FORMANT CORRELATES IN GREEK FRICATIVE-VOWEL SEQUENCES

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ABSTRACT

The present study examined *F*1 and *F*2 onset, as well as locus equations in Greek fricative – vowel sequences as distinctive cues for the fricative place of articulation. The effects of voicing, speaker's gender and post-fricative vowel on both formants' onset values and locus equations were also investigated. The results showed that *F*2 onset values distinguished fricatives in terms of place of articulation, except for the labiodental and dental ones. *F*1 onset values differentiated voiceless from voiced fricatives with voiceless having significantly higher values than voiced ones. The locus equation coefficients i.e. slope and y-intercept, also distinguished voiced from voiceless fricatives. Moreover, palatal fricatives were clearly differentiated from the other places of articulation in terms of the y-intercept. A discriminant analysis using slope and *y*-intercept as predictors successfully categorized Greek palatal fricatives with 83.8% accuracy, while the overall percent correct classification was 54.3%.

Keywords: F1 onset, F2 onset, locus equations, fricatives, Greek

1. INTRODUCTION

The present study investigated *F*1 and *F*2 onset values, as well as locus equations, as potential cues capable of differentiating Greek fricatives' place of articulation in fricative-vowel sequences. The effects of voicing, speaker's gender, and post-fricative vowel were also examined on *F*1 and *F*2 onset and the effects of voicing and speaker's gender on locus equations.

Previous studies regarding the effect of a vowel's *F*2 onset on preceding English fricative consonants have shown that *F*2 onset is progressively higher as the place of constriction moves back in the oral cavity [3, 12]. The only study on Greek fricative consonants that examined the effect of vowel formants on fricative place of articulation has shown that despite some variability by vowel context, *F*2 values are reliably distinct among the five places of articulation of Greek fricatives [4]. This study extends the research on vowels' effect on Greek fricatives, by providing results for *F*1 onset and locus equations as well.

Locus equations are linear regressions of the onset of *F*2 transitions on their offsets measured in the vowel nucleus [6]. They are line regression fits to data points formed by plotting onsets of *F*2 transitions along the y axis and their corresponding mid vowel nuclei along the x axis [10, 11].

The duration and spectral moments of Greek fricatives have been studied before [6], but there have been no studies of the relevance of locus equations for place of articulation. Studies of English fricative consonants agree that locus equations' slope and y-intercept distinguish the labiodental place of articulation [2, 3, 9, 12]. Some of them, however, have shown that they can provide good classification for all fricatives place of articulation [2, 3].

2. METHODOLOGY

2.1.1. Speakers

Eight speakers, four females and four males, aged 20-35 years old, produced the experimental material. All were native speakers of Greek, born and raised in Athens, speaking what is commonly called standard Athenian. None of them had any history of speech or hearing disorders.

2.1.2. Material

The ten Greek fricative consonants [f], [v], [θ], [ð], [s], [z], [ç], [j], [x] and [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 all five Greek vowels [a], [e], [o], [i], [u]. Words beginning with [x] and [ɣ] were followed only by [a], [o], [u], since their allophones, [ç] and [j], appear before front vowels [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 (8 fricativesX5 vowelsX5 repetitions and 2 fricativesX3 vowelsX5 repetitions).

2.1.3. Procedure

All speakers were recorded in the Phonetics Laboratory of the University of Athens, in a sound treated room, 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, 11 kHz low-pass filter) and saved directly to hard disc using the 'CoolEditPro 2.1' software.

2.1.4. Analysis

Analysis was carried out using Praat. Fricative and vowel segmentation involved the simultaneous consultation of waveform and wideband spectrogram. For both voiced and voiceless fricatives, *F*1 and *F*2 were calculated at vowel onset and at the vowel midpoint using the formant tracking algorithm. Specifically, *F*1 and *F*2 at vowel onset were obtained using short-term LPC analysis (burg algorithm), at the first glottal pulse following cessation of the fricative. Similarly, *F*1 and *F*2 at vowel nucleus were estimated at the vowel's midpoint. In addition, wideband spectrograms, and FFT spectra were also consulted (using a 25ms full Hamming window (similar to [10] and [2])).

The statistical analysis was carried out using the "StatView" and "SPSS" software packages.

3. RESULTS

3.1. Formant onset values

Table 1 presents *F*1 and *F*2 onset values for each place of articulation, averaged across all speakers, voiced and voiceless tokens, and vowel contexts.

Table 1: Mean *F*1 and *F*2 onset values (Hz) (averaged across voiced and voiceless tokens, and vowels) as a function of place of articulation and speaker gender (M for male, F for female).

Place of articulation	F1 onset			F2 onset		
	M	F	Mean	M	F	Mean
Labiodental	452	505	478	1411	1582	1496
Dental	423	507	465	1375	1622	1499
Alveolar	454	457	456	1541	1774	1658
Palatal	351	405	378	1839	2229	2034
Velar	475	559	517	1249	1434	1341

3.1.1. F1 onset

Separate one-way ANOVAs for each of the examined factors (place, voicing, vowel, gender) revealed a main effect for place of articulation [$F(4,1835)=49.238$, $p<0.0001$]. Scheffe post hoc tests indicated that *F*1 onset values did not differentiate alveolars from labiodentals and dentals, as well as dentals from labiodentals.

A main effect of vowel [$F(4,1835)=182.565$, $p<0.0001$] obtained: *F*1 onset was 348 Hz in the context of /i/, 463 Hz before /e/, 402 Hz before /u/, 462 Hz before /o/, and 574 Hz before /a/. Post hoc tests indicated that *F*1 onset values significantly increased as a function of decreasing vowel height. All differences among vowels were significant except that between /o/ and /e/.

There was also a main effect of voicing [$F(1,1838)=56.610$, $p<0.0001$], since *F*1 onset values after voiceless fricatives (478Hz) were significantly higher than after voiced ones (429 Hz). As expected, there was a main effect for gender [$F(1,1838)=66.638$, $p<0.0001$]; *F*1 onset was significantly higher for females (480 Hz) than for males (427 Hz).

A four-way ANOVA for all the examined factors (excluding the cases of velar fricatives, since they appeared before 3 out of the 5 vowel contexts) revealed a genderXvowel interaction; post hoc tests revealed that while *F*1 onset differed significantly for males and females for /a/, /e/ and /i/, it was not significant for the back vowels /o, u/. A genderXplace interaction revealed that *F*1 onset did not differ significantly for males and females for the alveolar place of articulation.

Finally, a voiceXvowel interaction revealed that while *F*1 onset was significantly higher for voiceless fricatives for /a/, /e/ and /o/, it was not significant for the high vowels /i, u/.

3.1.2. F2 onset

Separate one-way ANOVAs for each of the examined factors (place, voicing, vowel, gender) revealed a main effect for place of articulation [$F(4,1834)=123.217$, $p<0.0001$]. Scheffe post hoc tests indicated that *F*2 onset values differentiate all places of articulation, except labiodental from dental.

A main effect of vowel [$F(4,1834)=191.235$, $p<0.0001$] obtained: *F*2 onset was 2119 Hz in the context of /i/, 1814 Hz before /e/, 1535 Hz before /u/, 1311 Hz before /o/, and 1500 Hz before /a/. Post hoc tests indicated that *F*2 onset values were higher for front vowels compared to back vowels. All differences among vowels were significant except that between /a/ and /u/.

There was no main effect of voicing. As expected, there was a main effect for gender [$F(1,1837)=120.256$, $p<0.0001$]; $F2$ onset was significantly higher for females (1754 Hz) than for males (1503 Hz).

A four-way ANOVA (excluding velars) for all the examined factors revealed a genderXvowel interaction; post hoc tests revealed that while $F2$ onset differed significantly for males and females for /a/, /e/ and /i/, it was not significant for the back vowels /o, u/.

3.2. Locus equations

Locus equation scatterplots were generated, for all subjects. Figures 1 and 2 illustrate typical locus equation scatterplots, representatively for voiced and voiceless tokens, respectively. The regression line equation showing slope and y-intercept is indicated above each plot as well as the r^2 value.

Figure 1: Locus equation scatterplot (averaged across female and male speakers, vowels and places of articulation) for voiced tokens.

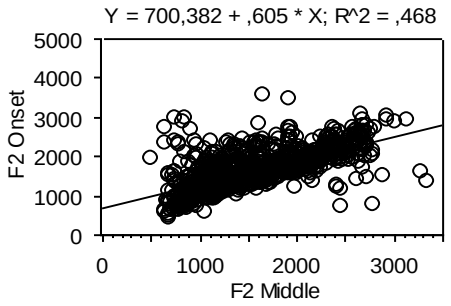
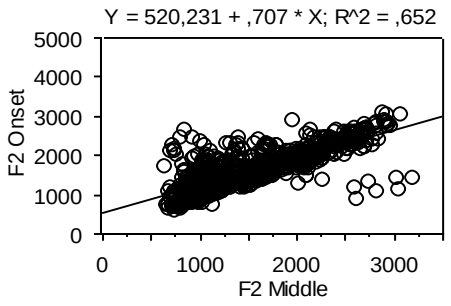


Figure 2: Locus equation scatterplot (averaged across female and male speakers, vowels and places of articulation) for voiceless tokens.



Slope and *y*-intercept values were derived for each place of articulation for each speaker, averaged across vowel context. Table 2 presents slope and y-intercept values for each place of articulation for females and males, averaged across voiced and voiceless tokens and all vowel contexts.

Table 2: Mean slope and y-intercept (in Hz) (averaged across voiced and voiceless tokens and vowels) as a function of place of articulation and speaker gender.

Place of articulation	slope			y intercept		
	M	F	Mean	M	F	Mean
Labiodental	0.633	0.594	0.613	477	576	527
Dental	0.745	0.603	0.674	333	621	477
Alveolar	0.529	0.484	0.507	754	941	847
Palatal	0.407	0.451	0.429	1198	1416	1307
Velar	0.896	0.791	0.843	254	406	330

A three-way ANOVA (placeXgenderXvoice) for slope revealed a main effect for place of articulation [$F(4,380)=6.578$, $p<0.0001$]. Post hoc tests indicated that only the slope value for velars was significantly different from that of the alveolar and palatal places of articulation. There was a main effect for voice [$F(1,380)=7.677$, $p<0.01$]; slope values were significantly higher for voiceless than for voiced fricatives (see Figures 1 and 2).

For the y-intercept, a main effect was observed for place [$F(4,380)=21.723$, $p<0.0001$]; subsequent post hoc tests revealed that the y-intercept did not differentiate labiodentals from alveolars, dentals from labiodentals, and velars from labiodentals and dentals. A main effect was observed for gender [$F(1,380)=6.390$, $p<0.05$], indicating that the y-intercept was significantly higher for females (792 Hz) than for males (603 Hz). Finally, the voice distinction had a main effect on the y-intercept [$F(1,380)=10.935$, $p<0.01$], indicating that the y-intercept was significantly higher for voiced than for voiceless fricatives (see Figures 1 and 2).

3.3. Discriminant analysis

In order to quantify how well locus equation coefficients serve as place descriptors for Greek fricative consonants a discriminant analysis was carried out, using slope and y-intercept as predictor variables for place of articulation category. The number of cases used was 400 (10 consonants X 8 speakers X 5 repetitions). Cross-validated classification scores for each place of articulation are shown in Table 3.

After cross-validation, the overall percent correct classification across the five groups was 54.3%. Of the total cases (400), 217 were correctly classified. While overall classification accuracy was not very high, it was clearly significant for the palatal place of articulation (83.8%). Classification errors rarely crossed the category of palatals, which were only confused with alveolars (16.3%).

Dentals were mostly confused with labiodentals, and velars with labiodentals.

Table 3: Predicted group membership (%) in terms of fricative place of articulation. Classification is based on a stepwise linear discriminant analysis with slope and y-intercept as predictors. Bold percentages indicate correct classification rates. Overall correct classification was 54.3%.

Place of articulation	Predicted group membership				
	Labio-dental	Dental	Alve-olar	Palatal	Velar
Labiodental	**52.5**	20.0	22.5	3.8	1.3
Dental	31.3	**43.8**	13.8	0	11.3
Alveolar	13.8	13.8	**47.5**	8.8	16.3
Palatal	0	0	16.3	**83.8**	0
Velar	26.3	15.0	3.8	11.3	**43.8**

4. DISCUSSION AND CONCLUSIONS

In the present study, the results indicate that both *F*1 and, especially, *F*2 onset values and locus equations provide important information for the Greek fricatives place of articulation.

First, *F*1 onset values distinguish velar and palatal place of articulation from the other three places. Although *F*1 onset failed to distinguish all fricative places of articulation, it did however differentiate voiced from voiceless fricatives, with voiceless fricatives having significantly higher *F*1 onset values than voiced ones. This distinction is also known to count for stop consonants and has been investigated extensively (e.g. [5, 7]).

Our results show that *F*2 onset values distinguish all fricative places of articulation, except labiodentals from dentals; unlike the results of Lee and Malandraki [4], which demonstrate that all five Greek fricatives' places of articulation can be distinguished clearly by the *F*2 onset values. However, in both studies the results indicate highest *F*2 values for palatals, followed by alveolars, dentals, labiodentals, and velars. Furthermore, Nirgianaki, et al [8] have shown that dental and labiodental place of articulation are also the only Greek fricative places that exhibit nondistinctive values for all four spectral moments.

Post-fricative vowel examination revealed that the higher the vowel the lower the *F*1 onset value and the more front the vowel the higher the *F*2 onset value. This result accords with Fourakis, et al. [1] data for Greek vowels' *F*1 and *F*2 at midpoint.

Regarding locus equations, slope differentiated velar fricatives from palatals and alveolars, and y-intercept palatals from all other places of articulation. In addition, male and female speakers were significantly distinguished by both slope and y-intercept. The combination of slope and y-intercept values could highly classify only the palatal place of articulation.

Comparing our results to those that have been reported for English fricatives, there are several findings in agreement, as well as some contradicting ones. Regarding slope and y-intercept, Greek palatal fricatives are significantly distinguished from the other places of articulation in terms of y-intercept, though the two coefficients serve to distinguish English labiodental fricatives from the other categories [2, 3, 9, 12]. Moreover, while locus equation coefficients can provide good classification for English fricative place of articulation [2, 3], they can highly classify only the palatal place of articulation for Greek fricatives.

Finally, Greek male speakers can be significantly differentiated from female speakers by both slope and y-intercept, though this has not been reported for English.

5. REFERENCES

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