ACOUSTIC CHARACTERISTICS OF GREEK VOWELS UNDER DIFFERENT PROSODIC CONDITIONS

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ABSTRACT

Five male native speakers produced five repetitions of words containing the five vowels of Greek when stressed, unstressed, or in focus and at two tempi of speech, normal and fast. Measurements were made of the first three formants, duration, F0, and overall amplitude. Main results: 1. The vowel space expanded in focus and contracted in the absence of stress. 2. F0 was heightened for vowels in focus, stress, and fast tempo. 3. Focus did not affect durations but tempo and stress did.

INTRODUCTION

The present paper reports an acoustic analysis of the Greek vowels. The analysis includes spectral, durational, fundamental frequency (F0), and amplitude correlates under different prosodic conditions of tempo, stress, and focus. Aspects of the acoustics of the Greek vowels have been reported separately by Fourakis [1], Botinis [2], and Jongman, Fourakis, and Sereno [3]. Fourakis [1] studied the effects of tempo and stress on duration and reported a similar effect (25%) of these two conditions on duration. The effect of the stress condition on duration was replicated by Botinis [2]. Botinis [2] studied the effects of stress and focus on the distribution of prosodic correlates and reported duration combined with intensity and F0 as the main acoustic correlates of stress and focus conditions respectively. The spectral correlates reported by Jongman et al [3] showed that the Greek vowels, when bearing lexical stress, are well separated in the acoustic space, allowing for maximal contrast between vowel categories. However, Jongman et al [3] did not examine formant characteristics under different conditions of tempo and stress. In this experiment, the effects of these variables on Greek vowels are analysed in a single experiment combining all conditions into one design.

EXPERIMENTAL METHOD

Speakers. The speakers were five Greek male students, with some knowledge of other languages (mostly English), who were recruited at Athens University. They spoke standard (Athenian) Greek and were between 20 and 23 years old.

Speech material. The test words were lexical stress minimal pairs. When a minimal pair could not be found, an extra word of similar structure was used to control for the difference. All words started with voiceless [p] followed by the target vowel and one or two voiceless obstruents (Table 1 below).

Table 1. Test words of minimal stress pairs and control words.

Stressed	Unstressed	Control
'pisa	pi'sta	'pista
(tar)	(loyal)	(track)
'pese	pe'ta	'peta
(fall)	(throw)	(fly)
'pasa	pa'sa	
(pass)	(pasha)	
'posa	po'sa	
(how)	(amounts)	
'pusi	pu'stça	'pusti
(fog)	(shabby trick)	(gay)

There were two conditions of elicitation. In one the subjects read lists containing the target words in the carrier sentence: [to 'sinθima "target word" tus a'resi po'li] 'they like the password "target word" a lot'. In the other condition the subjects were asked to respond to the question: [pço 'sinθima tus a'resi po'li] 'Which password do they like a lot?'. In the response, which was the same as above, the target word appeared in focus position. Only the words with stressed first syllables were used in this condition. The lists for each condition contained five repetitions of each target word and were read at a normal and a fast tempo with different randomisation of the sentences for each speaker and for each tempo of speech.

Measurements. All measurements were made using the Kay Elemetrics CSL hardware/software combination at Athens University Phonetics Laboratory. Utterances were digitised at 10KHz sampling rate with 16 bit resolution and measurements were made as follows:

1. An FFT was done using CSL's default settings at the middle of the vowel duration and the first three peaks in the resulting spectrum were measured. In addition, whenever necessary, the FFT was supplanted by LPC analysis.

2. Vowel duration was measured from the waveform from the first glottal pulse after the release burst of the initial stop to the cessation of all discernible voicing before the following obstruent.

3. The duration of three glottal pulses in the middle of the vowel was measured, and the period and the F0 were computed. In the case of very short vowels (unstressed, fast tempo) with less than three glottal pulses, all available pulses were used. Some productions did not include any appreciable voiced interval and were excluded from the analysis.

4. A measure of the overall amplitude of the target vowel portion was computed in dB RMS.

RESULTS

1. Spectral characteristics. Figures 1a and 1b show an F1 by F2 acoustic space in which the positions of the vowels are plotted by the mean frequencies of their formants at the normal and fast tempo when stressed, unstressed, or in focus. Two acoustic effects are evident. First, there is a compression of the acoustic space under the unstressed condition in terms of vowel scattering on the F1 and F2 frequency axis. This effect is evident under both normal (Fig. 1a) and fast tempo conditions (Fig. 1b). Second, there is an acoustic raising under the unstressed condition in terms of an F1 frequency decrease. This is evident for all vowels and both tempi except for the vowel [u] at the normal tempo (Fig. 1a). An additional F1 decrease under 300 Hz is caused under the fast tempo condition for the high vowels [i] and [u] (Fig. 1b).

In order to evaluate the global effect of tempo, stress, and focus on the vowel space as a whole, the area of the space expressed in Hz-squared was computed. This technique has also been employed by Fourakis [4] and Bradlow [5]. Table 2 below shows the results expressed as ratios of the vowel space in each condition to the vowel space in the normal-stressed condition.

Table 2. Ratios of vowel space under different prosodic conditions.

Condition	Ratios
normal-stressed	1.00
normal-unstressed	0.73
fast-stressed	1.07
fast-unstressed	0.87
normal-focus	1.29
fast-focus	1.09

FIGURES 1a AND 1b (FORMANTS)

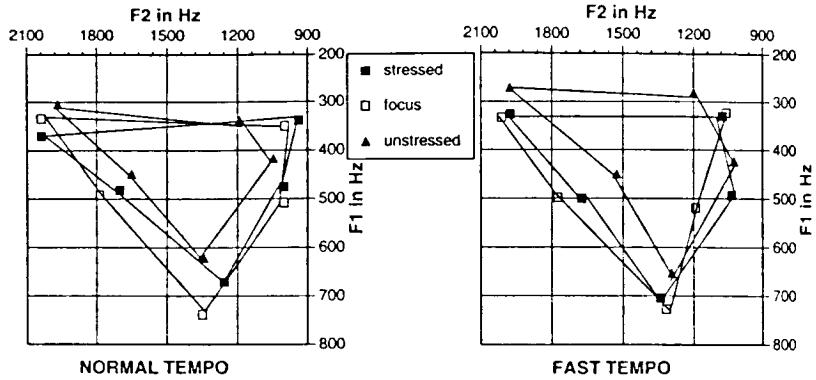


FIGURE 2 (DURATIONS)

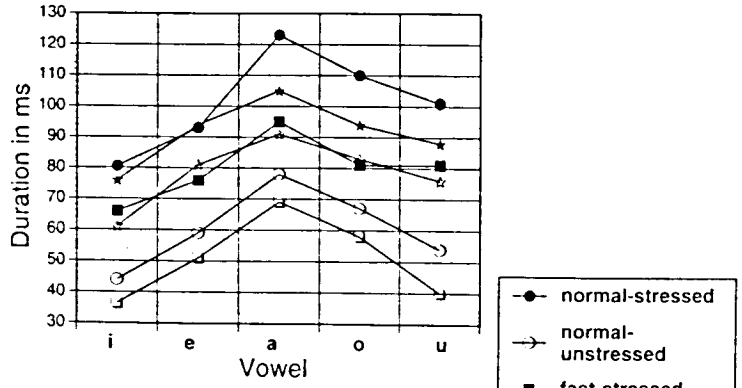
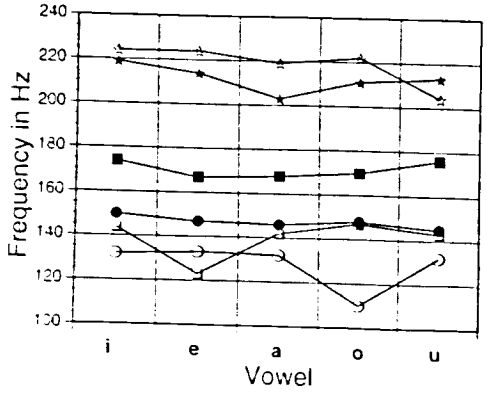


FIGURE 3 (F0)



The ratio values indicate two main effects. First, the vowel space is contracted when the vowels are unstressed regardless of tempo. Second, the vowel space is expanded when the vowels are in focus regardless of tempo.

2. Durations. Figure 2 shows the mean durations of each vowel for each condition of tempo, stress, and focus. Unstressed vowels are 40% shorter than stressed vowels at each tempo. Vowels spoken at the fast tempo are on the average 30% shorter than at the slow tempo when stressed, and 15% shorter when unstressed. Vowels in focus display a more complex pattern. At the normal tempo there is no difference between stressed and in-focus front vowels, but there is a considerable difference in the back vowels. Stressed vowels are longer than vowels in focus. At the fast tempo, there is no difference for any of the vowels. In summary, normal tempo vowels are longer than fast tempo vowels, stressed vowels are longer than unstressed vowels, and vowels in focus are as long as stressed vowels except for back vowels at normal tempo.

3. Fundamental frequency. Figure 3 shows vowel F0 for each vowel in each condition. Three effects are clear. First, vowels in focus have much higher F0 than in any other condition, regardless of tempo. Second, vowels at fast tempo have higher F0 than vowels at normal tempo and this is most regular under the stressed condition. Third, stressed vowels have higher F0 than unstressed vowels, regardless of tempo. No other condition has greater effect on F0 than the focus condition. This is a strong evidence that F0 is the main acoustic correlate of focus in Greek.

4. Amplitude. The results of vowel amplitude expressed in dB RMS show a regular distribution of higher amplitude for stressed vowels (a detailed acoustic analysis of the Greek vowels is forthcoming [6]).

CONCLUSIONS

The results show that tempo, stress and focus may compress, expand, or raise the acoustic space. These acoustic variations do not however reach the phonetic level of vowel distinctions at Athenian Greek. The effect of focus and the effect of tempo on formant structure have not been reported, to our knowledge, in acoustic literature on other languages. Neither has the effect of tempo on F0. On the other hand, the effect of stress and tempo on duration, the effect of stress on amplitude, and the effect of focus on F0 in Greek have been corroborated by the present investigation.

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