 1a (sustained fricatives), S_p' vs. S_p.

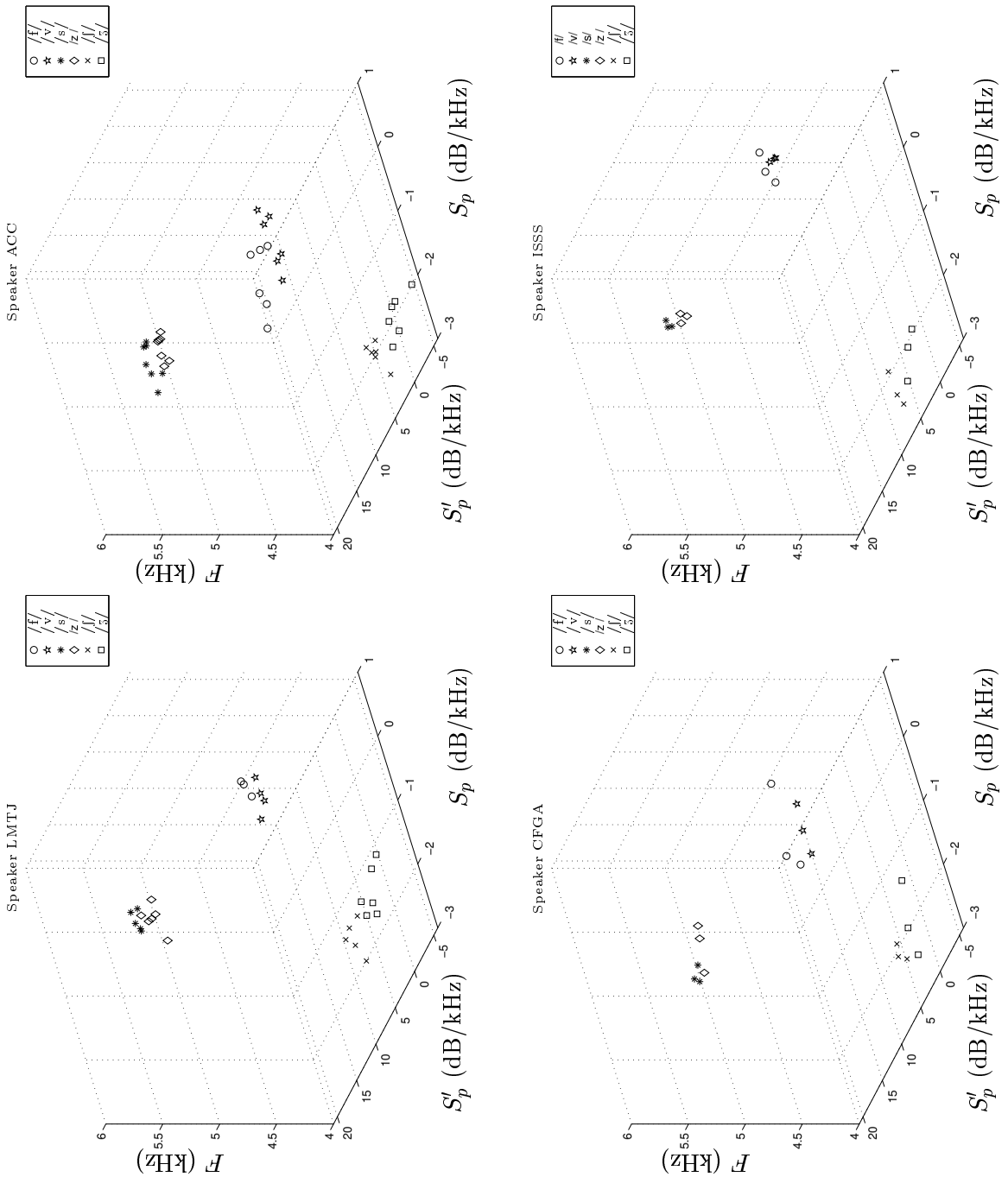


Figure 6.13: Corpus 1a (sustained fricatives), F vs. S_p' vs. S_p.

We have also looked at the influence of effort level on parameters A_d, S_p and S_p', as shown in Figures Figure 6.14 and 6.15, and found that there is no or little change in A_d, S_p or S_p' not as predicted.

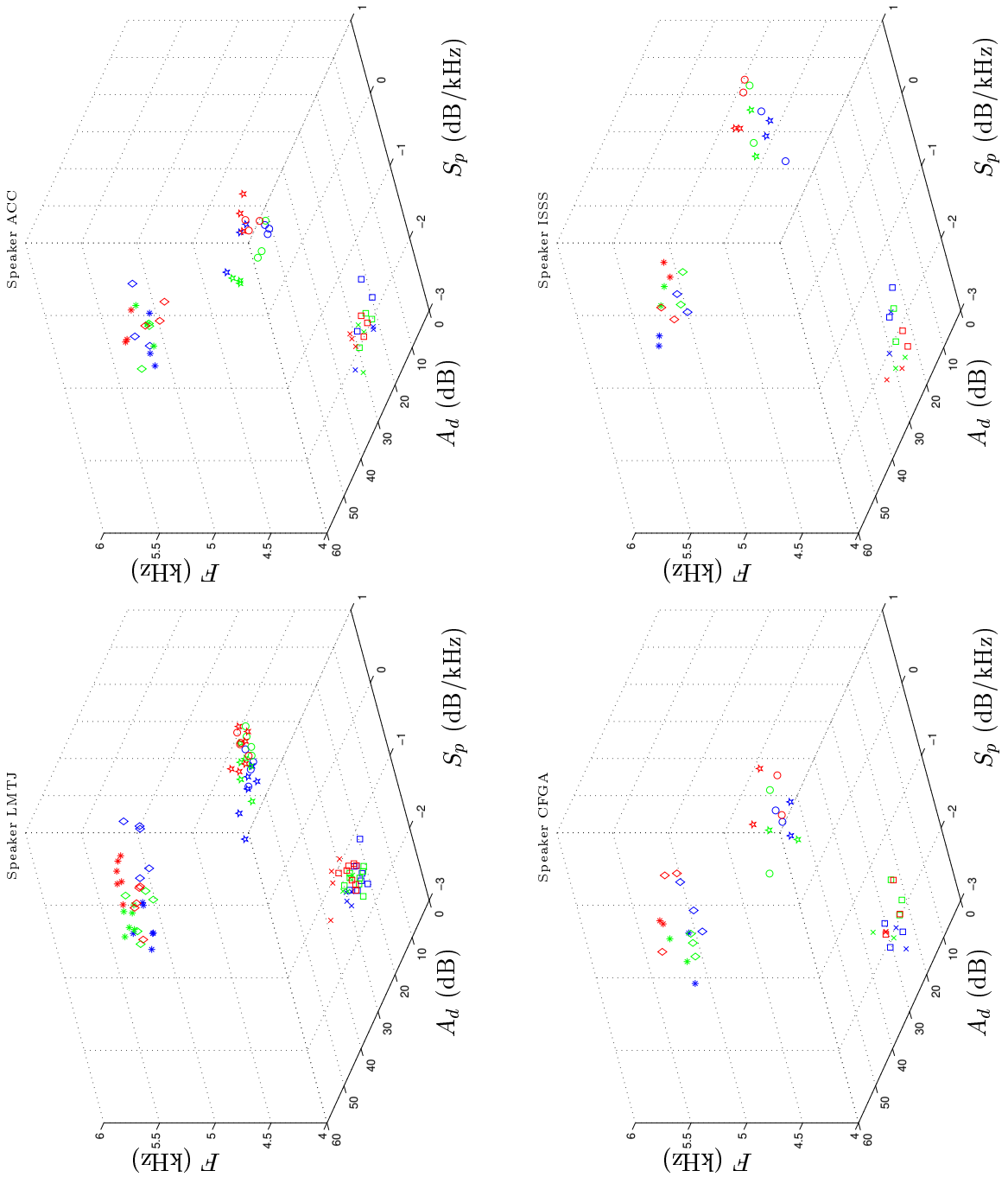


Figure 6.14: F vs. A_d vs. S_p. Corpus 1b: fricatives sustained at three different effort levels: soft (blue), medium (green) and loud (red). $\circ$ – /f/, $\star$ – /v/, $*$ – /s/, $\diamond$ – /z/, $\times$ – /ʃ/ and $\square$ – /ʒ/.

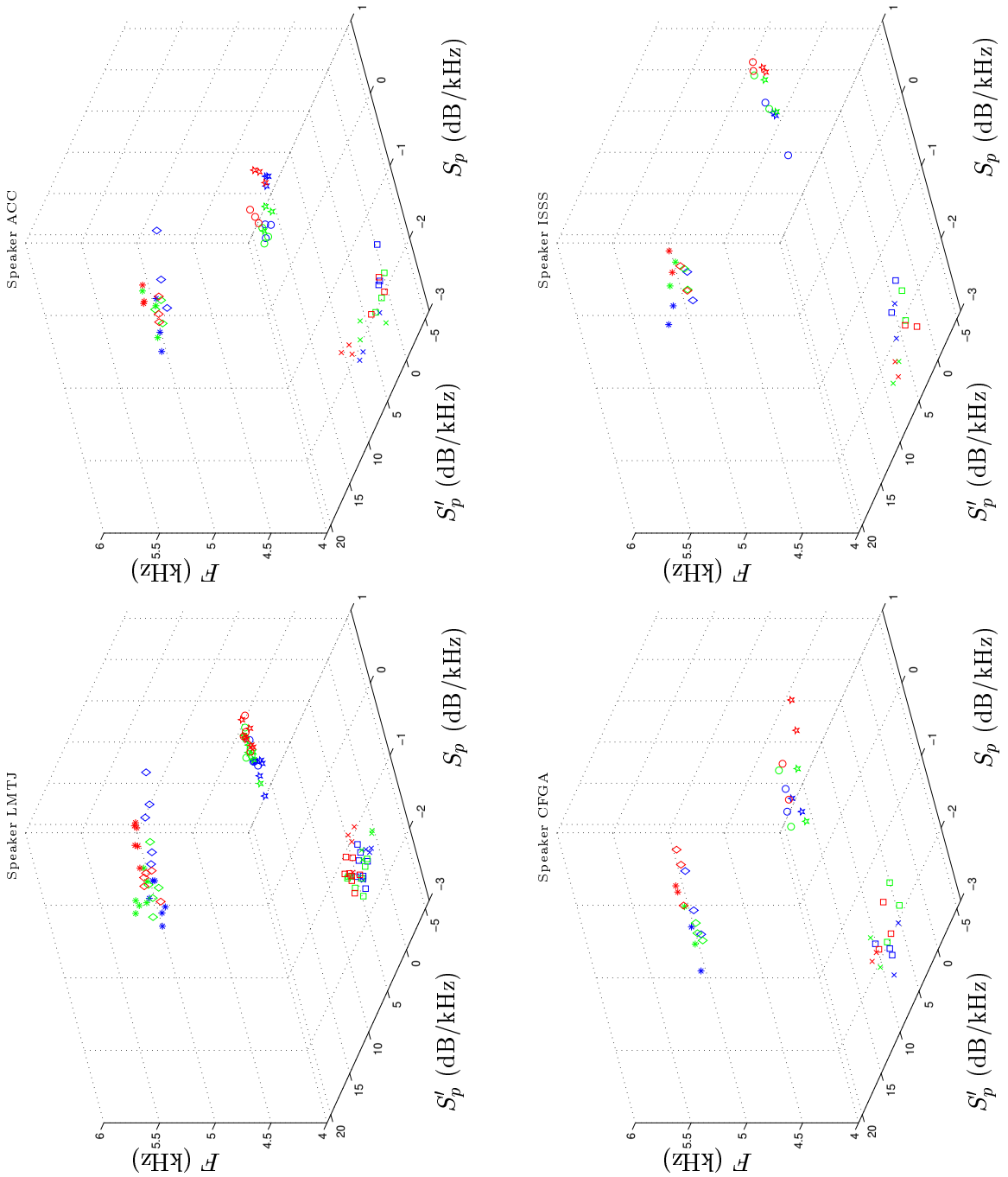


Figure 6.15: F vs. S'_p vs. S_p. Corpus 1b: fricatives sustained at three different effort levels: soft (blue), medium (green) and loud (red). $\circ$ – /f/, $\star$ – /v/, $*$ – /s/, $\diamond$ – /z/, $\times$ – /ʃ/ and $\square$ – /ʒ/.

6.4.2 Fricatives in Context

> "Physiological realization of the categorical feature specification [+ voice] – when considered in terms of several quasi-independent articulatory movements (which may or may not be specific to, but undeniably relevant to control of *closure voicing*) is neither place nor context-invariant." (Westbury 1983)

6.4.2.1 Fricatives in Nonsense Words (Corpus 2)

In Figures 6.16 and 6.17, A_d and S_p are plotted vs. location of the analysis window within the fricative for Corpus 2, subject LMTJ. For /f,v/ there is no consistent pattern; results in (Shadle et al. 1996) indicate that the vowel context may play more of a role. As for the sustained fricatives, A_d separates sibilants from /f, v/. A_d is higher on average at the middle of the fricative than at the beginning and end for /s, z, ʃ, ʒ/, as predicted.

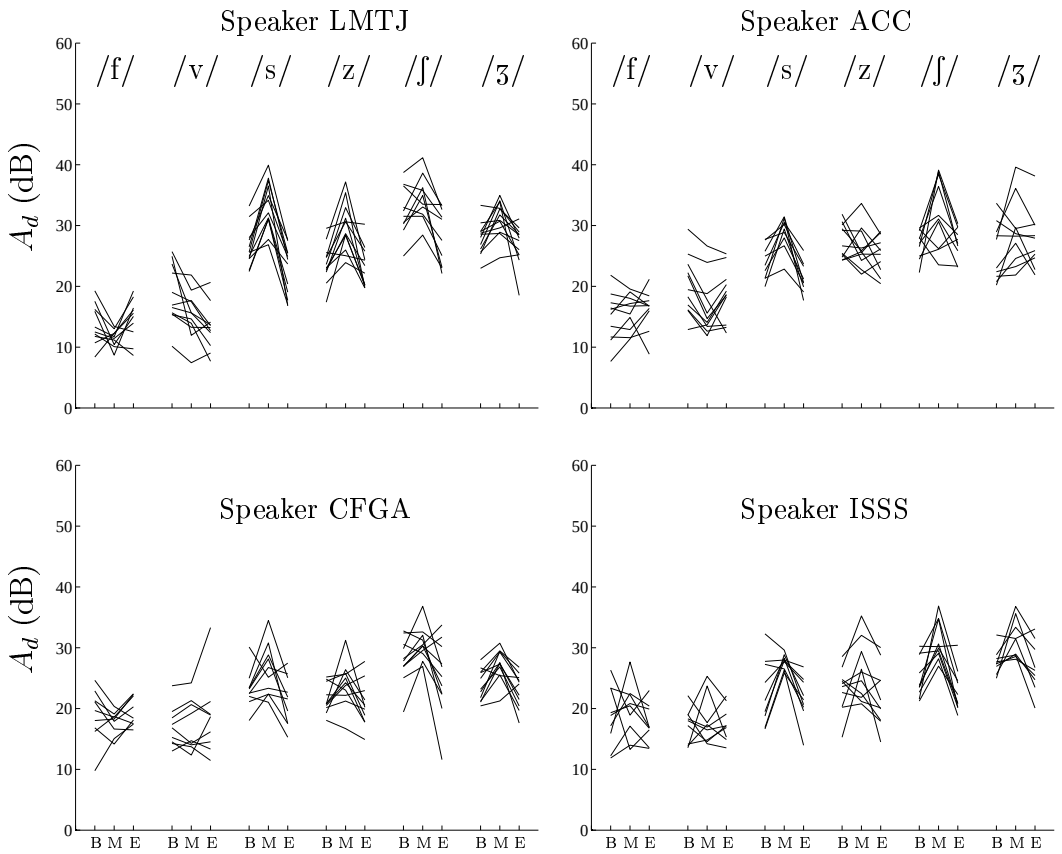


Figure 6.16: Dynamic amplitude of fricatives from Corpus 2, at the Beginning (B), Middle (M) and End (E) of the fricative.

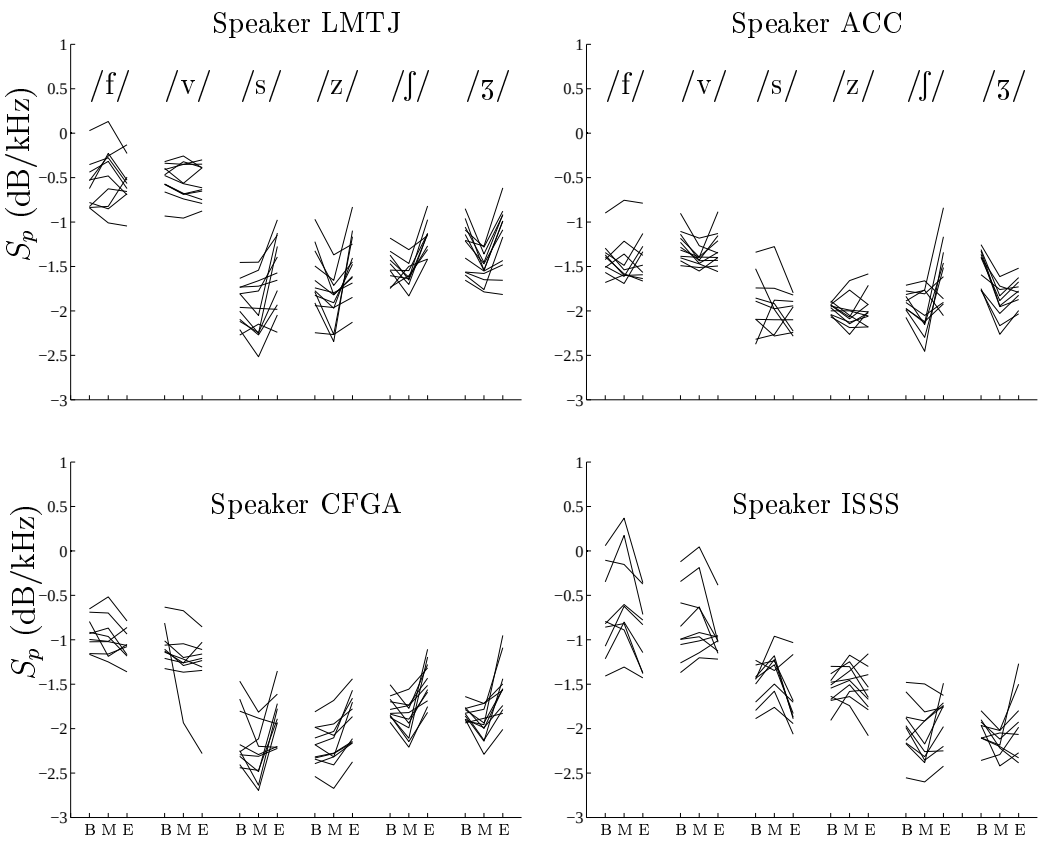


Figure 6.17: Spectral slope of fricatives from Corpus 2, at the Beginning (B), Middle (M) and End (E) of the fricative.

On a F vs. A_d or S'_p vs. S_p graph the fricatives in nonsense words (Corpus 2) produced by all four speakers cluster by place as shown in Figures 6.18 and 6.19. When we use place knowledge, i.e. use F, to plot A_d vs. S_p at the beginning, middle and end the results are also inconclusive, as shown in Figures 6.20 to 6.23.

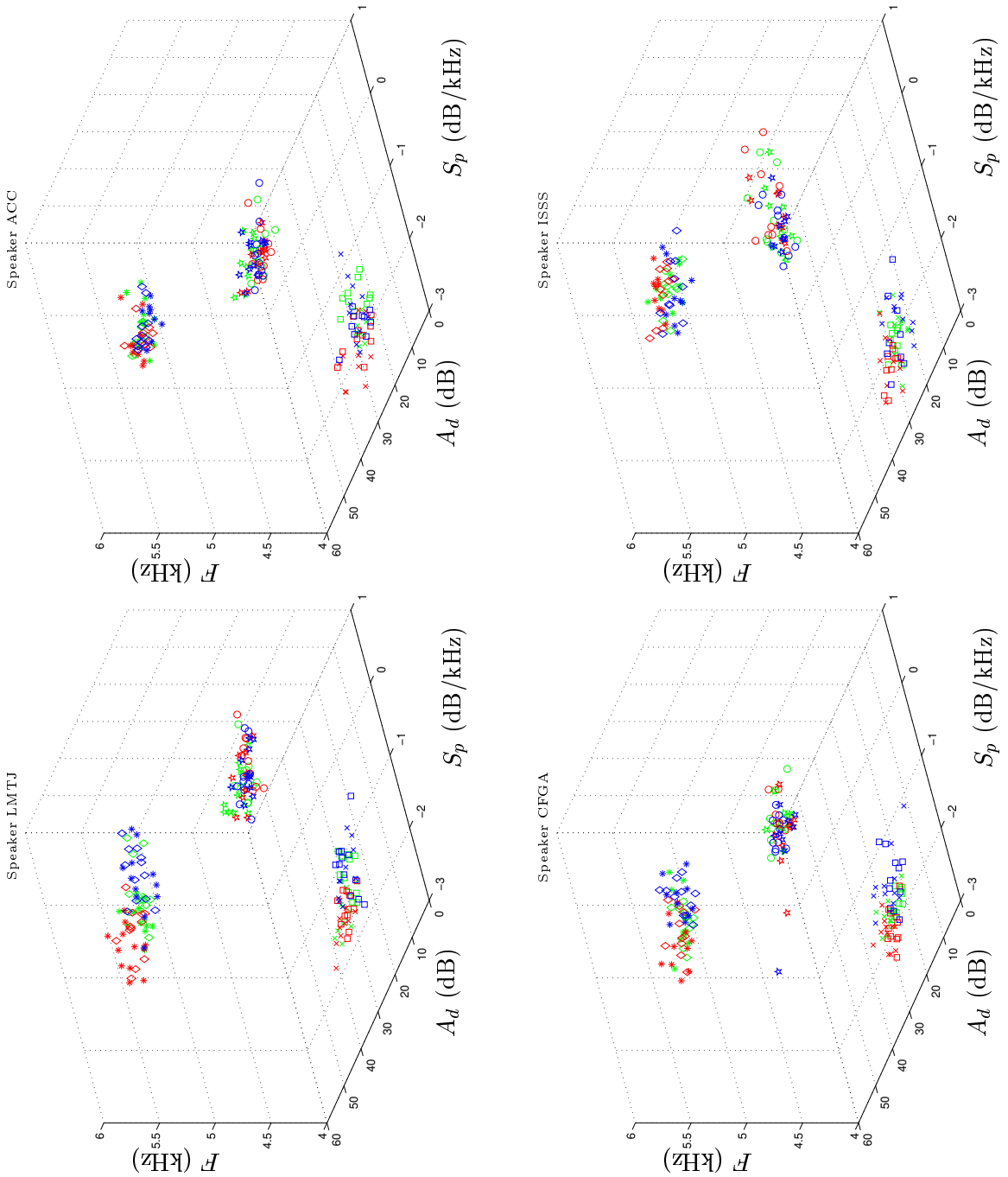


Figure 6.18: Corpus 2, F vs. A_d vs. S_p at the end (blue), beginning (green) and middle (red) of the fricative. $\circ$ – /f/, $\star$ – /v/, $*$ – /s/, $\diamond$ – /z/, $\times$ – /ʃ/ and $\square$ – /ʒ/.

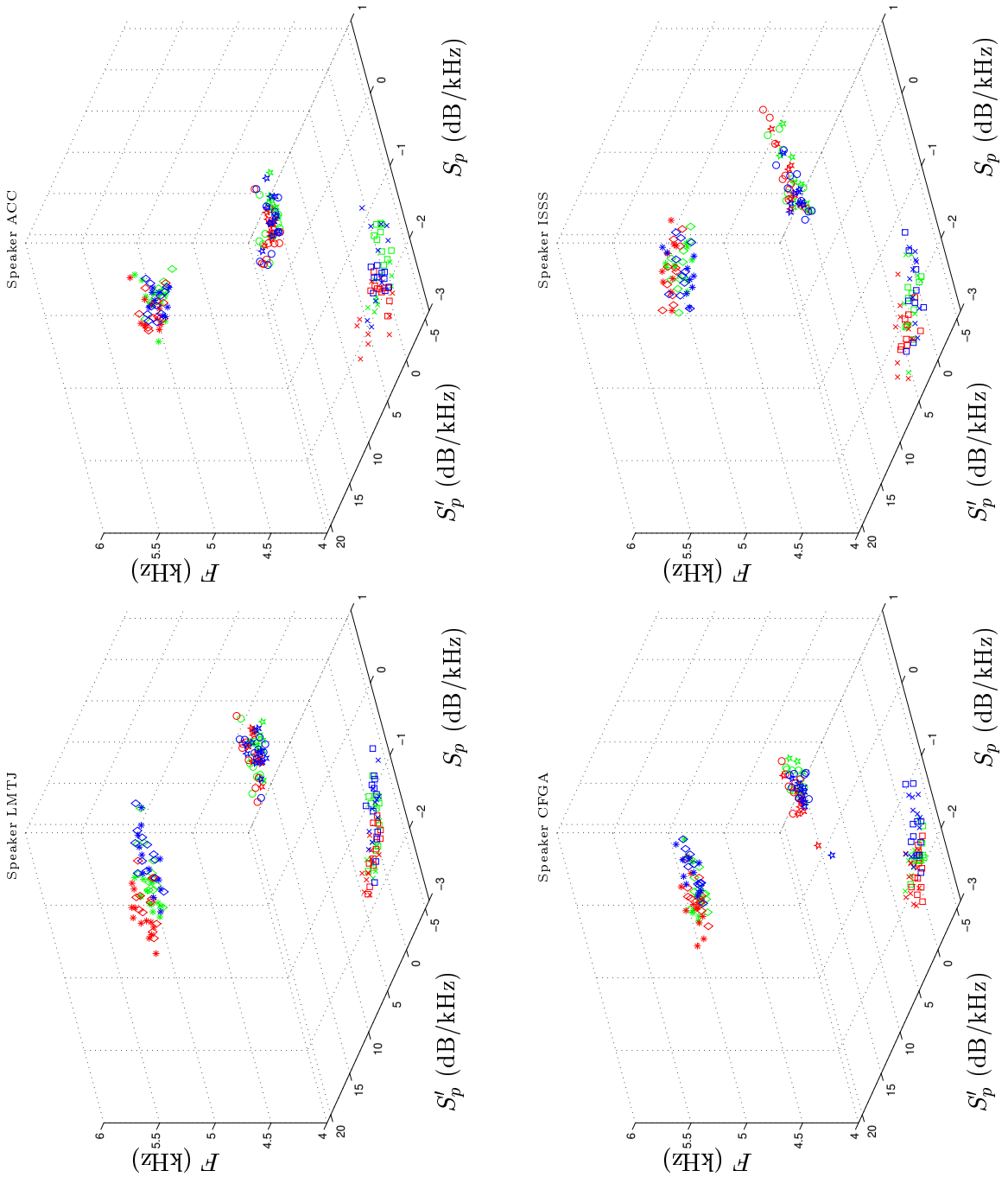


Figure 6.19: Corpus 2, F vs. S'_p vs. S_p at the end (blue), beginning (green) and middle (red) of the fricative. $\circ$ – /f/, $\star$ – /v/, $*$ – /s/, $\diamond$ – /z/, $\times$ – /ʃ/ and $\square$ – /ʒ/.

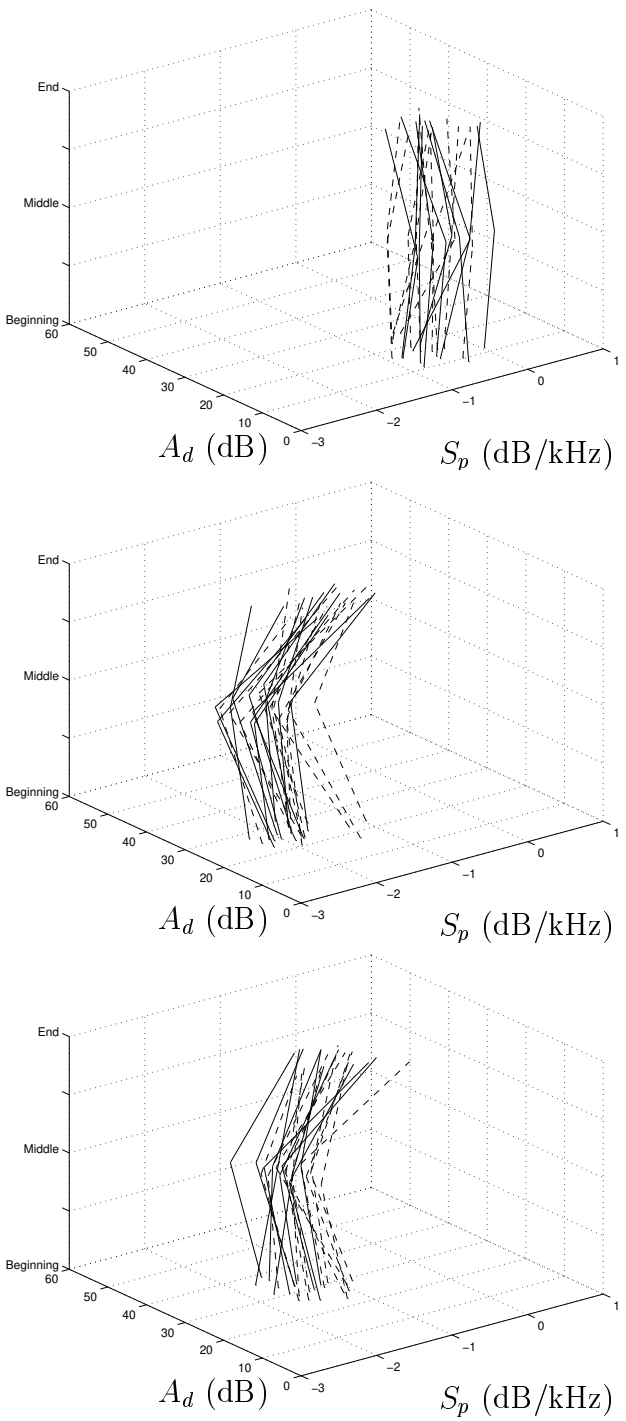


Figure 6.20: F vs. A_d vs. S_p at the beginning, middle and end of the fricative. Top: F=5 kHz, Labiodental (/f/ – solid line, and /v/ – dashed line); Middle: F=6 kHz, Alveolar (/s/ – solid line, and /z/ – dashed line); Bottom: F= 4kHz, Postalveolar (/ʃ/ – solid line, and /ʒ/ – dashed line). Corpus 2 (Speaker LMTJ).

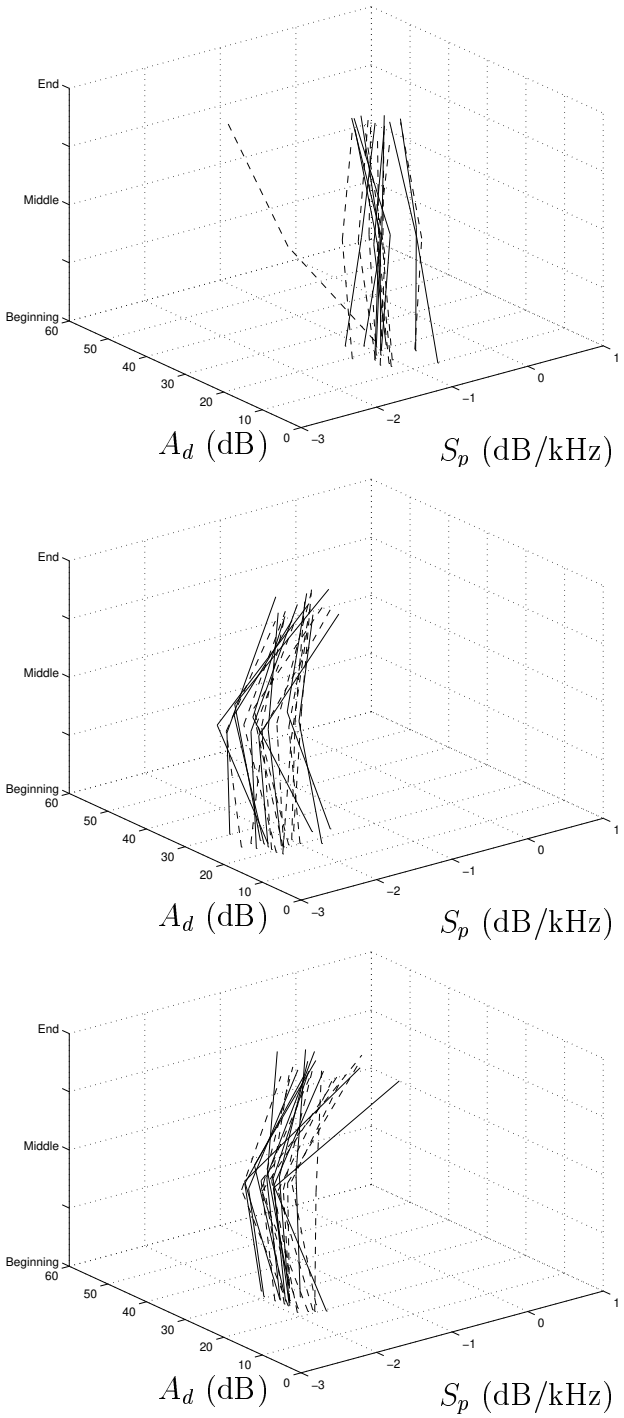


Figure 6.21: A_d vs. S_p at the beginning, middle and end of the fricative. Top: F=5 kHz, Labiodental (/f/ – solid line, and /v/ – dashed line); Middle: F=6 kHz, Alveolar (/s/ – solid line, and /z/ – dashed line); Bottom: F = 4kHz, Postalveolar (/ʃ/ – solid line, and /ʒ/ – dashed line). Corpus 2 (Speaker CFGA).

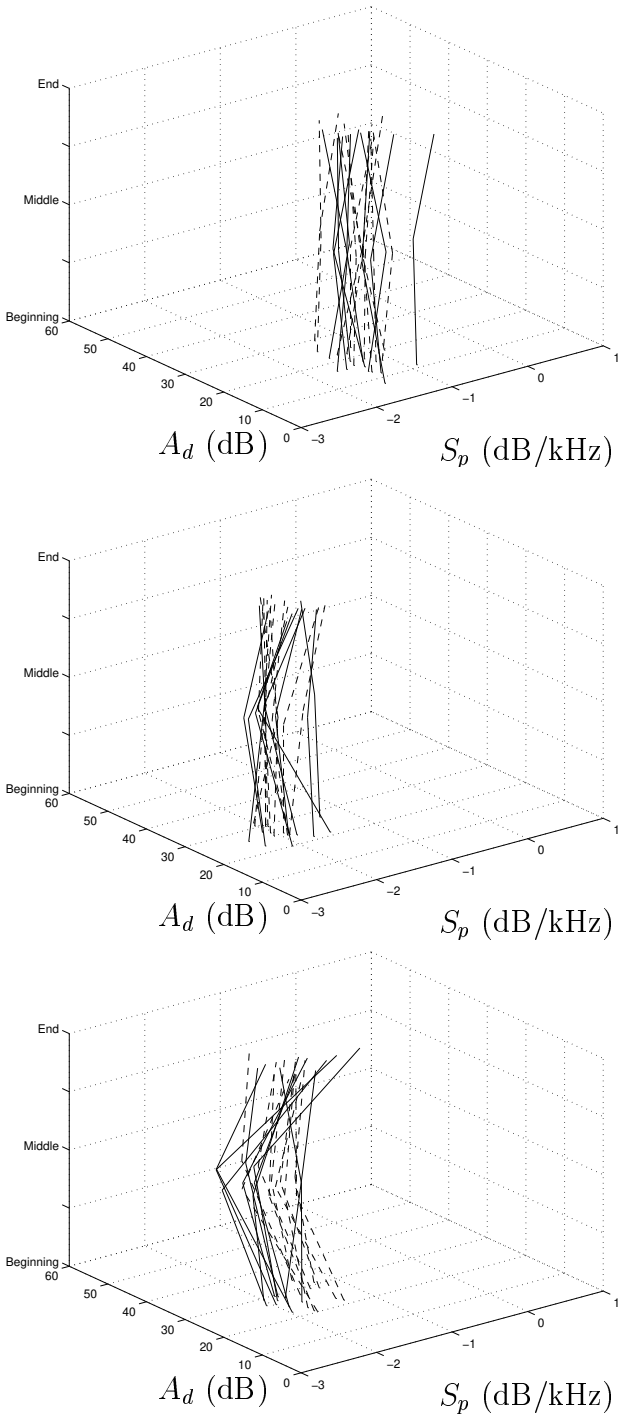


Figure 6.22: A_d vs. S_p at the beginning, middle and end of the fricative. Top: F=5 kHz, Labiodental (/f/ – solid line, and /v/ – dashed line); Middle: F=6 kHz, Alveolar (/s/ – solid line, and /z/ – dashed line); Bottom: F = 4kHz, Postalveolar (/ʃ/ – solid line, and /ʒ/ – dashed line). Corpus 2 (Speaker ACC).

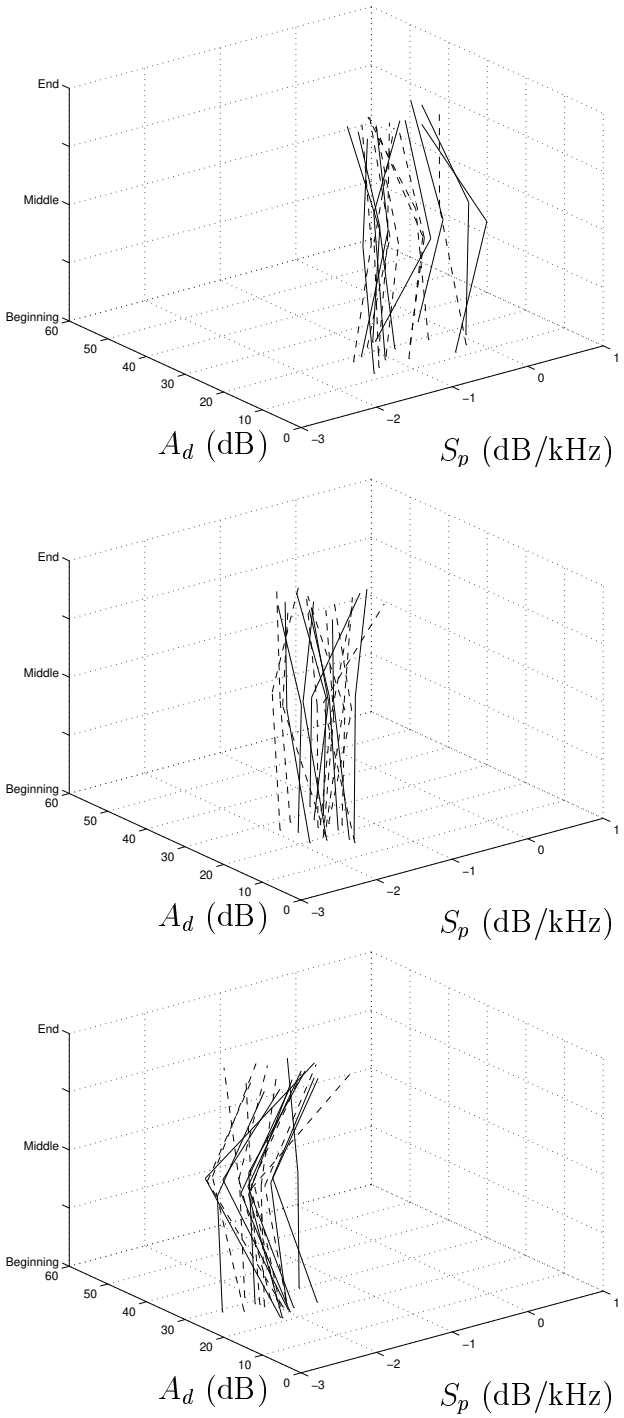


Figure 6.23: A_d vs. S_p at the beginning, middle and end of the fricative. Top: F=5 kHz, Labiodental (/f/ – solid line, and /v/ – dashed line); Middle: F=6 kHz, Alveolar (/s/ – solid line, and /z/ – dashed line); Bottom: F= 4kHz, Postalveolar (/ʃ/ – solid line, and /ʒ/ – dashed line). Corpus 2 (Speaker ISSS).

Preliminary comparisons of stressed and destressed fricatives indicate no or little change in A_d and S_p, as shown in Figures 6.24 and 6.25 for Corpus 2 fricatives , not as predicted. We note, though, that syllable stress is strongly correlated with the amount of devoicing, and since Portuguese fricatives devoice in over one half of words, there may be some interaction of these parameters, i.e.:

- Syllable stress is strongly correlated with the amount of devoicing.
- Portuguese fricatives devoice $> 50\%$.
- For fricatives in destressed syllables we predict: $A_d \searrow$ and $S_p \searrow$.
- For fricatives in stressed syllables we predict: $A_d \nearrow$ and $S_p \nearrow$.
- There may be some interaction!

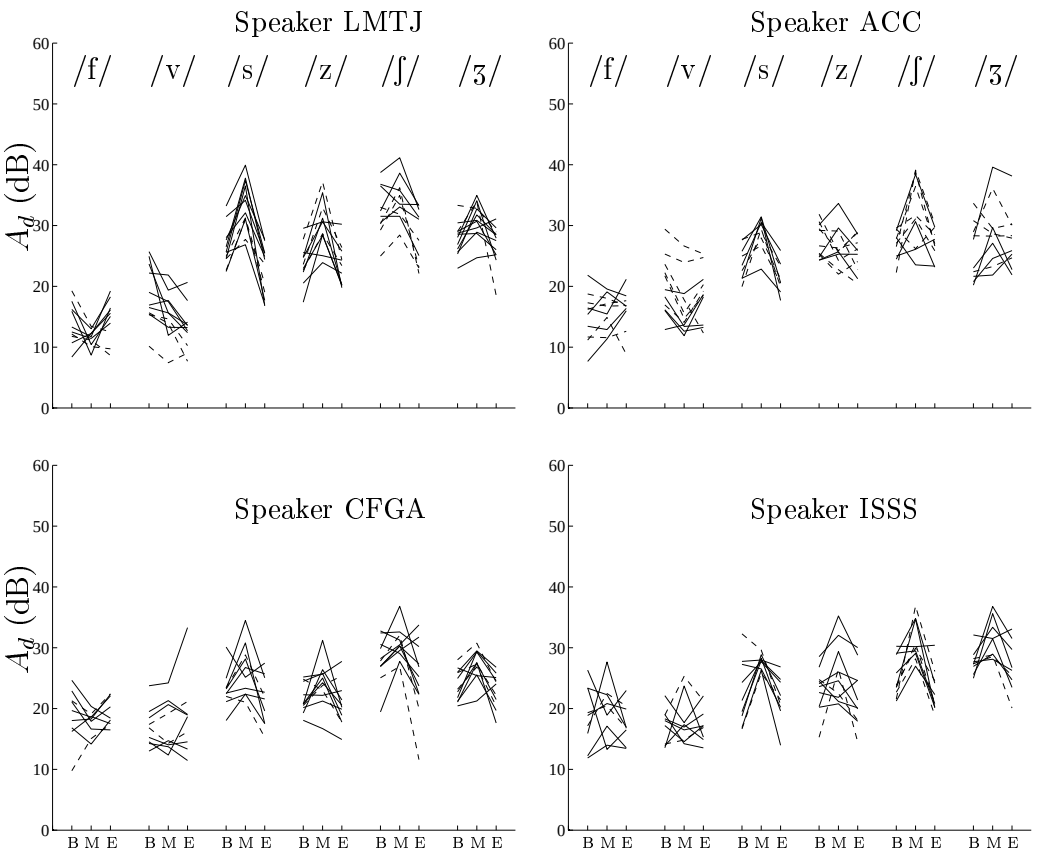


Figure 6.24: Dynamic amplitude of fricatives from Corpus 2, at the Beginning (B), Middle (M) and End (E) of the fricative. Fricatives in stressed syllables (solid line) and destressed syllables (dashed line).

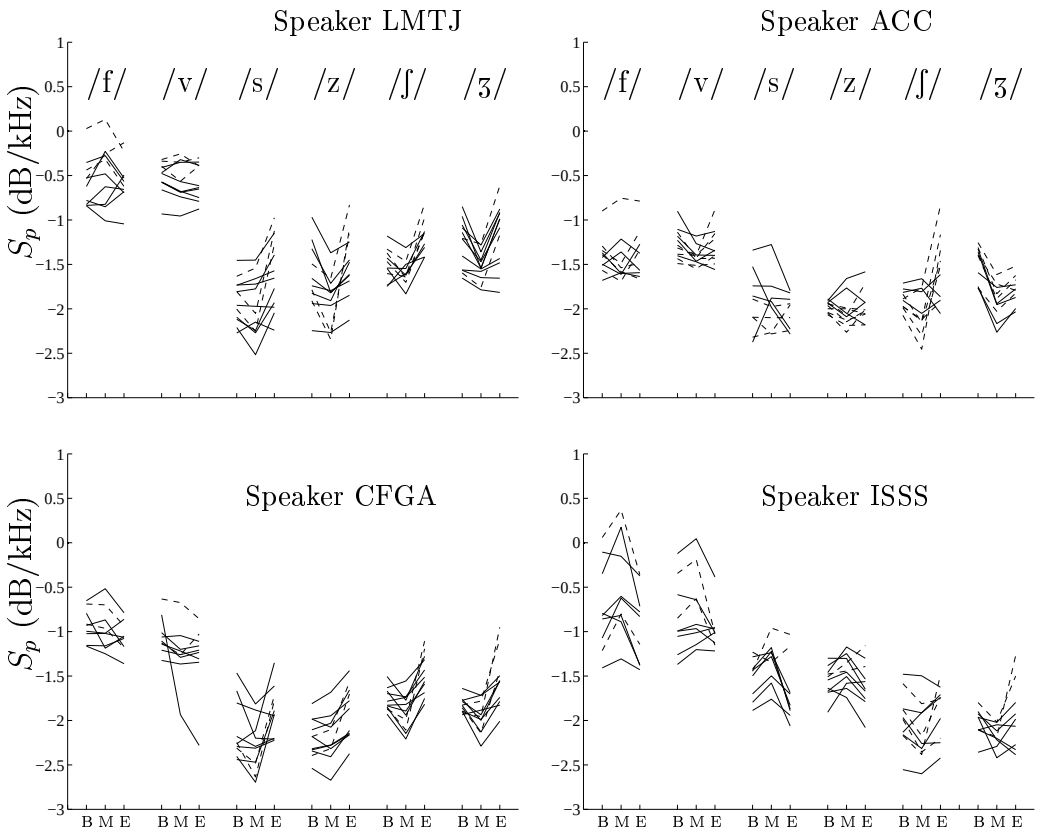


Figure 6.25: Spectral slope of fricatives from Corpus 2, at the Beginning (B), Middle (M) and End (E) of the fricative. Fricatives in stressed syllables (solid line) and destressed syllables (dashed line).

Figures 6.26 to 6.29, show the examples of Corpus 2 fricatives which occur in rounded and unrounded vowel context. There doesn't seem to be any consistent effect of rounding in the values of A_d and S_p.

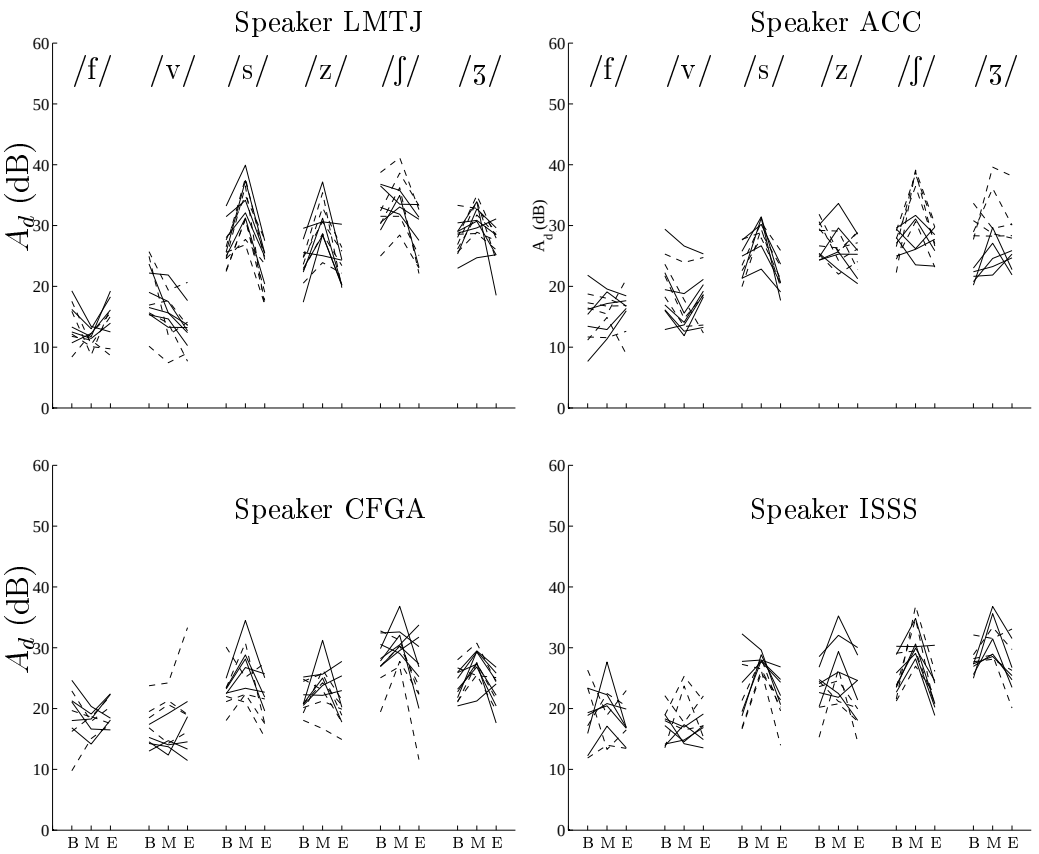


Figure 6.26: Dynamic amplitude of fricatives from Corpus 2, at the Beginning (B), Middle (M) and End (E) of the fricative. Fricatives in rounded vowel context (solid line) and unrounded vowel context (dashed line).

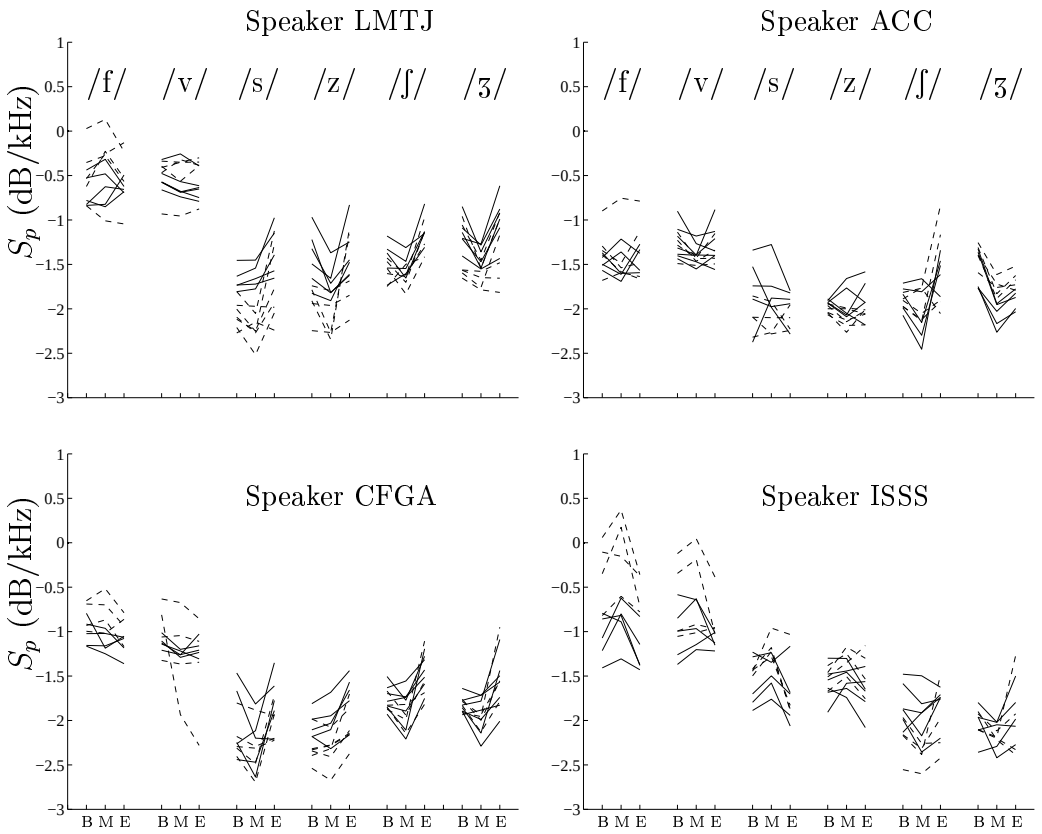


Figure 6.27: Spectral slope of fricatives from Corpus 2, at the Beginning (B), Middle (M) and End (E) of the fricative. Fricatives in rounded vowel context (solid line) and unrounded vowel context (dashed line).

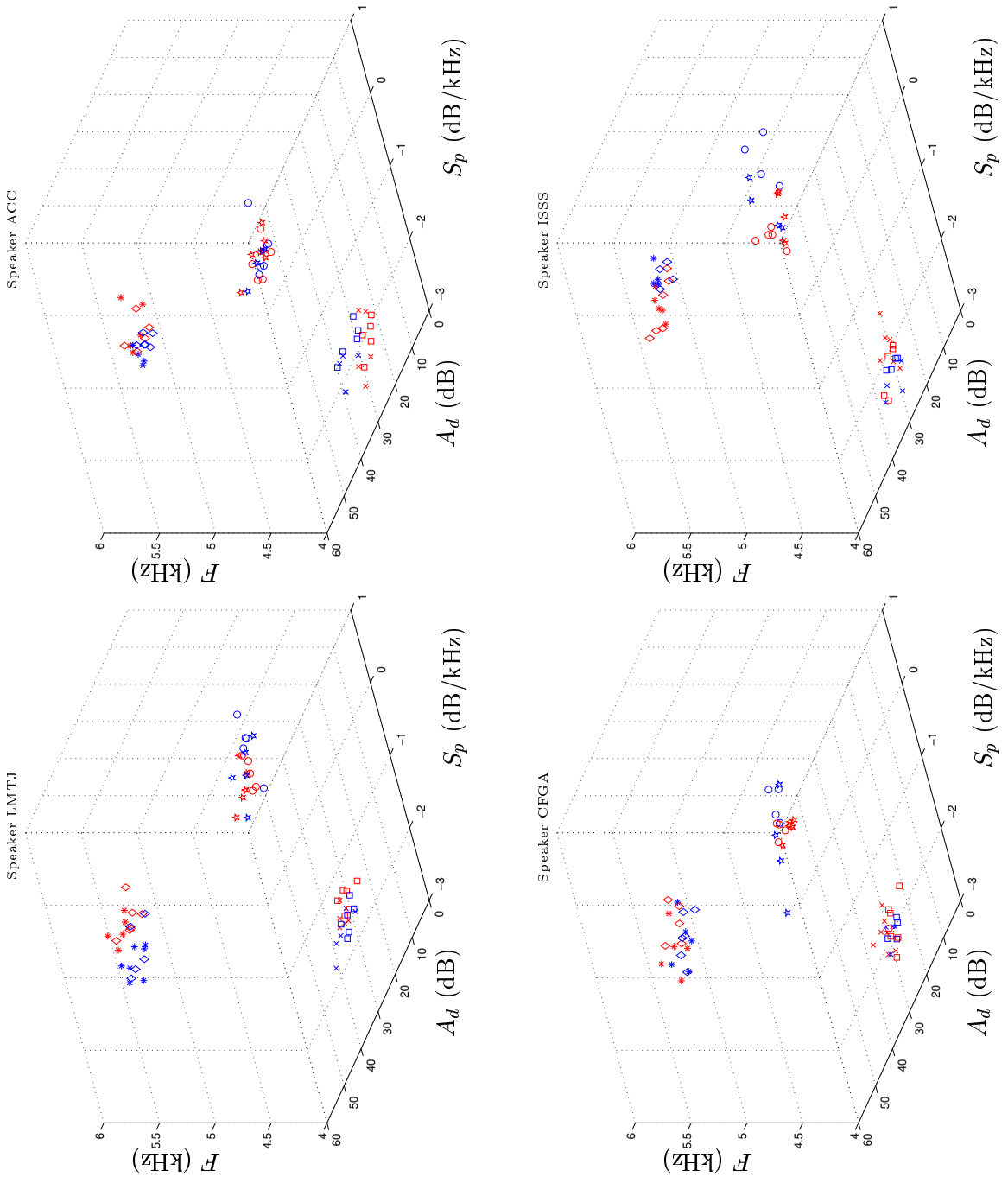


Figure 6.28: Corpus 2, F vs. A_d (middle) vs. S_p (middle). Fricatives in rounded vowel context (red) and unrounded vowel context (blue). $\circ$ – /f/, $\star$ – /v/, $*$ – /s/, $\diamond$ – /z/, $\times$ – /ʃ/ and $\square$ – /ʒ/.

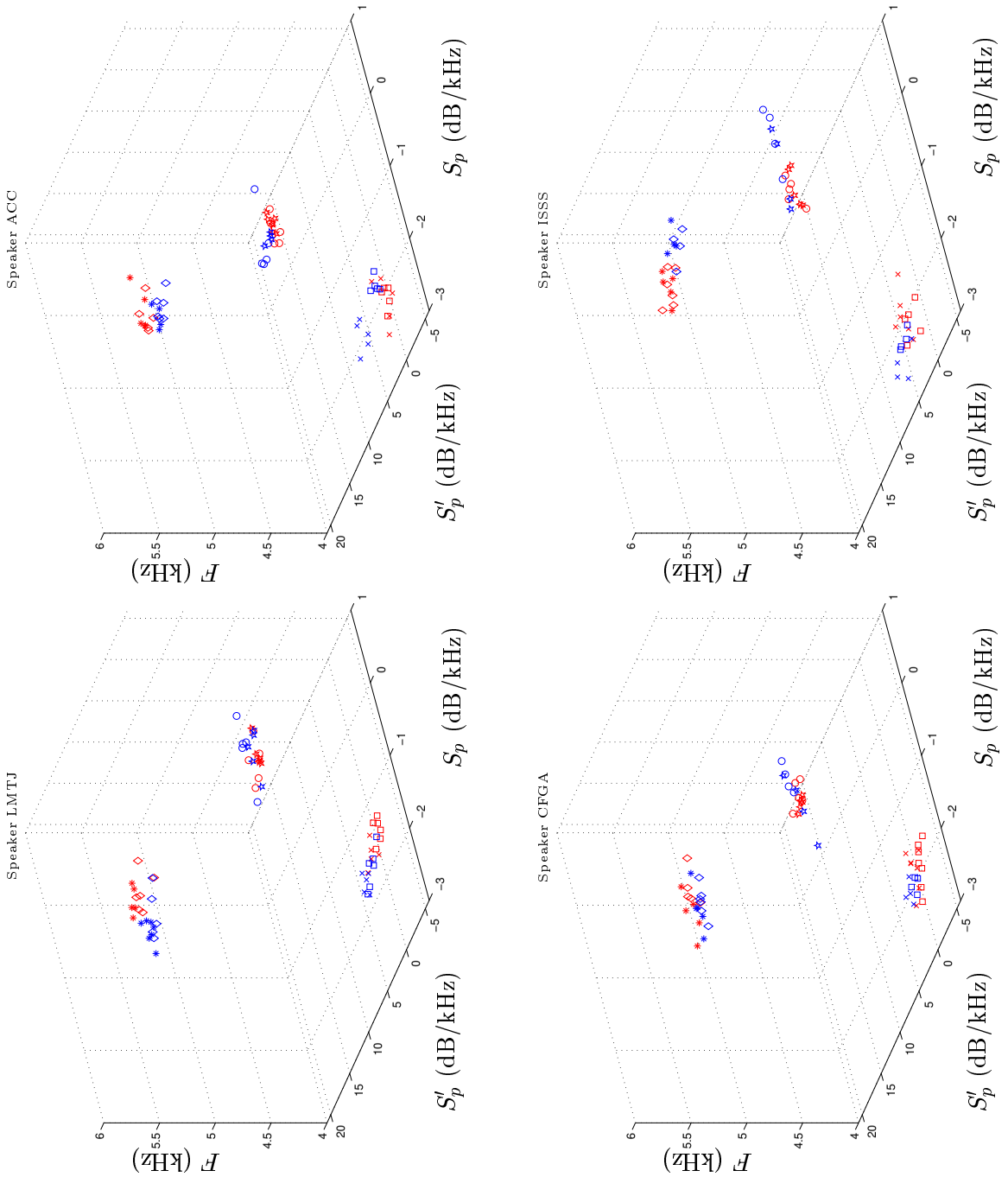


Figure 6.29: Corpus 2, F vs. S'_p (middle) vs. S_p (middle). Fricatives in rounded vowel context (red) and unrounded vowel context (blue). $\circ$ – /f/, $\star$ – /v/, $*$ – /s/, $\diamond$ – /z/, $\times$ – /ʃ/ and $\square$ – /ʒ/.

We were also interested in the following questions:

- Are the parameters capturing the feature stress?
- Is there a significant difference in the overall amplitude of the spectra of the various examples of a particular fricative?

To answer these questions we've superimposed the ensemble-averaged spectra at the middle of all examples of each fricative in Corpus 2 (Speaker LMTJ). The overall amplitude of stressed and destressed fricatives is the same, so the parameters seem to capture the main spectral features. The only significant difference seems to be the amplitude of the "voice-bar", which is 10-15 dB higher for stressed than for destressed fricatives.

6.4.2.2 Fricatives in Real Words (Corpus 3 and 4)

On a F vs. A_d or S_p' vs. S_p graph the fricatives in real words (Corpus 3 and 4), produced by all four speakers, cluster by place as shown in Figures 6.30 to 6.33.

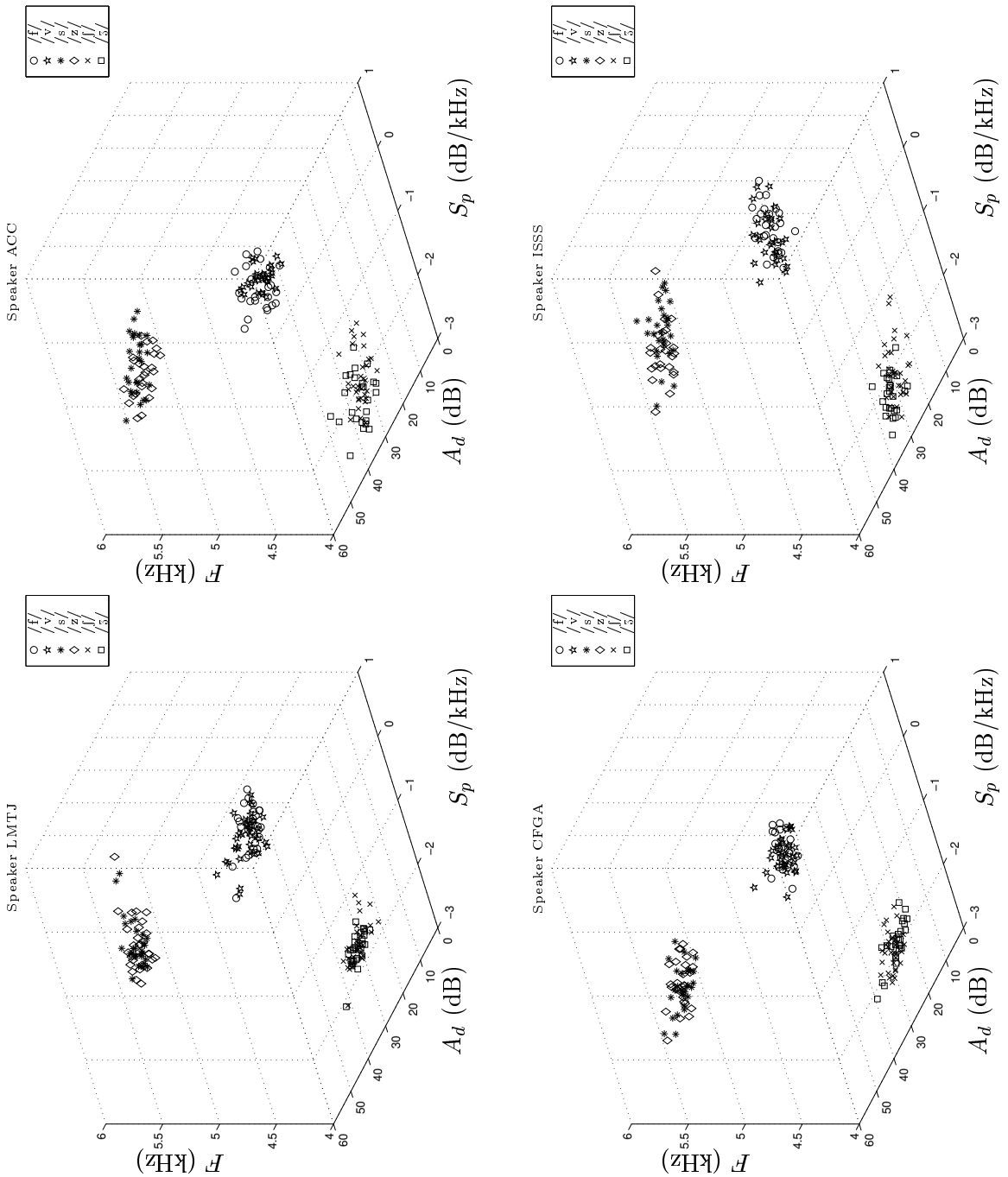


Figure 6.30: Corpus 3, F vs. A_d vs. S_p.

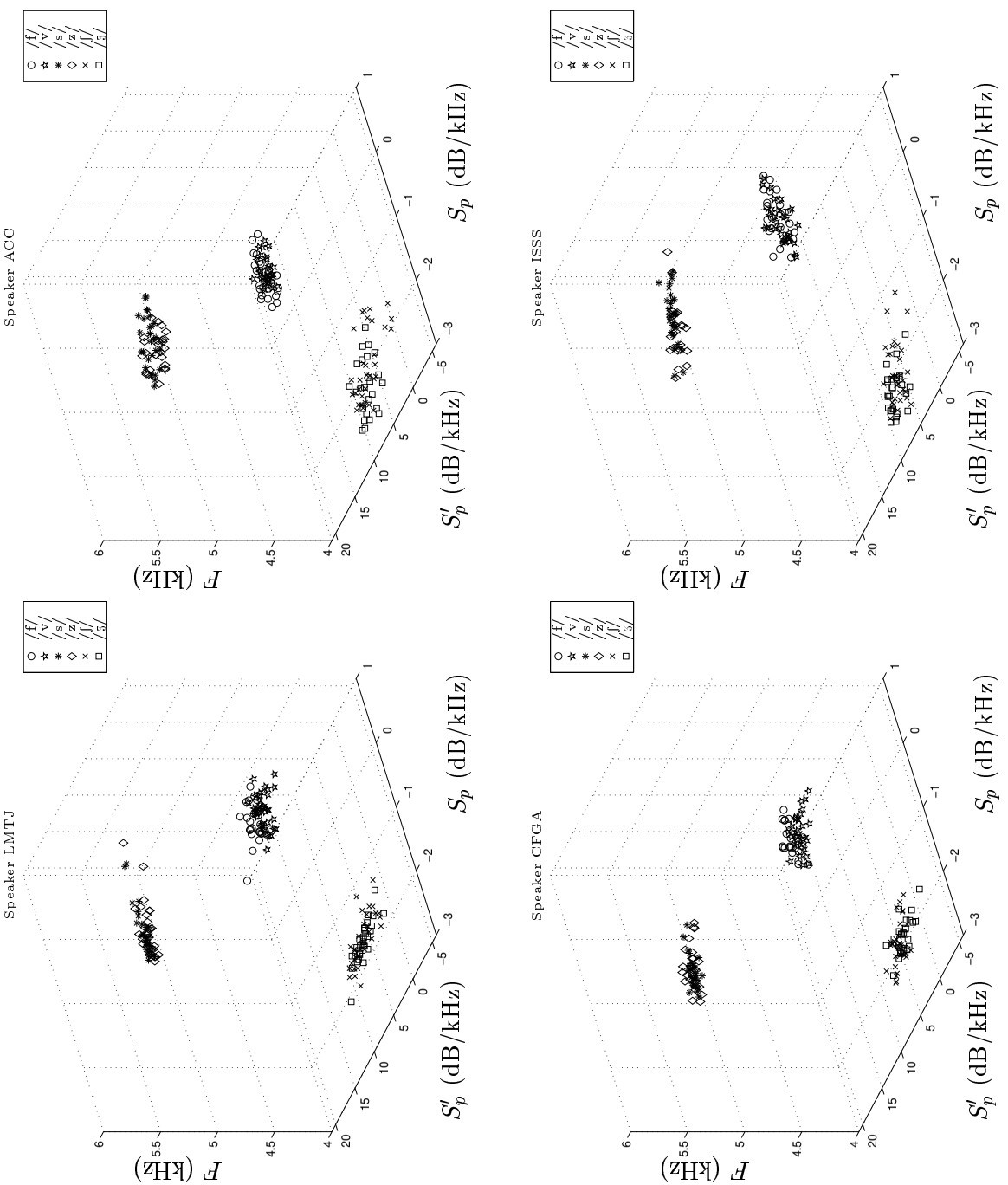


Figure 6.31: Corpus 3, F vs. S_p' vs. S_p.

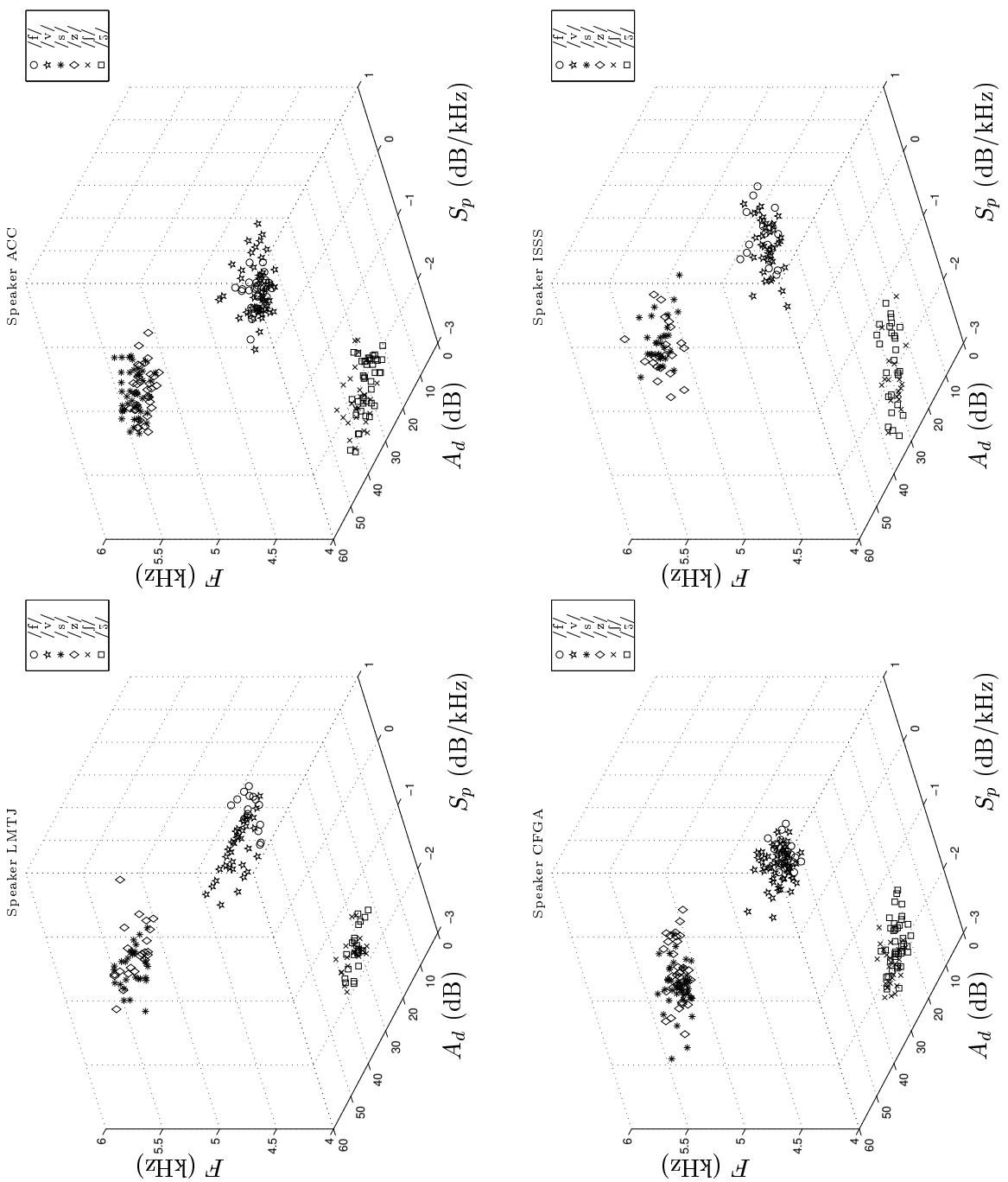


Figure 6.32: Corpus 4, F vs. A_d vs. S_p.

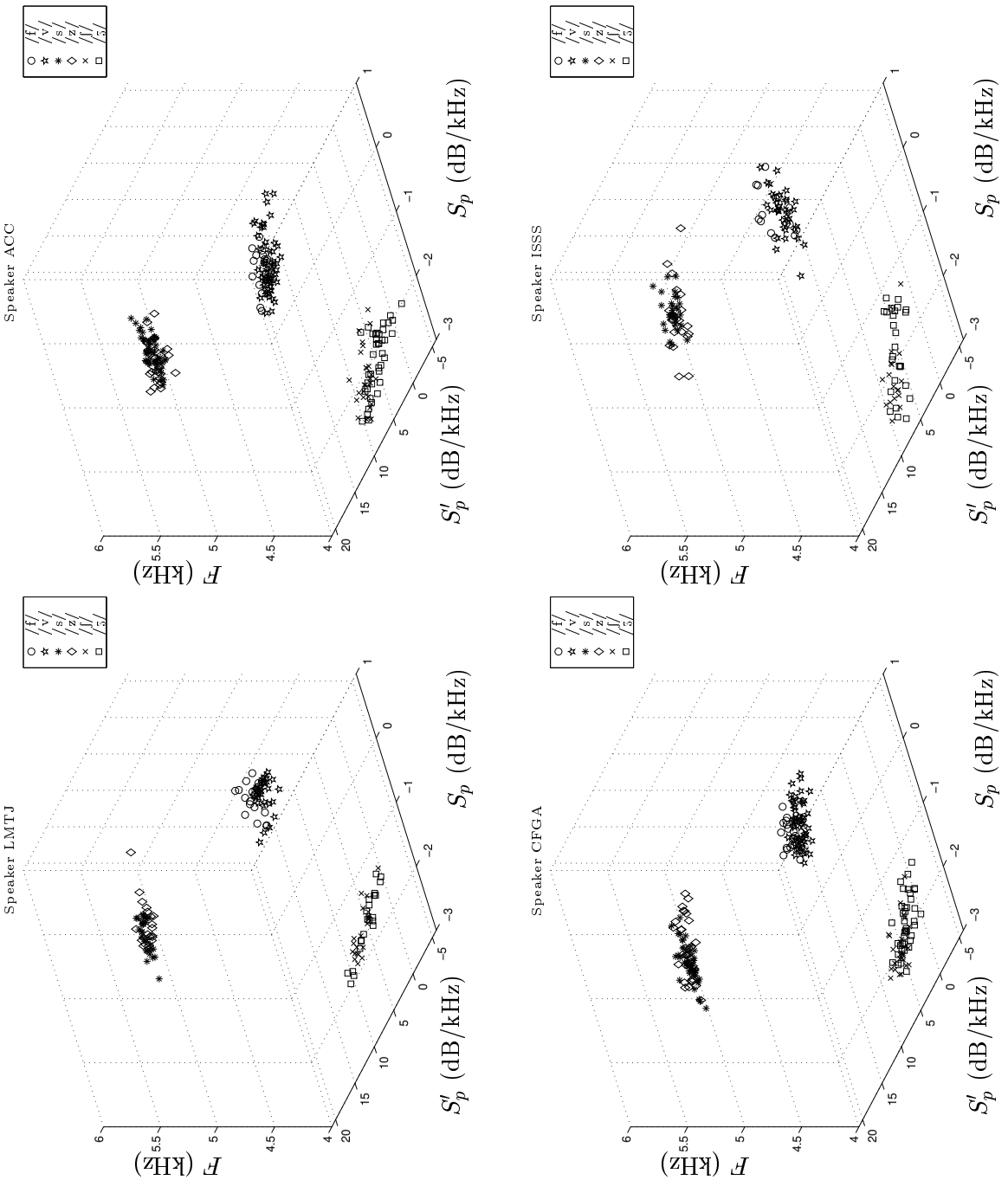


Figure 6.33: Corpus 4, F vs. S'_p vs. S_p.

6.4.2.3 Correlations Between Duration, Word Position, Vowel Context, Stress and Devoicing

> "*Vowel to fricative duration ratio* appears to be pertinent for recognition. Klatt (1976) has noted that many English speakers devoice postvocalic voiced fricatives indicating that vowel duration or vowel to fricative duration ratio may be assuming the functional load for the voicing contrast. It was noted by Raphael (1972) that when voicing was added during the frication portion, change in the preceding vowel duration became less effective in influencing the recognition scores." (Hogan and Rozsypal 1980)

In Figures 6.34 and 6.35 we've looked for duration and devoicing correlations, and analysed their effect on parameters A_d and S_p. There does not seem to be any correlation between these two factors (duration and devoicing) and the values of our parameters. The *vowel to fricative duration ratio*, as quoted before, might be a better candidate than the duration of the fricative to capture the effects of devoicing-duration correlations in A_d and S_p.

We also studied the correlation between the value of A_d, S_p and duration, and various other contextual factors (fricatives in stressed and destressed syllables; word-initial, word-medial and word-final fricatives; voiced, partially devoiced and devoiced fricatives), as shown in Figures 6.36 to 6.38, but without much success.

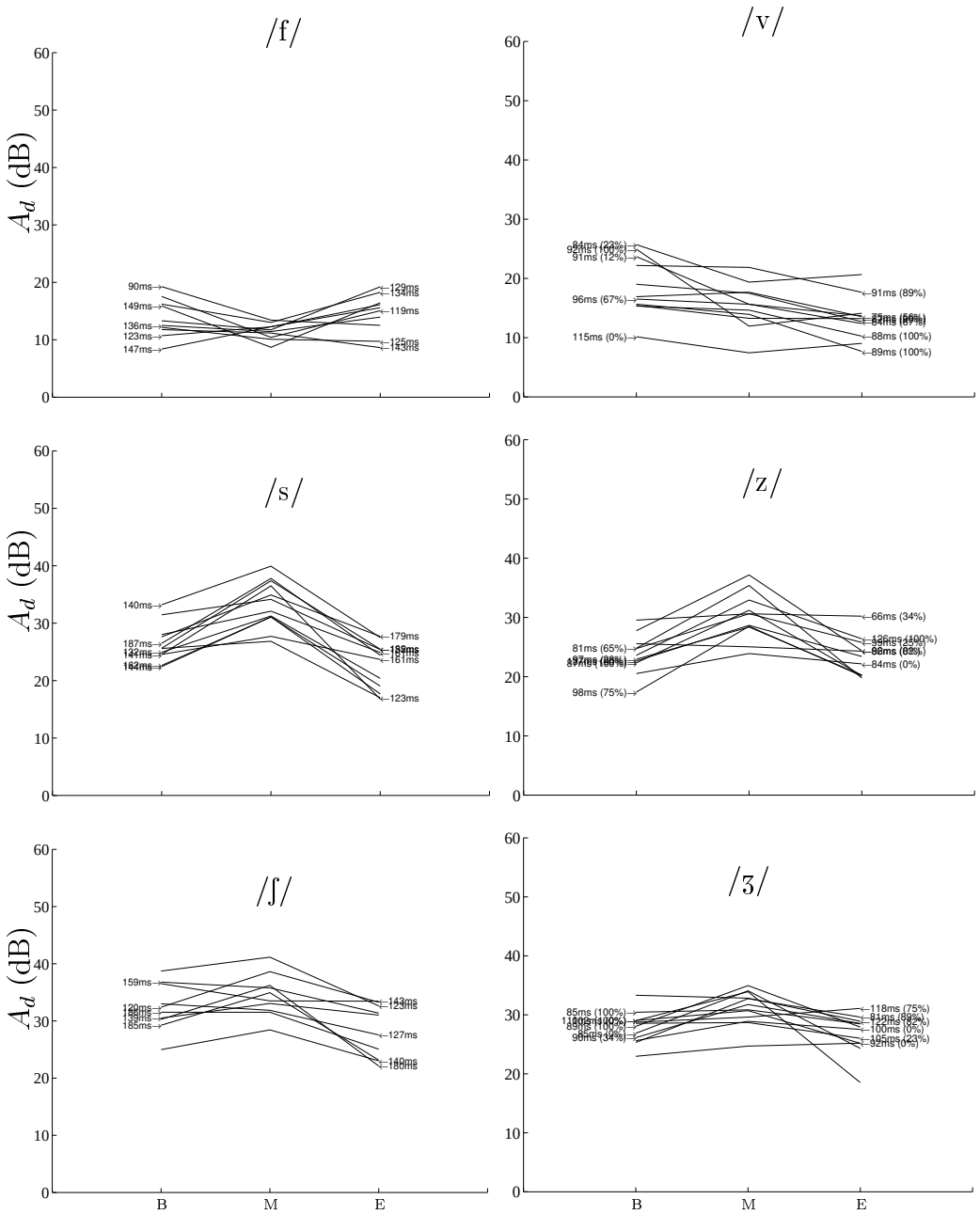


Figure 6.34: Dynamic amplitude at the Beginning (B), Middle (M) and End (E) of the fricatives. Duration of the fricatives and percentage of devoiced tokens are also shown. Corpus 2 (Speaker LMTJ).

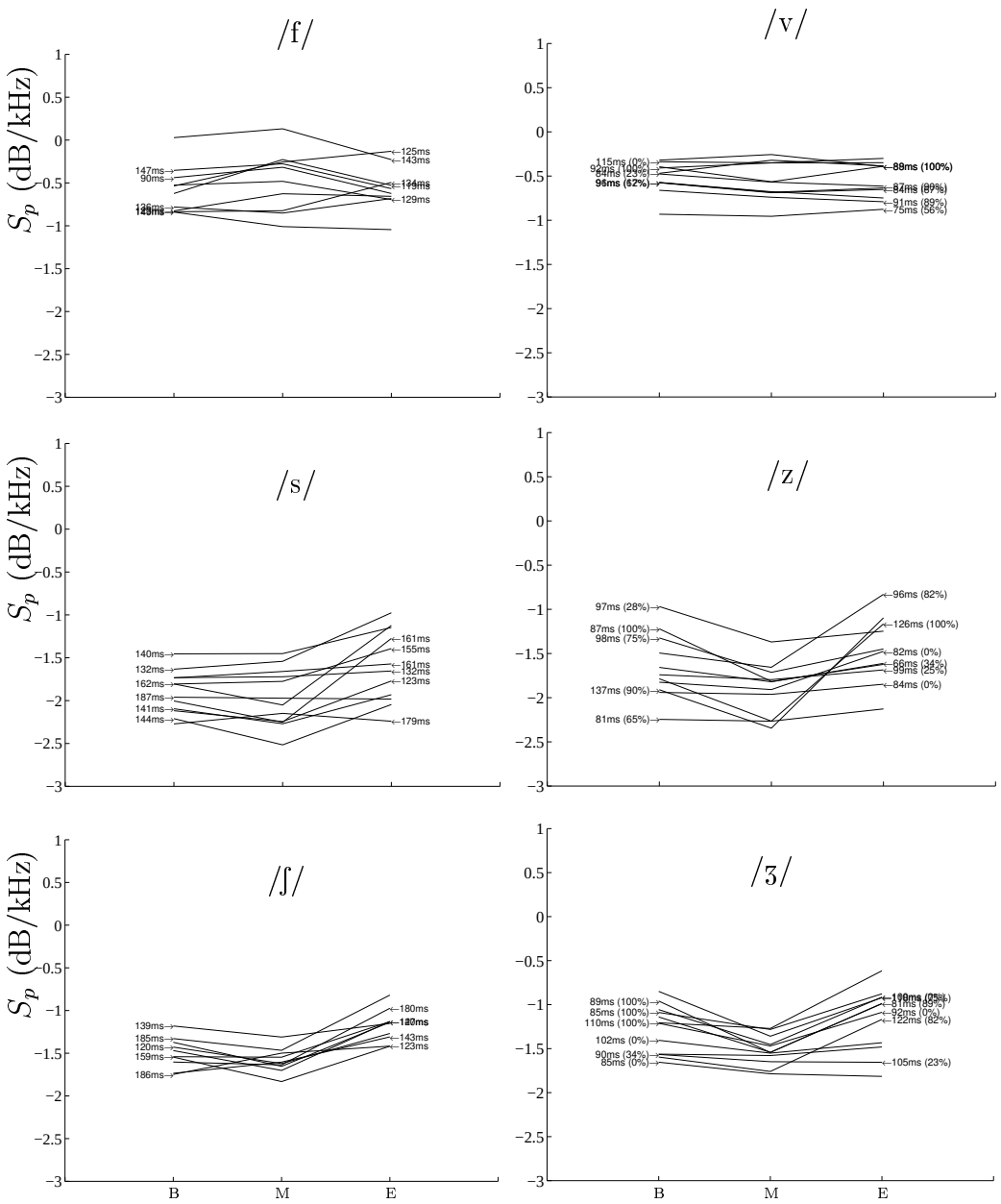


Figure 6.35: Spectral slope at the Beginning (B), Middle (M) and End (E) of the fricatives. Duration of the fricatives and percentage of devoiced tokens are also shown. Corpus 2 (Speaker LMTJ).

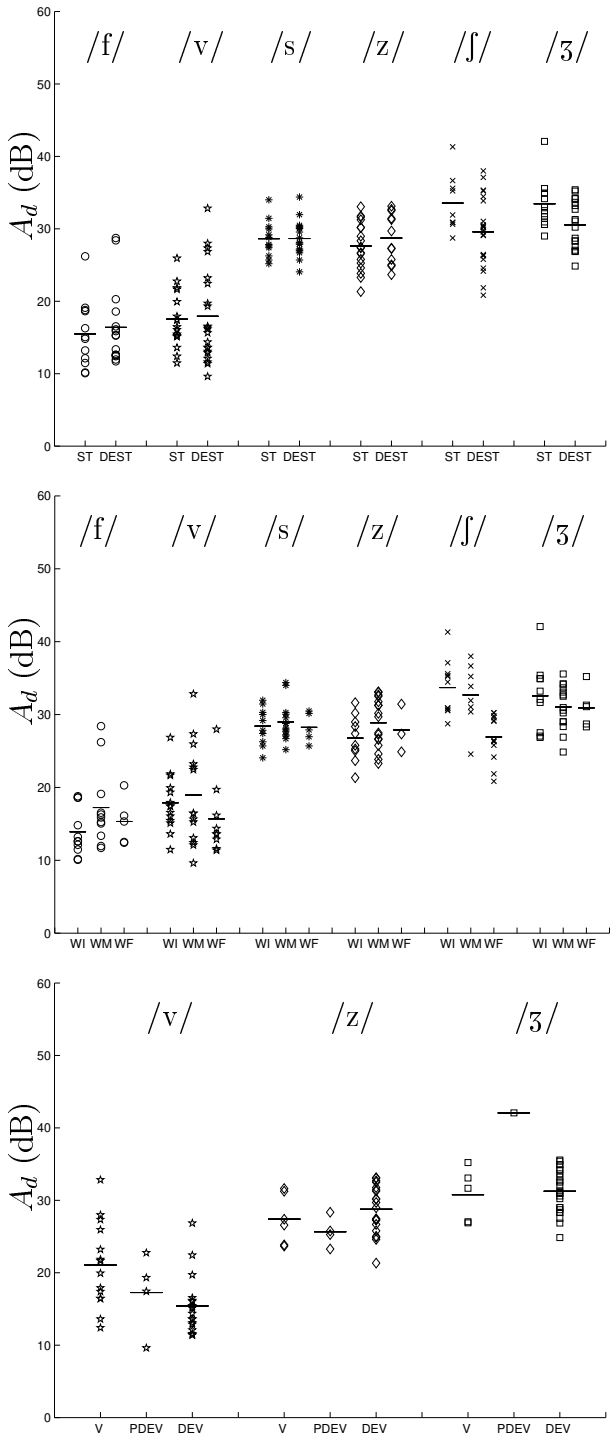


Figure 6.36: Dynamic amplitude for: fricatives in stressed (ST) and Destressed (DEST) syllables; word-initial (WI), word-medial (WM) and word-final (WF) fricatives; voiced (V), partially devoiced (PDEV) and devoiced (DEV) fricatives. Corpus 3 (Speaker LMTJ).

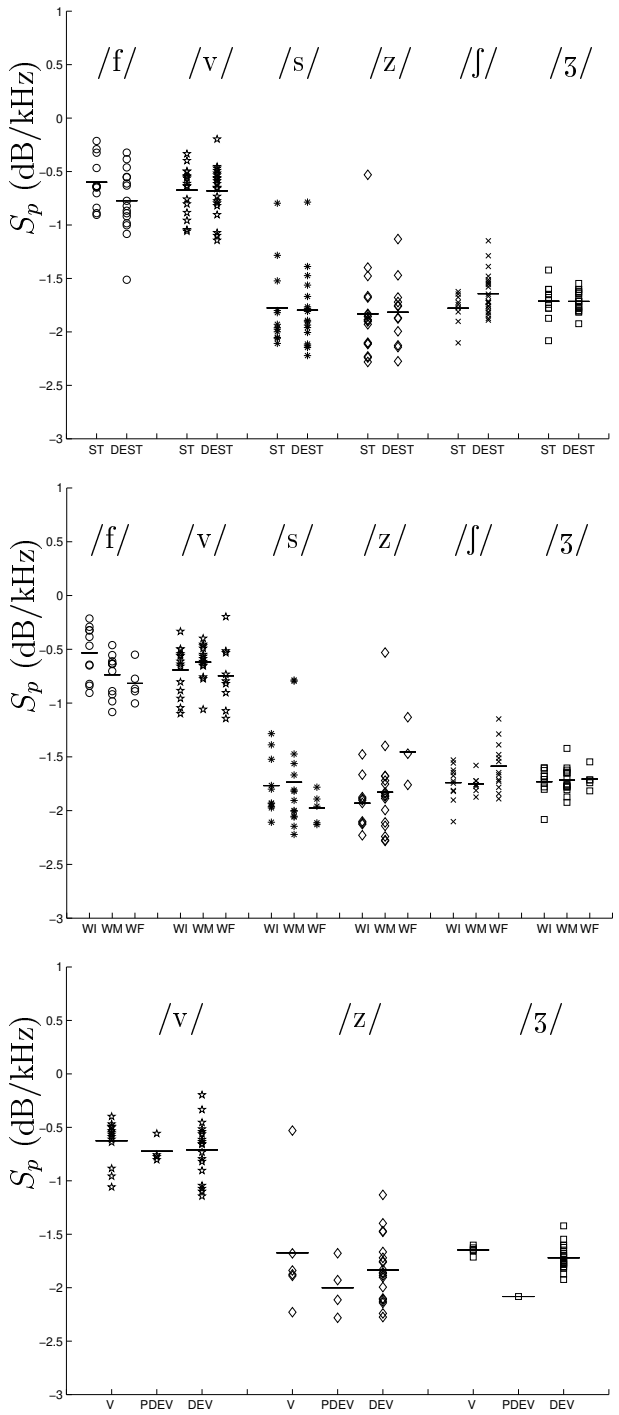


Figure 6.37: Spectral slope for: fricatives in stressed (ST) and Destressed (DEST) syllables; word-initial (WI), word-medial (WM) and word-final (WF) fricatives; voiced (V), partially devoiced (PDEV) and devoiced (DEV) fricatives. Corpus 3 (Speaker LMTJ).

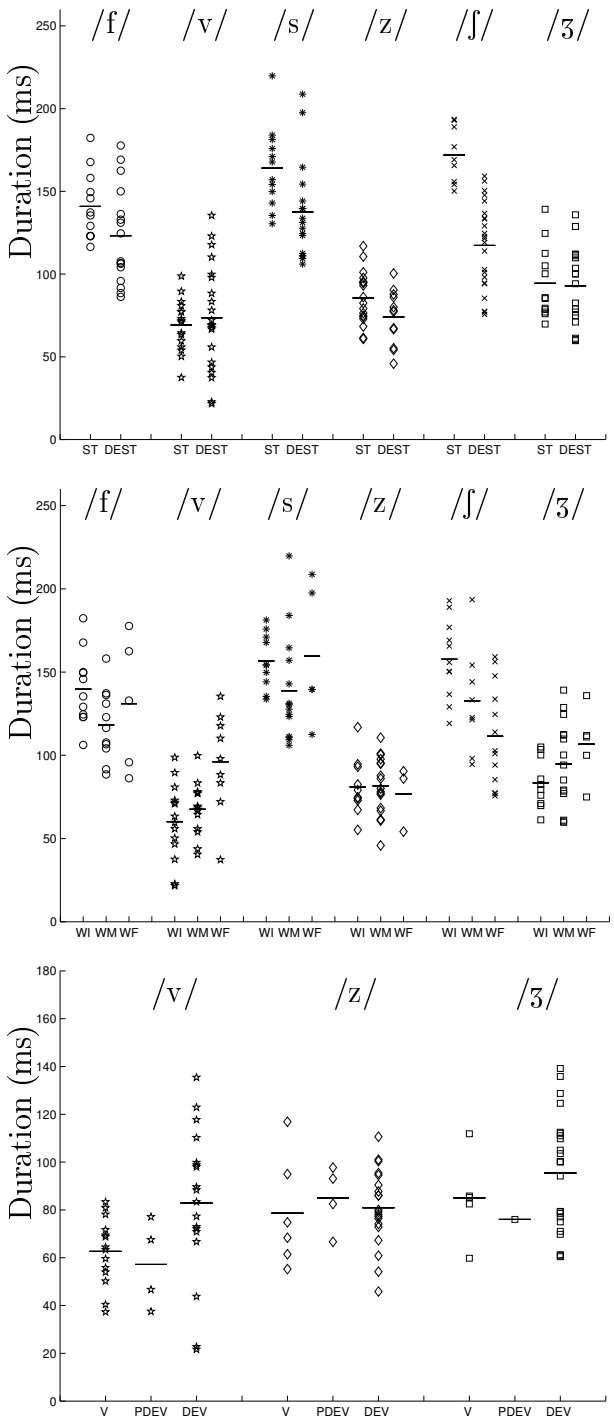


Figure 6.38: Duration for: fricatives in stressed (ST) and Destressed (DEST) syllables; word-initial (WI), word-medial (WM) and word-final (WF) fricatives; voiced (V), partially devoiced (PDEV) and devoiced (DEV) fricatives. Corpus 3 (Speaker LMTJ).

6.5 Conclusions

The parameters spectral slope, frequency of maximum amplitude, and dynamic amplitude, were developed to characterize fricative spectra, and applied to corpora recorded by four native Portuguese speakers. The parameters behaved as predicted for changes in effort level, voicing, and location within the fricative. Some combinations were also useful for separating the fricatives by place or by sibilance.

The parameters capture source-related changes for the most part *as predicted*; for the sustained fricatives, they also separate fricatives by place. However, for the nonsense words of corpus 2, comparisons of stressed and destressed fricatives indicate little or no change in A_d and S_p, *not as predicted*. Since this pattern occurs also in real words of Corpus 3, this may be a characteristic of Portuguese.

A combination of parameters A_d and S_p was also useful for separating the fricatives by sibilance, and a combination of parameters S_p and S'_p separated the fricatives both by place and sibilance.

6.6 Future work

Results from the four subjects seem, for most part to be consistent. Therefore it is possible that these parameters are capturing aspects of Portuguese that differ from English or French fricatives. Implications for modelling Portuguese fricatives, and fricative production mechanisms, should be discussed in the future. The quantified spectral characteristics of Portuguese fricatives can be related to specific properties of the transfer function and source spectrum during the production of these sounds.

Chapter 7

Future Work

7.1 Introduction

In this thesis, work on the acoustics of Portuguese fricatives has been described. Corpora were designed including Portuguese words, nonsense words following Portuguese phonology, and sustained fricatives at three different effort levels; these were recorded for one speaker. The speech corpus reflects the variety of phonetic contexts in which these speech sounds occur.

The parameters spectral slope, frequency of maximum amplitude, and dynamic amplitude, were developed to characterize fricative spectra, and applied to corpora.

7.2 Conclusions

Voiced fricatives devoice in over one half the cases in both nonsense and real words; two measures of devoicing were developed and compared. Spectral analysis revealed a correspondence between the effect of effort level and of syllable stress, and showed some effect of vowel context.

The parameters behaved as predicted for changes in effort level, voicing, and location within the fricative. Some combinations were also useful for

separating the fricatives by place or by sibilance.

7.3 Further Work

We plan to produce a refined set of distinctive features for the Portuguese fricatives. In the future, we will also conduct a parallel study of the characteristics of fricative consonants in Portuguese and English.

A large annotated database (dictionary) of Portuguese words could be used to look for the context in which the fricatives occur in the Portuguese language. One of the possible explanations for such high percentages of devoicing could be that, due to the structure of the language and its vocabulary, Portuguese speakers are very seldom faced with confusions between voiced and devoiced examples.

Appendix A

Listings of Corpus 3 and 4

A.1 Corpus 3: Real Words

The first number in the column designated as "Notes" (Tables A.1 to A.15) corresponds to the order in which particular words were read (see Appendix B).

Table A.1: Portuguese words with fricatives /f, v, s, z, ʃ, ʒ/ in initial and medial position (nearly minimal pairs).

Example	IPA	Notes	English Translation
fofa	ˈfofɐ	23	soft
viver	viˈver	122 *	to live
viva	ˈvivɐ	140	hurrah!, to live (verb form)
cessa	ˈsɛsɐ	64	ceases (verb form)
Zézé	ˈzɛzɛ	129	
chocha	ˈʃoʃɐ	80 *	weakened
bochecha	buˈʃeʃɐ	154	cheek
Gigi	ʒiˈʒi	145 *	

*Word used to form sentence in Corpus 4.

Table A.2: Portuguese words with fricative /f/ in initial position.

Example	IPA	Notes	English Translation
figo	ˈfigu	41	fig
ferir	fɨˈrir	18	to hurt
febra	ˈfebrɐ	61	slice of meat
ferro	ˈfɛRu	4	iron
falir	fɐˈlir	47	to be bankrupt
fala	ˈfalɐ	2 *	speech
foco	ˈfɔku	90	torch
fogo	ˈfogu	101 *	fire
furar	fuˈrar	44 *	to drill

A.2 Corpus 4: Real Words in Connected Speech

Sentences 11 and 12 were devised to reproduce some of the vocalic contexts used for Corpus 3 across word boundaries (this is signaled in the phonetic transcription by boxes). The following sentences were analysed:

1. “A Gigi é uma chocha e age em benefício da avó doce.”
   /ɐ ʒiˈʒi ɛ ˈumɐ ˈʃoʃɐ i ˈaʒɨ ɐ̃j bɨnɨˈfisju dɐ ɐˈvɔ ˈdosɨ/
   (Gigi is weak and acts in benefit of sweet grandmother.)

2. “A vaca foge do gelo na zona.”
   /ɐ ˈvakɐ ˈfɔʒɨ du ˈʒelu nɐ ˈzonɐ/
   (The cow runs from the ice in the zone.)

3. “A ave, no voo a subir, move a asa para zarpar da seta.”
   /ɐ ˈavɨ nu vow ɐ suˈbir ˈmɔvɨ ɐ ˈazɐ ˈpɐrɐ zɐrˈpar dɐ ˈsɛtɐ/
   (The bird, in a rising flight, moves his wing to escape from the arrow.)

4. “O chefe altivo fala à rosa de sede de beleza.”
   /u ˈʃɛfɨ alˈtivu ˈfalɐ a ˈrɔzɐ dɨ ˈsedɨ dɨ bɨˈlezɐ/
   (The haughty chief speaks to the rose about thirst and beauty.)

5. “Quero chorar hoje, arejar o sítio e vogar.”
   /ˈkɛru ʃuˈrar ˈoʒɨ ɐrɨˈʒar u ˈsitju i ˈvugar/
   (I want to cry today, ventilate the place and float.)

Table A.3: Portuguese words with fricative /v/ in initial position.

Example	IPA	Notes	English Translation
vila	ˈvilɐ	59	small town
vermelho	vɨrˈmɐʎu	86 *	red
ver	ver	102 *	to see
véu	ˈvɛw	104	veil
veia	ˈvɐjɐ	111, diphthong	vein
vaca	ˈvakɐ	92 *	cow
volta	ˈvɔltɐ	81 *	turn
voo	vow	17 *	flight
vogar	ˈvugar	7 *	to row, to float

6. “O bravo do Zé quer ajudar o judeu só.”
/u ˈbravu du zɛ kɛr ɐˈʒudar u ʒuˈdew sɔ/
(Brave Zé wants to help the lonely Jew.)

7. “O café cura a ressaca ao chegar da caça.”
/u kɐˈfɛ kurɐ ɐ Rɨˈsakɐ aw ʃɨˈgar dɐ ˈkasɐ/
(Coffee cures a hangover when you arrive from hunting.)

8. “Ver a mesinha nova de volta à sala, é benéfico para o modo de viver dos doze.”
/ver ɐ mɨˈziɲɐ ˈnɔvɐ dɨ ˈvɔltɐ a ˈsalɐ ɛ bɨˈnɛfiku ˈpɐrɐ u ˈmɔdu dɨ viˈver duʃ ˈdozɨ/
(It was beneficial for the way of living of the twelve, to see the new table back in the room.)

9. “Furar uma jóia choca a condessa Zita.”
/fuˈrar umɐ ˈʒɔjɐ ˈʃɔkɐ ɐ kõˈdesɐ ˈzitɐ/
(To drill a jewel shocks countess Zita.)

10. “O vermelho do fogo e o azul dos mares do Brasil.”
/u vɨrˈmɐʎu du ˈfogu i u ɐˈzul duʃ ˈmarɨʃ du brɐˈzil/
(The red of fire and the blue of the sea of Brasil.)

11. “A chá no sítio é possível achar.”
/ɐ ʃa n u ˈsi tju ɛ p uˈsi vɛl ɐˈʃa r/
(Tea in the place is possible to find.)

Table A.4: Portuguese words with fricative /s/ in initial position.

Example	IPA	Notes	English Translation
sítio	ˈsitju	77 *	place
secar	sɨˈkar	93	to dry
sede	ˈsedɨ	75 *	thirst
seta	ˈsɛtɐ	34 *	arrow
saber	sɐˈber	39	knowledge, to know
sala	ˈsalɐ	13 *	room
só	sɔ	5 *	alone
sopa	ˈsopɐ	83	soop
subir	suˈbir	139 *	to climb

12. “Cava sala meche ver o dever de assar.”
/ˈkav ɐ ˈsa lɐ ˈmɛʃ ɨ ver u d ɨˈver dɨ ɐˈsa r/
(Dig room touches see the duty to roast.)

Table A.5: Portuguese words with fricative /z/ in initial position.

Example	IPA	Notes	English Translation
Zita	ˈzitɐ	68 *	
zelar	ˈzɨlar	126	to watch over
zelo	ˈzelu	115	zeal
Zé	zɛ	85 *	
zarpar	zɐrˈpar	113 *	to escape
Zaire	ˈzajrɨ	99, diphthong	
Zópiro	ˈzɔpiru	10	
zona	ˈzonɐ	84 *	zone
zurrar	zuˈRar	16	to bray

Table A.6: Portuguese words with fricative /ʃ/ in initial position.

Example	IPA	Notes	English Translation
chicote	ʃiˈkɔtɨ	134	wip
chegar	ʃɨˈgar	65 *	to arrive
cheta	ˈʃetɐ	30	“não ter cheta” – “to be penniless”
cheque	ˈʃɛkɨ	36	cheque
chamar	ʃɐˈmar	28	to call
chá	ʃa	51 *	tea
choca	ˈʃɔkɐ	116 *	brooding (feminine), shocks (verb form)
choco	ˈʃoku	76	brooding (masculine), cuttle fish
chorar	ʃuˈrar	78 *	to cry

Table A.7: Portuguese words with fricative /ʒ/ in initial position.

Example	IPA	Notes	English Translation
girar	ʒiˈrar	48	to spin
gelado	ʒɨˈladu	127	ice cream
gelo	ˈʒelu	119 *	ice
germe	ˈʒɛrmɨ	72	germ
jaqueta	ʒɐˈketɐ	20	short jacket
jacto	ˈʒatu	123	jet
jóia	ˈʒɔjɐ	143 *	jewel
jogo	ˈʒogu	3	game
judeu	ʒuˈdew	32 *	Jew

Table A.8: Portuguese words with fricative /f/ in medial position.

Example	IPA	Notes	English Translation
efectuar	iˈfɛtwar	98	to accomplish
benefício	bɨnɨˈfisju	49, mult. fric.	benefit
trefo	ˈtrefu	107	cunning
benéfico	bɨˈnɛfiku	89 *	beneficial
afiar	ɐfiˈar	53, V_2CV_1	to sharpen
café	kɐˈfɛ	31, V_2CV_2 *	coffee
garrafa	gɐˈRafɐ	71, V_2CV_2	bottle
bafo	ˈbafu	26, V_2CV_3	breath
galhofa	gɐˈʎɔfɐ	128	frolic
mofo	ˈmofu	55	mould
bufa	ˈbufɐ	73	to blow (verb form)

Table A.9: Portuguese words with fricative /v/ in medial position.

Example	IPA	Notes	English Translation
altivo	alˈtivu	124 *	haughty, arrogant
dever	dɨˈver	22, V_1CV_1 *	duty, to owe
levar	lɨˈvar	105, V_1CV_2	to take
relevo	Rɨˈlevu	94	relief
leva	ˈlɛvɐ	149	takes (verb form)
avó	ɐˈvɔ	88, V_2CV_3 *	grandmother
cava	ˈkavɐ	24, V_2CV_2 *	digs (verb form)
bravo	ˈbravu	100, V_2CV_3 *	brave
nova	ˈnɔvɐ	147 *	new
ovelha	oˈvɐʎɐ	136	sheep
mover	muˈver	57, V_3CV_1	to move
uva	ˈuvɐ	40, V_3CV_2	grape

Table A.10: Portuguese words with fricative /s/ in medial position.

Example	IPA	Notes	English Translation
iça	ˈisɐ	148	lifts (verb form)
ressaca	Rɨˈsakɐ	82, V_1CV_2 *	hangover
condessa	kõˈdesɐ	153 *	countess
pêssego	ˈpesɨgu	87	peach
aquecer	ɐkɛˈser	131	to heat
passear	pɐˈsjar	103, V_2CV_1	to walk
assar	ɐˈsar	137, V_2CV_2 *	to roast
caça	ˈkasɐ	35 *	hunting
possa	ˈpɔsɐ	150	to be able to (verb form)
moça	ˈmosɐ	152	girl
possível	puˈsivɛl	95, mult. fric. *	possible

Table A.11: Portuguese words with fricative /z/ in medial position.

Example	IPA	Notes	English Translation
exacto	iˈzatu	43, V_1CV_2	exact
mesinha	mɨˈziɲɐ	50 *	small table
beleza	bɨˈlezɐ	135, V_1CV_2 *	beauty
peso	ˈpezu	60, V_1CV_3	weight
mezinha	mɛˈziɲɐ	27	traditional medicine
Brasil	brɐˈzil	58, V_2CV_1 *	
azar	ɐˈzar	97, V_2CV_2	bad luck
azul	ɐˈzul	33, V_2CV_3 *	blue
mazinha	maˈziɲɐ	37, V_2CV_1	bad girl
asa	ˈazɐ	19, V_2CV_2 *	wing
rosa	ˈrɔzɐ	14, V_3CV_2 *	rose
amoroso	ɐmuˈrozu	8	amorous, sweet
acusar	ɐkuˈzar	146	to acuse

Table A.12: Portuguese words with fricative /ʃ/ in medial position.

Example	IPA	Notes	English Translation
bicha	ˈbiʃɐ	142	cue
bexiga	bɨˈʃigɐ	106	bladder
este	ˈeʃtɨ	54, VCC	this one
meche	ˈmɛʃɨ	141 *	touches (verb form)
achar	ɐˈʃar	114,V_2CV_2 *	to find, to think
bolacha	buˈlaʃɐ	15, V_2CV_2	biscuit
tacho	ˈtaʃu	133, V_2CV_3	pot, pan
tocha	ˈtɔʃɐ	121	torch
mocho	ˈmoʃu	109	owl
capucho	kɐˈpuʃu	74	hood

Table A.13: Portuguese words with fricative /ʒ/ in medial position.

Example	IPA	Notes	English Translation
originar	oriʒiˈnar	1, V_1CV_1	to originate, to generate
tijolo	tiˈʒolu	110, V_1CV_3	brick
arejar	ɐrɨˈʒar	46 *	to ventilate
pejo	ˈpeʒu	25	modesty
Beja	ˈbɛʒɐ	52	
agir	ɐˈʒir	108, V_2CV_1	to act
cajado	kɐˈʒadu	63, V_2CV_2	hooked stick
ajudar	ɐˈʒudar	66, V_2CV_3 *	to help
haja	ˈaʒɐ	12	there is (verb form)
aloja	ɐˈlɔʒɐ	151	lodges (verb form)
tojo	ˈtoʒu	9	gorse
tugir	tuˈʒir	120, V_3CV_1	to speak low

Table A.14: Portuguese words with fricative /ʃ/ in final position.

Example	IPA	Notes	English Translation
diz	diʃ	96	says (verb form)
mares	ˈmarɨʃ	130 *	seas
mês	ˈmeʃ	112	month
pés	pɛʃ	62	feet
perdas	ˈpɛrdɐʃ	29	losses
capaz	kɐˈpaʃ	91	capable
pós	pɔʃ	70	dusts (noun form)
pôs	poʃ	144	put (verb form)
dos	ˈduʃ	138 *	of the

Table A.15: Portuguese words with fricatives /f, v, s, z, ʒ/ in "simulated" final position.

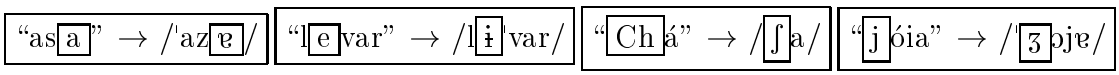
Example	IPA	Notes	English Translation
chefe	ˈʃɛfɨ	11 *	chief
Fafe	ˈfafɨ	125	
teve	ˈtevɨ	42	had (verb form)
leve	ˈlɛvɨ	6	light
ave	ˈavɨ	45 *	bird
move	ˈmɔvɨ	67 *	moves (verb form)
partisse	parˈtisɨ	117	left (verb form)
batesse	bɐˈtesɨ	69	hit (verb form)
asse	ˈasɨ	118	roast (verb form)
posse	ˈpɔsɨ	21	possession
doce	ˈdosɨ	56 *	sweet
doze	ˈdozɨ	132 *	twelve
age	ˈaʒɨ	79 *	acts (verb form)
hoje	ˈoʒɨ	38 *	today

Appendix B

Listings of Corpora as Presented to All Four Speakers

The listings of corpora in the following sections, include the instructions given to subjects in italics.

B.1 Corpus 1a



Sustain fricative for 5 s.

1. /uvvvv ... u/
2. /ɐʒʒʒʒ ... ɐ/
3. /ɐvvvv ... ɐ/
4. /uʃʃʃʃ ... u/
5. /ɨvvvv ... ɨ/
6. /ɐʃʃʃʃ... ɐ/
7. /uffff ... u/
8. /ussss ... u/
9. /ɐzzzz ... ɐ/
10. /ɨʒʒʒʒ ... ɨ/
11. /ɨssss ... ɨ/
12. /uzzzz ... u/
13. /ɐffff ... ɐ/
14. /ɨʃʃʃʃ ... ɨ/
15. /ɐssss ... ɐ/
16. /ɨzzzz ... ɨ/
17. /uʒʒʒʒ ... u/
18. /ɨffff ... ɨ/

B.2 Corpus 1b

“Chá” → /ʃa/ | “jóia” → /ʒɔjɐ/

Sustain for 5s.

Medium, soft and loud for each fricative.

Repeat corpus twice.

1. /ʃ/
   baixo
   alto
2. /s/
   baixo
   alto
3. /v/
   baixo
   alto
4. /ʒ/
   baixo
   alto
5. /f/
   baixo
   alto
6. /z/
   baixo
   alto
7. /s/
   baixo
   alto
8. /v/
   baixo
   alto
9. /f/
   baixo
   alto
10. /ʒ/
    baixo
    alto
11. /z/
    baixo
    alto
12. /ʃ/
    baixo
    alto

B.3 Corpus 2

“asa” → /ˈazɐ/ | “leˈvar” → /lɨˈvar/ | “Chá” → /ʃa/ | “jóia” → /ʒɔjɐ/

Do about 12 repetitions in one breath.

The stress was placed where Speaker LMTJ found it is most natural (respecting language specific phonological rules), and kept throughout all the repetitions and for Speakers CFGA, ACC and ISSS. There are also some

words with equal stress in both syllables. There are some reduced vowels.

1. /pɨˈʃu/
2. /ˈpɐfɨ/
3. /puˈʒu/
4. /pɨfɨ/
5. /pɐˈvu/
6. /pɨˈzɐ/
7. /pɨʒɐ/
8. /pɨʃɨ/
9. /pɨˈzu/
10. /ˈpɐvɨ/
11. /ˈpɐʒɨ/
12. /puvu/
13. /pɐzɐ/
14. /pɨˈsɐ/
15. /ˈpuvɨ/
16. /pɨsɨ/
17. /pɐˈʃɐ/
18. /pɐˈʒu/
19. /pɨˈvu/
20. /pɐˈʃu/
21. /pɐfɐ/
22. /ˈpuʒɨ/
23. /pɐˈzu/
24. /ˈpɐʃɨ/
25. /pɨˈfu/
26. /pɐvɐ/
27. /ˈpusɨ/
28. /puˈfɐ/
29. /ˈpɐsɨ/
30. /pɐʒɐ/
31. /pɨˈʃɐ/
32. /pusu/
33. /pɐˈfu/
34. /pɨvɨ/
35. /puzu/
36. /pɨzɨ/
37. /puˈvɐ/
38. /pɨˈfɐ/
39. /puʃu/
40. /ˈpufɨ/
41. /pɨˈʒu/
42. /ˈpuzɨ/
43. /pɨʒɨ/
44. /pufu/
45. /pɨˈvɐ/
46. /puˈʒɐ/
47. /pɨˈsu/
48. /ˈpuʃɐ/
49. /pɐsɐ/
50. /ˈpuʃɨ/
51. /ˈpɐzɨ/
52. /puˈsɐ/
53. /pɐsu/
54. /puˈzɐ/

B.4 Corpus 3

The carrier sentence is repeated in the following listings, because they were based on the material that the speaker read in the recording session.

1. “Diga originar, por favor.”
2. “Diga fala, por favor.”
3. “Diga jogo, por favor.”
4. “Diga ferro, por favor.”
5. “Diga só, por favor.”
6. “Diga leve, por favor.”
7. “Diga vogar, por favor.”
8. “Diga amoroso, por favor.”
9. “Diga tojo, por favor.”
10. “Diga Zópiro, por favor.”
11. “Diga chefe, por favor.”
12. “Diga haja, por favor.”
13. “Diga sala, por favor.”
14. “Diga rosa, por favor.”
15. “Diga bolacha, por favor.”
16. “Diga zurrar, por favor.”
17. “Diga voo, por favor.”
18. “Diga ferir, por favor.”
19. “Diga asa, por favor.”
20. “Diga jaqueta, por favor.”
21. “Diga posse, por favor.”
22. “Diga dever, por favor.”
23. “Diga fofa, por favor.”
24. “Diga cava, por favor.”
25. “Diga pejo, por favor.”
26. “Diga bafo, por favor.”
27. “Diga mezinha, por favor.”
28. “Diga chamar, por favor.”
29. “Diga perdas, por favor.”
30. “Diga cheta, por favor.”
31. “Diga café, por favor.”
32. “Diga judeu, por favor.”
33. “Diga azul, por favor.”
34. “Diga seta, por favor.”
35. “Diga caça, por favor.”
36. “Diga cheque, por favor.”
37. “Diga mazinha, por favor.”
38. “Diga hoje, por favor.”
39. “Diga saber, por favor.”
40. “Diga uva, por favor.”
41. “Diga figo, por favor.”
42. “Diga teve, por favor.”
43. “Diga exacto, por favor.”
44. “Diga furar, por favor.”
45. “Diga ave, por favor.”
46. “Diga arejar, por favor.”
47. “Diga falir, por favor.”
48. “Diga girar, por favor.”
49. “Diga benefício, por favor.”

50. “Diga mesinha, por favor.”
51. “Diga chá, por favor.”
52. “Diga Beja, por favor.”
53. “Diga afiar, por favor.”
54. “Diga este, por favor.”
55. “Diga mofo, por favor.”
56. “Diga doce, por favor.”
57. “Diga mover, por favor.”
58. “Diga Brasil, por favor.”
59. “Diga vila, por favor.”
60. “Diga peso, por favor.”
61. “Diga febra, por favor.”
62. “Diga pés, por favor.”
63. “Diga cajado, por favor.”
64. “Diga cessa, por favor.”
65. “Diga chegar, por favor.”
66. “Diga ajudar, por favor.”
67. “Diga move, por favor.”
68. “Diga Zita, por favor.”
69. “Diga batesse, por favor.”
70. “Diga pós, por favor.”
71. “Diga garrafa, por favor.”
72. “Diga germe, por favor.”
73. “Diga bufa, por favor.”
74. “Diga capucho, por favor.”
75. “Diga sede, por favor.”
76. “Diga choco, por favor.”
77. “Diga sítio, por favor.”
78. “Diga chorar, por favor.”
79. “Diga age, por favor.”
80. “Diga chocha, por favor.”
81. “Diga volta, por favor.”
82. “Diga ressaca, por favor.”
83. “Diga sopa, por favor.”
84. “Diga zona, por favor.”
85. “Diga Zé, por favor.”
86. “Diga vermelho, por favor.”
87. “Diga pêssego, por favor.”
88. “Diga avó, por favor.”
89. “Diga benéfico, por favor.”
90. “Diga foco, por favor.”
91. “Diga capaz, por favor.”
92. “Diga vaca, por favor.”
93. “Diga secar, por favor.”
94. “Diga relevo, por favor.”
95. “Diga possível, por favor.”
96. “Diga diz, por favor.”
97. “Diga azar, por favor.”
98. “Diga efectuar, por favor.”

99. “Diga Zaire, por favor.”
100. “Diga bravo, por favor.”
101. “Diga fogo, por favor.”
102. “Diga ver, por favor.”
103. “Diga passear, por favor.”
104. “Diga véu, por favor.”
105. “Diga levar, por favor.”
106. “Diga bexiga, por favor.”
107. “Diga trefo, por favor.”
108. “Diga agir, por favor.”
109. “Diga mocho, por favor.”
110. “Diga tijolo, por favor.”
111. “Diga veia, por favor.”
112. “Diga mês, por favor.”
113. “Diga zarpar, por favor.”
114. “Diga achar, por favor.”
115. “Diga zelo, por favor.”
116. “Diga choca, por favor.”
117. “Diga partisse, por favor.”
118. “Diga asse, por favor.”
119. “Diga gelo, por favor.”
120. “Diga tugir, por favor.”
121. “Diga tocha, por favor.”
122. “Diga viver, por favor.”
123. “Diga jacto, por favor.”
124. “Diga altivo, por favor.”
125. “Diga Fafe, por favor.”
126. “Diga zelar, por favor.”
127. “Diga gelado, por favor.”
128. “Diga galhofa, por favor.”
129. “Diga Zézé, por favor.”
130. “Diga mares, por favor.”
131. “Diga aquecer, por favor.”
132. “Diga doze, por favor.”
133. “Diga tacho, por favor.”
134. “Diga chicote, por favor.”
135. “Diga beleza, por favor.”
136. “Diga ovelha, por favor.”
137. “Diga assar, por favor.”
138. “Diga dos, por favor.”
139. “Diga subir, por favor.”
140. “Diga viva, por favor.”
141. “Diga meche, por favor.”
142. “Diga bicha, por favor.”
143. “Diga jóia, por favor.”
144. “Diga pôs, por favor.”
145. “Diga Gigi, por favor.”
146. “Diga acusar, por favor.”
147. “Diga nova, por favor.”

148. “Diga iça, por favor.”
149. “Diga leva, por favor.”
150. “Diga possa, por favor.”
151. “Diga aloja, por favor.”
152. “Diga moça, por favor.”
153. “Diga condessa, por favor.”
154. “Diga bochecha, por favor.”

B.5 Corpus 4

Read twice.

1. “A Gigi é uma chocha e age em benefício da avó doce.”
2. “A vaca foge do gelo na zona.”
3. “A ave, no voo a subir, move a asa para zarpar da seta.”
4. “O chefe altivo fala à rosa de sede de beleza.”
5. “Quero chorar hoje, arejar o sítio e vogar.”
6. “O bravo do Zé quer ajudar o judeu só.”
7. “O café cura a ressaca ao chegar da caça.”
8. “Ver a mesinha nova de volta à sala, é benéfico para o modo de viver dos doze.”
9. “Furar uma jóia choca a condessa Zita.”
10. “O vermelho do fogo e o azul dos mares do Brasil.”
11. “A chá no sítio é possível achar.”
12. “Cava sala meche ver o dever de assar.”

Appendix C

Listings of Recorded Material (Corpus 1a, 1b and 2)

This appendix lists the recorded material of Corpus 1a, 1b and 2 for all four speakers (LMTJ, CFGA, ACC and ISSS). There are some differences between the listings of Corpora presented in Appendix B and the tokens which the speakers produced. This is due to the fact that none of them were phonetically trained and Corpus 1a, 1b and 2 are unnatural corpora.

Table C.1: Corpus 1a (Speaker LMTJ).

	File N.	IPA
1	_18	[ɨffff ... ɨ]
2	_13	[ɐffff ... ɐ]
3	_7	[uffff ... u]
4	_5	[ɨvvvv ... ɨ]
5	_3	[ɐvvvv ... ɐ]
6	_1	[uvvvv ... u]
7	_12	[uvvvv ... u]
8	11_1r †	[ɨssss ... ɨ]
9	11_2r †	[ɨssss ... ɨ]
10	_15	[ɐssss ... ɐ]
11	_11	[ɐssss ... ɐ]
12	_8	[ussss ... u]
13	16_1r †	[ɨzzzz ... ɨ]
14	16_2r †	[ɨzzzz ... ɨ]
15	_9	[ɐzzzz ... ɐ]
16	_16	[ɐzzzz ... ɨ]
17	12_r1 †	[uzzzz ... u]
18	12_r2 †	[uzzzz ... u]
19	14_1r †	[ɨʃʃʃʃ ... ɨ]
20	14_2r †	[ɨʃʃʃʃ ... ɨ]
21	_6	[ɐʃʃʃʃ... ɐ]
22	_14	[ɐʃʃʃʃ... ɐ]
23	_4	[uʃʃʃʃ ... u]
24	10_1r †	[ɨʒʒʒʒ ... ɨ]
25	10_2r †	[ɨʒʒʒʒ ... ɨ]
26	_2	[ɐʒʒʒʒ ... ɐ]
27	_10	[ɐʒʒʒʒ ... ɐ]
28	17_1r †	[uʒʒʒʒ ... u]
29	17_2r †	[uʒʒʒʒ ... u]

Table C.2: Corpus 1a (Speaker CFGA).

	File N.	IPA
1	_18	[ɨffff ... ɨ]
2	_13	[ɐffff ... ɐ]
3	_7	[uffff ... u]
4	_5	[ɨvvvv ... ɨ]
5	_3	[ɐvvvv ... ɐ]
6	_1	[uvvvv ... u]
7	_11	[ɨssss ... ɨ]
8	_15	[ɐssss ... ɐ]
9	_8	[ussss ... u]
10	_16	[ɨzzzz ... ɨ]
11	_9	[ɐzzzz ... ɐ]
12	_12	[uzzzz ... u]
13	_14	[ɨʃʃʃʃ ... ɨ]
14	_6	[ɐʃʃʃʃ... ɐ]
15	_4	[uʃʃʃʃ ... u]
16	_10	[ɨʒʒʒʒ ... ɨ]
17	_2	[ɐʒʒʒʒ ... ɐ]
18	_17	[uʒʒʒʒ ... u]

†Re-Recording Session (25/1/1999).

Table C.3: Corpus 1a (Speaker ACC).

	File N.	IPA
1	18	[ɨffff ... ɨ]
2	18r1	[ɨffff ... ɨ]
3	13	[ɐffff ... ɐ]
4	13r1	[ɐffff ... ɐ]
5	7	[uffff ... u]
6	7r1	[uffff ... u]
7	5	[ɨvvvv ... ɨ]
8	5r1	[ɨvvvv ... ɨ]
9	3	[ɐvvvv ... ɐ]
10	3r1	[ɐvvvv ... ɐ]
11	1	[uvvvv ... u]
12	1r1	[uvvvv ... u]
13	11	[ɨssss ... ɨ]
14	11r1	[ɨssss ... ɨ]
15	11r2	[ɨssss ... ɨ]
16	15	[ɐssss ... ɐ]
17	15r1	[ɐssss ... ɐ]
18	8	[ussss ... u]
19	8r1	[ussss ... u]

	File N.	IPA
20	16	[ɨzzzz ... ɨ]
21	16r1	[ɨzzzz ... ɨ]
22	9	[ɐzzzz ... ɐ]
23	9r1	[ɐzzzz ... ɐ]
24	9r2	[ɐzzzz ... ɐ]
25	12	[uzzzz ... u]
26	12r1	[uzzzz ... u]
27	14	[ɨʃʃʃʃ ... ɨ]
28	14r1	[ɨʃʃʃʃ ... ɨ]
29	6	[ɐʃʃʃʃ... ɐ]
30	6r1	[ɐʃʃʃʃ... ɐ]
31	4	[uʃʃʃʃ ... u]
32	4r1	[uʃʃʃʃ ... u]
33	10	[ɨʒʒʒʒ ... ɨ]
34	10r1	[ɨʒʒʒʒ ... ɨ]
35	2	[ɐʒʒʒʒ ... ɐ]
36	2r1	[ɐʒʒʒʒ ... ɐ]
37	17	[uʒʒʒʒ ... u]
38	17r1	[uʒʒʒʒ ... u]

Table C.4: Corpus 1a (Speaker ISSS).

	File N.	IPA
1	_18	[ɨffff ... ɨ]
2	_13	[ɐffff ... ɐ]
3	_7	[uffff ... u]
4	_5	[ɨvvvv ... ɨ]
5	_3	[ɐvvvv ... ɐ]
6	_1	[uvvvv ... u]
7	_11	[ɨssss ... ɨ]
8	_15	[ɐssss ... ɐ]
9	_8	[ussss ... u]

	File N.	IPA
10	_16	[ɨzzzz ... ɨ]
11	_9	[ɐzzzz ... ɐ]
12	_12	[uzzzz ... u]
13	_14	[ɨʃʃʃʃ ... ɨ]
14	_6	[ɐʃʃʃʃ... ɐ]
15	_4	[uʃʃʃʃ ... u]
16	_10	[ɨʒʒʒʒ ... ɨ]
17	_2	[ɐʒʒʒʒ ... ɐ]
18	_17	[uʒʒʒʒ ... u]

Table C.5: Corpus 1b, Fricatives /f,v,s,z/ (Speaker LMTJ).

	File N.	IPA	Effort Level
1	5ar1	[f]	loud
2	5br1		soft
3	5nr1		medium
4	5ar2		loud
5	5br2		soft
6	5nr2		medium
7	9ar1		loud
8	9br1		soft
9	9nr1		medium
10	9ar2		loud
11	9br2		soft
12	9nr2		medium
13	3ar1	[v]	loud
14	3br1		soft
15	3nr1		medium
16	3ar2		loud
17	3br2		soft
18	3nr2		medium
19	3a1r †		loud
20	3b1r †		soft
21	3n1r †		medium
22	3a2r †		loud
23	3b2r †		soft
24	3n2r †		medium
25	8ar1		loud
26	8br1		soft
27	8nr1		medium
28	8ar2		loud
29	8br2		soft
30	8nr2		medium

	File N.	IPA	Effort Level
31	2ar1	[s]	loud
32	2br1		soft
33	2nr1		medium
34	2ar2		loud
35	2br2		soft
36	2nr2		medium
37	7ar1		loud
38	7br1		soft
39	7nr1		medium
40	7ar2		loud
41	7br2		soft
42	7nr2		medium
43	7a1r †		loud
44	7b1r †		soft
45	7n1r †		medium
46	7a2r †		loud
47	7b2r †		soft
48	7n2r †		medium
49	6ar1	[z]	loud
50	6br1		soft
51	6nr1		medium
52	6ar2		loud
53	6br2		soft
54	6nr2		medium
55	11ar1		loud
56	11br1		soft
57	11nr1		medium
58	11ar2		loud
59	11br2		soft
60	11nr2		medium
61	13ar2		loud
62	13br2		soft
63	13nr2		medium

†Re-Recording Session (25/1/1999).

Table C.6: Corpus 1b, Fricatives /ʃ,ʒ/ (Speaker LMTJ).

	File N.	IPA	Effort Level
64	1ar1	[ʃʃ]	loud
65	1br1		soft
66	1nr1		medium
67	1ar2		loud
68	1br2		soft
69	1nr2		medium
70	12ar1		loud
71	12br1		soft
72	12nr1		medium
73	12ar2		loud
74	12br2		soft
75	12nr2		medium
76	4ar1	[ʒ]	loud
77	4br1		soft
78	4nr1		medium
79	4ar2		loud
80	4br2		soft
81	4nr2		medium
82	4a1r †		loud
83	4b1r †		soft
84	4n1r †		medium
85	4a2r †		loud
86	4b2r †		soft
87	4n2r †		medium
88	10ar1		loud
89	10br1		soft
90	10nr1		medium
91	10ar2		loud
92	10br2		soft
93	10nr2		medium
94	10a1r		loud
95	10b1r		soft
96	10n1r		medium
97	10a2r		loud
98	10b2r		soft
99	10n2r		medium

† Re-Recording Session (25/1/1999).

Table C.7: Corpus 1b (Speaker CFGA).

	File N.	IPA	Effort Level
1	5a	[f]	loud
2	5b		soft
3	5n		medium
4	9a		loud
5	9b		soft
6	9n		medium
7	3a	[v]	loud
8	3b		soft
9	3n		medium
10	8a		loud
11	8b		soft
12	8n		medium
13	2a	[s]	loud
14	2b		soft
15	2n		medium
16	7a		loud
17	7b		soft
18	7n		medium
19	6a	[z]	loud
20	6b		soft
21	6n		medium
22	6a_r		loud
23	6b_r		soft
24	6n_r		medium
25	11a		loud
26	11b		soft
27	11n		medium
28	1a	[ʃ]	loud
29	1b		soft
30	1n		medium
31	12a		loud
32	12b		soft
33	12n		medium
34	4a	[ʒ]	loud
35	4b		soft
36	4n		medium
37	4a_r		loud
38	4b_r		soft
39	4n_r		medium
40	10a		loud
41	10b		soft
42	10n		medium

Table C.8: Corpus 1b (Speaker ACC).

	File N.	IPA	Effort Level
1	5a	[f]	loud
2	5b		soft
3	5n		medium
4	5ar		loud
5	5br		soft
6	5nr		medium
7	9a		loud
8	9b		soft
9	9n		medium
10	3a	[v]	loud
11	3b		soft
12	3n		medium
13	3ar		loud
14	3br		soft
15	3nr		medium
16	8a		loud
17	8b		soft
18	8n		medium
19	2a	[s]	loud
20	2b		soft
21	2n		medium
22	2ar		loud
23	2br		soft
24	2nr		medium
25	7a		loud
26	7b		soft
27	7n		medium

	File N.	IPA	Effort Level
28	6a	[z]	loud
29	6b		soft
30	6n		medium
31	6ar		loud
32	6br		soft
33	6nr		medium
34	11a		loud
35	11b		soft
36	11n		medium
37	1a	[ʃ]	loud
38	1b		soft
39	1n		medium
40	1ar		loud
41	1br		soft
42	1nr		medium
43	12a		loud
44	12b		soft
45	12n		medium
46	4a	[ʒ]	loud
47	4b		soft
48	4n		medium
49	4ar		loud
50	4br		soft
51	4nr		medium
52	10a		loud
53	10b		soft
54	10n		medium

Table C.9: Corpus 1b (Speaker ISSS).

	File N.	IPA	Effort Level
1	5a	[f]	loud
2	5b		soft
3	5n		medium
4	9a		loud
5	9b		soft
6	9n		medium
7	3a	[v]	loud
8	3b		soft
9	3n		medium
10	8a		loud
11	8b		soft
12	8n		medium
13	2a	[s]	loud
14	2b		soft
15	2n		medium
16	7a		loud
17	7b		soft
18	7n		medium

	File N.	IPA	Effort Level
19	6a	[z]	loud
20	6b		soft
21	6n		medium
22	11a		loud
23	11b		soft
24	11n		medium
25	1a	[ʃ]	loud
26	1b		soft
27	1n		medium
28	12a		loud
29	12b		soft
30	12n		medium
31	4a	[ʒ]	loud
32	4b		soft
33	4n		medium
34	10a		loud
35	10b		soft
36	10n		medium

Table C.10: Corpus 2 (Speaker LMTJ).

	File N.	IPA
1	4	[ˈpɨfɨ]
2	4r †	[pɨfɨ]
3	38	[pɨˈfɐ]
4	25	[pɨˈfu]
5	2	[ˈpɐfɨ]
6	21	[pɐfɐ]
7	33	[pɐˈfu]
8	40	[ˈpuf]
9	28	[puˈfɐ]
10	44	[pufu]
11	34r †	[pɨvɨ]
12	45	[pɨvɐ]
13	19r †	[pɨˈvu]
14	10	[ˈpɐv]
15	34	[ˈpɐv]
16	26	[pɐvɐ]
17	5	[pɐˈvu]
18	19	[pɐˈvu]
19	15	[ˈpuv]
20	37	[puˈvɐ]
21	12	[puvu]
22	16	[ˈpɨs]
23	16r †	[pɨsɨ]
24	16rr †	[pɨsɨ]
25	14	[pɨˈsɐ]
26	47	[pɨˈsu]
27	29	[ˈpɐs]
28	49	[pɐsɐ]
29	7	[pɐˈsɐ]
30	53	[pɐsu]
31	27	[ˈpus]
32	52	[puˈsɐ]
33	32	[pusu]

	File N.	IPA
34	36r †	[pɨzɨ]
35	6	[pɨˈzɐ]
36	13	[pɨˈzɐ]
37	6r †	[pɨˈzɐ]
38	9	[pɨˈzu]
39	51	[ˈpɐz]
40	36	[ˈpɐz]
41	23	[pɐˈzu]
42	42	[ˈpuz]
43	54	[puˈzɐ]
44	54r †	[puˈzɐ]
45	35	[puzu]
46	8	[ˈpɨʃɨ]
47	8r †	[pɨʃɨ]
48	31	[pɨˈʃɐ]
49	1	[pɨˈʃu]
50	24	[ˈpɐʃɨ]
51	17	[pɐˈʃɐ]
52	20	[pɐˈʃu]
53	50	[ˈpuʃ]
54	48	[ˈpuʃɐ]
55	39	[puʃu]
56	43	[pɨʒɨ]
57	43r †	[pɨʒɨ]
58	43rr †	[pɨʒɨ]
59	7r †	[pɨˈʒɐ]
60	41	[pɨˈʒu]
61	41r †	[pɨˈʒu]
62	11	[ˈpɐʒ]
63	30	[pɐʒɐ]
64	18	[pɐˈʒu]
65	22	[ˈpuʒ]
66	46	[puˈʒɐ]
67	3	[puˈʒu]

† Re-Recording Session (25/1/1999).

Table C.11: Corpus 2 (Speaker CFGA).

	File N.	IPA
1	4	[pɨfɨ]
2	38	[pɨˈfɐ]
3	25	[pɨˈfu]
4	2	[ˈpɐf]
5	21	[pɐfɐ]
6	33	[pɐˈfu]
7	40	[ˈpuf]
8	28	[puˈfɐ]
9	44	[pufu]
10	34	[pɨvɨ]
11	45	[pɨˈvɐ]
12	19	[pɨˈvu]
13	10	[ˈpɐv]
14	26	[pɐvɐ]
15	5	[pɐˈvu]
16	15	[ˈpuv]
17	37	[puˈvɐ]
18	12	[puvu]
19	16	[pɨsɨ]
20	14	[pɨˈsɐ]
21	47	[pɨˈsu]
22	29	[ˈpɐs]
23	49	[pɐsɐ]
24	49r	[pɐsɐ]
25	53	[pɐsu]
26	27	[ˈpus]
27	52	[puˈsɐ]
28	32	[pusu]

	File N.	IPA
29	36	[pɨzɨ]
30	36r	[pɨzɨ]
31	6	[pɨˈzɐ]
32	9	[pɨˈzu]
33	51	[ˈpɐz]
34	13	[pɐzɐ]
35	13r	[pɐzɐ]
36	23	[pɐˈzu]
37	42	[ˈpuz]
38	54	[puˈzɐ]
39	35	[puzu]
40	8	[pɨʃɨ]
41	31	[pɨˈʃɐ]
42	1	[pɨˈʃu]
43	1r	[pɨˈʃu]
44	24	[ˈpɐʃ]
45	17	[pɐˈʃɐ]
46	20	[pɐˈʃu]
47	20r	[pɐˈʃu]
48	50	[ˈpuʃ]
49	48	[puʃɐ]
50	39	[puʃu]
51	43	[pɨʒɨ]
52	7	[pɨˈʒɐ]
53	41	[pɨˈʒu]
54	11	[ˈpɐʒ]
55	30	[pɐʒɐ]
56	18	[pɐˈʒu]
57	22	[ˈpuʒ]
58	46	[ˈpuʒɐ]
59	46r1	[puˈʒɐ]
60	46r2	[puˈʒɐ]
61	3	[puˈʒu]

Table C.12: Corpus 2 (Speaker ACC).

	File N.	IPA
1	4	[ˈpɨf]
2	4r1	[ˈpɨfɨ]
3	38	[pɨˈfɐ]
4	25	[pɨˈfu]
5	2	[ˈpɐf]
6	21	[ˈpɐfɐ]
7	33	[pɐˈfu]
8	40	[ˈpuf]
9	28	[puˈfɐ]
10	44	[pufu]
11	34	[ˈpɨvɨ]
12	45	[pɨˈvɐ]
13	19	[pɨˈvu]
14	10	[ˈpɐv]
15	26	[ˈpɐvɐ]
16	5	[pɐˈvu]
17	5r1	[pɐˈvu]
18	15	[ˈpuvɨ]
19	15r1	[ˈpuvɨ]
20	37	[puˈvɐ]
21	12	[ˈpuvu]
22	16	[ˈpɨsɨ]
23	14	[pɨˈsɐ]
24	47	[pɨˈsu]
25	29	[ˈpɐsɨ]
26	49	[ˈpɐsɐ]
27	53	[pɐˈsu]
28	27	[ˈpusɨ]
29	52	[puˈsɐ]
30	32	[pusu]

	File N.	IPA
31	36	[ˈpɨzɨ]
32	6	[ˈpɨzɐ]
33	9	[pɨˈzu]
34	51	[ˈpɐz]
35	13	[ˈpɐzɐ]
36	13r1	[ˈpɐzɐ]
37	13r2	[ˈpɐzɐ]
38	23	[pɐˈzu]
39	42	[ˈpuzɨ]
40	54	[puˈzɐ]
41	35	[puzu]
42	8	[ˈpɨʃ]
43	31	[pɨˈʃɐ]
44	1	[pɨˈʃu]
45	24	[ˈpɐʃ]
46	24r1	[ˈpɐʃɨ]
47	17	[pɐˈʃɐ]
48	20	[pɐˈʃu]
49	50	[ˈpuʃ]
50	48	[ˈpuʃɐ]
51	39	[ˈpuʃu]
52	43	[pɨʒɨ]
53	7	[ˈpɨʒɐ]
54	7r1	[ˈpɨʒɐ]
55	41	[pɨˈʒu]
56	11	[ˈpɐʒɨ]
57	30	[ˈpɐʒɐ]
58	18	[pɐˈʒu]
59	22	[ˈpuʒɨ]
60	46	[puʒɐ]
61	3	[puˈʒu]

Table C.13: Corpus 2 (Speaker ISSS).

	File N.	IPA
1	4	[pɨfɨ]
2	38	[pɨˈfɐ]
3	25	[pɨˈfu]
4	2	[ˈpɐf]
5	21	[pɐfɐ]
6	33	[pɐˈfu]
7	40	[ˈpuf]
8	28	[puˈfɐ]
9	44	[pufu]
10	34	[pɨvɨ]
11	45	[pɨˈvɐ]
12	19	[pɨˈvu]
13	10	[ˈpɐv]
14	26	[pɐvɐ]
15	5	[pɐˈvu]
16	15	[ˈpuv]
17	37	[puˈvɐ]
18	12	[puvu]
19	16	[pɨsɨ]
20	14	[pɨˈsɐ]
21	47	[pɨˈsu]
22	29	[ˈpɐs]
23	49	[pɐsɐ]
24	53	[pɐˈsu]
25	27	[ˈpus]
26	52	[puˈsɐ]
27	32	[pusu]

	File N.	IPA
28	36	[pɨzɨ]
29	6	[pɨˈzɐ]
30	9	[pɨˈzu]
31	9r	[pɨˈzu]
32	51	[ˈpɐz]
33	13	[pɐzɐ]
34	23	[pɐˈzu]
35	42	[ˈpuz]
36	54	[puˈzɐ]
37	35	[puzu]
38	8	[pɨʃɨ]
39	31	[pɨˈʃɐ]
40	1	[pɨˈʃu]
41	24	[ˈpɐʃ]
42	17	[pɐˈʃɐ]
43	20	[pɐˈʃu]
44	50	[ˈpuʃ]
45	48	[ˈpuʃɐ]
46	48r	[ˈpuʃɐ]
47	39	[puʃu]
48	43	[pɨʒɨ]
49	7	[pɨˈʒɐ]
50	41	[pɨˈʒu]
51	11	[ˈpɐʒ]
52	30	[pɐʒɐ]
53	18	[pɐˈʒu]
54	22	[ˈpuʒ]
55	46	[puˈʒɐ]
56	3	[puʒu]

Appendix D

Listings of Recorded Material for All Speakers and Time Analysis for Speaker LMTJ (Corpus 3 and 4)

This appendix lists the results of the time analysis of Corpus 3 and 4 fricatives, and their VF and FV transitions for Speaker LMTJ. We also include a broad phonetic transcription of all recorded material and list re-recorded examples for Speaker LMTJ. The data presented includes: the VF transition duration, the fricative duration, the FV transition duration, the ratio of variances r_{σ^2}, and a manual classification of devoicing (listed in the column "Devoicing").

The file numbering of words from Corpus 4 has two parts: a number that refers to the sentence where the words occur (see sentence listings in Section A.2 in Appendix A) and a word number which is the same as the one used in Corpus 3 (see Appendix A).

When the phonetic transcription, of words with fricatives at the beginning or end, has an additional initial ([ɐ ˈvilɐ] in Table D.8) or final ([ˈmɔv ɐ] in Table D.26) phoneme, separated from the transcription of the word we are analysing by a white space, this means that there is co-articulation between the fricative and the final or initial phoneme of the previous or following word in the sentence.

Table D.1: Fricative /f/ in Corpus 3 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	figo	[ɐ ˈfigu]	41	58.8	145.8	38.5	59.2
2	ferir	[ɐ fˈrir]	18	78.8	150.0	-	128.2
3	febra	[ɐ ˈfebrɐ]	61	37.5	135.4	51.0	20.1
4	ferro	[ɐ ˈfɛRu]	4	64.6	182.3	80.2	128.1
5	falir	[ɐ fɐˈlir]	47	62.1	106.3	33.3	36.2
6	fala	[ɐ ˈfalɐ]	2	37.7	167.7	26.7	24.9
7	Fafe	[ɐ ˈf af]	125				
8	foco	[ɐ ˈfɔku]	90	71.3	122.9	36.0	146.9
9	fogo	[ɐ ˈfogu]	101	54.8	149.6	29.6	17.1
10	fofa	[ɐ ˈf ofɐ]	23	96.7	129.2	29.2	55.4
11	furar	[ɐ fuˈɾaɾ]	44	36.7	124.6	41.7	20.4
12	efectuar	[iˈfɛtwaɾ]	98	55.2	116.5	12.7	3.5
13	benefício	[bɨnɨˈf isju]	49_1r †	61.7	158.1	25.4	197.6
14		[bɨnɨˈf isju]	49_2r †	55.6	122.9	41.0	93.3
15	benéfico	[bɨˈnɛfiku]	89	44.4	107.7	30.0	64.2
16		[bɨˈnɛfiku]	49	51.7	106.7	23.3	24.9
17	afiar	[ɐfiˈaɾ]	53	108.3	104.2	66.7	97.4
18	café	[kɐˈfɛ]	31	52.9	137.3	32.3	92.4
19	garrafa	[gɐˈRafɐ]	71	71.5	88.5	33.1	15.9
10	fofa	[ˈfo f ɐ]	23	54.2	91.7	69.8	45.9
20	galhofa	[gɐˈʎofɐ]	128	72.5	136.3	37.7	47.8
21	bufa	[ˈbufɐ]	73	45.0	131.0	24.0	54.4
22	trefo	[ˈtɾef]	107	46.3	177.7	-	87.2
23	chefe	[ˈʃɛ f]	11	96.6	162.5	-	58.8
7	Fafe	[ˈfa f]	125	59.8	123.1	-	92.2
24	bafo	[ˈbaf]	26	62.5	95.8	-	97.2
25	mofo	[ˈmof]	55	50.4	86.3	-	52.2

† Re-Recording Session (25/1/1999).

Table D.2: Fricative /v/ in Corpus 3 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
26	vila	[ɐ ˈvilɐ]	59	66.3	50.2	73.3	4.5	
27	viver	[ɐ v iˈveɾ]	122	58.1	46.7	65.6	32.6	par. dev.
28	viva	[ɐ ˈv ivɐ]	140	84.2	63.3	54.0	66.7	
29	vermelho	[ɐ vɨɾˈmɐʎu]	86_1r †	32.3	21.7	26.3	161.1	dev.
30		[ɐ vɨɾˈmɐʎu]	86_2r †	39.0	22.7	37.1	185.3	dev.
31	ver	[ɐ veɾ]	102	44.0	89.6	36.9	118.9	dev.
32	véu	[ɐ ˈvɛw]	104	65.0	72.9	53.1	122.5	dev.
33	veia	[ɐ ˈvɐjɐ]	111	39.2	98.8	35.2	57.1	dev.
34	vaca	[ɐ ˈvakɐ]	92	36.9	71.7	58.5	6.9	
35		[ɐ ˈvakɐ]	92_1r †	47.5	55.8	62.1	3.5	
36		[ɐ ˈvakɐ]	92_2r †	50.4	80.8	41.7	11.2	
37	volta	[ɐ ˈvɔltɐ]	81	70.0	59.6	47.1	2.0	
38	voo	[ɐ vow]	17	61.5	70.8	65.6	118.9	dev.
39	vogar	[ɐ ˈvugaɾ]	7	81.5	37.5	47.9	30.6	par. dev.
27	viver	[vi v eɾ]	122	46.3	78.1	46.0	4.1	
40	possível	[pˈsi v ɛl]	95					
28	viva	[ˈvi v ɐ]	140	57.7	68.8	38.5	114.9	
41	dever	[dɨˈveɾ]	22	43.8	83.3	57.3	1.5	
42	levar	[lɨˈvaɾ]	105	59.8	77.3	34.4	58.9	dev.
43	leva	[ˈlɛvɐ]	149	64.4	55.8	40.6	25.1	
44	avó	[ɐˈvɔ]	88	40.2	64.4	32.5	9.3	
45	cava	[ˈkavɐ]	24_1r †	61.3	67.5	43.1	88.3	par. dev.
46		[ˈkavɐ]	24_2r †	62.3	99.8	28.8	49.8	dev.
47	cavo	[ˈkavu]	24	72.9	43.8	43.8	139.4	dev.
48	nova	[ˈnɔvɐ]	147	79.0	40.4	85.4	1.6	
49	ovelha	[oˈvɐʎɐ]	136	65.2	54.0	47.5	107.5	
50	mover	[muˈveɾ]	57	38.1	77.1	38.5	11.6	par. dev.
51	uva	[ˈuvɐ]	40	68.3	66.7	45.8	416.9	dev.
52	altivo	[alˈtiv]	124	46.0	110.2	-	44.2	dev.
53	teve	[ˈtev]	42	69.0	88.3	-	75.1	dev.
54	relevo	[Rɨˈlev]	94	58.3	117.7	-	34.4	dev.
55	leve	[ˈlɛv]	6	81.3	122.9	-	51.5	dev.
56	ave	[ˈav]	45	84.4	97.9	-	55.7	dev.
57	bravo	[ˈbɾav]	100	56.5	72.1	-	58.7	dev.
58	move	[ˈmɔv]	67	24.2	135.4	-	32.9	dev.
59		[ˈmɔv] *	67_1r †	99.6	37.3	-	1.2	
60		[ˈmɔv] *	67_2r †	63.5	83.3	-	458.1	dev.

* "Diga ..., bem dito."

† Re-Recording Session (25/1/1999).

Table D.3: Fricative /s/ in Corpus 3 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
61	sítio	[ɐ 'sitju]	77	62.9	181.3	36.3	27.6
62	secar	[ɐ s'kaɾ]	93	43.5	154.4	-	12.3
63	sede	[ɐ 'sedɨ]	75	44.6	167.7	42.1	53.6
64	seta	[ɐ 'sɛtɐ]	34	31.5	171.0	32.5	26.3
65	cessa	[ɐ 's ɛsɐ]	64	65.4	175.8	25.2	34.9
66	saber	[ɐ sɐ'beɾ]	39	45.2	133.8	31.3	10.3
67	sala	[ɐ 'salɐ]	13	64.8	135.4	38.5	47.4
68	só	[ɐ sɔ]	5	79.6	149.8	55.4	104.8
69	sopa	[ɐ 'sopɐ]	83	54.6	154.2	17.3	47.5
70	subir	[ɐ su'biɾ]	139	43.1	144.2	43.1	43.7
71	iça	['isɐ]	148	90.0	124.6	64.8	45.9
72	benefício	[bɨnɨ'fi s ju]	49_1r †				
73		[bɨnɨ'fi s ju]	49_2r †				
74	ressaca	[Rɨ'sakɐ]	82	73.3	142.9	35.8	28.9
75	condessa	[kõ'desɐ]	153	65.4	123.3	34.8	124.3
76	pêssego	['pesgu]	87	39.2	164.6	-	24.1
77	aquecer	[ɐkɛ'seɾ]	131	44.6	157.1	48.1	18.5
65	cessa	['sɛ s ɐ]	64	60.8	109.4	34.8	34.4
78	passear	[pɐ'sjaɾ]	103	61.0	184.0	49.0	39.1
79	assar	[ɐ'saɾ]	137	74.6	130.4	53.5	28.8
80	caça	['kasɐ]	35	61.7	127.7	30.6	22.6
81	possa	['pɔsɐ]	150	48.1	111.0	60.0	150.9
82	moça	['mosɐ]	152	38.1	111.0	41.3	20.9
83	possível	[p's ivɛl]	95	-	219.8	25.0	2.6
84	partisse	[paɾ'tis]	117	71.0	208.8	-	37.5
85	batesse	[bɐ'tes]	69	37.3	139.6	-	22.1
86	asse	['as]	118	67.3	197.5	-	60.6
87	posse	['pɔs]	21	29.2	139.6	-	13.2
88	doce	['dos]	56	36.7	112.5	-	113.7

† Re-Recording Session (25/1/1999).

Table D.4: Fricative /z/ in Corpus 3 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
89	Zita	[ɐ ˈzitɐ]	68	87.3	79.2	37.5	243.5	dev.
90	zelar	[ɐ ˈzɬlaɾ]	126	43.5	82.5	31.9	4.6	par. dev.
91	zelo	[ɐ ˈzelu]	115	93.1	116.9	64.0	6.6	
92	Zé	[ɐ zɛ]	85	58.3	94.6	24.6	29.9	dev.
93	Zézé	[ɐ ˈz ɛzɛ]	129	36.0	74.8	39.6	1.3	
94	zarpar	[ɐ zɐrˈpaɾ]	113	46.5	67.3	31.7	47.9	dev.
95	Zaire	[ɐ ˈzajɾɨ]	99	37.9	74.2	25.0	69.2	dev.
96	Zópiro	[ɐ ˈzɔpiɾu]	10	47.9	72.9	75.0	93.0	dev.
97	zona	[ɐ ˈzonɐ]	84	58.1	93.1	39.8	16.9	par. dev.
98	zurrar	[ɐ zuˈRaɾ]	16	40.6	55.2	55.2	2.2	
99	exacto	[iˈzatu]	43	46.9	76.5	36.5	67.3	dev.
100	mesinha	[mɨˈziɲɐ]	50	53.8	60.8	78.8	250.5	dev.
101		[mɨˈziɲɐ]	27	54.2	97.7	48.1	25.0	par. dev.
102	beleza	[bɨˈlezɐ]	135	63.5	87.7	22.3	27.5	dev.
103	peso	[ˈpezu]	60	45.8	80.0	21.5	55.8	dev.
104	mezinha	[mɛˈziɲɐ]	27_1r †	31.0	61.5	37.3	3.8	
105		[mɛˈziɲɐ]	27_2r †	32.0	95.4	65.0	133.7	dev.
93	Zézé	[ˈzɛ z ɛ]	129	45.2	78.1	24.0	32.5	dev.
106	Brasil	[bɾɐˈzil]	58	55.8	110.6	26.7	117.1	dev.
107	azar	[ɐˈzaɾ]	97	101.3	95.0	33.3	8.2	
108	azul	[ɐˈzul]	33	99.8	101.0	28.1	85.8	dev.
109	mazinha	[maˈziɲɐ]	37	64.6	86.0	36.9	62.8	dev.
110	asa	[ˈazɐ]	19_1r †	59.6	77.3	39.6	33.3	dev.
111		[ˈazɐ]	19_2r †	59.6	66.7	35.4	17.4	par. dev.
112	rosa	[ˈɾɔzɐ]	14	47.9	45.8	50.0	257.2	dev.
113	doze	[ˈdozɨ] *	132_2r †	32.3	100.4	45.6	105.3	dev.
114	acusar	[ɐkuˈzaɾ]	146	41.9	68.3	68.1	15.0	
115	doze	[ˈdoz]	132	56.7	90.4	-	199.4	dev.
116		[ˈdoz] *	132_1r †	24.0	86.0	-	27.1	dev.
117	amoroso	[ɐmuˈɾoz]	8	93.8	54.2	-	30.4	dev.

* "Diga ..., bem dito."

† Re-Recording Session (25/1/1999).

Table D.5: Fricative /ʃ/ in Corpus 3 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
118	chicote	[ɐ ʃiˈkɔtɨ]	134	47.5	119.2	38.5	124.2
119	chegar	[ɐ ʃɨˈgaɾ]	65	52.9	136.7	29.8	18.7
120	cheta	[ɐ ˈʃetɐ]	30	59.6	155.8	42.8	191.0
121	cheque	[ɐ ˈʃɛkɨ]	36	65.6	165.6	26.7	137.6
122	chefe	[ɐ ˈʃɛf]	11				
123	chamar	[ɐ ʃɐˈmaɾ]	28	36.0	129.2	32.3	35.4
124	chá	[ɐ ʃa]	51	71.0	150.2	52.5	127.6
125	choca	[ɐ ˈʃɔkɐ]	116	79.4	176.9	39.6	10.8
126	choco	[ɐ ˈʃoku]	76	59.2	189.0	21.3	47.7
127	chocha	[ɐ ˈʃoʃɐ]	80	74.4	192.9	25.8	27.0
128	chorar	[ɐ ʃuˈɾaɾ]	78	45.4	150.4	37.1	74.6
129	bicha	[ˈbiʃɐ]	142	62.9	144.2	48.8	38.8
130	bexiga	[bˈʃigɐ]	106	-	193.5	36.5	1.2
131	bochecha	[buˈʃeʃɐ]	154	52.1	122.7	36.3	103.7
132	este	[ˈeʃt]	54	44.4	98.1	-	141.3
133	achar	[ɐˈʃaɾ]	114	77.1	154.2	32.5	61.9
134	bolacha	[buˈlaʃɐ]	15	105.4	94.6	50.4	35.9
135	tocha	[ˈtɔʃɐ]	121	52.3	121.5	46.0	48.0
127	chocha	[ˈʃoʃɐ]	80	37.3	133.3	32.5	34.0
131	bochecha	[buˈʃeʃɐ]	154	38.3	151.9	24.0	28.9
136	diz	[diʃ]	96	44.6	114.0	-	16.5
137	mares	[ˈmaɾɨʃ]	130	69.0	101.0	-	192.3
138	mês	[ˈmeʃ]	112	29.0	124.6	-	23.7
139	pés	[pɛʃ]	62	122.5	77.1	-	334.5
140	meche	[ˈmɛʃ]	141	41.9	156.3	-	117.4
141	perdas	[ˈpɛɾdɐʃ]	29	48.1	75.6	-	164.5
142	capaz	[kɐˈpaʃ]	91	44.2	102.7	-	20.6
143	tacho	[ˈtaʃ]	133	62.3	147.7	-	48.0
144	pós	[pɔʃ]	70	71.0	85.4	-	93.9
145	pôs	[poʃ]	144	81.5	94.2	-	235.5
146	mocho	[ˈmoʃ]	109	33.5	159.2	-	30.0
147	dos	[ˈduʃ]	138	40.8	77.5	-	28.8
148	capucho	[kɐˈpuʃ]	74	49.6	133.8	-	68.0

Table D.6: Fricative /ʒ/ in Corpus 3 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
149	girar	[ɐ ʒiˈraɾ]	48	59.4	71.0	36.9	142.3	dev.
150	Gigi	[ɐ ʒ̊iˈʒi]	145	31.9	82.5	32.3	2.0	
151	gelado	[ɐ ʒɨˈladu]	127	39.8	103.5	32.3	11.2	dev.
152	gelo	[ɐ ˈʒelu]	119	37.9	105.0	38.5	5.4	dev.
153	germe	[ɐ ˈʒɛɾmɨ]	72	76.9	76.0	27.9	17.0	par. dev.
154	jaqueta	[ɐ ʒɐˈketɐ]	20	48.3	61.3	30.0	53.5	dev.
155	jacto	[ɐ ˈʒatu]	123	32.5	85.8	28.5	5.9	
156	jóia	[ɐ ˈʒɔjɐ]	143	59.8	79.4	32.9	103.0	dev.
157	jogo	[ɐ ˈʒogu]	3	82.3	69.8	114.6	8.2	dev.
158	judeu	[ɐ ʒuˈdew]	32	31.0	100.2	37.3	56.9	dev.
159	originar	[oɾiʒiˈnaɾ]	1	49.7	60.4	22.5	120.0	dev.
150	Gigi	[ʒiˈʒ̊i]	145	73.8	85.2	61.9	52.6	
160	tijolo	[tiˈʒolu]	110	31.0	100.2	26.9	27.1	dev.
161	arejar	[ɐɾɨˈʒaɾ]	46	36.0	112.5	28.1	59.9	dev.
162	pejo	[ˈpeʒu]	25	77.1	77.1	66.7	57.1	dev.
163	Beja	[ˈbɛʒɐ]	52	36.3	79.2	42.5	119.9	dev.
164	agir	[ɐˈʒiɾ]	108	89.2	124.6	35.2	81.9	dev.
165	cajado	[kɐˈʒadu]	63	55.2	61.0	77.5	58.1	dev.
166	ajudar	[ɐˈʒudaɾ]	66	24.0	78.5	14.8	2.3	dev.
167	haja	[ˈaʒɐ]	12_1r †	43.5	112.1	27.3	59.0	dev.
168		[ˈaʒɐ]	12_2r †	55.6	94.2	40.0	123.0	dev.
169		[ˈaʒɐ]	19	89.0	109.8	22.1	207.4	dev.
170	aloja	[ɐˈlɔʒɐ]	151	49.2	59.8	31.7	10.0	
171	hoje	[ˈoʒɨ] *	38_2r †	24.6	128.8	53.8	106.8	dev.
172	tugir	[tuˈʒiɾ]	120	45.8	139.2	38.5	73.2	dev.
173	age	[ˈaʒ]	79	108.8	135.8	-	89.4	dev.
174		[ˈaʒ]	12	75.0	100.0	-	42.2	dev.
175	hoje	[ˈoʒ]	38	56.0	111.0	-	224.9	dev.
176		[ˈoʒ] *	38_1r †	51.9	111.9	-	9.7	
177	tojo	[ˈtoʒ]	9	129.2	75.0	-	228.6	dev.

* "Diga ..., bem dito."

† Re-Recording Session (25/1/1999).

Table D.7: Fricative /f/ in Corpus 3 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	figo	[ɐ ˈfigu]	41				
2	ferir	[ɐ fɨˈɾiɾ]	18				
3	febra	[ɐ ˈfebɾɐ]	61				
4	ferro	[ɐ ˈfɛRu]	4				
5	falir	[ɐ fɐˈliɾ]	47				
6	fala	[ɐ ˈfalɐ]	2				
7	Fafe	[ɐ ˈf af]	125				
8	foco	[ɐ ˈfɔk]	90				
9	fogo	[ɐ ˈfogu]	101				
10	fofa	[ɐ ˈf ofɐ]	23				
11	furar	[ɐ fuˈɾaɾ]	44				
12	efectuar	[iˈfɛtwaɾ]	98				
13	benefício	[bɨnɨˈf isju]	49				
14	benéfico	[bɨˈnɛfik]	89				
15	afiar	[ɐfiˈaɾ]	53				
16	café	[kɐˈfɛ]	31				
17	garrafa	[gɐˈχa f ɐ]	71				
10	fofa	[ˈfo f ɐ]	23				
18	galhofa	[gɐˈʎɔfɐ]	128				
19	bufa	[ˈbufɐ]	73				
20	trefo	[ˈtɾef]	107			-	
21	chefe	[ˈʃɛ f]	11			-	
7	Fafe	[ˈfa f]	125			-	
22	bafo	[ˈbaf]	26			-	
23	mofo	[ˈmof]	55			-	

Table D.8: Fricative /v/ in Corpus 3 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
24	vila	[ɐ ˈvilɐ]	59					
25	viver	[ɐ v iˈveɾ]	122					
26	viva	[ɐ ˈv ivɐ]	140					dev.
27	vermelho	[ɐ vɨɾˈmeʎu]	86					dev.
28	ver	[ɐ veɾ]	102					dev.
29	véu	[ɐ ˈvɛw]	104					dev.
30	veia	[ɐ ˈvɐjɐ]	111					
31	vaca	[ɐ ˈvakɐ]	92					dev.
32	volta	[ɐ ˈvɔltɐ]	81					dev.
33	voo	[ɐ vow]	17					dev.
34	vogar	[ɐ ˈvugaɾ]	7					
25	viver	[viˈv eɾ]	122					dev.
35	possível	[pˈsi v l]	95			-		
26	viva	[ˈvi v ɐ]	140					
36	dever	[dɨˈveɾ]	22					dev.
37	levar	[lɨˈvaɾ]	105					dev.
38	leva	[ˈlɛvɐ]	149					dev.
39	avó	[ɐˈvɔ]	88					dev.
40	cava	[ˈkavɐ]	24					par. dev.
41	nova	[ˈnɔvɐ]	147					dev.
42	ovelha	[oˈvɐʎɐ]	136					dev.
43	mover	[muˈveɾ]	57					par. dev.
44	uva	[ˈuvɐ]	40					dev.
45	altivo	[alˈtiv]	124			-		dev.
46	teve	[ˈtev]	42			-		dev.
47	relevo	[χɨˈle v]	94			-		dev.
48	leve	[ˈlɛv]	6			-		dev.
49	ave	[ˈav]	45			-		dev.
50	bravo	[ˈbɾav]	100			-		dev.
51	move	[ˈmɔv]	67			-		dev.

Table D.9: Fricative /s/ in Corpus 3 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
52	sítio	[ɐ ˈsitju]	77				
53	secar	[ɐ sˈkaɾ]	93			-	
54	sede	[ɐ ˈsed]	75				
55	seta	[ɐ ˈsɛtɐ]	34				
56	cessa	[ɐ ˈs ɛsɐ]	64				
57	saber	[g sɐˈbeɾ]	39	-			
58	sala	[ɐ ˈsalɐ]	13				
59	só	[ɐ sɔ]	5				
60	sopa	[ɐ ˈsopɐ]	83				
61	subir	[ɐ suˈbiɾ]	139				
62	iça	[ˈisɐ]	148				
63	benefício	[bɨnɨˈfi s ju]	49				
64	ressaca	[χˈ s akɐ]	82	-			
65	condessa	[kõˈdesɐ]	153				
66	pêssego	[ˈpesg]	87			-	
67	aquecer	[ɐkɛˈseɾ]	131				
56	cessa	[ˈsɛ s ɐ]	64				
68	passear	[pɐˈsjaɾ]	103				
69	assar	[ɐˈsaɾ]	137				
70	caça	[ˈkasɐ]	35				
71	possa	[ˈpɔsɐ]	150				
72	moça	[ˈmosɐ]	152				
73	possível	[p s ivl]	95	-			
74	partisse	[paɾˈtis]	117			-	
75	batesse	[bɐˈtes]	69			-	
76	asse	[ˈas]	118			-	
77	posse	[ˈpɔs]	21			-	
78	doce	[ˈdos]	56			-	

Table D.10: Fricative /z/ in Corpus 3 (Speaker CFGA)

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
79	Zita	[ɐ ˈzitɐ]	68					par. dev.
80	zelar	[ɐ ˈzlaɾ]	126			-		dev.
81	zelo	[ɐ ˈzelu]	115					dev.
82	Zé	[ɐ zɛ]	85					dev.
83	Zézé	[ɐ ˈz ɛzɛ]	129					
84	zarpar	[ɐ zɐɾˈpaɾ]	113					dev.
85	Zaire	[ɐ ˈzajɾɨ]	99					dev.
86	Zópiro	[ɐ ˈzɔpiɾu]	10					dev.
87	zona	[ɐ ˈzonɐ]	84					dev.
88	zurrar	[ɐ z uˈχar]	16					dev.
89	exacto	[iˈzat]	43					dev.
90	mesinha	[mɨˈziɲɐ]	50					dev.
91		[mɨˈziɲɐ]	50r1					dev.
92		[mɨˈziɲɐ]	50r2					dev.
93	beleza	[bɨˈlezɐ]	135					par. dev.
94	mezinha	[mɛˈziɲɐ]	27					dev.
83	Zézé	[ˈzɛ z ɛ]	129					dev.
95	Brasil	[bɾɐˈzil]	58					par. dev.
96	azar	[ɐˈzaɾ]	97					dev.
97	azul	[ɐˈzul]	33					dev.
98	mazinha	[maˈziɲɐ]	37					dev.
99	asa	[ˈazɐ]	19					dev.
100	rosa	[ˈʁɔ z ɐ]	14					dev.
101	acusar	[ɐkuˈzaɾ]	146					dev.
102	peso	[ˈpez]	60			-		
103	doze	[ˈdoz]	132			-		dev.
104	amoroso	[ɐmuˈɾoz]	8			-		dev.

Table D.11: Fricative /ʃ/ in Corpus 3 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
105	chicote	[ɐ ʃiˈkɔt]	134				
106	chegar	[ɐ ʃɨˈgaɾ]	65				
107	cheta	[ɐ ˈʃetɐ]	30				
108	cheque	[ɐ ˈʃɛk]	36				
109	chefe	[ɐ ˈʃɛf]	11				
110	chamar	[ɐ ʃɐˈmaɾ]	28				
111	chá	[ɐ ʃa]	51				
112	choca	[ɐ ˈʃɔkɐ]	116				
113	choco	[ɐ ˈʃok]	76				
114	chocha	[ɐ ˈʃoʃɐ]	80				
115	chorar	[ɐ ʃuˈɾaɾ]	78				
116	bicha	[ˈbiʃɐ]	142				
117	bexiga	[bˈʃigɐ]	106	-			
118	bochecha	[bˈʃeʃɐ]	154				
119	este	[ˈeʃt]	54			-	
120	achar	[ɐˈʃaɾ]	114				
121	bolacha	[buˈlaʃɐ]	15				
122	tocha	[ˈtɔʃɐ]	121				
114	chocha	[ˈʃoʃɐ]	80				
118	bochecha	[bˈʃeʃɐ]	154	-			
123	diz	[diʃ]	96			-	
124	mares	[ˈmɾʃ]	130	-		-	
125	mês	[ˈmeʃ]	112			-	
126	pés	[pɛʃ]	62			-	
127	meche	[ˈmɛʃ]	141			-	
128	perdas	[ˈperdɐʃ]	29			-	
129	capaz	[kɐˈpaʃ]	91			-	
130	tacho	[ˈtaʃ]	133			-	
131	pós	[pɔʃ]	70			-	
132	pôs	[poʃ]	144			-	
133	mocho	[ˈmoʃ]	109			-	
134	dos	[ˈduʃ]	138			-	
135	capucho	[kɐˈpuʃ]	74			-	

Table D.12: Fricative /ʒ/ in Corpus 3 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
136	girar	[ɐ ʒiˈɾaɾ]	48					dev.
137	Gigi	[ɐ ʒ iˈʒi]	145					par. dev.
138	gelado	[ɐ ʒ ɬlad]	127			-		dev.
139	gelo	[ɐ ˈʒelu]	119					dev.
140	germe	[ɐ ˈʒɛɾm]	72					dev.
141	jaqueta	[ɐ ʒɐˈketɐ]	20					dev.
142	jacto	[ɐ ˈʒat]	123					dev.
143	jóia	[ɐ ˈʒɔjɐ]	143					
144	jogo	[ɐ ˈʒogu]	3					dev.
145	judeu	[ɐ ʒuˈdew]	32					dev.
146	originar	[oɾiʒiˈnaɾ]	1					dev.
137	Gigi	[ʒiˈ ʒ i]	145					dev.
147	tijolo	[tˈʒol]	110	-				dev.
148	arejar	[ɐɾɨˈʒaɾ]	46					dev.
149	Beja	[ˈbɛʒɐ]	52					dev.
150	agir	[ɐˈʒiɾ]	108					dev.
151	cajado	[kɐˈʒadu]	63					dev.
152	ajudar	[ɐˈʒudaɾ]	66					dev.
153	haja	[ˈaʒɐ]	12					dev.
154	aloja	[ɐˈlɔʒɐ]	151					dev.
155		[ɐˈlɔʒɐ]	151r1					dev.
156		[ɐˈlɔʒɐ]	151r2					dev.
157	tugir	[tuˈʒiɾ]	120					
158	pejo	[ˈpeʒ]	25			-		dev.
159	age	[ˈaʒ]	79			-		dev.
160	hoje	[ˈoʒ]	38			-		dev.
161	tojo	[ˈtoʒ]	9			-		dev.

Table D.13: Fricative /f/ in Corpus 3 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	figo	[ɐ ˈfig]	41				
2	ferir	[ɐ fɨˈɾiɾ]	18				
3	febra	[ɐ ˈfebɾɐ]	61				
4	ferro	[ɐ ˈfɛRu]	4				
5	falir	[ɐ fɐˈliɾ]	47				
6	fala	[ɐ ˈfalɐ]	2				
7	Fafe	[ɐ ˈ f af]	125				
8	foco	[ɐ ˈfɔk]	90				
9	fogo	[ɐ ˈfog]	101				
10	fofa	[ɐ ˈ f ofɐ]	23				
11	furar	[ɐ fuˈɾaɾ]	44				
12	efectuar	[iˈfɛtwaɾ]	98				
13	benefício	[bɨniˈ f isju]	49				
14	benéfico	[bɨˈnɛfik]	89				
15	afiar	[ɐfiˈaɾ]	53				
16	café	[kɐˈfɛ]	31				
17	garrafa	[gɐˈRafɐ]	71				
10	fofa	[ˈfo f ɐ]	23				
18	galhofa	[gɐˈʎofɐ]	128				
19	bufa	[ˈbufɐ]	73				
20	trefo	[ˈtɾef]	107			-	
21	chefe	[ˈʃɛ f]	11			-	
7	Fafe	[ˈfa f]	125			-	
22	bafo	[ˈbaf]	26			-	
23	mofo	[ˈmof]	55			-	

Table D.14: Fricative /v/ in Corpus 3 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
24	vila	[ɐ ˈvilɐ]	59					
25	viver	[ɐ v iˈveɾ]	122					dev.
26	viva	[ɐ ˈ v ivɐ]	140					par. dev.
27	vermelho	[ɐ vɨɾˈmeʎ]	86					
28	ver	[ɐ veɾ]	102					
29	véu	[ɐ ˈvɛw]	104					dev.
30	veia	[ɐ ˈvɐjɐ]	111					
31	vaca	[ɐ ˈvakɐ]	92					dev.
32	volta	[ɐ ˈvɔltɐ]	81					dev.
33	voo	[ɐ vow]	17					par. dev.
34	vogar	[ɐ ˈvugaɾ]	7					
25	viver	[vi v eɾ]	122					
35	possível	[puˈsi v ɛl]	95					
26	viva	[ˈvi v ɐ]	140					dev.
36	dever	[dɨˈveɾ]	22					dev.
37	levar	[lɨˈvaɾ]	105					
38	leva	[ˈlɛvɐ]	149					par. dev.
39	avó	[ɐˈvɔ]	88					dev.
40	cava	[ˈkavɐ]	24					par. dev.
41	nova	[ˈnɔvɐ]	147					dev.
42	ovelha	[oˈvɐʎɐ]	136					
43	mover	[muˈveɾ]	57					dev.
44	uva	[ˈuvɐ]	40					dev.
45	altivo	[alˈtiv]	124			-		dev.
46	teve	[ˈtev]	42			-		dev.
47	relevo	[Rɨˈlev]	94			-		dev.
48	leve	[ˈlɛv]	6			-		dev.
49	ave	[ˈav]	45			-		dev.
50	bravo	[ˈbɾav]	100			-		dev.
51	move	[ˈmɔv]	67			-		dev.

Table D.15: Fricative /s/ in Corpus 3 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
52	sítio	[ɐ ˈsitju]	77				
53	secar	[ɐ sˈkaɾ]	93			-	
54	sede	[ɐ ˈsed]	75				
55	seta	[ɐ ˈsɛtɐ]	34				
56	cessa	[ɐ ˈ s ɛsɐ]	64				
57	saber	[ɐ sɐˈbeɾ]	39				
58	sala	[ɐ ˈsalɐ]	13				
59	só	[ɐ sɔ]	5				
60	sopa	[ɐ ˈsopɐ]	83				
61	subir	[ɐ suˈbiɾ]	139				
62	iça	[ˈisɐ]	148				
63	benefício	[bɨnɨˈfi s ju]	49				
64	ressaca	[Rɨˈsakɐ]	82				
65	condessa	[kõˈdesɐ]	153				
66	pêssego	[ˈpesgu]	87			-	
67	aquecer	[ɐkɛˈseɾ]	131				
56	cessa	[ˈsɛ s ɐ]	64				
68	passear	[pɐˈsjaɾ]	103				
69	assar	[ɐˈsaɾ]	137				
70	caça	[ˈkasɐ]	35				
71	possa	[ˈpɔsɐ]	150				
72	moça	[ˈmosɐ]	152				
73	possível	[puˈ s ivɛl]	95				
74	partisse	[paɾˈtis]	117			-	
75	batesse	[bɐˈtes]	69			-	
76	asse	[ˈas]	118			-	
77	posse	[ˈpɔs]	21			-	
78	doce	[ˈdos]	56			-	

Table D.16: Fricative /z/ in Corpus 3 (Speaker ACC)

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
79	Zita	[ɐ ˈzitɐ]	68					dev.
80	zelar	[ɐ ˈzɨlaɾ]	126					
81	zelo	[ɐ ˈzel]	115					par. dev.
82	Zé	[ɐ zɛ]	85					
83	Zézé	[ɐ ˈz ɛzɛ]	129					par. dev.
84	zarpar	[ɐ zɐɾˈpaɾ]	113					par. dev.
85	Zaire	[ɐ ˈzajɾɨ]	99					par. dev.
86	Zópiro	[ɐ ˈzɔpiɾu]	10					dev.
87	zona	[ɐ ˈzonɐ]	84					dev.
88	zurrar	[ɐ zuˈʀaɾ]	16					dev.
89	exacto	[iˈzat]	43					
90	mesinha	[mɨˈzi̯ɲɐ]	50					dev.
91	beleza	[bɨˈlezɐ]	135					par. dev.
92	mezinha	[mɛˈzi̯ɲɐ]	27					dev.
83	Zézé	[ˈzɛ z ɛ]	129					par. dev.
93	Brasil	[bɾɐˈzil]	58					dev.
94	azar	[ɐˈzaɾ]	97					dev.
95	azul	[ɐˈzul]	33					dev.
96	mazinha	[maˈzi̯ɲɐ]	37					dev.
97	asa	[ˈazɐ]	19					dev.
98	rosa	[ˈɾɔzɐ]	14					par. dev.
99	acusar	[ɐkuˈzaɾ]	146					dev.
100	peso	[ˈpez]	60			-		dev.
101	doze	[ˈdoz]	132			-		dev.
102	amoroso	[ɐmuˈɾoz]	8			-		dev.

Table D.17: Fricative /ʃ/ in Corpus 3 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
103	chicote	[ɐ ʃiˈkɔt]	134				
104	chegar	[ɐ ʃɨˈgaɾ]	65				
105	cheta	[ɐ ˈʃetɐ]	30				
106	cheque	[ɐ ˈʃɛk]	36				
107	chefe	[ɐ ˈʃ ɛf]	11				
108	chamar	[ɐ ʃɐˈmaɾ]	28				
109	chá	[ɐ ʃa]	51				
110	choca	[ɐ ˈʃɔkɐ]	116				
111	choco	[ɐ ˈʃok]	76				
112	chocha	[ɐ ˈʃ oʃɐ]	80				
113	chorar	[ɐ ʃuˈɾaɾ]	78				
114	bicha	[ˈbiʃɐ]	142				
115	bexiga	[bˈʃigɐ]	106	-			
116	bochecha	[buˈʃe ʃ ɐ]	154				
117	este	[ˈeʃt]	54			-	
118	achar	[ɐˈʃaɾ]	114				
119	bolacha	[buˈlaʃɐ]	15				
120	tocha	[ˈtɔʃɐ]	121				
112	chocha	[ˈʃo ʃ ɐ]	80				
116	bochecha	[buˈʃ eʃɐ]	154				
121	diz	[diʃ]	96			-	
122	mares	[ˈmaɾʃ]	130	-		-	
123	mês	[ˈmeʃ]	112			-	
124	pés	[pɛʃ]	62			-	
125	meche	[ˈmɛʃ]	141			-	
126	perdas	[ˈpɐɾdɐʃ]	29			-	
127	capaz	[kɐˈpaʃ]	91			-	
128	tacho	[ˈtaʃ]	133			-	
129	pós	[pɔʃ]	70			-	
130	pôs	[poʃ]	144			-	
131	mocho	[ˈmoʃ]	109			-	
132	dos	[ˈduʃ]	138			-	
133	capucho	[kɐˈpuʃ]	74			-	

Table D.18: Fricative /ʒ/ in Corpus 3 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
134	girar	[ɐ ʒiˈraɾ]	48					dev.
135	Gigi	[ɐ ʒ i˕ʒi]	145					dev.
136	gelado	[ɐ ʒɨˈlad]	127					par. dev.
137	gelo	[ɐ ˈʒelu]	119					dev.
138	germe	[ɐ ˈʒɛɾm]	72					dev.
139	jaqueta	[ɐ ʒɐˈketɐ]	20					dev.
140	jacto	[ɐ ˈʒat]	123					dev.
141	jóia	[ɐ ˈʒɔjɐ]	143					dev.
142	jogo	[ɐ ˈʒog]	3					dev.
143	judeu	[ɐ ʒuˈdew]	32					dev.
144	originar	[oɾiʒiˈnaɾ]	1					dev.
135	Gigi	[ʒiˈ ʒ i˕]	145					dev.
145	tijolo	[tiˈʒol]	110					dev.
146	arejar	[ɐɾˈʒaɾ]	46	-				dev.
147	Beja	[ˈbɛʒɐ]	52					dev.
148	agir	[ɐˈʒiɾ]	108					dev.
149	cajado	[kɐˈʒa]	63					dev.
150	ajudar	[ɐˈʒudaɾ]	66					dev.
151	haja	[ˈaʒɐ]	12					dev.
152	aloja	[ɐˈlɔʒɐ]	151					dev.
153	tugir	[tuˈʒiɾ]	120					dev.
154	pejo	[ˈpeʒ]	25			-		dev.
155	age	[ˈaʒ]	79			-		dev.
156	hoje	[ˈoʒ]	38			-		dev.
157	tojo	[ˈtoʒ]	9			-		par. dev.

Table D.19: Fricative /f/ in Corpus 3 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	figo	[ɐ ˈfig]	41				
2	ferir	[ɐ f ɨˈɾiɾ̥]	18				
3	febra	[ɐ ˈfebɾɐ]	61				
4	ferro	[ɐ ˈf ɛχ]	4				
5	falir	[ɐ fɐˈliɾ]	47				
6	fala	[ɐ ˈfalɐ]	2				
7	Fafe	[ɐ ˈf af]	125				
8	foco	[ɐ ˈfɔk]	90				
9	fogo	[ɐ ˈfogu]	101				
10	fofa	[ɐ ˈf ofɐ]	23				
11	furar	[ɐ fuˈɾaɾ]	44				
12	efectuar	[iˈfɛtwaɾ]	98				
13	benefício	[bɨniˈf isju]	49				
14	benéfico	[bɨˈnɛfi]	89				
15	afiar	[ɐfiˈaɾ]	53				
16	café	[kɐˈfɛ]	31				
17	garrafa	[gɐˈχaˈf ɐ]	71				
10	fofa	[ˈfo f ɐ]	23				
18	galhofa	[gɐˈʎɔfɐ]	128				
19	bufa	[ˈbufɐ]	73				
20	trefo	[ˈtɾef]	107			-	
21	chefe	[ˈʃɛ f]	11			-	
7	Fafe	[ˈfa f]	125			-	
22	bafo	[ˈbaf]	26			-	
23	mofo	[ˈmof]	55			-	

Table D.20: Fricative /v/ in Corpus 3 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
24	vila	[ɐ ˈvilɐ]	59					dev.
25	viver	[ɐ vi̥ˈveɾ]	122					
26	viva	[ɐ ˈvivɐ]	140					
27	vermelho	[ɐ vɨ̥ɾˈmeʎu]	86					par. dev.
28	ver	[ɐ veɾ]	102					par. dev.
29	véu	[ɐ ˈvɛw]	104					par. dev.
30	veia	[ɐ ˈveɐjɐ]	111					
31	vaca	[ɐ ˈvakɐ]	92					par. dev.
32	volta	[ɐ ˈvɔltɐ]	81					
33	voo	[ɐ vow]	17					
34	vogar	[ɐ ˈvugaɾ]	7					
25	viver	[viˈveɾ]	122					
35	possível	[pˈsi vɛl]	95					
26	viva	[ˈvivɐ]	140					
36	dever	[dɨˈveɾ]	22					
37	levar	[lɨˈvaɾ]	105					dev.
38	leva	[ˈlɛvɐ]	149					dev.
39	avó	[ɐˈvɔ]	88					
40	cava	[ˈkavɐ]	24					dev.
41	nova	[ˈnɔvɐ]	147					dev.
42	ovelha	[oˈvɐʎɐ]	136					
43	mover	[muˈveɾ]	57					
44	uva	[ˈuvɐ]	40					dev.
45	altivo	[alˈtiv]	124			-		dev.
46	teve	[ˈtev]	42			-		dev.
47	relevo	[χɨˈle v]	94			-		dev.
48	leve	[ˈlɛv]	6			-		dev.
49	ave	[ˈav]	45			-		dev.
50	bravo	[ˈbɾav]	100			-		dev.
51	move	[ˈmɔv]	67			-		dev.

Table D.21: Fricative /s/ in Corpus 3 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
52	sítio	[ɐ ˈsitju]	77				
53	secar	[ɐ sˈkaɾ]	93			-	
54	sede	[ɐ ˈsed]	75				
55	seta	[ɐ ˈsɛtɐ]	34				
56	cessa	[ɐ ˈs ɛsɐ]	64				
57	saber	[ɐ sɐˈbeɾ]	39				
58	sala	[ɐ ˈsalɐ]	13				
59	só	[ɐ sɔ]	5				
60	sopa	[ɐ ˈsopɐ]	83				
61	subir	[ɐ s uˈbiɾ̥]	139				
62	iça	[ˈisɐ]	148				
63	benefício	[bɨnɨˈfi s ju]	49				
64	ressaca	[χˈ s akɐ]	82	-			
65	condessa	[kõˈdesɐ]	153				
66	pêssego	[ˈpesɡ]	87			-	
67	aquecer	[ɐkɛˈseɾ]	131				
56	cessa	[ˈsɛ s ɐ]	64				
68	passear	[pɐˈsjaɾ]	103				
69	assar	[ɐˈsaɾ]	137				
70	caça	[ˈkasɐ]	35				
71	possa	[ˈpɔsɐ]	150				
72	moça	[ˈmosɐ]	152				
73	possível	[pˈs ivl]	95	-			
74	partisse	[paɾˈtis]	117			-	
75	batesse	[bɐˈtes]	69			-	
76	asse	[ˈas]	118			-	
77	posse	[ˈpɔs]	21			-	
78	doce	[ˈdos]	56			-	

Table D.22: Fricative /z/ in Corpus 3 (Speaker ISSS)

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
79	Zita	[ɐ ˈzitɐ]	68					dev.
80	zelar	[ɐ ˈzlaɾ]	126			-		dev.
81	zelo	[ɐ ˈzelu]	115					dev.
82	Zé	[ɐ zɛ]	85					dev.
83	Zézé	[ɐ ˈzɛzɛ]	129					dev.
84	zarpar	[ɐ zɐɾˈpaɾ]	113					
85	Zaire	[ɐ ˈzajɾ̥]	99					dev.
86	Zópiro	[ɐ ˈzɔpiɾ̥]	10					dev.
87	zona	[ɐ ˈzonɐ]	84					
88	zurrar	[ɐ zuˈχaɾ]	16					dev.
89	exacto	[iˈzat]	43					dev.
90	mesinha	[mɨˈziɲɐ]	50					dev.
91	beleza	[bɨˈlezɐ]	135					dev.
92	mezinha	[mɛˈziɲɐ]	27					dev.
83	Zézé	[ˈzɛzɛ]	129					dev.
93	Brasil	[bɾɐˈzil]	58					dev.
94	azar	[ɐˈzaɾ]	97					dev.
95	azul	[ɐˈzul]	33					dev.
96	mazinha	[maˈziɲɐ]	37					dev.
97	asa	[ˈazɐ]	19					
98	rosa	[ˈχɔzɐ]	14					dev.
99	acusar	[ɐkuˈzaɾ]	146					dev.
100	peso	[ˈpez]	60			-		dev.
101	doze	[ˈdoz]	132			-		dev.
102	amoroso	[ɐmuˈɾoz]	8			-		dev.

Table D.23: Fricative /ʃ/ in Corpus 3 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
103	chicote	[ɐ ʃiˈkɔ]	134				
104	chegar	[ɐ ʃɨˈgaɾ]	65				
105	cheta	[ɐ ˈʃetɐ]	30				
106	cheque	[ɐ ˈʃɛk]	36				
107	chefe	[ɐ ˈʃɛf]	11				
108	chamar	[ɐ ʃɐˈmaɾ̥]	28				
109	chá	[ɐ ʃa]	51				
110	choca	[ɐ ˈʃɔkɐ]	116				
111	chocho	[ɐ ˈʃoʃ]	76				
112	chocha	[ɐ ˈʃoʃɐ]	80				
113	chorar	[ɐ ʃuˈɾaɾ]	78				
114	bicha	[ˈbiʃɐ]	142				
115	bexiga	[bˈʃigɐ]	106	-			
116	bochecha	[bˈʃeʃɐ]	154				
117	este	[ˈeʃt]	54			-	
118	achar	[ɐˈʃaɾ]	114				
119	bolacha	[bˈlaʃɐ]	15				
120	tocha	[ˈtɔʃɐ]	121				
112	chocha	[ˈʃoʃɐ]	80				
116	bochecha	[bˈʃeʃɐ]	154	-			
121	diz	[diʃ]	96			-	
122	mares	[ˈmaɾ̥ʃ]	130	-		-	
123	mês	[ˈmeʃ]	112			-	
124	pés	[pɛʃ]	62			-	
125	meche	[ˈmɛʃ]	141			-	
126	perdas	[ˈpeɾdɐʃ]	29			-	
127	capaz	[kɐˈpaʃ]	91			-	
128	tacho	[ˈtaʃ]	133			-	
129	pós	[pɔʃ]	70			-	
130	pôs	[poʃ]	144			-	
131	mocho	[ˈmoʃ]	109			-	
111	chocho	[ɐ ˈʃoʃ]	76			-	
132	dos	[ˈduʃ]	138			-	
133	capucho	[kɐˈpuʃ]	74			-	

Table D.24: Fricative /ʒ/ in Corpus 3 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
134	girar	[ɐ ʒiˈɾaɾ]	48					par. dev.
135	Gigi	[ɐ ʒ i̥ˈʒi]	145					dev.
136	gelado	[ɐ ʒˈladu]	127			-		dev.
137	gelo	[ɐ ˈʒelu]	119					dev.
138	germe	[ɐ ˈʒɛɾm]	72					dev.
139	jaqueta	[ɐ ʒɐˈketɐ]	20					dev.
140	jacto	[ɐ ˈʒat]	123					dev.
141	jóia	[ɐ ˈʒɔjɐ]	143					dev.
142	jogo	[ɐ ˈʒo̥g]	3					dev.
143	judeu	[ɐ ʒuˈdew]	32					par. dev.
144	originar	[oɾiʒiˈnaɾ]	1					
135	Gigi	[ʒiˈ ʒ i̥]	145					par. dev.
145	tijolo	[tˈʒol]	110	-				dev.
146	arejar	[ɐɾˈʒaɾ]	46	-				dev.
147	Beja	[ˈbɛʒɐ]	52					dev.
148	agir	[ɐˈ ʒ i̥ɾ]	108					dev.
149	cajado	[kɐˈʒad]	63					dev.
150	ajudar	[ɐˈʒudaɾ]	66					dev.
151	haja	[ˈaʒɐ]	12					dev.
152	aloja	[ɐˈlɔʒɐ]	151					dev.
153	tugir	[tuˈʒiɾ]	120					dev.
154	pejo	[ˈpeʒ]	25			-		dev.
155	age	[ˈaʒ]	79			-		dev.
156	hoje	[ˈoʒ]	38			-		dev.
157	tojo	[ˈtoʒ]	9			-		dev.

Table D.25: Fricative /f/ in Corpus 4 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	fala	[u ˈfalɐ]	4_2	64	149	36	11.3
2		[u ˈfalɐ]	4_2r	56	109	44	15.5
3	foge	[ɐ ˈfɔʒɨ]	2_155	62	132	40	43.5
4	foge	[ɐ ˈfɔʒ]	2_155r	38	126	-	61.7
5	fogo	[u ˈfogu]	10_101	52	148	40	24.1
6		[u ˈfogu]	10_101r	49	137	39	77.9
7	furar	[fuˈɾaɾ]	9_44	68	104	57	13.1
8		[fuˈɾaɾ]	9_44r	46	93	62	0.7
9	benefício	[bɨnɨˈfisju]	1_49	58	130	30	34.7
10		[bɨnɨˈfisju]	1_49r	57	131	32	28.2
11	benéfico	[bɨˈnɛfku]	8_89	54	109	-	21.0
12		[bɨˈnɛfiku]	8_89r	54	85	42	26.1
13	café	[kɐˈfɛ]	7_31	55	101	29	53.7
14		[kɐˈfɛ]	7_31r	56	114	35	40.7
15	chefe	[ˈʃɛfa]	4_11	39	89	-	44.3
16		[ˈʃɛfa]	4_11r	37	85	-	34.5

Table D.26: Fricative /v/ in Corpus 4 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
17	viver	[d v i'veɾ]	8_122	64	85	56	26.7	dev.
18		[ɨ v i'veɾ]	8_122r	34	49	48	44.8	dev.
19	vermelho	[u vɨɾ'meʎu]	10_86	34	43	32	1.8	
20		[u vɨɾ'meʎu]	10_86r	49	57	47	9.4	
21	ver	[veɾ]	12_102	24	94	39	1.5	
22		[veɾ]	12_102r	32	48	38	9.7	par. dev.
23	vaca	[ɐ 'vakɐ]	2_92	34	61	48	4.1	
24		[ɐ 'vakɐ]	2_92r	46	67	35	13.5	dev.
25	volta	[ɨ 'vɔltɐ]	8_81	25	44	43	5.4	
26		[d 'vɔltɐ]	8_81r	10	55	40	0.2	dev.
27	voo	[u vow]	3_17	43	77	40	1.6	
28		[u vow]	3_17r	32	65	56	1.0	
29	vogar	[i 'vugaɾ]	5_7	35	72	44	1.8	
30		[i 'vugaɾ]	5_7r	45	72	39	32.9	dev.
17	viver	[vi v eɾ]	8_122	41	68	44	49	dev.
18		[vi v eɾ]	8_122r	51	59	39	53.9	dev.
31	possível	[pu'si v ɛl]	11_95	41	58	33	1.5	
32		[pu'si v ɛl]	11_95r	39	53	38	8.9	par. dev.
33	altivo	[al'tivu]	4_124	48	66	29	58.0	dev.
34		[al'tivu]	4_124r	30	101	31	1.5	
35	dever	[dɨ'veɾ]	12_22	27	70	34	1.4	
36		[dɨ'veɾ]	12_22r	32	41	40	0.2	
37	avó	[ɐ'vɔ]	1_88	32	96	22	22.9	dev.
38		[ɐ'vɔ]	1_88r	43	45	56	42.6	dev.
39	ave	['avɨ]	3_45	37	75	27	5.4	par. dev.
40		['avɨ]	3_45r	49	70	37	10.7	par. dev.
41	cava	['kavɐ]	12_24	24	56	32	3.6	
42		['kavɐ]	12_24r	36	60	42	16.9	dev.
43	bravo	['bɾavu]	6_100	45	57	49	2.2	
44		['bɾavu]	6_100r	45	63	30	51.3	dev.
45	nova	['nɔvɐ]	8_147	39	52	43	10.4	
46		['nɔvɐ]	8_147r	39	49	48	2.4	
47	move	['mɔv ɐ]	3_67	32	42	-	1.3	
48		['mɔv ɐ]	3_67r	38	56	-	14.7	dev.

Table D.27: Fricative /s/ in Corpus 4 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
49	sítio	[u ˈsitju]	5_77	82	162	35	33.6
50		[u ˈsitju]	5_77r	49	154	30	25.8
51		[u ˈsitju]	11_77	24	152	39	3.5
52		[u ˈsitju]	11_77r	26	156	38	21.6
53	sede	[dɨ ˈsedɨ]	4_75	104	161	37	17.8
54		[d ˈsedɨ]	4_75r	-	142	39	8.0
55	seta	[ɐ ˈsɛtɐ]	3_34	44	129	43	10.8
56		[ɐ ˈsɛtɐ]	3_34r	45	155	41	22.7
57	sala	[a ˈsalɐ]	8_13	70	128	44	31.4
58		[a ˈsalɐ]	8_13r	56	145	40	33.8
59		[ɐ ˈsalɐ]	12_13	49	144	42	24.7
60		[a ˈsalɐ]	12_13r	40	146	35	84.5
61	só	[w sɔ]	6_5	51	151	48	43.7
62		[w sɔ]	6_5r	57	173	45	66.9
63	subir	[ɐ suˈbiɾ]	3_139	34	144	32	16.1
64		[ɐ suˈbiɾ]	3_139r	41	148	43	10.8
65	benefício	[bɨnɨˈfi s ju]	1_49	34	117	55	8.0
66		[bɨnɨˈfi s ju]	1_49r	33	141	30	5.1
67	ressaca	[Rɨˈsakɐ]	7_82	53	164	39	83.6
68		[Rˈsakɐ]	7_82r	-	169	43	7.3
69	condessa	[kõˈdesɐ]	9_153	39	95	43	9.0
70		[kõˈdesɐ]	9_153r	42	113	41	18.2
71	assar	[ɐˈsaɾ]	12_137	50	163	67	10.8
72		[ɐˈsaɾ]	12_137r	50	146	50	47.2
73	possível	[puˈs ivɛl]	11_95	34	134	37	7.1
74		[puˈs ivɛl]	11_95r	29	161	45	4.5
75	caça	[ˈkas]	7_35	82	144	-	1.2
76	doce	[ˈdos]	1_56	79	272	-	14.0
77		[ˈdos]	1_56r	92	250	-	23

Table D.28: Fricative /z/ inCorpus 4 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
78	Zita	[ɐ ˈzitɐ]	9_68	58	100	44	50.6	dev.
79		[ɐ ˈzitɐ]	9_68r	48	106	55	12.8	dev.
80	Zé	[u zɛ]	6_85	55	91	31	20.7	dev.
81		[u zɛ]	6_85r	52	85	40	50.1	dev.
82	zarpar	[ɐ zɐɾˈpaɾ]	3_113	33	49	24	4.1	
83		[ɐ zɐɾˈpaɾ]	3_113r	33	50	40	3.8	
84	zona	[ɐ ˈzonɐ]	2_84	60	107	24	14.5	par. dev.
85		[ɐ ˈzonɐ]	2_84r	45	125	52	13.6	dev.
86	mesinha	[mɨˈziɲɐ]	8_50	32	58	22	4.6	
87		[mɨˈziɲɐ]	8_50r	23	86	21	5.5	par. dev.
88	Brasil	[bɾɐˈzil]	10_58	65	129	53	21.3	dev.
89		[bɾɐˈzil]	10_58r	46	128	44	52.2	dev.
90	azul	[ɐˈzul]	10_33	46	98	31	28.3	par. dev.
91		[ɐˈzul]	10_33r	47	100	40	32.7	dev.
92	asa	[ˈazɐ]	3_19	33	56	31	25.3	dev.
93		[ˈazɐ]	3_19r	24	73	44	20.6	dev.
94	rosa	[ˈɾɔzɐ]	4_14	36	71	45	67.8	dev.
95		[ˈɾɔzɐ]	4_14r	42	90	50	58.0	dev.
96	beleza	[bɨˈlez]	4_135	42	121	-	20.2	dev.
97		[bɨˈlez]	4_135r	72	109	-	2.9	dev.
98	doze	[ˈdoz]	8_132	104	149	-	29.5	dev.
99		[ˈdoz]	8_132r	65	268	-	30.3	dev.

Table D.29: Fricative /ʃ/ in Corpus 4 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
100	chegar	[w ʃɨˈgaɾ]	7_65	44	138	58	30.5
101		[w ʃɨˈgaɾ]	7_65r	50	132	61	14.8
102	chefe	[u ˈʃɛf]	4_11	32	186		26.4
103		[u ˈʃɛf]	4_11r	31	153		9.4
104	chá	[ɐ ʃa]	11_51	40	154	28	51.3
105		[ɐ ʃa]	11_51r	34	171	49	12.4
106	choca	[ɐ ˈʃɔkɐ]	9_116	58	132	42	17.4
107		[ɐ ˈʃɔkɐ]	9_116r	53	120	42	204.7
108	chocha	[ɐ ˈʃoʃɐ]	1_80	42	147	39	56.0
109		[ɐ ˈʃoʃɐ]	1_80r	41	158	38	55.2
110	chorar	[u ʃuˈɾaɾ]	5_78	48	133	35	96.5
111		[u ʃuˈɾaɾ]	5_78r	34	153	36	16.2
112	meche	[ˈmɛʃɨ]	12_141	48	182	74	20.8
113		[ˈmɛʃɨ]	12_141r	46	167	53	24.2
114	achar	[ɐˈʃaɾ]	11_114	52	146	48	21.8
115		[ɐˈʃaɾ]	11_114r	40	148	49	29.8
108	chocha	[ˈʃoʃɐ]	1_80	45	107	42	63.2
109		[ˈʃoʃɐ]	1_80r	32	143	29	35.0
116	mares	[ˈmaʃ]	10_130	38	40	-	33.2
117		[ˈmaʃ]	10_130r	50	44	-	159.0
118	dos	[ˈduʃ]	8_138	39	47	-	77.3
119		[ˈduʃ]	10_138r	40	65	-	35.3

Table D.30: Fricative /ʒ/ in Corpus 4 (Speaker LMTJ).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
120	Gigi	[ɐ ʒ i'ʒi]	1_145	52	90	25	14.2	dev.
121		[ɐ ʒ i'ʒi]	1_145r	46	56	34	102.9	dev.
122	gelo	[u 'ʒelu]	2_119	60	77	32	20.7	dev.
123		[u 'ʒelu]	2_119r	41	73	39	10.0	par. dev.
124	jóia	[ɐ 'ʒɔjɐ]	9_143	38	88	21	31.3	dev.
125		[ɐ 'ʒɔjɐ]	9_143r	38	104	24	32.9	dev.
126	judeu	[u ʒu'dew]	6_32	39	73	30	14.6	dev.
127		[u ʒu'dew]	6_32r	30	93	34	14.6	dev.
120	Gigi	[ʒi' ʒ i]	1_145	41	109	39	2.6	
121		[ʒi' ʒ i]	1_145r	44	124	28	7.5	par. dev.
128	arejar	[ɐɾɨ'ʒaɾ]	5_46	37	97	23	16.9	dev.
129		[ɐɾɨ'ʒaɾ]	5_46r	24	68	40	8.0	par. dev.
130	ajudar	[ɐ'ʒudaɾ]	6_66	57	85	39	89.4	dev.
131		[ɐ'ʒudaɾ]	6_66r	43	85	34	53.0	dev.
132	age	['aʒɨ]	1_79	19	65	32	9.6	dev.
133		['aʒɨ]	1_79r	19	74	35	36	dev.
134	foge	['fɔ ʒ ɨ]	2_155	17	56	32	3.7	par. dev.
135	foge	['fɔ ʒ d]	2_155r	47	92	-	85.5	dev.
136	hoje	['oʒ]	5_38	79	156	-	78.0	dev.
137		['oʒ ɐ]	5_38r	47	104		58.4	dev.
138	dos	['duʒ d]	8_138r	38	48	-	3.6	
139		['duʒ m]	10_138	21	49	-	14.5	

Table D.31: Fricative /f/ in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	fala	[u ˈfalɐ]	4_2				
2		[u ˈfalɐ]	4r1_2				
3		[u ˈfalɐ]	4r2_2				
4	foge	[ɐ ˈfɔʒɨ]	2_155				
5		[ɐ ˈfɔʒɨ]	2r1_155				
6		[ɐ ˈfɔʒɨ]	2r2_155				
7	fogo	[u ˈfogu]	10_101				
8		[u ˈfogu]	10r1_101				
9		[u ˈfogu]	10r2_101				
10	furar	[fuˈɾaɾ]	9_44	-			
11		[fuˈɾaɾ]	9r1_44	-			
12		[fuˈɾaɾ]	9r2_44	-			
13	benefício	[bɨnɨˈfisju]	1_49				
14		[bɨnɨˈfisju]	1r1_49				
15		[bɨnɨˈfisju]	1r2_49				
16	benéfico	[bɨˈnɛfik]	8_89				
17		[bɨˈnɛfik]	8r1_89				
18		[bɨˈnɛfi]	8r2_89				
19	café	[kɐˈfɛ]	7_31				
20		[kɐˈfɛ]	7r1_31				
21		[kɐˈfɛ]	7r2_31				
22	chefe	[ˈʃɛfa]	4_11				
23		[ˈʃɛfa]	4r1_11				
24		[ˈʃɛfa]	4r2_11				

Table D.32: Fricative /v/ (Word-Initial) in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
25	viver	[ɨ v i'veɾ]	8_122					
26		[ɨ v i'veɾ]	8r1_122					
27		[ɨ v 'veɾ]	8r2_122			-		
28	vermelho	[u vɨɾ'meʎu]	10_86					
29		[u vɨɾ'meʎu]	10r1_86					par. dev.
30		[u vɨɾ'meʎu]	10r2_86					dev.
31	ver	[veɾ]	8_102	-				dev.
32		[veɾ]	8r1_102	-				
33		[veɾ]	8r2_102	-				
34		[ʃ veɾ]	12_102	-				
35		[ʃ veɾ]	12r1_102	-				par. dev.
36		[ʃ v eɾ]	12r2_102	-				dev.
37	vaca	[ɐ 'vakɐ]	2_92					
38		[ɐ 'vakɐ]	2r1_92					dev.
39		[ɐ 'vakɐ]	2r2_92					
40	volta	[ɨ 'vɔltɐ]	8_81					dev.
41		[ɨ 'vɔltɐ]	8r1_81					dev.
42		[ɨ 'vɔltɐ]	8r2_81					par. dev.
43	voo	[u vow]	3_17					dev.
44		[u vow]	3r1_17					par. dev.
45		[u vow]	3r2_17					dev.
46	vogar	[i 'vugaɾ]	5_7					dev.
47		[i 'vugaɾ]	5r1_7					dev.
48		[i 'vugaɾ]	5r2_7					dev.

Table D.33: Fricative /v/ (Word-Medial and Word-Final) in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
25	viver	[viˈ v ɐɾ]	8_122					par. dev.
26		[viˈ v ɐɾ]	8r1_122					par. dev.
27		[vˈ v ɐɾ]	8r2_122	-				dev.
49	possível	[pˈsi v l]	11_95			-		
50		[pˈsi v l]	11r1_95			-		
51		[pˈsi v l]	11r2_95			-		
52	altivo	[alˈtivu]	4r1_124					dev.
53	dever	[dɨˈver]	12_22					par. dev.
54		[dɨˈver]	12r1_22					dev.
55		[dɨˈver]	12r2_22					dev.
56	avó	[ɐˈvɔ]	1_88					dev.
57		[ɐˈvɔ]	1r1_88					dev.
58		[ɐˈvɔ]	1r2_88					dev.
59	ave	[ˈavɨ]	3_45					
60		[ˈavɨ]	3r1_45					par. dev.
61		[ˈavɨ]	3r2_45					par. dev.
62	cava	[ˈkavɐ]	12_24					
63		[ˈkavɐ]	12r1_24					
64		[ˈkavɐ]	12r2_24					
65	bravo	[ˈbɾavu]	6r1_100					par. dev.
66		[ˈbɾavu]	6r2_100					
67	nova	[ˈnɔvɐ]	8_147					
68		[ˈnɔvɐ]	8r1_147					dev.
69		[ˈnɔvɐ]	8r2_147					dev.
70	altivo	[alˈtiv f]	4_124			-		dev.
71		[alˈtiv f]	4r2_124			-		par. dev.
72	bravo	[ˈbɾav d]	6_100			-		
73	move	[ˈmɔv ɐ]	3_67					par. dev.
74		[ˈmɔv ɐ]	3r1_67					dev.
75		[ˈmɔv ɐ]	3r2_67					par. dev.

Table D.34: Fricative /s/ in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
76	sítio	[u ˈsitju]	5_77				
77		[u ˈsitju]	5r1_77				
78		[u ˈsitju]	5r2_77				
79		[u ˈsitju]	11_77				
80		[u ˈsitju]	11r1_77				
81		[u ˈsitju]	11r2_77				
82	sede	[ɨ ˈsedɨ]	4_75				
83		[ɨ ˈsedɨ]	4r1_75				
84		[ɨ ˈsedɨ]	4r2_75				
85	seta	[ɐ ˈsɛt]	3_34				
86		[ɐ ˈsɛt]	3r1_34				
87		[ɐ ˈsɛt]	3r2_34				
88	sala	[a ˈsalɐ]	8_13				
89		[a ˈsalɐ]	8r1_13				
90		[a ˈsalɐ]	8r2_13				
91		[ɐ ˈsalɐ]	12_13				
92		[ɐ ˈsalɐ]	12r1_13				
93		[ɐ ˈsalɐ]	12r2_13				
94	só	[w sɔ]	6_5				
95		[w sɔ]	6r1_5				
96		[w sɔ]	6r2_5				
97	subir	[ɐ suˈbiɾ]	3_139				
98		[ɐ suˈbiɾ]	3r1_139				
99		[ɐ suˈbiɾ]	3r2_139				
100	benefício	[bɨnɨˈfi s ju]	1_49				
101		[bɨnɨˈfi s ju]	1r1_49				
102		[bɨnɨˈfi s ju]	1r2_49				
103	ressaca	[ɐ χˈ s akɐ]	7_82	-			
104		[ɐ χˈ s akɐ]	7r1_82	-			
105		[ɐ χˈ s akɐ]	7r2_82	-			
106	condessa	[kɔ̃ˈdesɐ]	9_153				
107		[kɔ̃ˈdesɐ]	9r1_153				
108		[kɔ̃ˈdesɐ]	9r2_153				
109	assar	[ɐˈsaɾ]	12_137				
110		[ɐˈ s aɾ̥]	12r1_137				
111		[ɐˈsaɾ]	12r2_137				
112	possível	[pˈ s ivl]	11_95	-			
113		[pˈ s ivl]	11r1_95	-			
114		[pˈ s ivl]	11r2_95	-			
115	caça	[ˈkas]	7_35			-	
116		[ˈkas]	7r1_35			-	
117		[ˈkas]	7r2_35			-	
118	doce	[ˈdos]	1_56			-	
119		[ˈdos]	1r1_56			-	
120		[ˈdos]	1r2_56			-	

Table D.35: Fricative /z/ in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
121	Zita	[ɐ ˈzitɐ]	9_68					dev.
122		[ɐ ˈzit]	9r1_68					dev.
123		[ˈzitɐ]	9r2_68	-				dev.
124	Zé	[u zɛ]	6_85					dev.
125		[u zɛ]	6r1_85					dev.
126		[u zɛ]	6r2_85					dev.
127	zarpar	[ɐ zɐɾˈpaɾ]	3_113					dev.
128		[ɐ zɐɾˈpaɾ]	3r1_113					dev.
129		[ɐ zɐɾˈpaɾ]	3r2_113					dev.
130	zona	[ɐ ˈzonɐ]	2_84					dev.
131		[ɐ ˈzonɐ]	2r1_84					par. dev.
132		[ɐ ˈzonɐ]	2r2_84					
133	mesinha	[mɨˈziɲɐ]	8_50					dev.
134		[mɨˈziɲɐ]	8r1_50					dev.
135		[mɨˈziɲɐ]	8r2_50					dev.
136	beleza	[bɨˈlezɐ]	4_135					dev.
137	Brasil	[bɾɐˈzil]	10_58					dev.
138		[bɾɐˈzil]	10r1_58					dev.
139		[bɾɐˈzil]	10r2_58					dev.
140	azul	[ɐˈzul]	10_33					dev.
141		[ɐˈzul]	10r1_33					dev.
142		[ɐˈzul]	10r2_33					
143	asa	[ˈazɐ]	3_19					dev.
144		[ˈazɐ]	3r1_19					dev.
145		[ˈazɐ]	3r2_19					dev.
146	rosa	[ˈχɔ z ɐ]	4_14					
147		[ˈʁɔ z ɐ]	4r1_14					par. dev.
148		[ˈχɔ z ɐ]	4r2_14					par. dev.
149	beleza	[bɨˈlez]	4r1_135			-		dev.
150		[bɨˈlez]	4r2_135			-		dev.
151	doze	[ˈdoz]	8_132			-		dev.
152		[ˈdoz]	8r1_132			-		dev.
153		[ˈdoz]	8r2_132			-		dev.

Table D.36: Fricative /ʃ/ in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
154	chegar	[w ʃɨˈgaɾ]	7_65				
155		[w ʃɨˈgaɾ]	7r1_65				
156		[w ʃɨˈgaɾ]	7r2_65				
157	chefe	[u ˈʃɛf]	4_11				
158		[u ˈʃɛf]	4r1_11				
159		[u ˈʃɛf]	4r2_11				
160	chá	[ɐ ʃa]	11_51				
161		[ɐ ʃa]	11r1_51				
162		[ɐ ʃa]	11r2_51				
163	choca	[ɐ ˈʃɔkɐ]	9_116				
164		[ɐ ˈʃɔkɐ]	9r1_116				
165		[ɐ ˈʃɔkɐ]	9r2_116				
166	chocha	[ɐ ˈʃoʃɐ]	1_80				
167		[ɐ ˈʃoʃɐ]	1r1_80				
168		[ɐ ˈʃoʃɐ]	1r2_80				
169	chorar	[u ʃuˈɾaɾ]	5_78				
170		[u ʃuˈɾaɾ]	5r1_78				
171		[u ʃuˈɾaɾ]	5r2_78				
172	meche	[ˈmɛʃɨ]	12_141				
173		[ˈmɛʃɨ]	12r2_141				
174	achar	[ɐˈʃaɾ]	11_114				
175		[ɐˈʃaɾ]	11r1_114				
176		[ɐˈʃaɾ]	11r2_114				
166	chocha	[ˈʃoʃɐ]	1_80				
167		[ˈʃoʃɐ]	1r1_80				
168		[ˈʃoʃɐ]	1r2_80				
177	meche	[ˈmɛʃ v]	12r1_141			-	

Table D.37: Fricative /ʒ/ in Corpus 4 (Speaker CFGA).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
178	Gigi	[ɐ ʒ i'ʒi]	1_145					
179		[ɐ ʒ i'ʒi]	1r1_145					
180		[ɐ ʒ i'ʒi]	1r2_145					par. dev.
181	gelo	[u 'ʒelu]	2_119					dev.
182		[u 'ʒelu]	2r1_119					dev.
183		[u 'ʒelu]	2r2_119					dev.
184	jóia	[ɐ 'ʒɔjɐ]	9_143					dev.
185		[ɐ 'ʒɔjɐ]	9r1_143					dev.
186		[ɐ 'ʒɔjɐ]	9r2_143					dev.
187	judeu	[u ʒu'dew]	6_32					dev.
188		[u ʒu'dew]	6r1_32					dev.
189		[u ʒu'dew]	6r2_32					dev.
178	Gigi	[ʒi' ʒ i]	1_145					
179		[ʒi' ʒ i]	1r1_145					par. dev.
180		[ʒi' ʒ i]	1r2_145					dev.
190	arejar	[ɐɾɨ'ʒaɾ]	5_46					par. dev.
191		[ɐɾɨ'ʒaɾ]	5r1_46					dev.
192		[ɐɾ'ʒaɾ]	5r2_46	-				dev.
193	ajudar	[ɐ'ʒudaɾ]	6_66					dev.
194		[ɐ'ʒudaɾ]	6r1_66					dev.
195		[ɐ'ʒudaɾ]	6r2_66					dev.
196	age	['aʒɨ]	1r2_79					dev.
197	hoje	['oʒɨ]	5r1_38					dev.
198		['oʒɨ]	5r2_38					dev.
199	foge	['fɔ ʒ ɨ]	2_155					
200		['fɔ ʒ ɨ]	2r1_155					
201		['fɔ ʒ ɨ]	2r2_155					dev.
202	mares	['maɾʒ]	10_130	-		-		dev.
203		['maɾʒ]	10r1_130	-		-		dev.
204		['maɾʒ]	10r2_130	-		-		dev.
205	age	['aʒ ɐ̃]	1_79					dev.
206		['aʒ ɐ̃]	1r1_79					dev.
207	hoje	['oʒ]	5_38			-		dev.
208	dos	['duʒ d]	8_138			-		par. dev.
209		['duʒ d]	8r1_138			-		dev.
210		['duʒ d]	8r2_138			-		dev.
211		['dʒ m]	10_138	-		-		dev.
212		['duʒ m]	10r1_138			-		dev.
213		['duʒ m]	10r2_138			-		dev.

Table D.38: Fricative /f/ in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	fala	[u ˈfalɐ]	4_2				
2		[u ˈfalɐ]	4r1_2				
3		[u ˈfalɐ]	4r2_2				
4	foge	[ɐ ˈfɔʒɨ]	2_155				
5		[ɐ ˈfɔʒɨ]	2r1_155				
6		[ɐ ˈfɔʒɨ]	2r2_155				
7	fogo	[u ˈfogu]	10_101				
8		[u ˈfogu]	10r1_101				
9		[u ˈfogu]	10r2_101				
10	furar	[fuˈɾaɾ]	9_44	-			
11		[fuˈɾaɾ]	9r1_44	-			
12		[fuˈɾaɾ]	9r2_44	-			
13	benefício	[bɨnɨˈfisju]	1_49				
14		[bɨnɨˈfisju]	1r1_49				
15		[bɨnɨˈfisju]	1r2_49				
16	benéfico	[bɨˈnɛfik]	8_89				
17		[bɨˈnɛfi]	8r1_89				
18		[bɨˈnɛfik]	8r2_89				
19	café	[kɐˈfɛ]	7_31				
20		[kɐˈfɛ]	7r1_31				
21		[kɐˈfɛ]	7r2_31				
22	chefe	[ˈʃɛfa]	4_11				
23		[ˈʃɛfa]	4r1_11				
24		[ˈʃɛfa]	4r2_11				

Table D.39: Fricative /v/ (Word-Initial) in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
25	viver	[d v i'veɾ]	8_122	-				
26		[d v i'veɾ]	8r1_122	-				
27		[d̥ v i'veɾ]	8r2_122					dev.
28	vermelho	[u vɨɾ'meʎu]	10_86					
29		[u vɨɾ'meʎu]	10r1_86					dev.
30		[u vɨɾ'meʎu]	10r2_86					dev.
31	ver	[veɾ]	8_102	-				
32		[veɾ]	8r1_102	-				dev.
33		[veɾ]	8r2_102	-				
34		[ʃ̥ veɾ]	12_102	-	-	-	-	dev.
35		[ʃ̥ veɾ]	12r1_102	-	-	-	-	dev.
36		[ʃ̥ veɾ]	12r2_102	-	-	-	-	dev.
37	vaca	[ɐ 'vakɐ]	2_92					dev.
38		[ɐ 'vakɐ]	2r1_92					dev.
39		[ɐ 'vakɐ]	2r2_92					dev.
40	volta	[d 'vɔltɐ]	8r1_81	-	-	-	-	dev.
41		[d 'vɔltɐ]	8r2_81	-	-	-	-	dev.
42	voo	[u vow]	3_17					
43		[u vow]	3r1_17					par. dev.
44		[u vow]	3r2_17					dev.
45	vogar	[i 'vugaɾ]	5_7					
46		[i 'vugaɾ]	5r1_7					
47		[i 'vugaɾ]	5r2_7					dev.

Table D.40: Fricative /v/ (Word-Medial and Word-Final) in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
25	viver	[viˈ v ɐɾ]	8_122					
26		[viˈ v ɐɾ]	8r1_122					dev.
27		[viˈ v ɐɾ]	8r2_122					
48	possível	[puˈsi v ɛl]	11_95					
49		[puˈsi v ɛl]	11r1_95					
50		[puˈsi v ɛl]	11r2_95					
51	altivo	[alˈtivu]	4_124					dev.
52		[alˈtivu]	4r2_124					par. dev.
53	dever	[dɨˈver]	12_22					dev.
54		[dɨˈver]	12r1_22					dev.
55		[dɨˈver]	12r2_22					
56	avó	[ɐˈvɔ]	1_88					par. dev.
57		[ɐˈvɔ]	1r1_88					
58		[ɐˈvɔ]	1r2_88					
59	ave	[ˈavɨ]	3_45					dev.
60		[ˈavɨ]	3r1_45					dev.
61		[ˈavɨ]	3r2_45					dev.
62	cava	[ˈkavɐ]	12_24					dev.
63		[ˈkavɐ]	12r1_24					dev.
64		[ˈkavɐ]	12r2_24					dev.
65	bravo	[ˈbɾavu]	6_100					dev.
66		[ˈbɾavu]	6r1_100					
67		[ˈbɾavu]	6r2_100					dev.
68	nova	[ˈnɔvɐ]	8_147					
69		[ˈnɔvɐ]	8r1_147					
70		[ˈnɔvɐ]	8r2_147					
71	altivo	[alˈtiv f]	4r1_124			-		dev.
72	move	[ˈmɔv ɐ]	3_67					dev.
73		[ˈmɔv ɐ]	3r1_67					
74		[ˈmɔv ɐ]	3r2_67					dev.

Table D.41: Fricative /s/ in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
75	sítio	[u ˈsitju]	5_77				
76		[u ˈsitju]	5r1_77				
77		[u ˈsitju]	5r2_77				
78		[u ˈsitju]	11_77				
79		[u ˈsitju]	11r1_77				
80		[u ˈsitju]	11r2_77				
81	sede	[d ˈsedɨ]	4_75	-			
82		[ˈsedɨ]	4r1_75	-			
83		[d ˈsedɨ]	4r2_75	-			
84	seta	[ɐ ˈsɛtɐ]	3_34				
85		[ɐ ˈsɛtɐ]	3r1_34				
86		[ɐ ˈsɛtɐ]	3r2_34				
87	sala	[a ˈsalɐ]	8r1_13				
88		[a ˈsalɐ]	8r2_13				
89		[ɐ ˈsalɐ]	12_13				
90		[ɐ ˈsalɐ]	12r1_13				
91		[ɐ ˈsalɐ]	12r2_13				
92	só	[w sɔ]	6_5				
93		[w sɔ]	6r1_5				
94		[w sɔ]	6r2_5				
95	subir	[ɐ suˈbiɾ]	3_139				
96		[w suˈbiɾ]	3r1_139				
97		[ɐ suˈbiɾ]	3r2_139				
98	benefício	[bɨnɨˈfi s ju]	1_49				
99		[bɨnɨˈfi s ju]	1r1_49				
100		[bɨnɨˈfi s ju]	1r2_49				
101	ressaca	[Rˈsakɐ]	7_82	-			
102		[Rˈsakɐ]	7r1_82	-			
103		[Rˈsakɐ]	7r2_82	-			
104	condessa	[kõˈdesɐ]	9_153				
105		[kõˈdesɐ]	9r1_153				
106		[kõˈdesɐ]	9r2_153				
107	assar	[ɐˈsaɾ]	12_137				
108		[ɐˈsaɾ]	12r1_137				
109		[ɐˈsaɾ]	12r2_137				
110	caça	[ˈkasɐ]	7_35				
111		[ˈkasɐ]	7r1_35				
112		[ˈkasɐ]	7r2_35				
113	possível	[puˈ s ivɛl]	11_95				
114		[puˈ s ivɛl]	11r1_95				
115		[puˈ s ivɛl]	11r2_95				
116	doce	[ˈdos]	1_56			-	
117		[ˈdos]	1r1_56			-	
118		[ˈdos]	1r2_56			-	

Table D.42: Fricative /z/ in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
119	Zita	[ɐ ˈzitɐ]	9_68					dev.
120		[ɐ ˈzitɐ]	9r1_68					par. dev.
121		[ɐ ˈzitɐ]	9r2_68					dev.
122	Zé	[u zɛ]	6_85					dev.
123		[u zɛ]	6r1_85					dev.
124		[u zɛ]	6r2_85					dev.
125	zarpar	[ɐ zɐɾˈpaɾ]	3_113					dev.
126		[ɐ zɐɾˈpaɾ]	3r1_113					par. dev.
127		[ɐ zɐɾˈpaɾ]	3r2_113					dev.
128	zona	[ɐ ˈzonɐ]	2_84					dev.
129		[ɐ ˈzonɐ]	2r1_84					dev.
130		[ɐ ˈzonɐ]	2r2_84					dev.
131	mesinha	[mɨˈziɲɐ]	8_50					
132		[mɨˈziɲɐ]	8r1_50					dev.
133		[mɨˈziɲɐ]	8r2_50					dev.
134	beleza	[bɨˈlezɐ]	4_135					
135		[bɨˈlezɐ]	4r1_135					dev.
136		[bɨˈlezɐ]	4r2_135					dev.
137	Brasil	[bɾɐˈzil]	10_58					dev.
138		[bɾɐˈzil]	10r1_58					dev.
139		[bɾɐˈzil]	10r2_58					dev.
140	azul	[ɐˈzul]	10_33					dev.
141		[ɐˈzul]	10r1_33					dev.
142		[ɐˈzul]	10r2_33					dev.
143	asa	[ˈazɐ]	3_19					dev.
144		[ˈazɐ]	3r1_19					dev.
145		[ˈazɐ]	3r2_19					
146	rosa	[ˈɾɔzɐ]	4_14					dev.
147		[ˈɾɔzɐ]	4r1_14					dev.
148		[ˈɾɔzɐ]	4r2_14					dev.
149	doze	[ˈdozɨ]	8r2_132					dev.
150	doze	[ˈdoz]	8_132			-		dev.
151		[ˈdoz]	8r1_132			-		dev.

Table D.43: Fricative /ʃ/ in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
152	chegar	[w ʃɨˈgaɾ]	7_65				
153		[w ʃɨˈgaɾ]	7r1_65				
154		[w ʃˈgaɾ]	7r2_65			-	
155	chefe	[u ˈʃɛf]	4_11				
156		[u ˈʃɛf]	4r1_11				
157		[u ˈʃɛf]	4r2_11				
158	chá	[ɐ ʃa]	11_51				
159		[ɐ ʃa]	11r1_51				
160		[ɐ ʃa]	11r2_51				
161	choca	[ɐ ˈʃɔkɐ]	9_116				
162		[ɐ ˈʃɔkɐ]	9r1_116				
163		[ɐ ˈʃɔkɐ]	9r2_116				
164	chocha	[ɐ ˈʃoʃɐ]	1_80				
165		[ɐ ˈʃoʃɐ]	1r1_80				
166		[ɐ ˈʃoʃɐ]	1r2_80				
167	chorar	[u ʃuˈɾaɾ]	5_78				
168		[u ʃuˈɾaɾ]	5r1_78				
169		[u ʃuˈɾaɾ]	5r2_78				
170	achar	[ɐˈʃaɾ]	11_114				
171		[ɐˈʃaɾ]	11r1_114				
172		[ɐˈʃaɾ]	11r2_114				
164	chocha	[ˈʃoʃɐ]	1_80				
165		[ˈʃoʃɐ]	1r1_80				
166		[ˈʃoʃɐ]	1r2_80				
173	meche	[ˈmɛʃ v]	12_141			-	
174		[ˈmɛʃ v]	12r1_141			-	
175		[ˈmɛʃ v]	12r2_141			-	

Table D.44: Fricative /ʒ/ in Corpus 4 (Speaker ACC).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
176	Gigi	[ɐ ʒ i'ʒi]	1_145					dev.
177		[ɐ ʒ i'ʒi]	1r1_145					dev.
178		[ɐ ʒ i'ʒi]	1r2_145					dev.
179	gelo	[u 'ʒelu]	2_119					par. dev.
180		[u 'ʒelu]	2r1_119					par. dev.
181		[u 'ʒelu]	2r2_119					dev.
182	jóia	[ɐ 'ʒɔjɐ]	9_143					dev.
183		[ɐ 'ʒɔjɐ]	9r1_143					dev.
184		[ɐ 'ʒɔjɐ]	9r2_143					dev.
185	judeu	[u ʒu'dew]	6_32					dev.
186		[u ʒu'dew]	6r1_32					dev.
187		[u ʒu'dew]	6r2_32					par. dev.
176	Gigi	[ʒi' ʒ i]	1_145					dev.
177		[ʒi' ʒ i]	1r1_145					dev.
178		[ʒi' ʒ i]	1r2_145					dev.
188	arejar	[ɐɾ'ʒaɾ]	5_46	-				par. dev.
189		[ɐɾ'ʒaɾ]	5r1_46	-				par. dev.
190		[ɐɾ'ʒaɾ]	5r2_46	-				par. dev.
191	ajudar	[ɐ'ʒudaɾ]	6_66					dev.
192		[ɐ'ʒudaɾ]	6r1_66					dev.
193		[ɐ'ʒudaɾ]	6r2_66					dev.
194	age	['aʒɨ]	1_79					dev.
195		['aʒɨ]	1r1_79					dev.
196		['aʒɨ]	1r2_79					dev.
197	hoje	['oʒɨ]	5_38					
198		['oʒɨ]	5r1_38					dev.
199		['oʒɨ]	5r2_38					dev.
200	foge	['fɔ ʒ ɨ]	2_155					dev.
201		['fɔ ʒ ɨ]	2r1_155					dev.
202		['fɔ ʒ ɨ]	2r2_155					
203	mares	['maɾʒ]	10_130	-		-		dev.
204		['maɾʒ d]	10r1_130	-		-		par. dev.
205		['maɾʒ d]	10r2_130	-		-		dev.
206	dos	['duʒ]	8_138			-		dev.
207		['duʒ d]	8r1_138			-		
208		['duʒ]	8r2_138			-		
209		['duʒ m]	10_138			-		par. dev.
210		['duʒ]	10r1_138			-		
211		['duʒ]	10r2_138			-		par. dev.

Table D.45: Fricative /f/ in Corpus 4 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
1	fala	[u 'falɐ]	4_2				
2		[u 'falɐ]	4r_2				
3	foge	[ɐ 'fɔʒɨ]	2_155				
4		[ɐ 'fɔʒɨ]	2r_155				
5	fogo	[u 'fogu]	10_101				
6		[u 'fogu]	10r_101				
7	furar	[fu'ɾaɾ]	9_44	-			
8		[fu'ɾaɾ]	9r_44	-			
9	benefício	[bɨnɨ'fisju]	1_49				
10		[bɨnɨ'fisju]	1r_49				
11	benéfico	[bɨ'nɛfik]	8_89				
12		[bɨ'nɛfik]	8r_89				
13	café	[kɐ'fɛ]	7_31				
14		[kɐ'fɛ]	7r_31				
15	chefe	['ʃɛfa]	4_11				
16		['ʃɛfa]	4r_11				

Table D.46: Fricative /v/ in Corpus 4 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
17	viver	[d v i'veɾ]	8_122	-				dev.
18		[d v i'veɾ]	8r_122	-				dev.
19	vermelho	[u vɨɾ'meʎu]	10_86					
20		[u vɨɾ'meʎu]	10r_86					par. dev.
21	ver	[veɾ]	8_102	-				
22		[veɾ]	8r_102	-				
23		[ʃ veɾ]	12_102	-				
24		[ʃ veɾ]	12r_102	-				dev.
25	vaca	[ɐ 'vakɐ]	2_92					dev.
26		[ɐ 'vakɐ]	2r_92					
27	volta	[d 'vɔltɐ]	8_81	-				
28		[d 'vɔltɐ]	8r_81	-				par. dev.
29	voo	[u vow]	3_17					
30		[u vow]	3r_17					
31	vogar	[i 'vugaɾ]	5_7					dev.
32		[i 'vugaɾ]	5r_7					dev.
17	viver	[vi v eɾ]	8_122					
18		[vi v eɾ]	8r_122					
33	possível	[p'si v ɛl]	11_95					
34		[p'si v ɛl]	11r_95					
35	dever	[dɨ'ver]	12_22					par. dev.
36		[d'ver]	12r_22	-				
37	avó	[ɐ'vɔ]	1_88					dev.
38		[ɐ'vɔ]	1r_88					dev.
39	ave	['avɨ]	3_45					dev.
40		['avɨ]	3r_45					
41	cava	['kavɐ]	12_24					
42		['kavɐ]	12r_24					
43	bravo	['bɾavu]	6_100					
44		['bɾavu]	6r_100					
45	nova	['nɔvɐ]	8_147					dev.
46		['nɔvɐ]	8r_147					dev.
47	altivo	[al'tiv f]	4_124			-		
48		[al'tiv f]	4r_124			-		
49	move	['mɔv ɐ]	3_67					dev.
50		['mɔv ɐ]	3r_67					dev.

Table D.47: Fricative /s/ in Corpus 4 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
51	sítio	[u ˈsitju]	5_77				
52		[u ˈsitju]	5r_77				
53		[u ˈsitju]	11_77				
54		[u ˈsitju]	11r_77				
55	sede	[d ˈsedɨ]	4_75	-			
56		[d ˈsedɨ]	4r_75	-			
57	seta	[ɐ ˈsɛtɐ]	3_34				
58		[ɐ ˈsɛtɐ]	3r_34				
59	sala	[ɐ ˈsalɐ]	8_13				
60		[ɐ ˈsalɐ]	8r_13				
61		[ɐ ˈsalɐ]	12_13				
62		[ɐ ˈsalɐ]	12r_13				
63	só	[w sɔ]	6_5				
64		[w sɔ]	6r_5				
65	subir	[ɐ suˈbiɾ]	3_139				
66		[ɐ s uˈbiɾ̥]	3r_139				
67	benefício	[bɨnɨˈfi s ju]	1_49				
68		[bɨnɨˈfi s ju]	1r_49				
69	ressaca	[χˈ s akɐ]	7_82	-			
70		[χˈ s akɐ]	7r_82	-			
71	condessa	[kõˈdesɐ]	9_153				
72		[kõˈdesɐ]	9r_153				
73	assar	[ɐˈ s aɾ̥]	12_137				
74		[ɐˈ s aɾ̥]	12r_137				
75	caça	[ˈkasɐ]	7_35				
76		[ˈkasɐ]	7r_35				
77	possível	[pˈ s ivɛl]	11_95	-			
78		[pˈ s ivɛl]	11r_95	-			
79	doce	[ˈdos]	1_56			-	
80		[ˈdos]	1r_56			-	

Table D.48: Fricative /z/ in Corpus 4 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
81	Zita	[ɐ ˈzitɐ]	9_68					dev.
82		[ɐ ˈzitɐ]	9r_68					
83	Zé	[u zɛ]	6_85					par. dev.
84		[u zɛ]	6r_85					dev.
85	zarpar	[ɐ zɐɾˈpaɾ]	3_113					dev.
86		[ɐ zɐɾˈpaɾ]	3r_113					dev.
87	zona	[ɐ ˈzonɐ]	2_84					dev.
88		[ɐ ˈzonɐ]	2r_84					dev.
89	mesinha	[mɨˈzipɐ]	8_50					dev.
90		[mɨˈzipɐ]	8r_50					dev.
91	beleza	[bɨˈlezɐ]	4_135					dev.
92		[bɨˈlezɐ]	4r_135					dev.
93	Brasil	[bɾɐˈzil]	10_58					
94		[bɾɐˈzil]	10r_58					dev.
95	azul	[ɐˈzul]	10_33					par. dev.
96		[ɐˈzul]	10r_33					par. dev.
97	asa	[ˈazɐ]	3_19					dev.
98		[ˈazɐ]	3r_19					dev.
99	rosa	[ˈχɔ z ɐ]	4_14					par. dev.
100		[ˈχɔ z ɐ]	4r_14					
101	doze	[ˈdoz]	8_132			-		dev.
102		[ˈdoz]	8r_132			-		dev.

Table D.49: Fricative /ʃ/ in Corpus 4 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}
103	chegar	[w ʃˈgaɾ]	7_65			-	
104		[w ʃˈgaɾ]	7r_65			-	
105	chefe	[u ˈʃɛf]	4_11				
106		[u ˈʃɛf]	4r_11				
107	chá	[ɐ ʃa]	11_51				
108		[ɐ ʃa]	11r_51				
109	choca	[ɐ ˈʃɔkɐ]	9_116				
110		[ɐ ˈʃɔkɐ]	9r_116				
111	chocha	[ɐ ˈʃoʃɐ]	1_80				
112		[ɐ ˈʃoʃɐ]	1r_80				
113	chorar	[ɾ ʃuˈɾaɾ]	5_78	-			
114		[ɾ ʃuˈɾaɾ]	5r_78	-			
115	achar	[ɐˈʃaɾ]	11_114				
116		[ɐˈʃaɾ̥]	11r_114				
111	chocha	[ˈʃoʃɐ]	1_80				
112		[ˈʃoʃɐ]	1r_80				
117	meche	[ˈmɛʃ v]	12_141			-	
118		[ˈmɛʃ v]	12r_141			-	

Table D.50: Fricative /ʒ/ in Corpus 4 (Speaker ISSS).

	Example	IPA	File N.	VF (ms)	F (ms)	FV (ms)	r_{σ^2}	Devoicing
119	Gigi	[ɐ ʒ i'ʒi]	1_145					par. dev.
120		[ɐ ʒ i'ʒi]	1r_145					dev.
121	gelo	[u 'ʒelu]	2_119					par. dev.
122		[u 'ʒelu]	2r_119					par. dev.
123	jóia	[ɐ 'ʒɔjɐ]	9_143					dev.
124		[ɐ 'ʒɔjɐ]	9r_143					dev.
125	judeu	[u ʒu'dew]	6_32					dev.
126		[u ʒu'dew]	6r_32					dev.
119	Gigi	[ʒi' ʒ i]	1_145					dev.
120		[ʒi' ʒ i]	1r_145					
127	arejar	[ɐɾi̥ ʒ aɾ]	5_46					dev.
128		[ɐɾ̥ ʒ aɾ]	5r_46	-				par. dev.
129	ajudar	[ɐ'ʒudaɾ]	6_66					dev.
130		[ɐ'ʒudaɾ]	6r_66					dev.
131	age	['aʒɨ]	1_79					dev.
132		['aʒɨ]	1r_79					dev.
133	hoje	['oʒɨ]	5r_38					dev.
134	foge	['fɔ ʒ ɨ]	2_155					par. dev.
135		['fɔ ʒ ɨ]	2r_155					dev.
136	dos	['duʒɨ]	8_138					par. dev.
137	mares	['maɾʒ]	10_130	-		-		dev.
138		['maɾʒ]	10r_130	-		-		dev.
139	hoje	['oʒ]	5_38			-		dev.
140	dos	['duʒ]	8r_138			-		dev.
141		['duʒ]	10_138			-		dev.
142		['duʒ]	10r_138			-		dev.

Appendix E

Results of an Initial Frequency Analysis of Corpus 1a, 1b, 2 and 3 (Speaker LMTJ)

In this Appendix we present the results of an initial spectral analysis of Corpus 1a, 1b, 2 and 3 for Speaker LMTJ, which served as a reference for later analysis of Speakers CFGA, ACC and ISSS. This included a complete list of all the peaks, broad peaks and troughs visible in the spectra of each fricative. It has to be noted that some of these peaks are rarely visible, and so they have been disregarded in the discussion presented in Chapter 5. The influence of vowel context is also reported.

Table E.1: Peaks of fricative /f/.

	Peak 1 (kHz)	Peak 2 (kHz)	Peak 3 (kHz)	Peak 4 (kHz)	Peak 5 (kHz)	Peak 6 (kHz)	Peak 7 (kHz)
Corpus 1a (sustained)	-	1	1.6	2.1	2.5-2.6	3.9	4.9
Corpus 1b (sustained at three different effort levels) *	0.5	1	1.7	-	2.6	4	-
Corpus 2 (nonsense words)	0.5-0.8	1	1.4-1.7	2.1-2.5	2.8-3	3.8-4	4.2-5
Corpus 3 (nearly minimal pairs)	-	1.2	-	2.5	-	-	4.2
Corpus 3 (initial position in real words)	-	0.8-1.1 [a]	1.4-1.7	2.1 [b]	2.5-2.7	3.8-4	4.4-5.1 [b]
Corpus 3 (medial position in real words)	0.5 kHz for /efu/ and /ɛfi/.	0.8-1.1	1.4-1.8	2.1-2.4 [b]	2.6	3.8-4	4.1-5.1
Corpus 3 (final position in real words)	-	1	1.6	2.1 kHz for /ɛf/.	2.6	3.6 kHz for /ɛf/ and 4 kHz for /af/.	5 kHz for /ɛf/ and 4.5 kHz for /af/.

[a] Not visible for /fu/.

[b] Not always visible.

* There is an additional peak around 6-7 kHz for loud effort level.

Table E.2: Broad peaks and trough of fricative /f/.

	Broad Peak 1 (kHz)	Broad Peak 2 (kHz)	Trough (kHz)
Corpus 1a (sustained)	11.9	15.3-15.5	-
Corpus 1b (sustained at three different effort levels)	-	-	-
Corpus 2 (nonsense words)	11-12	14-16 [a]	3-3.8
Corpus 3 (nearly minimal pairs)	-	-	-
Corpus 3 (initial position in real words)	11.5 kHz for /fu/.	14.9-16.7 for /fi/, /fɨ/, /fɔ/ and /fu/.	3-3.2
Corpus 3 (medial position in real words)	-	-	3-3.4
Corpus 3 (final position in real words)	-	-	3

[a] Not always visible.

Table E.3: Peaks of fricative /v/.

	Peak 1 (kHz)	Peak 2 (kHz)	Peak 3 (kHz)	Peak 4 (kHz)	Peak 5 (kHz)	Peak 6 (kHz)	Peak 7 (kHz)
Corpus 1a (sustained)	-	0.9-1	1.4-1.6	2.1 [a]	2.5	3.6-4	4.5-5.1
Corpus 1b (sustained at three different effort levels)	-	1	1.5	-	2.5	3.8-4	-
Corpus 2 (nonsense words)	0.4-0.7	0.8-1	1.2-1.7	1.8-2.3	2.5-2.7	3.6-3.9	4.2-5
Corpus 3 (nearly minimal pairs)	-	-	-	1.8	2.5	3.7	4.5
Corpus 3 (initial position in real words)	-	0.8-1 [a]	1.6 [b]	2.1 [a]	2.5	3.5-4	4.5-5.2 [c]
Corpus 3 (medial position in real words)	-	0.8-1 [a]	1.3-1.5	1.8-2.4 [a]	2.5	3.7-3.9	4.1-5.2
Corpus 3 (final position in real words)	-	0.9	1.3-1.5	1.8-2.4	2.6	3.5-3.9	4.2-5

[a] Not always visible.

[b] Shifted down by 200 Hz for /vo/ and /vu/.

[c] Not visible for /vi/ and /vaj/.

Table E.4: Broad peaks and troughs of fricative /v/.

	Broad Peak 1 (kHz)	Broad Peak 2 (kHz)	Trough 1 (kHz)	Trough 2 (kHz)
Corpus 1a (sustained)	11.5-12.3	15.1-15.5	-	-
Corpus 1b (sustained at three different effort levels)	-	-	-	-
Corpus 2 (nonsense words)	11-12	14-16 [a]	2	3.1-3.4 [a]
Corpus 3 (nearly minimal pairs)	-	-	-	-
Corpus 3 (initial position in real words)	-	-	-	3.2 [a]
Corpus 3 (medial position in real words)	-	-	-	3-3.3 [a]
Corpus 3 (final position in real words)	-	-	2 kHz for back vowel context.	3.2

[a] Not always visible.

Table E.5: Peaks of fricative /s/.

	Peak 1 (kHz)	Peak 2 (kHz)	Peak 3 (kHz)	Peak 4 (kHz)	Peak 5 (kHz)
Corpus 1a (sustained)	0.5 kHz for /ɐs...ɐ/ and /us...u/.	1	1.7	-	2.6
Corpus 1b (sustained at three different effort levels)	0.5 [a]	0.9-1.2	1.9	-	2.5-2.7
Corpus 2 (nonsense words) *	0.4-0.5	0.9-1.2	1.6-1.8	2.2-2.4	2.6-2.9
Corpus 3 (nearly minimal pairs)	-	0.9	1.6	-	2.5
Corpus 3 (initial position in real words)	-	0.9 [b]	1.5-1.8	2.1-2.3	2.6
Corpus 3 (medial position in real words)	0.4-0.5 [a]	0.8-1 [a]	1.5-1.8	2.1 kHz for /ɨˈsa/ and /ɐˈsja/.	2.5-2.7
Corpus 3 (final position in real words)	-	0.9	1.6	2.2	2.7

[a] Not always visible.

[b] Not visible for /si/, /sɨ/ and /se/.

* There is an additional peak around 6.2-6.9 kHz for /pusu/.

Table E.6: Broad peaks and trough of fricative /s/.

	Broad Peak (kHz)	Secondary Broad Peak (kHz)	Trough (kHz)
Corpus 1a (sustained)	5 kHz for /ɨs...ɨ/ and /ɐs...ɐ/, and 4.4 kHz for /us...u/.	9.4-10.3	-
Corpus 1b (sustained at three different effort levels)	5.1-5.4	-	-
Corpus 2 (nonsense words)	3.5-5.4 [a]	9-12	3-3.3
Corpus 3 (nearly minimal pairs)	5.2	-	3.2
Corpus 3 (initial position in real words) *	4.5-4.8 kHz for back vowel contexts and 5.1-6 kHz for non-back vowel contexts.	9.3-10 kHz for /sɛ/, /so/ and /su/.	2.9-3.2 [b]
Corpus 3 (medial position in real words)	4.3-5 kHz for close and close-mid vowel contexts preceding the fricative and 5.1-6 kHz for open-mid and open vowel contexts preceding the fricative.	-	-
Corpus 3 (final position in real words)	5-5.5 [c]	9.8-10.1 [d]	-

[a] The /u/ vowel context shifts down the broad peak by 700 Hz, and the final /ɨ/ vowel context shifts down the broad peak by 700-1100 Hz.

[b] Not always visible.

[c] Shifted down to 4 kHz for back vowel contexts.

[d] Shifted down by 1 kHz for back vowel contexts.

* There is an additional secondary broad peak around 16-17.1 kHz for /sɨ/, /sa/, /so/ and /su/.

Table E.7: Peaks and broad peak of fricative /z/.

	Peak 1 (kHz)	Peak 2 (kHz)	Peak 3 (kHz)	Peak 4 (kHz)	Peak 5 (kHz)	Broad Peak (kHz)
Corpus 1a (sustained)	-	-	1.7-1.9	2.2 kHz for /ɐz...ɐ/ and /ɐz...ɨ/.	2.8	5-5.3 kHz for /ɨz...ɨ/, /ɐz...ɐ/ and /uz...u/, and 6.4 kHz for /ɐz...ɨ/.
Corpus 1b (sustained at three different effort levels)	-	-	1.7	-	2.5-2.8	5-5.4
Corpus 2 (nonsense words)	0.4-0.5 [a]	0.7-1 [a]	1.6-1.8	2.2-2.3 [a]	2.6-2.8	4-5.5
Corpus 3 (nearly minimal pairs)	-	1.1	1.7	-	2.6	6
Corpus 3 (initial position in real words)	-	0.9-1 [a]	1.6-1.8	2.1	2.6	5-6.2 [b]
Corpus 3 (medial position in real words)	-	0.9-1.1 [a]	1.4-1.8	2.2 [a]	2.6-2.8	3.8-4.7 kHz for back vowel contexts and 4.7-6 kHz for non-back vowel contexts.
Corpus 3 (final position in real words)	-	-	1.6	-	2.6	4.3-5

[a] Not always visible.

[b] Shifted down to 4 kHz for /zo/.

Table E.8: Peaks, prominent peak, secondary broad peak and trough of fricative /ʃ/.

	Peak 1 (kHz)	Peak 2 (kHz)	Peak 3 (kHz)	Peak 4 (kHz) *	Prominent Peak (kHz)	Secondary Broad Peak (kHz)	Trough (kHz)
Corpus 1a (sustained)	-	1 [a]	2	2.6 [a]	2.4-2.6 [b]	11	-
Corpus 1b (sustained at three different effort levels)	-	-	2	2.6	3.6-4.1	-	-
Corpus 2 (nonsense words)	0.4-0.5	0.8-0.9	1.6-1.9	-	2.3-3	10-11.6 [a]	1.1-1.3
Corpus 3 (nearly minimal pairs)	-	-	1.7	2.6 [a]	2.5 [b]	9.8-11	-
Corpus 3 (initial position in real words)	-	0.9 [a]	1.8	2.6 [c]	2.6 [b]	10.4-11.5	1.1
Corpus 3 (medial position in real words)	-	1 [a]	1.8	2.6 [a]	2.2-2.6 [b]	-	1.1
Corpus 3 (final position in real words)	-	0.8 [a]	1.7	2.6 [a]	2.3-2.5 [b]	-	0.8-1.2

[a] Not always visible.

[b] Shifted up to 3.1-3.8 kHz when Peak 4 (around 2.6 kHz) is visible.

[c] Not visible for back vowel contexts.

*Peak 4 is sometimes the most prominent peak in the spectrum of the fricative.

Table E.9: Peaks, prominent peak, secondary broad peak and trough of fricative /ʒ/.

	Peak 1 (kHz)	Peak 2 (kHz)	Peak 3 (kHz)	Peak 4 (kHz) *	Prominent Peak (kHz)	Secondary Broad Peak (kHz)	Trough (kHz)
Corpus 1a (sustained)	-	0.9-1 [a]	1.9	2.6 [a]	2.4-2.6 [b]	-	-
Corpus 1b (sustained at three different effort levels)	-	-	2	2.6	3.4-3.7	-	-
Corpus 2 (non-sense words)	0.4	0.8 [c]	1.6-1.8	-	2.4-3	10.2-10.6 [a]	1.1-1.3
Corpus 3 (nearly minimal pairs)	-	-	2	2.6	3.5	-	1
Corpus 3 (initial position in real words)	-	0.9 [a]	1.6-1.9	2.5-2.6 [a]	2.5-2.6 [b]	-	1.1
Corpus 3 (medial position in real words)	-	0.9 [a]	1.5-1.8	2.6 [d]	3.1-3.6 [e]	-	1-1.2
Corpus 3 (final position in real words)	-	0.8	1.5-1.8	-	2.6	-	1.2

[a] Not always visible.

[b] Shifted up to 3.3-3.5 kHz when Peak 4 (around 2.6 kHz) is visible.

[c] Only visible for /ˈpɐʒɨ/, /pɐʒɐ/, /pɐˈʒu/, /ˈpuʒɨ/, /puˈʒɐ/ and /puˈʒu/.

[d] Only visible for /iʒi/, /ɨˈʒa/, /aʒɨ/ and /aʒɐ/.

[e] Shifted down to 2.2-2.6 kHz for back vowel contexts.

* Peak 4 is sometimes the most prominent peak in the spectrum of the fricative.

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