Temporal characteristics of Greek fricatives

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Abstract

The present study examines the temporal characteristics of Greek fricatives as distinctive cues for their place of articulation. The effects of voicing (voiced, voiceless), speaker's gender (fe-male, male) and post-fricative vowel ([a], [e], [i], [o], [u]) on fricative duration are also inve-stigated. The results show that fricative duration does not distinguish fricatives in terms of pla-ce of articulation. However, it clearly differentiates voiced from voiceless fricatives, with voi-celess fricatives having significantly longer durations than voiced ones. It is also demonstrated that females produce significantly longer fricatives than males. Finally, this study reveals that the higher the vowel the longer the preceding fricative (i>u>o>e>a).

Keywords: Greek, fricatives, duration

1 Introduction

The present study examines the durations of Greek fricative consonants in word initial position as a function of voicing (voiced, voiceless), speaker's gender (female, male), post-fricative vowel ([a], [e], [o], [i], [u]) and place of articulation (labiodental, dental, alveolar, palatal, velar).

Very little research has been done so far on the acoustics of Greek fricative consonants, compared for example to the stops. Most studies examine [s], while there is almost no information about the acoustics of the other Greek fricatives except for the duration data of Fourakis (1986).

According to Panagopoulos (1991), Greek [s] appears to be shorter than English [s]. Although these data are not detailed, Greek [s] and [z] are reported to be on average 73 and 61 ms respectively, compared to 170 and 172 ms of the same consonants in his English data. Fourakis (1986) reports an average duration of 118 ms for word-initial [s] and Nicolaidis (2002) 113 ms for intervocalic [s]. Botinis et al. (1999) report 76 ms duration for word-initial [s], averaged across stressed and unstressed syllables.

As far as the duration of the other fricatives is concerned, Fourakis (1986) presents [f] to be on average 113 ms, [θ] 114 ms and [x] 118 ms. His data show also that all these fricatives had shorter duration before [a], while they were longer before [e] and longest before [i]. However, the speakers who produced the data were all male adults and the case of /x/'s allophone, [ç], was not addressed. Finally, there is no report for the duration of Greek voiced fricatives.

Fricative duration has been shown to distinguish English voiced from voiceless fricatives in syllable-initial position, with voiceless fricatives having longer noise durations than voiced ones (Baum and Blumstein 1987; Behrens

and Blumstein 1988; Crystal and House 1988; Jongman et al. 2000). It has also been shown to differentiate sibilant from non-sibilant fricatives, with the first having significant longer durations than the second (Jongman et al. 2000).

This introduction section is followed by the experimental methodology and results sections and the paper is concluded by the discussion and conclusions section.

2 Experimental methodology

2.1 Participants

Four speakers, two females and two males, 25–35 years old, recorded the experiment's material. They are native speakers of Greek, born and grown up in Athens (they speak what is considered to be standard Athenian) and none of them has any history of speech or hearing disorders.

2.2 Material

The ten Greek fricative consonants [f], [v], [θ], [ð], [s], [z], [x], [γ], [ç] and [j] were recorded in real, two-syllable words (Consonant – Vowel – Consonant – Vowel). Each fricative was in initial position and the following vowel was varying over the 5 Greek vowels [a], [e], [o], [i] and [u]. Words beginning with [x] and [γ] were only followed by [a], [o], [u], since /x/'s and /γ/'s allophones, palatals [ç] and [j], appear before [e] and [i]. The carrier phrase was "I said … again" (ˈipa … ksaˈna). All words were stressed on the first syllable. Each CVCV token was repeated five times, yielding a total of 230 tokens per speaker (8 fricativesX5 vowelsX5repetitions and 2 fricativesX3 vowelsX5 repetitions).

2.3 Procedure

Speakers were recorded in the Phonetics Laboratory of University of Athens, in a soundproof booth, with a high-quality microphone (RODE NT2-A), microphone pre-amp and a console (SOUNDCRAFT SPIRIT M4) connected with a sound card (AUDIOPHILE 2496 (M-AUDIO)) to a computer. All recordings were sampled at 44 kHz (16 bit quantization) and saved directly in hard disc using the 'CoolEditPro 2.1' software.

2.4 Analysis

Fricative segmentation involved the simultaneous consultation of waveform and wideband spectrogram. Fricative onset was defined as the point at which high frequency energy first appeared on the spectrogram and/or the point at which the number of zero crossings rapidly increased. The offset of voiceless fricatives was defined as the point immediately prior to the initiation of the vowel's first pitch period. For the voiced fricatives, the earliest pitch period in the fricative showing a change in the waveform pattern from that seen throughout the fricative was identified. The last zero crossing of the preceding pitch period was designated as the end of the voiced fricative (see Yeni-Komshian and Soli 1981). Frication duration was defined as the interval between fricative onset and end. Finally, the statistical analysis was carried out in the "StatView" software.

3 Results

The results are presented first, for each one of the Greek fricative places of articulation and then, for all fricatives.

3.1 Labiodentals

A three-way ANOVA (voicingXvowelXgender) with fricative duration as the dependent variable revealed a main effect of voicing ($F(1,180)=109.908$, $p<0.0001$), indicating duration was significantly greater for voiceless labiodental fricatives (120.84 ms) than for voiced ones (99.05 ms) (Figure 1). A main effect of gender ($F(1,180)=318.853$, $p<0.0001$) indicated that labiodentals produced by male speakers (91.39ms) had significantly shorter durations than those produced by female speakers (128.50ms) (Figure 1). The factor of post-fricative vowel was also shown to be significant ($F(4,180)= 6.090$, $p= 0.0001$), since post hoc tests revealed significant differences between labiodentals before [a] and the high vowels [i] and [u], as well as before [a] and [o], [e] and [u] (Figure 2). A significant interaction between voicing and speaker's gender ($F (1,180)=25.561$, $p<0.0001$), revealed that female speakers produced even longer voiceless labiodental fricatives than voiced ones (Figure 1).

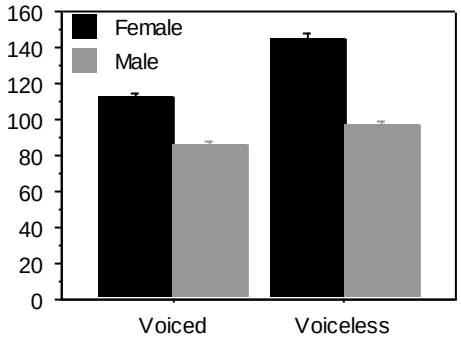

Figure 1. Mean duration (ms) of labiodental fricatives as a function of voicing and speaker's gender.

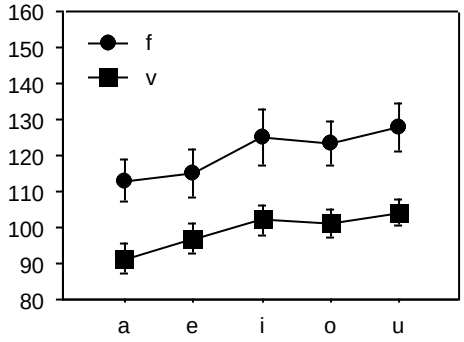

Figure 2. Mean duration (ms) of labiodental fricatives as a function of post-fricative vowel.

3.2 Dentals

A three-way ANOVA (voicingXvowelXgender) with fricative duration as the dependent variable revealed a main effect of voicing ($F(1,180)=116.187$, $p<0.0001$), indicating duration was significantly greater for voiceless dental fricatives (119.07ms) than for voiced ones (95.61ms) (Figure 3). A main effect of gender ($F(1,180)=340.429$, $p<0.0001$) indicated that dentals produced by male speakers (87.27ms) had significantly shorter durations than those produced by female speakers (127.42ms) (Figure 3). The factor of post-fricative vowel was also shown to be significant ($F(4,180)=7.804$, $p<0.0001$), since post hoc tests revealed significant differences between dentals before [a] and the high vowels [i] and [u] (Figure 4). A significant interaction between voicing and speaker's gender ($F (1,180)=7.508$, $p=0.0068$), revealed that female speakers produced even longer voiceless dental fricatives than voiced ones (Figure 3).

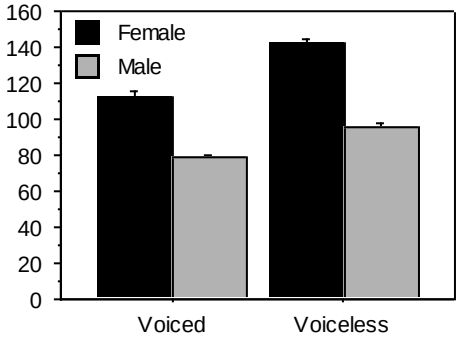

Figure 3. Mean duration (ms) of dental fricatives as a function of voicing and speaker's gender.

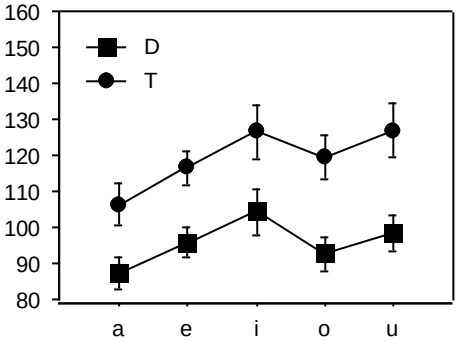

Figure 4. Mean duration (ms) of dental fricatives as a function of post-fricative vowel.

3.3 Alveolars

A three-way ANOVA (voicingXvowelXgender) with fricative duration as the dependent variable revealed a main effect of voicing ($F(1,180)=466.438$, $p< 0.0001$), indicating duration was significantly greater for voiceless alveolar fricatives (127.43ms) than for voiced ones (95.68ms) (Figure 5). A main effect of gender ($F(1,180)=597.215$, $p<0.0001$) indicated that alveolars produced by male speakers (93.59ms) had significantly shorter durations than those produced by female speakers (129.52ms) (Figure 5). The factor of post-fricative vowel was also shown to be significant ($F(4,180)=12.325$, $p<0.0001$), since post hoc tests revealed significant differences between alveolars before most vowels ([a]-[i], [a]-[u], [e]-[i], [e]-[u], [o]-[e]) (Figure 6). There was no significant interaction between voicing, speaker's gender and post-fricative vowel.

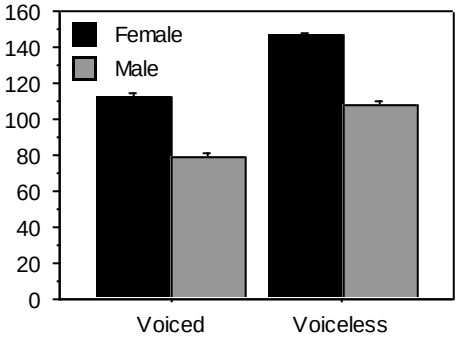

Figure 5. Mean duration (ms) of alveolar fricatives as a function of voicing and speaker's gender.

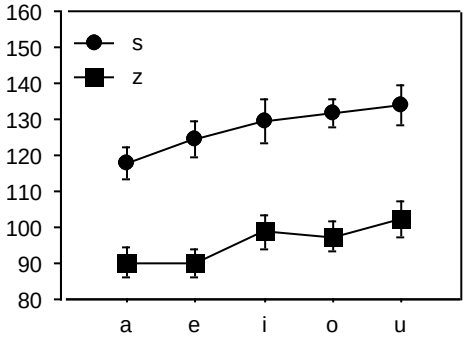

Figure 6. Mean duration (ms) of alveolar fricatives as a function of post -fricative vowel.

3.4 Palatals

A three-way ANOVA (voicingXvowelXgender) with fricative duration as the dependent variable revealed a main effect of voicing ($F(1,180)=254.076$, $p<0.0001$), indicating duration was significantly greater for voiceless palatal fricatives (121.02ms) than for voiced ones (87.92ms) (Figure 7). A main effect of gender ($F(1,180)=345.215$, $p<0.0001$) indicated that palatals produced by male speakers (85.18ms) had significantly shorter durations than those produ-

ced by female speakers (123.76ms) (Figure 7). The factor of post-fricative vowel was also shown to be significant ($F(4,180)=16.341$, $p<0.0001$), since post hoc tests revealed significant differences between palatals before [i] and all other vowels (Figure 8). A significant interaction between voicing and speaker's gender ($F(1,180)=26.054$, $p<0.0001$), revealed that female speakers produced even longer voiceless palatal fricatives than voiced ones (Figure 7).

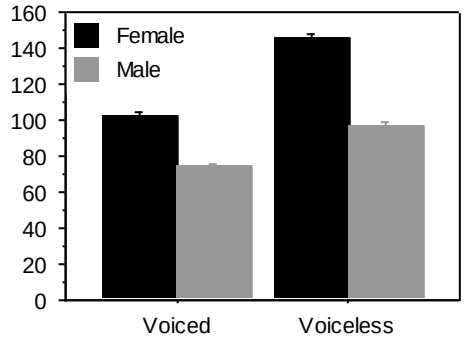

Figure 7. Mean duration (ms) of palatal fricatives as a function of voicing and speaker's gender.

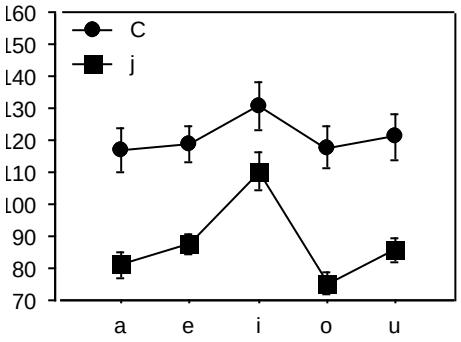

Figure 8. Mean duration (ms) of palatal fricatives as a function of post-fricative vowel.

3.5 Velars

A three-way ANOVA (voicingXvowelXgender) with fricative duration as the dependent variable revealed a main effect of voicing ($F(1,108)=313.460$, $p< 0.0001$), indicating duration was significantly greater for voiceless velar fricatives (125.21ms) than for voiced ones (85.48ms) (Figure 9). A main effect of gender ($F(1,108)=235.816$, $p<0.0001$) indicated that velars produced by males (88.11ms) had significantly shorter durations than those produced by females (122.58ms) (Figure 9). The factor of post-fricative vowel was also significant ($F(2,108)=15.072$, $p<0.0001$); post hoc tests revealed significant differences between velars before [a]-[o] and [a]-[u] (Figure 10). There was no significant interaction between voicing, speaker's gender and post-fricative vowel.

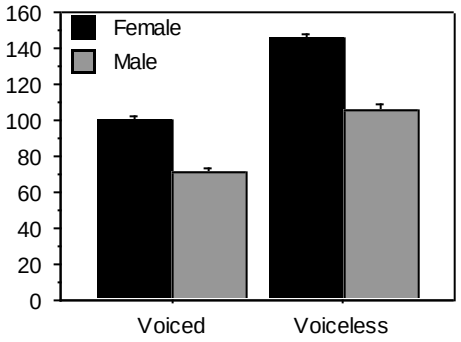

Figure 9. Mean duration (ms) of velar fricatives as a function of voicing and speaker's gender.

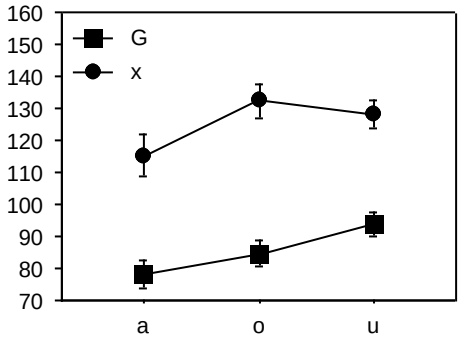

Figure 10. Mean duration (ms) of velar fricatives as a function of post-fricative vowel.

3.6 Fricatives

A four-way ANOVA (voicingXvowelXgenderXplace) with fricative duration as the dependent variable revealed a main effect of voicing ($F(1,900)= 893.626$, $p<0.0001$), indicating duration was significantly greater for voiceless fricatives (122.50ms) than for voiced ones (93.38ms) (Figure 11). A main effect of gender ($F(1,900)=1528.755$, $p<0.0001$) indicated that fricatives produced by male speakers (89.20ms) had significantly shorter durations than those produced by female speakers (126.68ms) (Figure 11). A significant interaction between voicing and gender ($F(1,900)=54.775$, $p<0.0001$) revealed that female speakers produced even longer voiceless fricatives than voiced ones (Figure 11). The factor of post-fricative vowel was also shown to be significant ($F(4,900)=33.303$, $p<0.0001$), since post hoc tests revealed significant differences between fricatives before all vowels of different height ($p<0.0001$) (Figure 12). A significant interaction between post-fricative vowel and gender ($F(4,900)=5.420$, $p=0.0003$) revealed that differences between vowels were greater for female than male speakers (Figure 12). These differences were also greater for voiced than voiceless fricatives; the factor of post-fricative vowel interacted significantly with the factor of voicing ($F(4,900)=3.616$, $p=0.0062$) (Figure 13).

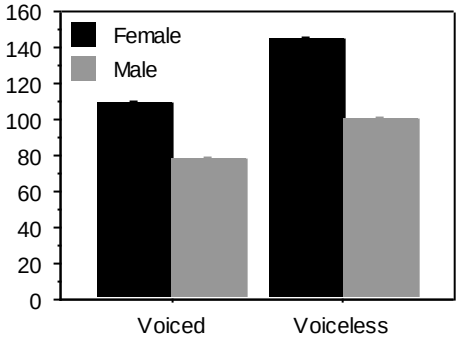

Figure 11. Mean duration (ms) of all fricatives as a function of voicing and speaker's gender.

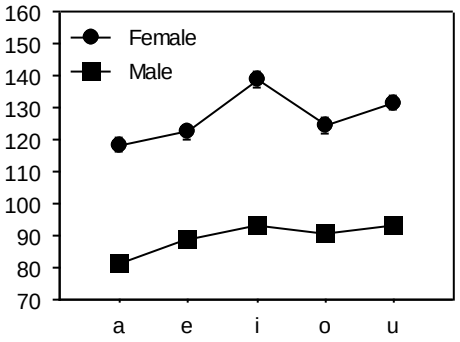

Figure 12. Mean duration (ms) of all fricatives as a function of voicing and speaker's gender.

Place of articulation was shown to be significant ($F(4,900)=7.295$, $p<0.0001$), but post hoc tests revealed significant differences only between the alveolar and palatal ($p<0.0001$), the alveolar and velar ($p=0.0004$) and, the labiodental and palatal place of articulation ($p=0.0003$) (see Table 1). There was a significant interaction between voicing and place of articulation ($F(4,900)=9.577$, $p<0.0001$), showing that the difference between voiced and voiceless fricatives was smaller for dental and labiodental fricatives than for the other places of articulation (Figure 14). Finally, post-fricative vowel interacted significantly with place of articulation ($F(12,720)=4.227$, $p<0.0001$), with a main effect of the difference of palatals before [i] and [o].

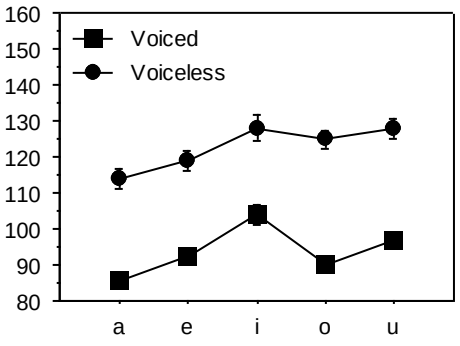

Figure 13. Mean duration (ms) of all fricatives as a function of voicing and post-fricative vowel.

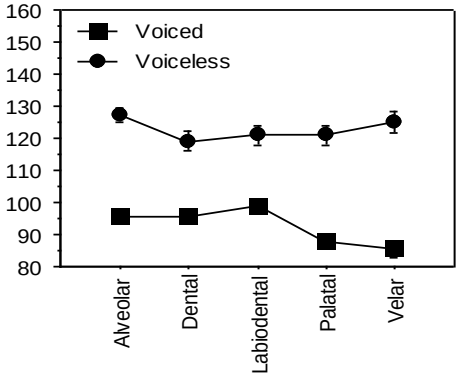

Figure 14. Mean duration (ms) of all fricatives as a function of voicing and place of articulation.

Fricative	Mean Duration	Mean Duration (Place of articulation)
[v]	99.05 (18.09)	109.95 (26.84)
[f]	120.84 (29.68)	
[ð]	95.61 (22.99)	107.34 (28.74)
[θ]	119.07 (29.22)	
[z]	95.68 (20.20)	111.55 (26.70)
[s]	127.43 (22.71)	
[j]	87.92 (21.90)	104.47 (31.10)
[ç]	121.02 (30.18)	
[γ]	85.48 (19.08)	105.34 (29.95)
[x]	125.21 (25.34)	

Table 1. Mean duration for each fricative and each place of articulation in ms. Numbers in parentheses indicate standard deviation.

4 Discussion and Conclusions

The results indicate that duration can provide important information for the acoustic structure of Greek fricative consonants.

To sum up, the factor of voicing affects the duration of fricatives of all places of articulation significantly. All voiced fricatives are considerably shorter than voiceless ones. This difference is smaller for dental and labiodental fricatives. It is also evident that fricatives produced by female speakers are significantly longer than the ones produced by male speakers. Post-fricative vowel is also a significant factor for the duration of Greek fricative consonants. According to the results, duration increased with increasing vowel height: mean duration for fricatives preceding [i] was 115.85, [u]: 112.16, [o]: 107.51, [e]: 105.59, [a]: 99.69. Differences between vowels of different heights were all significant ($p<0.0001$); differences between vowels of the same height ([i]-[u], [e]-[o]) were not significant. Finally, it is demonstrated that place of arti-

culation does not affect significantly the duration of Greek fricative consonants.

Comparing the results demonstrated by the present research with those reported in previous studies, there are several findings in accordance, as well as some contradicting ones. Concerning the duration of Greek sibilant fricatives [s] and [z], our results (127.43ms and 95.68ms, respectively) are much greater from those reported by Panagopoulos (1991) (73ms and 61ms), as well as from those reported in Botinis et al. (1999) (for the voiceless sibilant [s] 76ms). However, Botinis el al. report averaged data both from stressed and unstressed syllables, which is a case not examined in the present study.

On the other hand, our findings regarding [s] agree with the ones of Fourakis (1986) (118ms) and Nicolaidis (2002) (113ms) to a large extent. Fourakis' data for the other voiceless fricatives, as well as the fact that post-fricative vowel height is significant for fricative duration are also in accordance with our results. Yet, our study extends the one of Fourakis in that its results are averaged for both male and female speakers, voiced and voiceless tokens and all Greek vowels (in contrast to Fourakis' examination of voiceless tokens produced by males, before [a], [e] and [i]).

The effect of voicing on frication duration, with voiceless fricatives being significantly longer than voiced ones, is not a particular characteristic of Greek, as similar results have been previously reported for English (Baum and Blumstein 1987; Behrens and Blumstein 1988; Crystal and House 1988; Jongman et al. 2000).

The factor of speaker's gender, not having been examined in previous studies on Greek fricatives, affected frication duration significantly. As explicitly analyzed, female speakers produce significantly longer fricatives of all places of articulation than male speakers. Opposed to this, Jongman et al. (2000) have revealed a main effect of gender ($F(1,2876)=566.32$, $p<0.0001$; $\eta^2=0.021$), but indicating that English fricatives produced by female speakers (0.351) had slightly smaller normalized durations than those produced by male speakers (0.368). Finally, the increase of frication duration with increasing vowel height is also evident in English (Jongman et al. 2000).

In sum, the current study indicates that duration distinguishes voiced from voiceless fricatives, as well as fricatives produced by male and female speakers. However, frication duration is not a distinctive cue for Greek fricatives' place of articulation. Regarding the vowel context, we further need to evaluate both the role of fricative and vowel duration in the syllable, in order to get complete information for the vowel effect on consonant duration.

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