Acoustic structure of fricative consonants in Greek

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Abstract

The present study examines the temporal and spectral characteristics of Greek fricatives (duration and spectral moments, i.e. mean, variance, skewness, kurtosis) as distinctive cues for their place of articulation. The effects of voicing, speaker's gender and post-fricative vowel on both duration and spectral moments are also investigated. The results indicate that noise duration does not distinguish fricatives in terms of place of articulation. However, voiceless fricatives have longer durations than voiced ones. Spectral moments distinguish fricatives in terms of place of articulation, except for the labiodental from dental place.

Key words: Greek, fricatives, duration, spectral moments

Introduction

Very little is known about the Greek fricative consonants. Most studies examine [s] (e.g. Nicolaidis, 2002); while there is almost no information about the acoustics of the other Greek fricatives except for the duration data of Fourakis (1986). This study examines duration and spectral moments of Greek fricatives in word initial position as a function of voicing, speaker's gender, post-fricative vowel and place of articulation.

Noise duration has been shown to distinguish English voiced from voiceless fricatives, with voiceless being longer than voiced (Baum & Blumstein, 1987; Behrens & Blumstein, 1988). Spectral moments' analysis is a statistical procedure that differentiates English fricatives' place of articulation (Jongman et al., 2000). According to it, an FFT derived spectrum is treated as a random probability distribution from which the first four moments (center of gravity, standard deviation, skewness and kurtosis) are computed. Center of gravity corresponds to the mean of the distribution. Standard deviation captures the amount of spectral energy's dispersion around the mean. Skewness indicates whether the distribution is tilted to the left or the right. Kurtosis captures whether the shape is more peaked or flat.

Methodology

4 speakers, 2 females and 2 males, recorded the experimental material. All are native speakers of Greek and none of them has any history of speech or hearing disorders. The ten Greek fricative consonants [f], [v], [θ], [ð], [s], [z], [ç], [ʝ], [x], [ɣ] were recorded in real, two-syllable words

(CVCV) stressed on the first syllable. Each fricative was in initial position and the following vowel varied over the five Greek vowels [a], [e], [o], [i], [u]. Words beginning with [x] and [ɣ] were followed by [a], [o], [u], since /x/'s allophone, [ç], appears before [e] and [i]. The carrier phrase was "I said …again" (ˈipa…ksaˈna). Each token was repeated five times, yielding a total of 230 tokens per speaker. Fricative segmentation involved the simultaneous consultation of waveform and wideband spectrogram. Spectral moments were computed from FFTs calculated using a 40-ms full Hamming window at three different locations in the fricative: onset, middle and end.

Results

Frication duration

Table 1 shows the duration of each fricative. A four-way ANOVA (placeXvoicingXvowelXgender) revealed a main effect of voicing [$F(1,720)=780.588$, $p<0.0001$], i.e. voiceless fricatives were significantly longer (122.50) than voiced ones (93.38). A main effect of gender [$F(1,720)=1483.418$, $p<0.0001$] showed that fricatives produced by males (89.20) were significantly shorter than those produced by females (126.68). Place of articulation was also significant [$F(1,720)=9.929$, $p<0.0001$], although not all places, in accordance with post hoc tests. Differences between almost all vowels of different height were significant.

Table 1. Mean duration (ms) for each fricative and each place of articulation.

Fricative		Voiced	Voiceless	Place of articulation
[v]	[f]	99.05	120.84	109.95
[ð]	[θ]	95.61	119.07	107.34
[z]	[s]	95.68	127.43	111.55
[ʝ]	[ç]	87.92	121.02	104.47
[ɣ]	[x]	85.48	125.21	105.34

Spectral moments

One-way ANOVAs for all factors across window locations, with four moments as dependent variables, revealed a main effect of spectral mean on place of articulation [$F(4,915)=85.623$, $p<0.0001$]. Labiodentals, dentals and alveolars were not differentiated by first moment, although differences were significant for all other paired comparisons (Table 2). Variance had a main effect on place of articulation [$F(4,915)=492.092$, $p< 0.0001$], although it was not significant neither for labiodentals-dentals, nor for alveolars-palatals. Skewness was also significant [$F(4,915)=114.051$, $p<0.0001$], although post hoc tests showed that it did not differentiate alveolars and dentals from labiodentals; palatals from velars. Kurtosis [$F(4,915) =52.246$, $p<0.0001$] failed to differentiate labiodentals, dentals and alveolars.

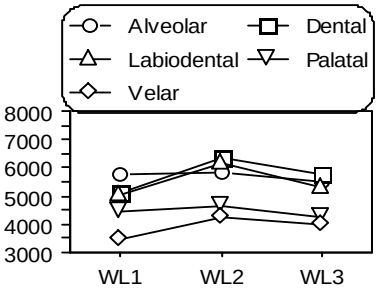

Figure 1. Spectral mean in Hz (averaged across vowels, voiced-voiceless tokens, gender) for each window location, as a function of place of articulation.

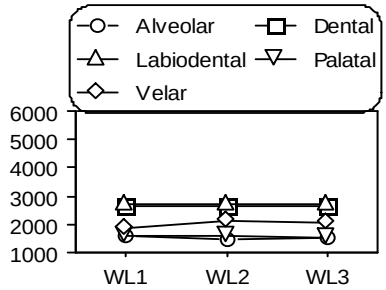

Figure 2. Spectral variance in Hz (averaged across vowels, voiced-voiceless tokens, gender) for each window location, as a function of place of articulation.

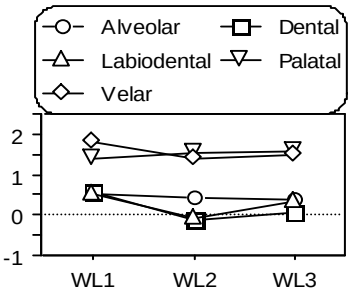

Figure 3. Spectral skewness (averaged across vowels, voiced-voiceless tokens, gender) for each window location, as a function of place of articulation.

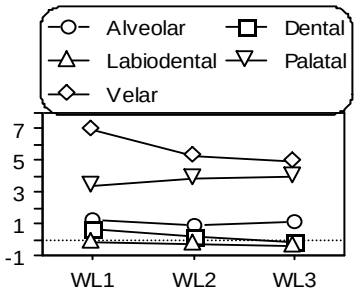

Figure 4. Spectral kurtosis (averaged across vowels, voiced-voiceless tokens, gender) for each window location, as a function of place of articulation.

Voicing had a significant effect on fourth spectral moment [F(1,918)= 6.400, p=0.0116]. Voiced fricatives were characterized by higher values for kurtosis (2.178) than voiceless fricatives (1.365), revealing that the first had better defined peaks. Gender was proved to be significant for spectral mean [F (1,918)=23.535, p<0.0001], indicating higher values for female than male speakers (5367 vs. 4953, respectively). Post-fricative vowel was significant for first [F(4,915)=7.596, p<0.0001], third [F(4,915)=7.362, p<0.0001] and fourth moment [F(4,915)=4.990, p=0.0006], since post hoc tests revealed significant differences mainly between fricatives before [a] - [e] and [a] - [i].

Table 2. Mean spectral moment values for each place of articulation, averaged across window location, speaker's gender, voiced-voiceless tokens and vowel context.

Place of articulation	Mean (Hz)	Variance(Hz)	Skewness	Kurtosis
Labiodental	5484	2721	0.270	-0.278
Dental	5738	2649	0.161	0.181
Alveolar	5700	1526	0.453	1.079
Palatal	4471	1573	1.508	3.731
Velar	3905	1995	1.496	9.647

Conclusions

The results indicate that both duration and spectral moments provide important information for the acoustic structure of Greek fricatives.

First, voiced fricatives of all places of articulation are considerably shorter than voiceless ones. Also, fricatives produced by females are significantly longer than those produced by males. Post-fricative vowel examination revealed that the higher the vowel, the longer the preceding fricative. It was also found that dental and labiodental place of articulation do not exhibit distinctive values for all spectral moments. Velars are distinguished by all four moments and palatals by three (mean, skewness, kurtosis), though alveolars are highly related to labiodentals and dentals. They can be distinguished from labiodentals by variance and from dentals by variance and skewness. Across moments, window location 1 (onset) contains the most distinctive in-formation. Finally, voiced fricatives can be distinguished from voiceless ones, apart from duration, by the fourth moment (kurtosis).

References

Baum S.R., Blumstein S.E. 1987. Preliminary observations on the use of duration as a cue to syllable-initial fricative consonant voicing in English. Journal of the Acoustical Society of America 82, 1073-1077.

Behrens, S.J., Blumstein, S.E. 1988. Acoustic characteristics of English voiceless fricatives: A descriptive analysis. Journal of Phonetics 16, 295-298.

Fourakis, M.. 1986. A Timing model for word-initial CV syllables in Modern Greek. Journal of the Acoustical Society of America 79, 1982-1986.

Jongman, A., Wayland, R., Wong, S. 2000. Acoustic characteristics of English fricatives. Journal of the Acoustical Society of America 108, 1252-1263.

Nicolaidis, K. 2002. Durational variability in vowel-consonant-vowel sequences in Greek: The influence of phonetic identity, context and speaker. Selected Papers on Theoretical and Applied Linguistics from the 14th International Symposium, 280-294, April 20-22, 2000, Thessaloniki.