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Analysis of Stop Consonant Production in European Portuguese

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Introduction

- The present study examines the acoustic properties correlated with:
  - Voicing
    - VOT,
    - Stop duration,
    - Closure duration,
    - Release duration,
    - Voicing into closure duration,
    - Duration of preceding vowel and
    - Duration of following vowel
  - The place of articulation
    - Spectral characteristics
- of stop consonants /p, b, t, d, k, g/ of European Portuguese (EP).

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Literature Review

- Andrade (1980) compared VOT of Portuguese homorganic stops, in initial position, before a vowel, in words produced by a speaker of EP. Results showed that:
  - Some voiced stops had a period of prevoicing followed by a devoiced period
  - VOT was larger for velars, than for labials and dentals, as in English (Klatt, 1975).
- Alphen and Smits (2004) showed that stops are often devoiced and there are multiple acoustic properties related with voicing distinction.
- Viana (1984) and Veloso (1995) observed that stop duration and duration of the following vowel, were acoustic properties that cued voicing in EP.

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Literature Review

- Fuchs (2005) also suggested
  - Closure duration,
  - Duration of following vowel,
  - Duration of preceding vowel and
  - Voicing into closure duration,
- as voicing cues.

- The shape of the spectrum of the stop release was analysed by Blumstein and Stevens (1978):
  - Labial stops had a diffuse-falling or diffuse-flat pattern.
  - Alveolar stops, also had a diffuse spread of peaks of energy, but the amplitudes of these peaks were greater at high frequencies (diffuse-rising pattern).

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Literature Review

- Velar stops had a mid-frequency spectral peak (compact pattern).
- Labial and alveolar stops shared the property of diffuseness and were distinguished by the shape of the spectral energy distribution.

- Forrest et al. (1988) concluded that the simultaneous evaluation of mean, skewness, and kurtosis differentiates the place of stop articulation:
  - [p] and [t] differ consistently in skewness and mean but not in kurtosis.
  - [k] is similar to [p] in mean and skewness but differs from [t] in kurtosis.

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Recording Method

- Subjects - six native speakers of EP (three men, three women).
- Corpus - 54 words, containing stops /p, b, t, d, k, g/ in:
  - Initial position, followed by the vowels /a, i, u/;
  - Medial position, preceded by the vowels /a, i, u/ and followed by the vowel /ɐ/;
  - Final position, preceded by the vowels /ɔ, a/.
- The words were produced without any context (Corpus 1) and within the frame sentence "Diga,... por favor." (Corpus 2).

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Recording Method

- The corpus was recorded using a Philips SBC ME 400 unidirectional condenser microphone located 20 cm in front of the subject's mouth.
- A laringograph signal (Lx) was also collected using a laryngograph processor (model EG-PC3 produced by Tiger DRS, Inc., USA).
- The acoustic and Lx signals were pre-amplified (Rane MS 1-b) and recorded with a Sony PCM-R300 DAT recorder, each with 16 bits and a sampling frequency of 48 kHz.

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Analysis Method - Temporal Analysis

- All corpus words were manually analysed (Figure 1) to detect the:
  - beginning of preceding vowel (IV1)
    - second formant intensity becomes characteristic for a vowel (Fuchs, 2005).
  - end of preceding vowel and beginning of closure (IO)
    - second formant is no longer visible in the spectrogram
  - voice offset (FV)
    - vocal fold vibration end.
  - beginning of prevoicing (IPV)
    - the moment in time at which evidence of vocal fold vibration could be detected.

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Analysis Method - Temporal Analysis

- end of prevocing (FPV)
  - onset of burst spectrum (Alphen and Smits, 2004).
- end of closure and beginning of release (IR)
  - onset of burst spectrum.
- end of release and beginning of following vowel (FR)
  - second formant intensity becomes characteristic for a vowel.
- end of following vowel (FV2)
  - second formant is no longer visible in the spectrogram.

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Analysis Method - Temporal Analysis

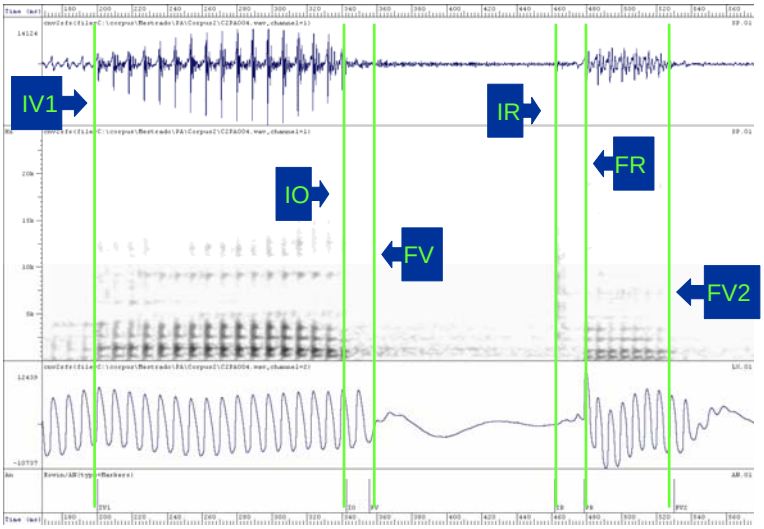

Figure 1: Anotation of the sequence VCV of word [napɐ] produced by speaker PA.

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Analysis Method - Temporal Analysis

- The following measurements where obtained:
  - Duration of preceding vowel,
  - Voicing into closure duration,
  - Prevoicing duration,
  - Closure duration,
  - VOT,
  - Release duration,
  - Duration of following vowel and,
  - Stop duration.

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Analysis Method - Temporal Analysis

- In the anotation files we also registed
  - the position in word
    - initial (0)
    - medial (1)
    - final (2)
  - type of voicing
    - if the duration of voicing was > ½ of closure duration – voiced,
    - if the duration of voicing was between 1/3 to ½ - partially devoiced,
    - if the duration of voicing was < 1/3 – devoiced,
    - if the voicing was absent – voiceless (Jesus and Shadle, 2002).

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Analysis Method - Spectral Analysis

- Multitaper spectra were calculated with 11ms windows left aligned to the release of the stop.
- Spectral peak and trough frequencies of words produced by speakers ML and LJ (Corpus 1) were analysed as shown in Figure 2.

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Analysis Method - Spectral Analysis

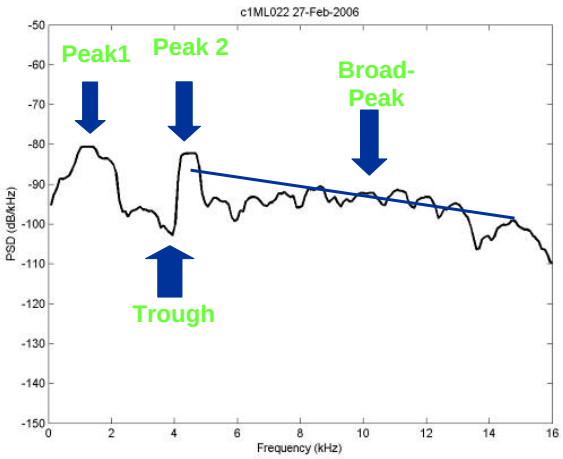

Figure 2: Spectrum of stop [t] in word [natɐ] of Corpus 1 produced by speaker ML.

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Analysis Method - Spectral Analysis

- Parameterization of stop spectra (Slopes)
  - The frequency (F) at which the spectral amplitude was maximum, excluding the fundamental frequency and its harmonics in voiced stops was also calculated.
  - It provided an endpoint for line fits used to determine the spectral slope (Figure 3). The average values for all Corpus 1 stops produced by speakers ML and LJ were:
    - $F_{[p, b]}$ = 3,7 kHz
    - $F_{[t, d]}$ = 3,9 kHz
    - $F_{[k, g]}$ = 4,6 kHz

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Analysis Method - Spectral Analysis

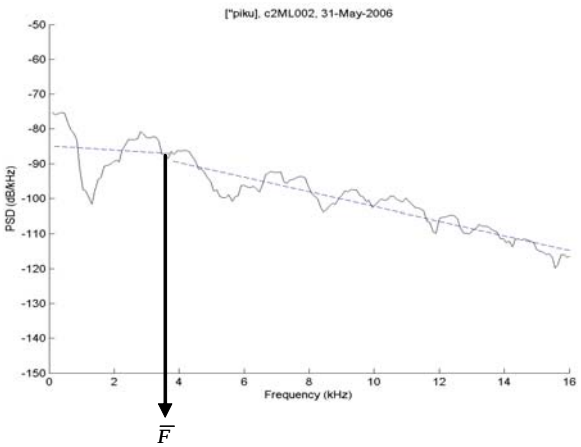

Figure 3: Multipaper spectra for [p] produced in initial position by speaker ML.

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Analysis Method - Spectral Analysis

- Parameterization of stop spectra (Moments)
  - The following four moments were calculated (Forrest et al., 1988):
    - Mean,
    - Variance,
    - Skewness,
    - Kurtosis.

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Results - Temporal Analysis

- Results of temporal analysis showed that when speakers ML, IM and SC (female), LJ, PA and HR (male) produced the words in a frame sentence, the stop duration and the closure duration, were longer for voiceless than for voiced stops, in all word positions, as shown in Figures 4 and 5.

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Results - Temporal Analysis

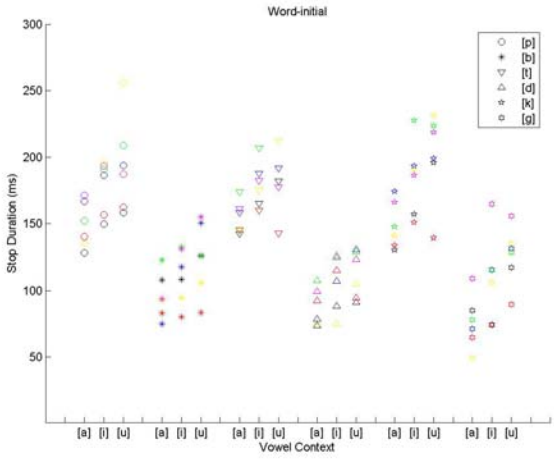

Figure 4: Stop duration of [p t k b d g] in initial position. Speaker LJ - black; Speaker ML – blue; Speaker HR – red; Speaker IM – green; Speaker PA – yellow; Speaker SC – magenta. Phonemes are presented in SAMPA.

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Results - Temporal Analysis

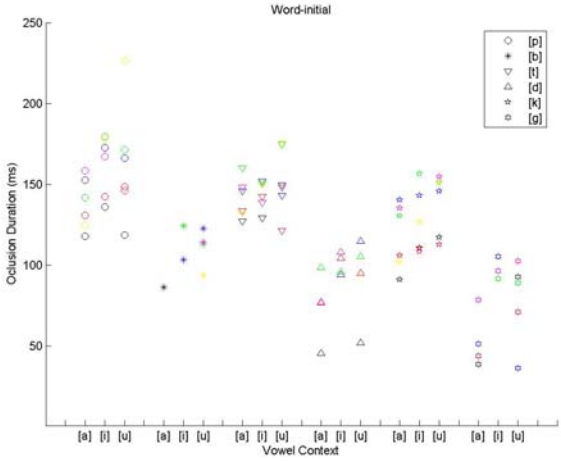

Figure 5: Oclusion duration of [p t k b d g] in initial position. Speaker LJ - black; Speaker ML – blue; Speaker HR – red; Speaker IM – green; Speaker PA – yellow; Speaker SC – magenta. Phonemes are presented in SAMPA.

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Results - Temporal Analysis

- The voicing into closure duration, the duration of preceding vowel and the duration of following vowel were generally shorter for voiceless than for voiced stops.
- VOT was on average shorter for [p] than for [t], and shorter for [t] than for [k].
  - [p] 19 ms
  - [t] 25 ms
  - [k] 43 ms

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Results - Spectral Analysis

- Spectral peak and trough frequencies (KHz)

	Trough	Peak 1	Peak 2	Broad-peak 1	Broad-peak 2
[p]	0.8-4.6			1.4-5.6	
[b]	0.7-5.0			1.5-5.6	
[t]	1.7-7.0	0.3-3.7	0.2-4.6	6.0-10.4	
[d]	1.5-5.5	0.3-1.7	2.4-5.6	5.2-9.9	11.0-12.8
[k]	2.9-6.3	0.6-3.8	3.9-5.4	7.1-9.4	10.0-13.2
[g]	0.8-7.4	1.0-2.6	3.9-4.9	6.8-9.1	12.0-13.6

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Results - Spectral Analysis

- Parameterization of stop spectra (Slopes)
  - Voiceless bilabial stops, in initial position, followed by vowel [a] had spectra with steeper negative slopes than dentals and velars.
  - Spectra of velars followed by vowel [i] had positive slopes, bilabials were mostly flat and dentals had a negative slope.
  - Dentals followed by vowel [u] had a positive, sometimes flat slope, and bilabials and velars had a negative slope.
  - Velars in medial position had a less negative slope than bilabials and dentals.
  - Word-final dentals had a less negative slope than bilabials and velars.

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Results - Spectral Analysis

- Parameterization of stop spectra (Moments)
  - [p] and [t] have different values of skewness and mean but approximately the same kurtosis and variance for all speakers.
  - [k], [p] and [t] do not differ in kurtosis.
  - The mean of [k] and [p] are quite similar (except for speaker ML).
  - The values of [k] and [p] skewness are the same for speakers SC, PA and IM.

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Results - Spectral Analysis

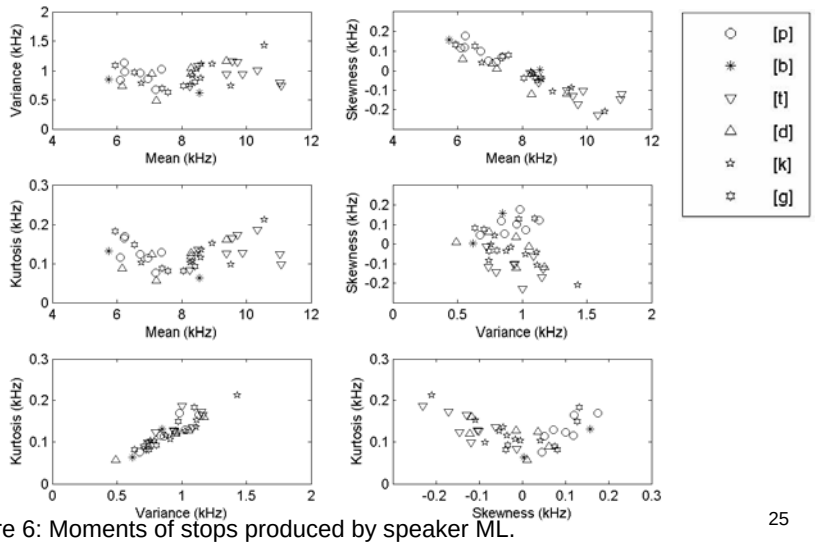

Figure 6: Moments of stops produced by speaker ML.

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Conclusions

- Voiceless stops were on average longer than voiced. This agrees with previous results for EP (Viana, 1984; Veloso, 1995).
- Place of articulation and VOT were correlated as previously reported by Klatt (1975) and Andrade (1980).
- The results showed that different acoustic properties are important for voicing distinction in EP.

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Conclusions

- We were not able to observe the spectral patterns reported by Blumstein and Stevens (1978).
- Bilabial and dental stops differ in terms of mean and skewness but not in kurtosis, confirming previous results for English (Forrest et al., 1988).
- Velar stops are similar to other places of articulation in terms of kurtosis. This differs from previous results for English (Forrest et al., 1988).
- The differences in method (the position of stops in word and the vowel context) in these studies could be a reason for the results divergence.

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