The acoustics of Cypriot Greek fricatives

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Abstract

This study examines the effects of *stress*, *place of articulation* (POA) and *vowel* context on Cypriot Greek voiceless singleton non-sibilant fricative duration, normalised intensity, centre of gravity, standard deviation, skewness, and kurtosis. The findings show significant effects of *POA* on all measurements. Moreover, there were significant effects of *stress* and *vowel* context on duration, centre of gravity, skewness, and kurtosis. To conclude, this study, provides the first instrumental/acoustic data on CG fricatives and advances our knowledge on the effects of *stress* and *vowel* context on the fricatives' acoustic structure.

Key words: fricatives, spectral moments, Cypriot Greek.

Introduction

Cypriot Greek (CG) contains singletons and geminates voiceless and voiced fricatives, which are articulated in the labiodental /f v/, dental /θ ð/, alveolar /s z/, post-alveolar /ʃ ʒ/, palatal /ç ʝ/, and velar /x ɣ/ place of articulation. Previous research on CG fricatives provides mostly impressionistic evidence (e.g. Newton 1972). Eftychiou (2008) provides additional evidence about the centre of gravity of / s /. This study examines the effects of *stress*, *place of articulation* (POA), and following *vowel* on CG / f θ ç x / duration, normalised intensity, centre of gravity, skewness, and kurtosis.

Methodology

Twenty-five CG female speakers, born and raised in Nicosia, at their early twenties produced the experimental materials. The later consisted of a set of nonsense words, each containing one of the four fricative ([f θ ç x]) in both stressed and unstressed word initial position. In Greek, [ç] precedes front vowels /i e/. Specifically, the nonsense words had a CVCV structure: \ ˈCVsa (e.g. / ˈfasa ˈxasa ˈçisa/) or CVˈsa (e.g., faˈsa, xaˈsa, çiˈsa, etc./). The carrier phrase was: "/ ˈipes <keyword> ˈpale /" (You told <keyword> again). Each subject produced 64 utterances (i.e. 4 segments × 2 stress placement × 2 vowels × 4 repetitions); a total sum of 1600 productions. Filler words were added in the carrier sentences to provide variation within the experimental material and to minimise speaker's attention on the experimental words. To calculate the acoustic parameters the Discrete Fourier Transformations (DFTs) were averaged using Shadle (2012)'s time-averaging procedure. Within time-averaging, a number of DFTs were taken from across the duration of the

fricative and averaged for each token. The analysed duration of the fricative is always equivalent to the centre 80% of the total duration, cutting off the transitions. Then the first four spectral moments that correspond to the mean (sometimes called the centroid or centre of gravity), standard deviation, skewness, and kurtosis were calculated from the fricative spectra. Linear mixed effects analysis of the relationship between stress, vowel, and segment as fixed effects on the measurements were conducted using R (R Core Team, 2012) and lme4 (Bates, Maechler & Bolker, 2012). As random effects, we had intercepts for speakers and items, as well as by-subject and by-item random slopes for the effect of segment.

Results

The results about fricatives' duration are reported first and then the results about fricatives' spectral moments: normalised intensity, centre of gravity, skewness, and kurtosis.

Table 1. Mean duration in ms (and SD in parentheses) of fricatives preceding stressed and unstressed /a/ and /i/.

	Unstressed		Stressed	
Sounds	a	i	a	i
f	103 (25)	116 (25)	80 (21)	90 (17)
θ	105 (36)	109 (35)	83 (24)	90 (25)
ç	-	117 (27)	-	95 (20)
x	117 (29)	-	95 (21)	-

Duration. Table 1 reports the results from the fricative duration. Stressed fricatives are longer than unstressed fricatives. Unstressed fricatives preceding the vowel /a/ are longer than unstressed fricatives preceding the vowel /i/. Stressed and unstressed /x/ are longer than stressed and unstressed /f/ and /θ/ correspondingly. POA significantly affected duration ($\chi^2(3)=10.24$, $p < .05$); stress also had significant effects on the duration estimate ($\chi^2(1)=128.64$, $p < .0001$) and vowel ($\chi^2(1)=13.23$, $p < .0001$).

Table 2. Mean intensity in dB (and SD in parentheses) of fricatives preceding stressed and unstressed /a/ and /i/.

	Unstressed		Stressed	
Sounds	a	i	a	i
f	31 (8)	34 (9)	34 (9)	34 (9)
θ	33 (10)	33 (10)	35 (9)	33 (10)
ç	-	33 (6)	-	33 (6)
x	37 (4)	-	38 (4)	-

Normalised Intensity. Table 2 reports the fricatives' normalised intensity. There was a significant effect of *POA* on normalised intensity ($\chi^2(3)=10.24$, $p < .001$). *Stress* and *Vowel* had no significant effects.

Centre of Gravity. Table 3 reports the fricatives' Center of Gravity. There were significant effects of *POA* ($\chi^2(3)= 98.40$, $p < .0001$), *Stress* ($\chi^2(1)= 9.36$, $p < .05$), and *Vowel* ($\chi^2(1)= 24.94$, $p < .0001$) on the Centre of Gravity.

Table 3. Mean Centre of Gravity (and SD in parentheses) of fricatives preceding stressed and unstressed /a/ and /i/.

	Unstressed		Stressed	
Sounds	a	i	a	i
f	6116 (3877)	7624 (2948)	7231(3722)	8687 (3088)
θ	5798 (3666)	7290 (3527)	6596 (3434)	7901 (3600)
ç	-	6702 (1755)	-	7205 (1905)
x	2607 (720)	-	2841 (861)	-

Standard Deviation. Table 4 reports the results mean values and their corresponding SDs for the standard deviation measurements. There was a significant effect of *POA* on standard deviation ($\chi^2(3)=122.97$, $p < .0001$). *Stress* and *Vowel* had no significant effects.

Table 4. Mean Standard Deviation (and SD in parentheses) of fricatives preceding stressed and unstressed /a/ and /i/.

	Unstressed		Stressed	
Sounds	a	i	a	i
f	4439 (1470)	4710 (1008)	4625 (1413)	4521 (995)
θ	4146 (1310)	4230 (1424)	4688 (1070)	4278 (1279)
ç	-	3618 (697)	-	3591 (536)
x	2487 (990)	-	2818 (927)	-

Skewness. There were significant effects of *POA* ($\chi^2(3)= 81.64$, $p < .0001$), *Stress* ($\chi^2(1)= 6.37$, $p < .05$), and *Vowel* ($\chi^2(1)= 17.68$, $p < .0001$) on Skewness.

Table 5. Skewness (and SD in parentheses) of fricatives preceding stressed and unstressed /a/ and /i/.

	Unstressed		Stressed	
Sounds	a	i	a	i
f	1.83 (3.48)	0.29 (1.44)	0.73 (2.3)	-0.09 (1.1)
θ	1.52 (2.48)	0.69 (2.34)	0.92 (1.8)	0.57 (2.4)
ç	-	0.77 (0.98)	-	0.70 (1.34)
x	3.87 (2.13)	-	3.44 (2.22)	-

Kurtosis. There were significant effects of *POA* ($\chi^2(3)= 32.57, p < .0001$), and *Stress* ($\chi^2(1)= 4.06, p < .05$) on Kurtosis. *Vowel* also had a minor effect ($\chi^2(1)= 3.66, p = 056$).

Table 6. Kurtosis (and SD in parentheses) of fricatives preceding stressed and unstressed /a/ and /i/.

	Unstressed		Stressed	
Sounds	a	i	a	i
f	16.94 (54)	1.02 (5)	5.33 (16)	0.41 (2)
θ	8.44 (16)	7.32 (23)	3.32 (8)	6.12 (21)
ç	-	1.38 (5)	-	1.48 (8)
x	28.58 (39)	-	20.44 (31)	-

Discussion

This study investigated the effects of *POA*, *stress*, and *vowel* context on duration, intensity, centre of gravity, standard deviation, skewness, and kurtosis of CG fricatives. The findings show significant effects of *POA* on all measurements. Moreover, there were significant effects of *stress* and *vowel* context on duration, centre of gravity, skewness, and kurtosis. Specifically, stressed fricatives are longer than unstressed fricatives (see also Nirgianaki, 2014). Also stressed and unstressed /x/ is longer than stressed and unstressed /f/ and /θ/ correspondingly. Unstressed fricatives preceding the *vowel* /a/ are longer than unstressed fricatives preceding the vowel /i/. Furthermore, *stress* and *vowel* had significant effects on the centre of gravity and skewness but not on standard deviation and normalized intensity. *Stress* has significant effects on kurtosis as well. To conclude, the study provides the first to our knowledge evidence for CG fricatives.

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