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GREEK VOWEL DURATIONS AND PROSODIC INTERACTIONS

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The present study is an experimental investigation of temporal structures in Greek prosody as instantiated in segmental durations, contextual effects and prosodic interactions. Nonsense disyllabic CVCV words were produced in a carrier sentence under crossed binary conditions of stress, focus and tempo. The results indicate: (1) the durations of vowels depend primarily on high/low and secondarily on front/back articulatory settings; (2) immediate consonant context shows compensatory to vowel duration patterns; (3) syllable position does not have a constant duration effect on either consonant or vowel; (4) stress has a larger lengthening effect on the vowel than the consonant; (5) focus has no constant effect on either the consonant or the vowel; (6) tempo has a fairly similar effect on both the consonant and the vowel. In terms of the prosodic factors investigated, stress has the largest effect on both consonant and vowel durations, followed by tempo. There were significant interactions between vowel category and stress, as well as between stress and tempo, for vowel durations but not for consonant durations. The study is concluded with a comparison of results with earlier results of studies on Greek prosody.

1. Introduction

This is an experimental study of vowel category durations as well as contextual effects and prosodic interactions in Greek. The following questions have been addressed: (1) what is the duration effect of vowel categories? (2) what is the duration effect of vowel categories on immediate consonant context? (3) what is the effect of syllable position, stress, focus and tempo on consonant and vowel durations? The short-term target is the examination of main effects, as well as interactions of the investigated prosodic categories, on the temporal organisation of Greek and the long-term target is the accumulation of new knowledge on Greek prosody as well as the advance of language typology and prosodic theory.

Prosodic parameters are not only basic prerequisites for speech production but also functional correlates of variable linguistic distinctions associated with main components of the language such as the morphological, syntactic, and semantic components. Duration may be associated with the realisation of these distinctions in various combinations with the other prosodic parameters of intensity and voice fundamental frequency. On the other hand, duration may be related to segmental (usually referred to as "intrinsic" or "micro-prosodic") and prosodic effects (Lehiste, 1970; Di Cristo and Hirst, 1986). Intrinsic effects are mainly physiologically determined with, presumably, limited linguistic function whereas prosodic effects may have a high functional load. In addition to vowel category, syllable position, stress, focus and tempo investigated in the present study, a variety of other factors may have durational effects on various linguistic units, some of which are reported below.

Intrinsic effects are associated with different articulatory settings, e.g. other prosodic effects being equal, low (/a/) vowels are longer than (/e/ and */o/)* mid vowels which, in turn, are longer than (/i/ and /u/) high vowels (Lehiste, 1970; Gopal, 1996). The vowel articulatory settings define the function area of the vocal tract which determines the quality of the vowels and thus vowel distinctions. Different articulators may however have different velocity which mainly depends on the size and mass of the corresponding articulators. Somewhat simplified, the targets (or movements) of the vowel production gestures have a distinctive function and hardly the velocity of the articulators which determines the intrinsic durations of the vowels.

In addition to intrinsic durations, vowel systems may exhibit length distinctions associated with durational differences (Crystal and House, 1988; Gopal, 1990; Anderson and Port, 1994). Usually, length distinctions in vowels are binary, short vs. long. Oftentimes, length distinctions are combined with vowel quality variations such as in English or Swedish, i.e. short vowels may have considerable different acoustic structure in comparison to the corresponding long vowels. Even three-way distinctions may be found, such as in Estonian, but are very seldom in the majority of language families. Consonants may also exhibit length distinctions although less commonly than vowels do. Segmental length has major implications for syllable structure and other prosodic categories such as accent. Length may be a main factor for syllable weight such as the "heavy" vs. "light" classification of a syllable, which is the decisive context for stress or accent distribution. In Swedish, e.g., stress may be assigned only to heavy syllables, whereas the acute vs. grave accent distribution is associated with vowel length, i.e. only long vowels may carry the acute vs. grave accent distinction. The Swedish accentual structure is fairly similar to the Classical Greek one where accentual distinction, i.e. acute vs. circumflex, is mainly

dependent on vowel length according to which only long vowels may carry the accent distinction. A neutralisation of length distinctions in post-classical times brought about a neutralisation of accent distinctions which turned into stress ones.

Immediate context may have a substantial effect on segmental durations. Vowels are longer before voiced stops than voiceless stops (Klatt, 1976; Crystal and House, 1988; Gopal, 1996). Syllable structure and number of segments per syllable may effect segment durations, e.g. a consonant in a cluster may have shorter duration than the corresponding consonant in a simple consonant-vowel syllabic structure (Klatt, 1976; Botinis, Fourakis and Prinou, 1999). The number of segments per linguistic unit may also affect segment durations, e.g. the more the syllables per word the shorter the durations of corresponding syllables and thus segments (Lehiste, 1972, Campbell and Isard, 1991). Stress is the most discussed and well-studied prosodic category with lengthening effects which are distributed to the stressed syllabic segments. The same is also widely assumed for focus and related concepts such as nucleus, emphasis and contrastive stress (Cooper, Eady and Mueller, 1985: Beckman. 1986; Turk and White, 1999). Rhythmic structuring and the division of speech unit into stress groups, i.e. a stressed syllable and any unstressed syllables up to but not including the succeeding stressed syllable, may have variable effects on segment durations. The phenomenon of "isochrony" has often been reported, i.e. the tendency of stress groups for regular inter-stress intervals and minimisation of duration differences in consecutive stress groups. Languages with isochrony tendencies, such as English, are referred to as "stressed-timed" languages vs. "syllable-timed" languages, such as French, where the duration of stress groups is dependent on the number of syllables (Lehiste, 1977; Dauer, 1983). The interplay of prosody and syntax has also drawn considerable attention and the phenomenon of "final lengthening," according to which, the boundaries of higher order constituents have greater lengthening effects on segmental durations than lower order nested constituents in a cumulative way (Klatt, 1976; Cooper and Paccia-Cooper, 1980; Gussenhoven and Rietveld, 1992).

In general, duration may correlate with variable linguistic units from segments and words to syntactic, semantic and discourse units. A deep understanding, especially of the interaction effects of different prosodic categories, is however expected to contribute substantially to prosodic and linguistic theory and pave the way for powerful prosodic models as well as diverse technological applications such as speech synthesis and speech recognition.

2. Experimental procedures

The speech material of this investigation consisted of a set of nonsense key words in the carrier sentence /to 'klab_____'pezi ka'li musi'ki/ 'the club ____ plays good music'. The key words had a CVCV syllabic structure with a constant segmental set up except for the first vowel which varied over / i / , /e/, /a/, *lol* or /u/. The first and second consonants were always /s/ and the final vowel always /a/. That is the CVCV sequence varied over /s{ i,e,a,o,u }sa/.

The speakers were four female adults with standard Athenian pronunciation who produced the experimental sentences, and thus the key words, with alternative stress patterns (penultimate or ultimate stress), at two tempi (normal and fast), six times for each keyword. The key words were also pronounced in two focus conditions, i.e. in focus and non-focus. The non-focus productions were pronounced more or less "neutrally" i.e. the speakers had no contextual information. The focus productions, on the other hand, were pronounced as a response to a question, which elicited the key word as the information required by the question. Thus, the stereotypical (and constant) question "which club plays good music" was defining the contextual frame for a focus production of the key word, i.e. "the club {focus production of the key word} plays good music".

The speech material was recorded in a sound-treated room and some basic instructions were provided just before the recordings. No particular difficulty was observed and very few mispronunciations were produced, which were excluded from further analysis. Speakers varied the prosodic conditions, especially tempo, on an individual basis, in accordance with their speech habits. The speech analysis was carried out at the Department of Linguistics of the University of Athens.

All utterances were digitized at 16 kHz sampling rate and stored on a PC computer disk for further processing. Durational measurements of each segment in the CVCV sequence were made from the waveform. As the waveform patterns of fricatives and vowels are very distinct, this presented no difficulty and standard criteria were used. The measurements of consonants and vowels were classified under the binary prosodic category conditions of syllable position (antepenultimate vs. penultimate), stress (+stress vs. -stress), focus (+focus vs. -focus), and tempo (fast vs. normal). There were a total of 960 utterances (5 vowels x 2 stress x 2 focus x 2 tempo x 4 speakers x 6 productions).

3. **Results**

Statistical processing was carried out with the software package StatView and the results are presented in tables and figures. The following conventions are used: C=consonant, i.e. the fricative /s/ at both syllables; V=vowel, i.e. penultimate *HI,* /e/, /a/, /o/ or /u/ but only ultimate /a/; Pt=penultimate; Ut=ultimate; W=word; S=stress; F=focus; Nl/Ft=normal/fast tempo.

Tables I-II show the detailed results of this study. Consonant and five vowel durations as a function of syllable position, stress, focus and tempo are included in Table I whereas all penultimate vowels but /a/ are excluded from measurements in Table II, i.e. this Table shows the results for the sequence /sasa/, for which only the prosodic factors may show an effect.

Table I. Duration correlates of consonant and vowel (in ms) for each of the five vowel contexts (i, e, a, o, u) in the penultimate syllable as a function of the prosodic categories of syllable position ([Pt]~[Ut]), stress ([+S]~[-S]). focus ([+F]~[-F]) and tempo ([Ft]~[Nl]).

				Consonant					***Vowel***				
Vowel category				i	e	a	o	u	i	e	a	o	u
Prosodic category													
[Pt]	[+S]	[+F]	[Ft]	118.7	111.4	109.6	112.0	112.5	81.7	104.6	119.0	109.8	93.4
			[Nl]	137.3	129.1	124.0	126.7	136.7	98.2	127.0	141.1	130.3	106.8
		[-F]	[Ft]	113.5	107.0	105.5	108.0	106.0	90.1	115.6	126.2	122.1	102.7
			[Nl]	137.8	128.9	126.7	125.5	127.5	110.5	143.8	159.6	145.2	121.6
	[-S]	[+F]	[Ft]	96.5	84.9	83.3	84.4	85.7	44.3	63.5	73.4	67.5	54.8
			[Nl]	110.4	98.2	97.4	94.7	100.7	53.4	71.7	83.2	73.3	60.1
		[-F]	[Ft]	99.3	87.0	85.3	86.0	93.0	52.0	67.9	77.8	73.8	57.6
			[Nl]	109.2	98.7	97.8	95.1	99.4	63.0	75.7	90.8	82.3	67.3
[Ut]	[+S]	[+F]	[Ft]	110.5	102.0	102.8	95.8	97.3	110.4	108.1	109.7	119.3	111.0
			[Nl]	129.7	121.4	118.7	117.2	123.9	134.1	126.5	132.8	134.6	147.3
		[-F]	[Ft]	111.8	109.4	102.6	100.9	103.3	125.0	123.8	117.1	128.1	130.3
			[Nl]	125.4	123.6	122.6	119.1	120.5	144.1	140.5	141.6	146.0	153.0
	[-S]	[+F]	[Ft]	89.9	87.6	84.0	73.2	77.6	68.3	62.9	62.6	64.8	67.9
			[Nl]	108.8	102.6	101.2	98.7	100.3	73.7	67.2	65.9	71.9	69.7
		[-F]	[Ft]	81.5	84.1	79.8	72.7	73.5	67.3	69.0	64.0	72.7	71.7
			[Nl]	101.8	105.3	101.2	91.5	96.4	81.0	82.9	74.4	74.1	79.0

Table II. Consonant and vowel [a] durations (in ms) as a function of prosodic categories of syllable position ([Pt]~[Ut]), stress ([+S]~[-S]), focus ([+F]~[-F]) and tempo ([Ft]~[NI]) (all penultimate vowels but /a/ are excluded from calculations).

Prosodic category			*Consonant*	*Vowel*	*Syllable*
Syllable}	[Pt]}	Means	102.6	107.5	210.1
		SD	21.7	33.5	50.1
		Min	50.0	51.0	114.0
		Max	170.0	196.0	335.0
	Ratio [Pt]:[Ut]		1.02	1.13	1.08
	[Ut]}	Means	100.3	94.9	195.2
		SD	19.4	36.4	51.0
		Min	55.0	34.0	98.0
		Max	141.0	201.0	332.0
Stress}	[+S]}	Means	112.8	129.0	241.8
		SD	16.5	26.9	38.9
		Min	78.0	53.0	155.0
		Max	170.0	201.0	335.0
	Ratio [+S]:[-S]		1.25	1.76	1.48
	[-S]}	Means	90.1	73.4	163.5
		SD	17.8	15.7	24.9
		Min	50.0	34.0	98.0
		Max	141.0	117.0	235.0
Focus}	[+F]}	Means	101.5	97.4	199.0
		SD	20.0	33.0	47.6
		Min	50.0	34.0	114.0
		Max	148.0	192.0	320.0
	Ratio [+F]:[-F]		0.01	0.93	0.96
	[-F]}	Means	101.3	105.0	206.3
		SD	21.2	37.5	54.2
		Min	51.0	41.0	98.0
		Max	170.0	201.0	335.0
Tempo}	[Ft]}	Means	94.1	93.7	187.8
		SD	20.2	30.2	45.4
		Min	50.0	34.0	98.0
		Max	170.0	182.0	326.0
	Ratio [Ft]:[Nl]		0.85	0.84	0.84
	[Nl]}	Means	111.2	111.2	222.4
		SD	16.8	39.5	51.6
		Min	77.0	46.0	138.0
		Max	147.0	201.0	335.0

3.1. Duration effects of vowel categories

The duration effects of vowel categories are given in table IIIa (also shown in figure 4b, left), pooled across prosodic factors. Table IIIb shows ratios of vowel durations comparing the duration of each vowel to the duration of all the others.

Table IIIa. Mean, standard deviation (SD), minimum (Min), and maximum (Max) durations of penultimate vowel categories pooled across prosodic conditions.

V	i	e	a	o	u
Mean	73.4	95.0	107.5	99.5	82.2
SD	25.2	31.1	33.5	31.5	27.8
Min	22.0	46.0	51.0	27.0	26.0
Max	131.0	175.0	196.0	181.0	148.0

Table IIIb. Two-dimensional ratio of penultimate vowel category durations pooled across prosodic conditions (*means significance at least p<0.05 level).

v/v	i	e	a	o	u
i	1.00	0.77*	0.68*	0.74*	0.89*
e	1.29*	1.00	0.88*	0.95	1.16*
a	1.46*	1.13*	1.00	1.08*	1.31*
o	1.36*	1.05	0.93*	1.00	1.21*
u	1.12*	0.87*	0.76*	0.83*	1.00

The data in Table IIIa show an /i<u<e<o<a/ hierarchical order of vowel durations which is highly significant (df 4; F=34.8, p<0.0001). A tripartite categorisation is observed, according to which the low vowel /a/ is longer than the mid vowels /e/ and /o/ which, in turn, are longer than the high vowels / i / and /u/. Furthermore, the back vowels /u/ and /o/ are noticeably longer than the respective front vowels / i / and /e/. Scheffe's post-hoc test showed significant differences between high and mid vowels (/i/~/e/, p<0.0001; /u/~/o/, p<0.0001) as well as between mid vowels and low /a/ (/e/~/a/, p<0.0002; /o/~/a/, p<0.01). Significant differences were also found in the front-back articulatory setting between *HI* and /u/ (p<0.007) but not between /e/ and /o/.

The ratios of vowel durations in tables IIIb have a fairly hierarchical structure, in accordance with durations in Table IIIa. The largest difference is found in the /a/:/i/ ratio (1.46, table Illb) which corresponds a to 34.1 ms difference (i.e. /a/= 107.5 and /i/=73.4 ms).

3.2. Contextual effects of vowel categories

Figure 1 shows vowel category effects on word durations. All five words have fairly the same duration and thus there are no significant effects. This is an indication that intrinsic durations of vowel categories in the penultimate syllable may be compensated for at the word level.

Figure 2 shows the effects of penultimate vowel categories on syllable durations. Although there are noticeable differences, especially in the penultimate syllable, there are no significant effects, mainly as a result of considerable compensation of intrinsic vowel category differences at the syllabic level.

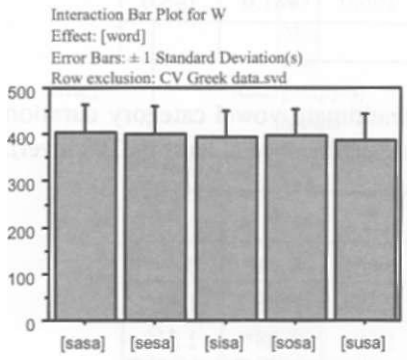

Figure 1. Penultimate vowel category effects on word durations (the ultimate syllable is excluded from calculations).

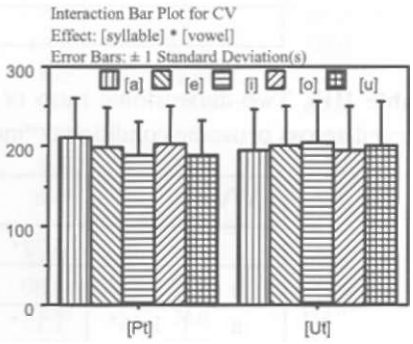

Figure 2. Penultimate vowel category effects on syllable durations: penultimate left, ultimate right.

Figure 3a shows the duration of prevocalic (tautosyllabic) and postvocalic (heterosyllabic) consonants for each of the five penultimate vowels. There are significant vowel effects on immediate consonant context. As mentioned above (3.1) vowels have different intrinsic durations the effects of which are carried over on the prevocalic consonant (df 4; $F=6.7$, $p<0.0001$) in a compensatory pattern with significant differences between /i/ and all other vowels: /i/~/e/ ($p<0.0002$), /i/~/a/ ($p<0.0001$), /i/~/o/ ($p<0.0001$) and /i/~/u/ ($p<0.002$) but also on the postvocalic consonant (df 4; $F=7.8$, $p<0.0001$) between / i / and

/a/ ($p<0.01$), /i/ and /o/ ($p<0.0001$). / i / and /u/ ($p<0.0002$), /a/ and /o/ ($p<0.01$), and /e/ and /o/ ($p<0.0002$).

Figure 3b shows the duration of each of the five penultimate vowels as well as the contextual effects on ultimate vowels. Intrinsic vowel durations (left) show a distribution structure in accordance with the high-low and front-back articulatory settings (see 3.1 above). Although ultimate vowels (right) show some variability related to the identity of the penultimate vowel, differences did not reach the significance level.

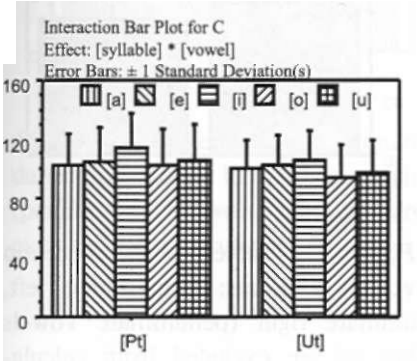

Figure 3a. Penultimate vowel category effects on consonant durations: penultimate left, ultimate right.

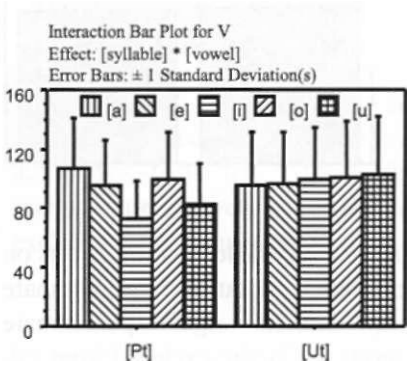

Figure 3b. Penultimate vowel category effects on vowel durations: penultimate left, ultimate right.

3.3. Prosodic effects on segment categories

The discussion of data presented in Figures 4 through 7 includes only durations of the sequences /sasa/ in order to exclude intrinsic vowel effects on the penultimate syllable.

Figures 4a-b show the effects of syllable position (penultimate vs. ultimate) on consonant and vowel segment durations. Syllable position has no significant effect on the consonant duration, whereas the penultimate vowel was significantly longer than the ultimate one (df 1; $F=10.8$, $p<0.001$).

Figures 5a-b show the effects of stress (+stress vs. -stress) on consonant and vowel segment durations. Stress has a highly significant effect on both consonant (df 1; $F=146$, $p<0.0001$) and vowel durations (df 1; $F=538$, $p=<0001$). The effect is much larger on vowels than on consonants.

Figures 6a-b show the effects of focus on consonant and vowel segment durations. Focus has no significant effect on consonant durations, whereas vowels in focus are significantly shorter than when not in focus (df 1; $F=3.8$, $p<0.05$).

Figures 7a-b show the effects of tempo on consonant and vowel segment durations. Tempo has a highly significant effect on both consonant (df 1; F=67.9, p<0.000) and vowel durations (df I; F=21, p<0.0001).

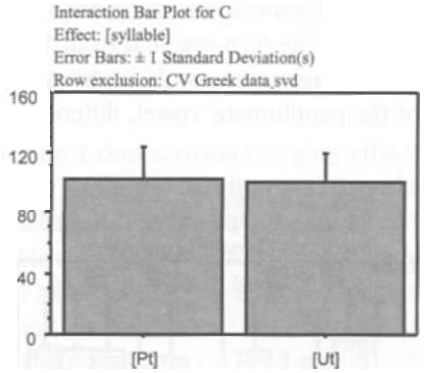

Figure 4a. Syllable position effects on consonant durations: penultimate left, ultimate right (penultimate vowels but /a/ are excluded from calculations).

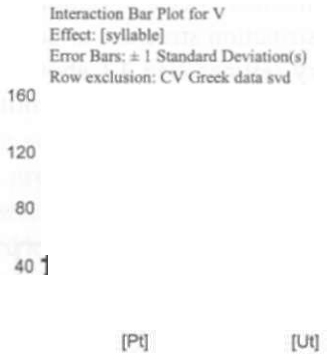

Figure 4b. Syllable position effects on vowel durations: penultimate left, ultimate right (penultimate vowels but /a/ are excluded from calculations).

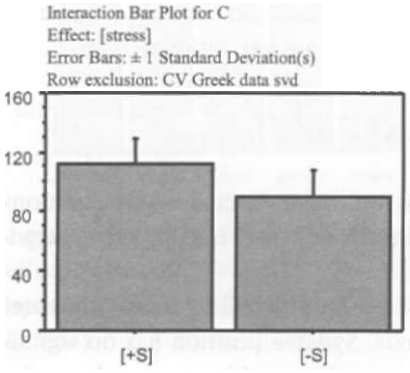

Figure 5a. Stress effects on consonant durations: +stress left, -stress right (penultimate vowels but /a/ are excluded from calculations).

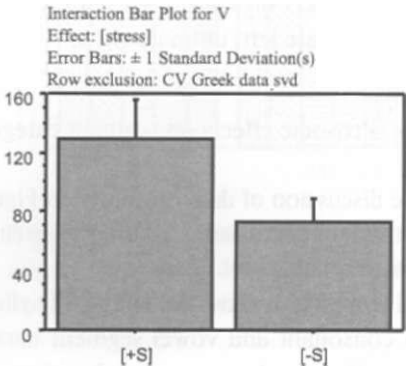

Figure 5b. Stress effects on vowel durations: +stress left, -stress right (penultimate vowels but /a/ are excluded from calculations).

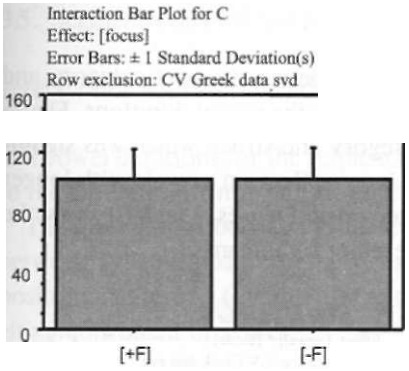

Figure 6a. Focus effects on consonant durations: +focus left, -focus right (penultimate vowels but /a/ are excluded from calculations).

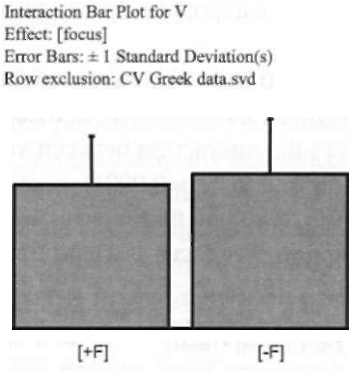

Figure 6b. Focus effects on vowel durations: +focus left, -focus right (penultimate vowels but /a/ are excluded from calculations).

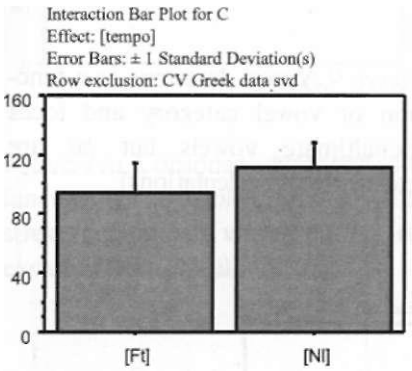

Figure 7a. Tempo effects on consonant durations: fast tempo left, normal tempo right (penultimate vowels but /a/ are excluded from calculations).

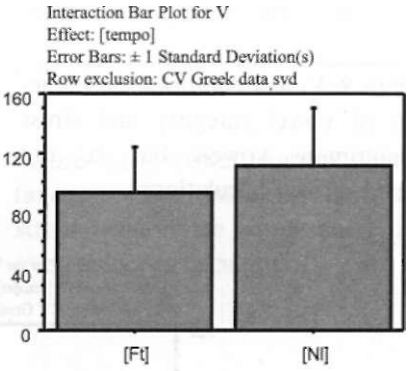

Figure 7b. Tempo effects on vowel durations: fast tempo left, normal tempo right (penultimate vowels but /a/ are excluded from calculations).

3.4. Vowel category and prosodic interactions

Figures 8-10 show the effects of the interaction between vowel category and the prosodic factors of stress, focus and tempo on the vowel durations. Figure 8 shows the interaction between vowel category and stress, which was significant (df 4; F=6.2, p<0.0001). as stress has larger effect on vowels with longer intrinsic durations than vowels with shorter ones. Figures 9 and 10 show the interaction with focus and tempo which were not significant.

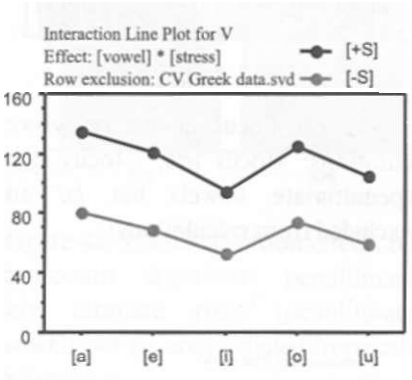

Figure 8. Vowel durations as a function of vowel category and stress (penultimate vowels but /a/ are excluded from calculations).

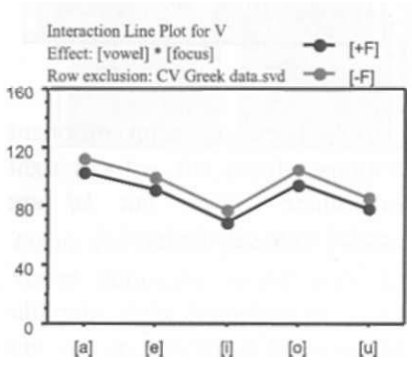

Figure 9. Vowel durations as a function of vowel category and focus (penultimate vowels but /a/ are excluded from calculations).

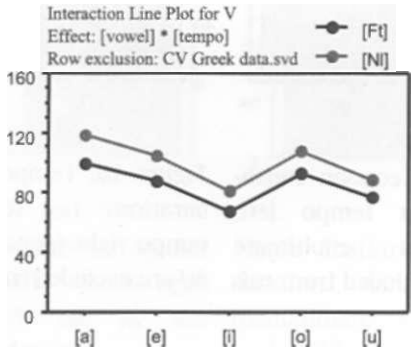

Figure 10. Vowel durations as a function of vowel category and tempo (penultimate vowels but /a/ are excluded from calculations).

3.5. Segment category and prosodic interactions

Interactions with syllable position. Figures 11-13 show the effects of the interaction between syllable position and the three prosodic factors on consonant and vowel durations for the sequence /sasa/, thus excluding any differences due to the different intrinsic durations of vowels in the penultimate syllable.

The interactions between syllable position and stress (Figures 1 la and 1 lb), between syllable position and focus (Figures 12a and 12b), between syllable position and tempo (Figures 13a and 13b), did not reach a significant level for either consonant or vowel.

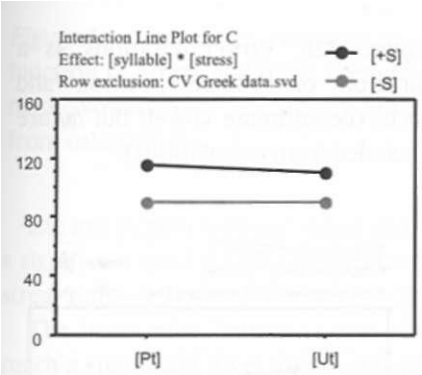

Figure 11a. Consonant durations as a function of syllable position and stress (penultimate vowels but /a/ are excluded from calculations).

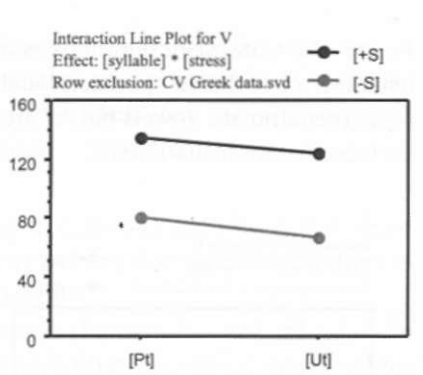

Figure 11b. Vowel durations as a function of syllable position and stress (penultimate vowels but /a/ are excluded from calculations).

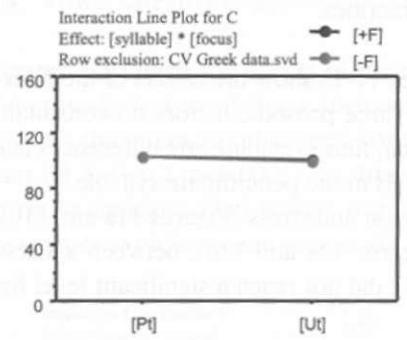

Figure 12a. Consonant durations as a function of syllable position and focus (penultimate vowels but /a/ are excluded from calculations)

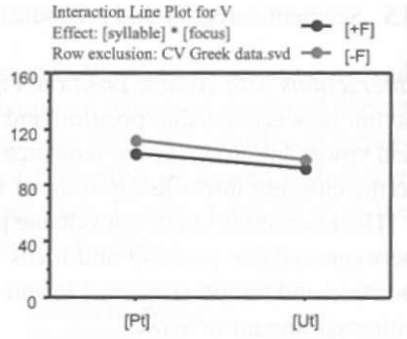

Figure 12b. Vowel durations as a function of syllable position and focus (penultimate vowels but /a/ are excluded from calculations).

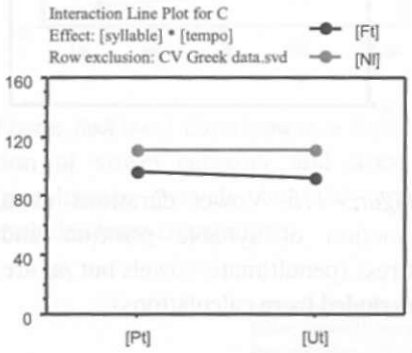

Figure 13a. Consonant durations as a function of syllable position and tempo (penultimate vowels but /a/ are excluded from calculations).

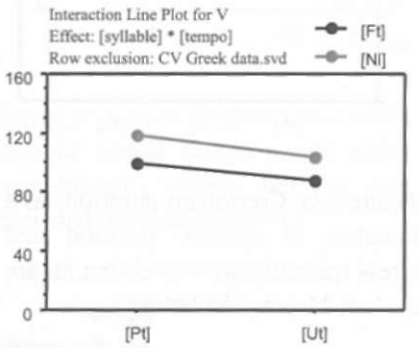

Figure 13b. Vowel durations as a function of syllable position and tempo (penultimate vowels but /a/ are excluded from calculations).

Interactions with stress. Figures 14-15 show the effects of the interaction between stress and the two remaining prosodic factors (focus and tempo) on consonant and vowel durations for the sequence /sasa/, thus excluding any differences due to the different intrinsic durations of vowels in the penultimate syllable.

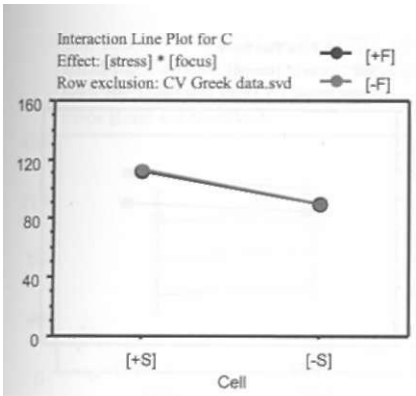

Figure 14a. Consonant durations as a function of stress and focus (penultimate vowels but /a/ are excluded from calculations).

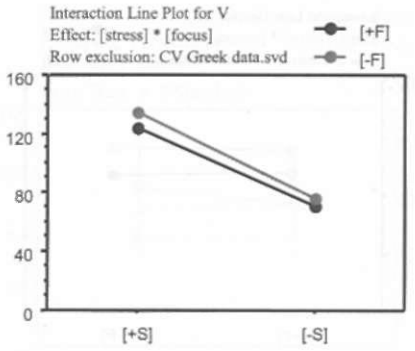

Figure 14b. Vowel durations as a function of stress and focus (penultimate vowels but /a/ are excluded from calculations).

The interaction between stress and focus (Figures 14a and 14b) did not reach a significant level for either consonant or vowel duration, as the main effect of stress remained constant in both focus conditions.

The interaction between stress and tempo (Figures 15a and 15b) did not reach a significant level for consonant durations but was indeed significant for vowel durations (df 1; F=16.4, p<0.0001). Stressed syllables were shortened more than unstressed syllables when changing from normal to fast tempo.

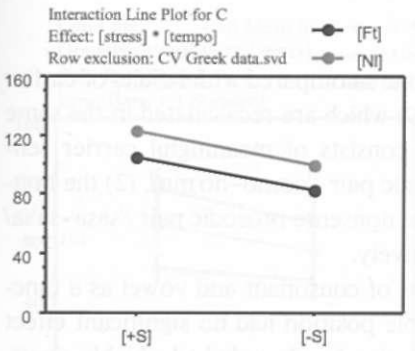

Figure 15a. Consonant durations as a function of stress and tempo (penultimate vowels but /a/ are excluded from calculations).

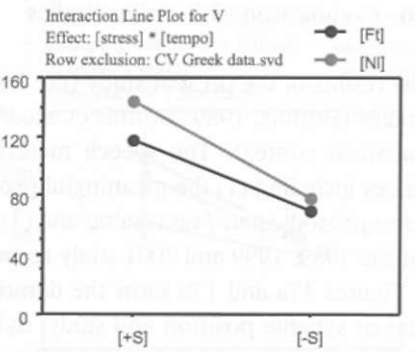

Figure 15b. Vowel durations as a function of stress and tempo (penultimate vowels but /a/ are excluded from calculations).

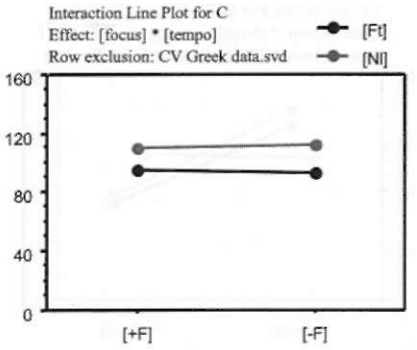

Figure 16a. Consonant durations as a function of focus and tempo (penultimate vowels but /a/ are excluded from calculations).

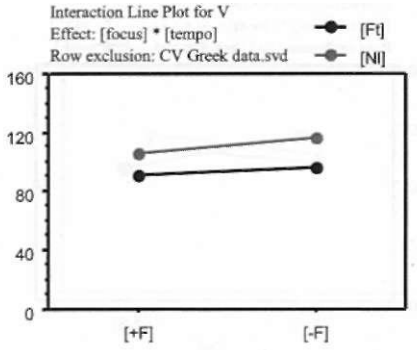

Figure 16b. Vowel durations as a function of focus and tempo (penultimate vowels but /a/ are excluded from calculations).

Interactions with focus. Figures 16 shows the effects of the interaction between focus and tempo on consonant and vowel durations for the sequence /sasa/, thus excluding any differences due to the different intrinsic durations of vowels in the penultimate syllable.

The interaction between focus and tempo (Figures 16a and 16b) did not reach a significant level for either consonant or vowel.

3.6. Comparison with earlier studies

The results of the present study (i.e. 2001) are compared with results of earlier studies (Botinis, 1989; Botinis et al., 1999) which are recalculated in the same statistical context. The speech material consists of meaningful carrier sentences including (1) the meaningful prosodic pair /'nomo-no'mo/, (2) the nonsense prosodic pair /sasa-sa'sa/ and (3) the nonsense prosodic pair /'sasa-sa'sa/ for the 1989, 1999 and 2001 study respectively.

Figures 17a and 17b show the durations of consonant and vowel as a function of syllable position and study. Syllable position had no significant effect on consonant or vowel durations. On the other hand, study had a highly significant effect on both consonant (df 2; $F=103.2$, $p<0.0001$) and vowel (df 2; $F=10.7$, $p<0.0001$) durations. Scheffe's post hoc test showed significant differences between all three studies ($p<0.0001$). There was no significant interaction between syllable position and study for either consonant or vowel.

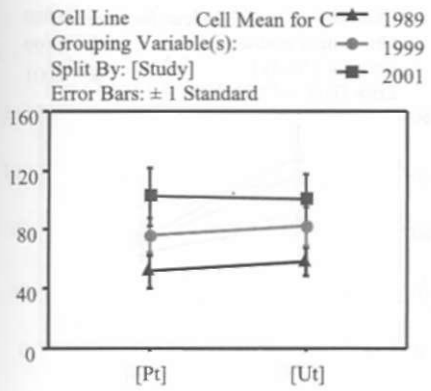

Figure 17a. Consonant durations as a function of syllable position (Pt vs. Ut) and study (1989 vs. 1999 vs. 2001).

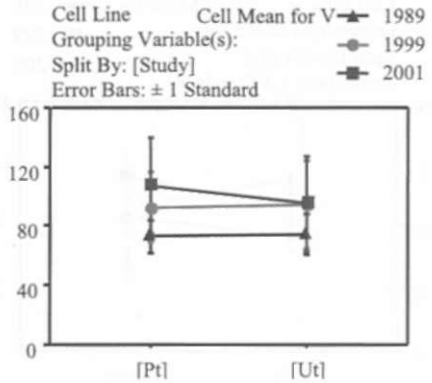

Figure 17b. Vowel durations as a function of syllable position (Pt vs. Ut) and study (1989 vs. 1999 vs. 2001).

Figures 18a and 18b show the durations of consonant and vowel as a function of stress and study. Stress had a highly significant effect on both consonant (df 1: F=65.8, p<0.0001) and vowel (df 1; F=314.8, p<0.0001) durations. There was highly significant interaction between stress and study (df 2; F=18.7, 0.0001) for the vowel but not for the consonant. This is mainly due to the difference of the three studies with regards to the vowel of the stressed syllable.

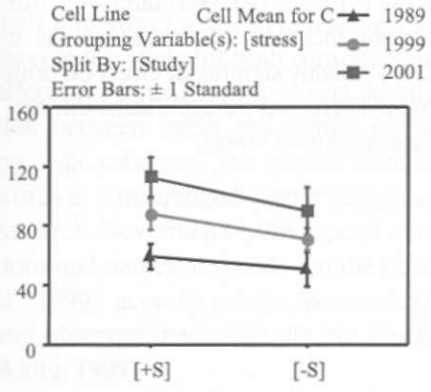

Figure 18a. Consonant durations as a function of stress (+S vs. -S) and study (1989 vs. 1999 vs. 2001).

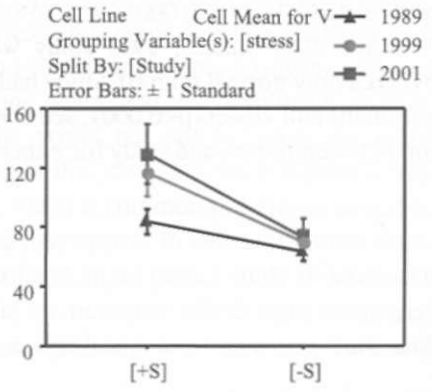

Figure 18b. Vowel durations as a function of stress (+S vs. -S) and study (1989 vs. 1999 vs. 2001).

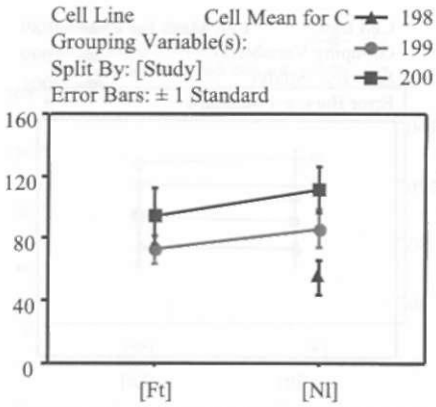

Figure 19a. Consonant durations as a function of focus (+F vs. -F) and study (1989 vs. 1999 vs. 2001).

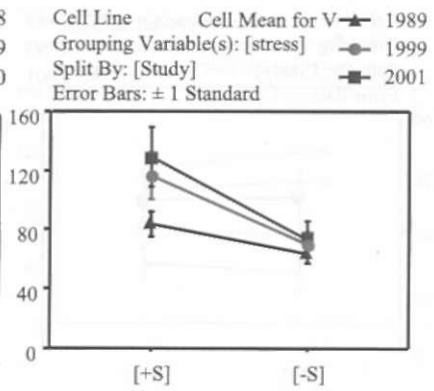

Figure 19b. Vowel durations as a function of focus (+F vs. -F) and study (1989 vs. 1999 vs. 2001).

Figures 19a and 19b show the durations of consonant and vowel as a function of focus and study. Focus had no significant effect on either consonant or vowel whereas study had a highly significant effect on both consonant and vowel ($p<0.0001$, see above). There was no significant interaction between focus and study for either consonant or vowel.

Figures 20a and 20b show the durations of consonant and vowel as a function of tempo and study. Tempo had a highly significant effect on both consonant (df 1; $F=36.4$, $p<0.0001$) and vowel (df 1; $F=8.7$, $p<0.003$) durations (for 1999 and 2001 studies; 1989 study was not included in calculations as it involved only normal tempo). Study had also a highly significant effect on both consonant and vowel ($p<0.0001$, see above). There was no significant interaction between tempo and study for either consonant or vowel.

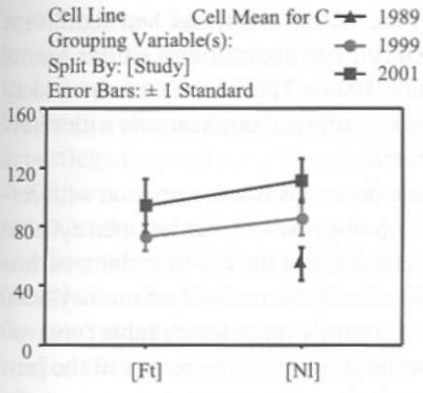

Figure 20a. Consonant durations as a function of tempo (Ft vs. Nl) and study (1989 vs. 1999 vs. 2001).

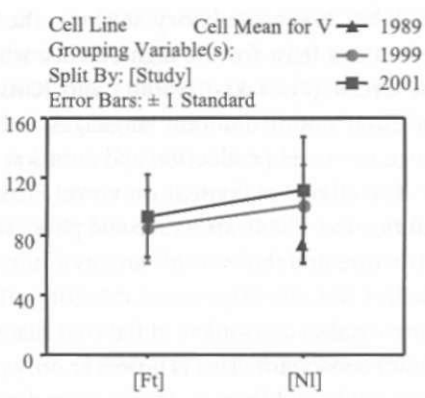

Figure 20b. Vowel durations as a function of tempo (Ft vs. Nl) and study (1989 vs. 1999 vs. 2001).

4. Discussion

The main results of the present study indicate that different vowel categories have different intrinsic durations in Greek which may have carry over effects on the immediate consonant context. Furthermore, different prosodic categories may have different effects with regards to vowel categories but only vowel category and stress reached a significance interaction level. On the other hand, different prosodic categories may have different effects on consonant and vowel segment categories. Stress and tempo reached a significance level in this study for both consonant and vowel but syllable position and focus effects were restricted to vowel durations. There was also significant interaction between stress and tempo for the vowel but not between any other prosodic category. The speech material in this study has been nonsense key words in a meaningful carrier sentence, which is common practice in phonetic research. Nevertheless, this type of word may appear in various familiar situations and names in Greek. On the other hand, in an earlier study (Fourakis et al., 1999), acoustic results of meaningful vs. nonsense words were compared and observed deviations did not reach a significant level (see also Turk and White, 1999).

Microprosodic effects of vowel categories, i.e. intrinsic durations, according to which the high vs. low articulatory setting has significant effects on vowel durations, is well-documented in prosodic research (Klatt, 1976; Lehiste, 1970; Di Cristo and Hirst. 1986). In the present study however, in addition to the

high vs. low articulatory settings, the front vs. back settings had significant effects, at least for the high vowels, which is a corroboration of earlier results in Greek (Fourakis, Botinis and Katsaiti, 1999). This finding is not widely attested among different languages and has theoretical implications with reference to vowel production and duration correlates.

The effects of context on vowel intrinsic durations is a major issue with reference to syllable structure and phonetic typology. Greek has an open syllable structure and thus vowels are, as a rule, syllabified to the left-branching consonant. Consequently, vowel category effects should be realised on tautosyllabic (prevocalic) consonant in the first place and hardly on heterosyllabic (postvocalic) consonant. This is however only partially shown in the results of the present study and there is thus no conclusive evidence of syllable structure duration correlates. Syllable structure theory, on the other hand, is mainly based on segmental distribution rather on phonetic reality. In an earlier study on duration correlates of syllable structure (Botinis et al., 1999), syllable onset structure, defined as the number of segments with onset branching, had a direct effect on segment durations: segments per syllabic onset and onset segment durations were negatively correlated. Furthermore, segments per syllable onset were negatively correlated with syllabic nucleus (vowel) duration, but to a remarkably less degree than syllable onset durations. On the other hand, there were no carry over effects of syllabic onset structure on postsyllabic segments, regardless of onset or nucleus structure. Apparently, extensive research is required on syllable structure and its durational correlates.

Prosodic categories may have variable effects on segmental durations. Among the most well-studied are syllable (segment) position, stress, focus (and related terms such as sentence stress, sentence and nuclear accent), and tempo. Syllable position is related to final lengthening at syntactic boundaries, especially if they coincide with prosodic breaks and pauses (Lehiste, 1972; Gussenhoven and Rietveld, 1992). In the present study, however, no final lengthening was observed although the ultimate syllable was the final boundary of a noun phrase. On the contrary, the ultimate vowel was found to be shorter than the penultimate one. This may partly depend on speech material and production style. In more complex syntactic structures, especially with prosodic breaks, final lengthening may characterise Greek prosody too.

Stress is well-studied in Greek, with constant duration correlates (e.g. Fourakis, 1986; Botinis, 1989; Botinis et al., 1999; Fourakis et al., 1999). Stressed segments and syllables are considerably longer than unstressed ones and the lengthening effect of stress is much bigger on vowel than consonant segments. Furthermore, stress has different effects on different vowels, i.e. there are significant interactions between vowel category and stress, according

to which stress has bigger effects on lower vowels than higher vowels and thus longer and shorter intrinsic durations respectively. Duration is also a perceptual correlate of stress and, in combination with a measure of intensity, which has been referred to as "energy integral", has been claimed to be the main acoustic/perceptual correlates of stress in Greek (Botinis, 1989).

Focus is also associated with durational correlates, according to which segments in the domain of focus are considerably longer than out of focus (Turk and Sawusch, 1997; Turk and White, 1999). In an earlier study (Botinis, 1989) focus had noticeable segmental effects but not across all speakers. This led to the conclusion that duration is not a constant correlate of focus. In subsequent studies (Botinis et al., 1999; Fourakis et al., 1999), focus had no noticeable effects on segmental durations. In Fourakis et al. (1999), much like the present study, even the opposite effect was observed, i.e. segments in focus were even shorter than segments out of focus. It was thus concluded, in accordance with Botinis (1989), that voice fundamental frequency (FO) is a constant acoustic correlate of focus in Greek and this conclusion was also corroborated in a perceptual study (Botinis et al., 2000).

Tempo may have disproportionate effects and significant interactions among different segment distinctions and prosodic categories (Crystal and House, 1988; Gopal, 1990, 1996). In earlier studies (Botinis et al., 1999; Fourakis et al., 1999) a shift from normal to fast tempo resulted to a shortening of the vowels in the neighbourhood of 16% and these results are corroborated in the present study. Furthermore, in the present study, tempo and stress showed significant interactions as stressed segments showed larger duration variability than unstressed ones as a function of tempo, and these results are in accordance with earlier results (Botinis et al., 1999; Fourakis et al., 1999).

Summarising the prosodic effects in this study, stress and tempo had highly significant effects on consonant and vowel durations, as well as significant interactions on vowels but not consonants. A shift from stressed to unstressed syllable resulted in a shortening of 20% for the consonant and 43% for the vowel (irrespective of tempo) which is a larger effect of stress in comparison to earlier studies. A shift from normal to fast tempo resulted in a shortening of 15% for the consonant and 16% for the vowel (irrespective of stress) which is in good agreement with earlier studies. A shift from stressed syllable at normal tempo to unstressed syllable at fast tempo resulted however to a shortening of 32% for the consonant and 52% for the vowel. The effect of a prosodic factor was thus considerably minimised in the presence of another factor, which is in accordance with the incompressibility notion, suggested by Klatt (1976), and hence the significant interactions between stress and tempo.

5. **Conclusions**

With reference to the questions put in the introduction, the following main conclusions have been drawn: First, Greek vowels may have different intrinsic durations which primarily depend on the high vs. low articulatory settings, i.e. high vs. mid vs. low, and secondarily on the front vs. back articulatory settings. Second, vowels may have compensatory duration effects on prevocalic (tautosyllabic) but also on postvocalic (heterosyllabic) consonants. Third, stress and tempo may have significant main effects on consonants and vowels, as well as significant interactions on vowels but not consonants. Syllable position and focus do not show constant effects on segmental durations.

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