Greek Phonetics: The State of the Art

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1. Introduction

Phonetics is the area of linguistics that studies the production and perception of speech sounds. Research in the past decades has clearly shown that speech is extremely variable, and that the characteristics of individual sounds and the ways they are perceived are altered by a variety of factors that have to do with linguistic structure—such as segmental context, syllabic and prosodic constituency (among many, de Jong 1991, Cho & Keating 2001, Keating et al. 2003)—social factors—such as speaking style, addressee identity, social and geographical accent (Clopper, Pisoni & de Jong 2005, Foulkes, Docherty & Watt 2005, Khattab 2007)—and even individual characteristics of the talkers, from anatomical differences to social and individual characteristics, such as gender and sexual orientation (e.g., Johnson, Strand & D'Imperio 1999, Strand 1999, Pierrehumbert et al. 2004; for a review, see Pierrehumbert 2006). Thus, although the main *descriptive* aim of phonetics is to document the articulation, acoustics and perception of the sounds found in the languages of the world, its *theoretical* aim is to develop coherent theories of how speech sounds are produced and how their articulatory and acoustic features contribute to speech perception. In particular, in the past few years a great deal of phonetic research has aimed at understanding how, on the one hand, speakers achieve goals such as producing style-specific speech and adapting their speech to ongoing sound changes in their speech community, and how, on the other, listeners can simultaneously extract the linguistic message from among the speaker-induced, contextual and social variation encoded in the signal *and* use the variability they encounter for indexical purposes, such as for understanding the sociolinguistic and even some pragmatic implications of a given speech event.

These issues are investigated by means of a variety of experimental protocols and techniques that address articulation (e.g., electropalatography, ultrasound, physiological measurements of nasal and oral flow), acoustics (e.g., waveforms, spectrograms, spectra, intensity curves and pitch tracks) and perception (e.g., eye tracking, various types of

identification and discrimination experiments with auditory stimuli). Although qualitative studies and corpora-based studies are gaining ground, in the vast majority of phonetic research scholars strive to create controlled materials that vary only along the parameters investigated by each experiment. This type of control allows for the statistical treatment of the data, which, in turn, permits us to generalize from the small experimental corpus to the speech community at large with some degree of confidence.

Phonetics is often equated with phonology, and the two terms have often been used as quasi synonyms, particularly in the realm of Greek linguistics. The two fields, although related, are autonomous and distinct in terms of their subject matter, goals and methodologies. Phonology seeks to find general patterns of sound organization in the grammars of diverse languages by examining how different languages structure their sound systems, the common principles that underlie phonological structure and, by extension, the limits of possible phonological variability. Thus phonology is interested in what makes sounds contrastive in a given system, in the grammatical combinations of sounds, in how sounds are organized into syllables and larger prosodic units and how they interact with morphology and (to an extent) phonetics. Traditionally phonological research was based on intuition and impressionistic data collection (that is transcriptions made from the auditory impressions of the investigators, a method that we now know to be extremely unreliable; e.g., Nolan 1992, Scobbie et al. 2000, Miller, Namaseb & Iskarous 2007). Phonetics, as mentioned, relies primarily on experimental methodologies and its subject matter is the investigation of speech production and perception.

Although the above differences are well established, it is also the case that in the past twenty years or so the two fields have been brought closer by research that combines theoretical concerns of phonology with phonetic methodologies (an approach that has become known as *laboratory phonology*; see Pierrehumbert, Beckman & Ladd 2000). The underlying premise of work in this field is that phonological structure is reflected in phonetic realization, and that therefore it is in principle possible to test phonological theories by phonetic means; these typically take the form either of perceptual experiments, in which particular aspects of the acoustic signal are manipulated, or of production experiments, that is, of controlled observations of the linguistic behavior of speakers (either in the laboratory or in the field where appropriate). This approach has been very fruitful and has contributed to a better understanding of phonological structure. In particular it has shown without doubt that there is no such thing as a

"universal phonetics" component which interprets abstract phonological structures and renders them into specific articulations that remain largely the same across languages (or even within the same language). Rather, laboratory phonology research has shown that linguistic varieties can differ in minute non-contrastive ways, such as in the duration of aspiration for stops (e.g., Cho & Ladefoged 1999), the extent to which speech segments are coarticulated in a given context (e.g., Cohn 1993), or the exact realization of tonal categories (e.g., Atterer & Ladd 2004, Arvaniti & Garding 2007). Such language-specific detail suggests that the phonetics of a language must be learnt by its speakers in the same way that they learn their language's phonology, morphology, syntax, semantics and pragmatics. By extension, then, this body of research strongly suggests that phonetics must be part of a speaker's grammar.

In addition, research on laboratory phonology has shown that several phenomena that have been regarded as categorical phonological changes—assimilations, lenitions, deletions, substitutions and so on—are often gradient phenomena, subject to variation depending on style and rate of speech (e.g., Nolan 1992, Holst and Nolan 1995, Zsiga 1995). Further, this line of research has clearly demonstrated that many subtle articulatory effects are impossible to detect aurally, yet can have repercussions for our understanding of a wide range of phenomena, from the phonological patterning of sounds (e.g., Miller et al. 2007) to the exact nature of phonological disorders (e.g., Scobbie et al. 2000). In short, laboratory phonology research has shown that intuition and auditory transcription are inadequate and often misleading tools in the study of speech, and that empirical research using phonetic instrumental techniques is essential for understanding most speech phenomena whether classified as phonological or phonetic. It is important to note that studies on Greek phonetics have contributed key insights regarding these main points, and several other issues within phonetic theory and the relationship between phonetics and phonology.

This rapprochement between phonetics and phonology was the reaction to the traditional generative view that phonetics deals with *performance* and phonology deals with *competence*. This division had in fact kept phonetics outside the scope of linguistics, at least in the U.S.A., where generative linguistics has reigned supreme since the late 1950s.[1] In contrast, phonetics has been an extremely productive and well respected field of linguistic research in many European countries, thanks to the work of pioneers such as Henry Sweet, André Classe, Daniel Jones, David Abercrombie, L'Abbé Rousselot, Georges Straka, Pierre Delattre and many others.

Greece, unfortunately, is not among the European countries with a strong phonetic tradition. Indeed one of the most striking characteristics of the field of Greek linguistics is how little research there is in phonetics compared to practically all other areas of linguistic inquiry. A brief perusal of the proceedings of the 1st, 2nd, 3rd and 4th International Conference on Greek Linguistics (these proceedings are the only ones with a thematic categorization that renders a comparison straightforward) shows that on average there were five times more syntax papers and twice as many morphology papers than phonetics *and* phonology papers combined. The result of this shortage of phonetic research on Greek is that at the beginning of the 21st century many aspects in Greek phonetics are addressed by only a small number of studies (sometimes by just one), while we still have big gaps in our knowledge: e.g., as far as I could ascertain, we have limited information on the perception of Greek consonants, we know little about the function of vowel reduction and elision in Greek, our knowledge of the realization of Greek sandhi "rules" is still incomplete, while the *phonetic* study of the acquisition of Greek and of Greek dialects is virtually non-existent (but see Arvaniti 1998a, Papazachariou 2005, 2006, Payne & Eftychiou 2006, Armosti et al. 2006, Armosti 2007, Eftychiou 2007 on dialects, and Kong, Beckman & Edwards 2007 on acquisition). Furthermore, much of the work is couched within frameworks that are so different from each other, and occasionally idiosyncratic, that in many cases drawing comparisons across studies and reviewing previous results can be an arduous task. As a result, the body of research on Greek phonetics does not show a cumulative progression of knowledge with newer studies building on solid previously published results.

The reasons why phonetics has been so neglected by Greek linguists could perhaps be traced back to the Greek philological tradition which allotted a very small role to phonetics (and to phonology, for that matter), possibly because of the emphasis on the written code that was a corollary of diglossia. It is probably not an accident that many grammars of Greek devote a chapter to the writing system (e.g., Householder, Kazazis & Koutsoudas 1964, Mackridge 1987, Holton, Mackridge & Warburton 1997, 2004), a topic rarely, if ever, addressed in the grammars of other languages. The downplaying of the spoken side of the language was further reinforced by the generative tradition which viewed syntax as the core of linguistic study. In the field of Greek linguistics in particular this new emphasis on syntax was also seen as a "salutary innovation" away from the preoccupation with morphology that had previously dominated the field (Mackridge 1988:154). The result of all these forces together and the dearth of phonetic

research are reflected in the negligible role allotted to phonetics and phonology in published Greek grammars and linguistics textbooks (often treated together, as in Philippaki-Warburton 1992). As an indication, Mackridge (1987) devotes to the sounds *and* spelling of Greek together 38 out of 500 pages (less than 8% of his book), Joseph & Warburton (1987) have only a phonology chapter (which is 24 pages long or 8.5% of their book), Holton et al. (1997) devote to the sound system 27 pages out of 520 (5% of the book), while in Holton et al. (2004) the discussion of the sound system takes up eleven out of 300 pages (less than 4% of the book). As a result of this neglect there are currently no reference works to Greek phonetics, so that anyone interested in basic information, e.g., for applications such as speech synthesis, has to create her own analysis (see e.g., Kotropoulos, Mavrommatidou & Pitas 2001). Inevitably, the neglect of phonetics extends also to the educational system: e.g., Greek school children gain no knowledge as to the phonetic reality of the accents they are taught to use in Ancient Greek, and ignore the reasons why [i] or [e] are today spelled in so many different ways. It is not a coincidence either that at the level of higher education the first phonetics textbook—Ladefoged's *A Course in Phonetics*, translated by Mary Baltazani—has just appeared in Greece (Ladefoged 2007).

This dearth of research on Greek phonetics is unfortunate not only because it means that many aspects of spoken Greek are still little understood or even totally undocumented, but also because the research done so far shows very clearly how useful and multifaceted the contribution of phonetics can be. Studies in Greek phonetics have informed both phonology (e.g., Arvaniti, Ladd & Mennen 2000, 2006a, 2006b) and phonetic theory (Jongman, Fourakis & Sereno 1989, Hawks & Fourakis 1995, Arvaniti, Ladd & Mennen 1998), have shed light on the relationship between phonetics and phonology (Arvaniti 2001b, Arvaniti et al. 2006a, Baltazani 2006b), and have provided crucial evidence on other aspects of linguistic structure (see the interface work on syntax, focus, semantics and discourse of Botinis 1993, Keller & Alexopoulou 2001, Baltazani 2003b, 2004, 2006a, Georgiafentis & Sfakianaki 2004). They are also relevant to various areas of applied linguistics—such as second language acquisition (e.g., Arvaniti 1999d, 2001d, 2003b, Mennen 2004, 2007, Lengeris & Hazan 2007) and the speech training of the hearing impaired (e.g., Nicolaidis 2002a, 2004, Nicolaidis 2007, Nicolaidis & Sfakianaki 2007)—as well as in speech technology (e.g., Christogiannis et al. 2000a, Christogiannis et al. 2000b).

In this paper I review our knowledge of Greek phonetics so far, discussing in turn, the consonant and vowel systems, stress, rhythm and timing, sandhi, prosodic phrasing, and

intonation. My main goal is to present a comprehensive review of what is known so far on each topic, as well as to discuss the disputed points in the literature and identify the areas in which more research is clearly necessary. A secondary goal is to provide a comprehensive list of publications in Greek phonetics, in the hopes that scholars will be able to consult this previous work and build on existing results. Inevitably perhaps (given my own interests), in many cases I connect the phonetic evidence to the phonological views of the same phenomena and *briefly* present the phonological consequences of specific results (though the reader is warned not to expect full blown phonological analyses and discussions of morphophonology, both of which are outside the scope of a phonetics review). On the other hand, I am not reviewing here research on acquisition, second language learning, dialectology, clinical and computational approaches except when the information from such studies bears on a contentious point. Finally, although my main focus is on peer-reviewed research, I have tried to address other types of publications to the extent this was possible; in the interest of space, if multiple non-refereed publications of the same author(s) cover essentially the same material, only one or two of them are cited and discussed.

2. The Greek consonants

Various aspects of the consonant system of Greek have been investigated phonetically though a fair amount of information is still missing, while what we know is often based on a limited number of studies. Part of the problem stems from the fact that even the phonological inventory of Greek consonants is not entirely agreed upon (the main issues still being those discussed in Householder 1964, that is the status of voiced stops, palatals and affricates). A full length discussion of the phonological inventory of Greek is beyond the scope of this paper. In what follows I assume the relatively uncontroversial system presented in Arvaniti (1999a), and discuss, where appropriate, the extent to which phonetic results can help us resolve a controversy. Arvaniti (1999a) provides a chart along the lines of Table 1 below, which comprises voiced and voiceless stops and fricatives, nasals, and liquids in five places of articulation.

Table 1. The phonologically contrastive consonants of Greek (after Arvaniti 1999a).

	Bilabial	Labio-dental	Interdental	Alveolar	Velar
Plosive	p b			t d	k g
Fricative		f v	θ ð	s z	x ɣ
Nasal	m			n	
Tap				ɾ	
Lateral approx				l	

2.1 The stop consonants

It is generally agreed that Greek has voiceless stops in bilabial, alveolar and velar places of articulation. The phonological status of the Greek voiced stops, [b d g], on the other hand, has often been disputed; e.g., Mirambel (1959) and Householder (1964) argue that [b d g] are phonemes, while Newton (1961, 1972) treats them as sequences of homorganic clusters of nasal+voiceless stop in which the plosive assimilates for voice to the nasal and the nasal assimilates for place to the plosive. A detailed discussion of the pros and cons of each position (and of others that have been proposed since those early studies) is beyond the scope of this paper (but see Malikouti-Drachman 1993 and especially Malikouti-Drachman 2001:189 ff. for a full discussion of this issue). Independently of which phonological analysis we adopt, it remains indisputable that voiced stops are phonetically present in Greek, and for this reason they are discussed in some detail below.

Several studies have examined the voiceless stops of Greek, [p], [t] and [k], and show that these are voiceless unaspirated plosives (Fourakis 1986a, 1986b, Arvaniti 1987, Botinis, Fourakis & Prinou 2000, Arvaniti 2001c, Nicolaidis 2002b).[2] Despite the fact that [p], [t] and [k] are described as voiceless, in running speech they can show substantial carryover voicing, especially in intervocalic position (Nicolaidis 2001, 2002b). Nicolaidis (2002b) in particular found that on average 38% of the closure for [p] and 25% of the closure for [t] was voiced intervocalically.

Most of the above studies also agree that [p] has the longest closure of the three stops and the shortest Voice Onset Time (henceforth VOT), [k] has the shortest closure and longest VOT, while [t] is intermediate between the two. A summary of durations from various studies is given in Table 2. These data should be considered indicative only, as several studies (e.g., Botinis 1989,

Nicolaidis 1998, Arvaniti 1991a, 2000) show that consonants are longer in stressed than in unstressed syllables, while Nicolaidis (2002b) reports that the duration of [p] and [t] is not affected by place of articulation (see Table 2), but is affected by the quality of the following vowel, with closure duration for [t] being longer before [i] than before [a] and VOT for both [p] and [t] being longer before [i] than [a] (similar results are also reported in Arvaniti 1987, but the effect is not as consistent). Fourakis (1986b), on the other hand, found effects of vowel quality only on VOT length: in his data, stops show longer VOT before the high vowels [i] and [u] than before the other vowels of Greek. By and large, these durational measurements are in line with what has been reported in the literature regarding the effects of place of articulation, stress and vocalic context on the duration of stop consonants (e.g., Klatt 1976, Cho & Ladefoged 1999). There are two possible reasons why certain effects surface in some studies and not in others. First, stops have been investigated in different contexts (stress, word position) and some durational effects may be weaker or non-existent in some cases. In addition, most studies relied on a small number of speakers and therefore they may have been lacking statistical power to detect small but consistent durational effects. This may be particularly true for the VOTs of [p] and [t] which are very short (see Table 2), since short-lag VOT has been shown to be resistant to durational changes (Kessinger & Blumstein 1997), a conclusion that seems to agree with the results of Fourakis (1986a). Thus, it would be worthwhile examining the timing of Greek voiceless stops using a large number of speakers and controlling more consistently the contexts in which the stops appear.

Table 2. Mean closure and VOT durations for Greek voiceless stops (a) in word initial position followed by a stressed [a] (based on Fourakis 1986b and Arvaniti 1987), (b) in intervocalic position with data pooled over stress (based on Arvaniti 2001c and Nicolaidis 2002b; note that Nicolaidis 2002b does not examine [k]).

		[p]	[t]	[k]
closure	Fourakis (1986b)	113	101	90
	Arvaniti (1987)	88	85	86
	Arvaniti (2001c)	56	50	44
	Nicolaidis (2002b)	69	63	
VOT	Fourakis (1986b)	9	16	23
	Arvaniti (1987)	11	15	26
	Arvaniti (2001c)	13	16	23
	Nicolaidis (2002b)	14	22	

Regarding the voiced stops, the prevailing notion is that they are either preceded by a full blown homorganic nasal and hence transcribed as sequences of two segments [mb, nd, ŋg] (e.g., Householder 1964, Thumb 1964, Mackridge 1987, Joseph & Philippaki-Warburton 1987), or that they are produced with *prenasalization*, that is as one segment in which the early part of the stop closure is accompanied by nasal murmur, and hence transcribed as [^{m}b, ^{n}d, ^{ŋ}g] (e.g., Thumb 1964 for word-initial stops, Arvaniti & Joseph 2000). This lack of consistent transcription may be due to the variable production of voiced stops (Householder 1964, Warburton 1970b) which goes at least as far back as the beginning of the 20th century (Arvaniti & Joseph 2002, 2004). However, several more recent studies show that nasality rarely accompanies voiced stops any more, at least in the variety spoken in Athens and possibly in that of Thessaloniki. Crucially, when nasality is present it does not increase the duration of the stop closure (Charalambopoulos et al. 1992, Arvaniti & Joseph 2000). In addition, nasality varies in extent, sometimes lasting almost as long as the oral closure but at others being present only for a brief period of time at closure beginning (Arvaniti & Joseph 2000). This overall timing pattern suggests that the nasal and oral elements are co-produced as one segment. Because of the variability in the duration of the nasal element, however, it is not possible to say whether Greek voiced stops with nasality should be transcribed as [^{m}b, ^{n}d, ^{ŋ}g]—transcriptions that suggest the nasal element is short—or as [m͡b, n͡d, ŋ͡g]—transcriptions that suggest the nasal element is only slightly shorter than the oral closure. Although the choice between these two transcription options should most probably depend on the extent nasality is present in the token to be transcribed, it is clear that transcribing voiced stops as [mb, nd, ŋg], that is as sequences of two segments, is inaccurate and to an extent misleading. [3]

In addition, the studies on the realization of voiced stops have shown that the frequency with which a speaker produces nasalized tokens is partly controlled by sociolinguistic factors. Thus, Pagoni (1989), who examined the social network of 22 Athenians, found that older more educated and more conservative speakers used a larger number of nasalized tokens. Similarly, Charalambopoulos et al. (1992), based on a sample of 20 talkers from Thessaloniki, observed that young speakers use nasalization only rarely in contrast to a small number of older speakers

in their study, who used it extensively. Finally, Arvaniti (1995) and Arvaniti and Joseph (2000) using a sample of 30 Athenian speakers stratified for age, gender and social class elicited data in both formal and casual style, and found that in the overwhelming majority of the data of the younger speakers (45 years or younger at the time of the study) and almost half of the data of the speakers older than 45, [b], [d] and [g] were produced as prevoiced oral stops without any nasality during stop closure.

In addition, the pronunciation of Greek voiced stops appears to depend also on style and linguistic context: in fast and in casual speech nasalisation is rarer and voiced plosives are often lenited to voiced fricatives, while in word-initial position, voiced stops are extremely rarely, if ever, produced with prenasalization (Tzivaki 1985, Mikros 1997, Arvaniti & Joseph 2000).

The exact place of articulation of stops (and of the other Greek consonants) is examined in a series of EPG studies by Nicolaidis (Nicolaidis 1991, 1994, 1997a, 2000, 2001, 2003a). These studies are based on one or two speakers and therefore they should be treated with some caution, as Nicolaidis herself advises, since small numbers of speakers—a necessary "evil" of time-consuming articulatory research—could reflect idiosyncratic patterns of variation (e.g., Nicolaidis 1997b). The data show a great deal of variability in the articulation of the consonants examined. This was particularly true of [t], the place of articulation of which can vary a great deal depending on the following vowel, with [i] resulting in the most fronted occlusion. The results of Nicolaidis (1991) suggest that [t] is best described as dental, while those of Nicolaidis (1994) show predominantly [t]s that are best described as *dentoalveolar* since they involve tongue tip contact with both the upper teeth (which cannot be registered by EPG) and the first row of electrodes, which is located in the alveolar region. On the other hand, the data of Nicolaidis (2000) and (2001) sometimes suggest a somewhat more posterior articulation.

This variability in the exact place of [t] occlusion could well be due to the different contexts in which [t] was examined. In Nicolaidis (1991) [t] was examined in unstressed syllables in the contexts [ˈi_i], [ˈi_a], [ˈa_a] and [ˈa_i]; in this post-stress context, the articulation of [t] is likely to be more affected by the following vowel, since post-stress syllables have been shown to be very short in Greek (Dauer 1980a, Botinis 1989, Arvaniti 1991a, 2000, Baltazani 2007a), and therefore likely to exhibit little coarticulatory resistance. Further, while some of Nicolaidis's work relies on laboratory speech (e.g., Nicolaidis 1991, 1993), other studies rely on

running speech (e.g., Nicolaidis 2000, 2001), which according to Nicolaidis (1994:230) involves largely a "raising and advancing of the tongue" compared to isolated sentences.

More generally, Nicolaidis (2001) shows that both [t] and [k] are lenited in running speech in various ways and that for /t/, at least, the degree of lenition correlates strongly with decreasing duration. In her data, Greek [t] was actually produced with an incomplete closure or as a fricative in approximately 35-39% of the tokens, depending on speaker. In addition, over 40% of [t] tokens were produced with full or partial voicing, while complete deletion of [t] especially in function words (such as articles) was also attested (4% of the data). On the other hand, [k] presented a pattern of less extreme lenition, in that [k] was never completed elided and was not voiced as frequently as [t]: only 18% of the [k] tokens of speaker JM and 35% of CN's were voiced. The data of speaker JM also show a large proportion (53%) of [k]s with incomplete closure; although such a result would suggest that [k] is lenited more frequently than [t], at least by some speakers, Nicolaidis points out that this percentage may be exaggerated because it includes several tokens of [k] for which the closure is posterior to the last row of EPG electrodes (and thus cannot be fully registered).

Overall, Nicolaidis's results from spontaneous speech clearly cast doubt on the canonical view of Greek stop consonants as voiced and voiceless plosives in labial, alveolar and velar place of articulation. Her results show that the lingual consonants at least can exhibit extensive lenition that is manifested as (a) voicing (if phonologically voiceless), (b) incomplete closure and (c) substantial variation in the exact place of articulation. Data such as those of Nicolaidis (2001) clearly show how important it is to examine spontaneous speech patterns and use them in conjunction with controlled laboratory data in order to obtain a thorough view of the variation found in speech.

2.2 The fricatives

Less is known about the fricatives than the stops of Greek, as most studies examine [s] to the exclusion of all other fricatives. Impressionistic descriptions of the articulation of Greek [s] vary a great deal. Newton (1972:10) describes it as dental; Joseph & Phillipaki-Warburton (1987) classify it as apicodental, while according to Mackridge (1987) the place of articulation of [s] is relatively anterior and can vary depending on context.

Panagopoulos (1991) compares the acoustics of [s] and [z] in Greek and English and shows that spectrally Greek [s] and [z] are somewhat in between their English counterparts and the postalveolar pair [ʃ] and [ʒ]: in English, fricative noise starts around 3.7 KHz for the alveolars, and 2.1 KHz for the postalveolars, while for the Greek [s] and [z] fricative noise starts around 3 KHz. This difference suggests that Greek [s] and [z] are retracted alveolars. This description is in line with the articulatory results of Nicolaidis (2001, 2004): examination of her data shows that the constriction for Greek [s] involves the second and third row of electrodes (e.g. Nicolaidis 2001:71), while English data obtained in similar environments (e.g., Zsiga 1995) show a maximum constriction involving the first two rows of electrodes instead. Zsiga's data support the traditional descriptions of English [s] and of similar alveolar sibilants as being articulated in the "forward part of the alveolar ridge" (see Ladefoged & Maddieson 1996:146ff. and references therein). It should be noted, however, that in spontaneous speech Greek [s] shows considerable variability due to coarticulation (Nicolaidis 1994, 2001): [s] is fronted when followed by [t] and in some cases the front vowel [i], while in the [a_a] context in may be so retracted as to be best described as an advanced postalveolar. In addition, in intervocalic position [s] may show a degree of lenition (that is, a more open articulation) which is not, however, accompanied by carryover voicing as happens with voiceless stops (Nicolaidis 2002b).

Regarding duration, Greek [s] appears to be generally shorter than English [s]. Panagopoulos (1991) reports a large difference in duration between Greek alveolars and their English counterparts, with the Greek [s] being 73 ms on average and [z] being 61 ms on average, while the means for the same consonants in his English data were 170 ms and 172 ms respectively. Although it may be the case that such a durational difference exists, the data of Panagopoulos are not presented in sufficient detail to judge how representative these means are. An average [s] duration derived by pooling the data of Fourakis (1986a), Fourakis (1986b) and Arvaniti (1987) is closer to that reported for word-initial [s] in English (110 ms for Greek vs. 170 ms for English), while durations similar to those reported by Panagopoulos appear in the data of Fourakis (1986a) and Arvaniti (1987) only when [s] is followed by another consonant, as in [sp] and [sk] (in these contexts, [s] mean duration is 66 ms). Intervocalically, [s] may be somewhat shorter than word initially: Arvaniti (2001c) reports an average duration of 100 ms for intervocalic [s], while Nicolaidis (2002b) reports an average duration of 113 ms.[4]

As mentioned, there is little information about the articulation and acoustics of most of the other fricatives of Greek (but see 2.4 below), except for the duration data of Fourakis (1986b). Fourakis provides durations for [f], [θ] and [x] in word-initial stressed syllables in which the consonants are followed by [i], [e] or [a]. His results show that the durations of these three consonants are comparable to that of [s], being on average 113 ms for [f], 114 ms for [θ] and 118 ms for [x], with [s] in his data having a mean duration of 119 ms. His data show the same effect reported in Nicolaidis (2002b), namely shorter durations before the low vowel [a] and longer durations before the front vowels [i] and [e], although in the case of /x/ in particular it is clear that we are not dealing with the same effect found in [f] and [θ], since /x/ has a velar allophone [x] before [a], but a palatal allophone [ç] before [e] and [i]. This point is not addressed in Fourakis (1986b).

In addition to these very limited production data, Tserdanelis (2001, 2002) provides some information regarding the perception of the Greek fricatives in clusters. Specifically, Tserdanelis used an AX paradigm—in which listeners hear two stimuli and have to decide if the second one is the same as or different from the first—to test the perceptibility of intervocalic clusters of stops and fricatives among Greek and English listeners. The clusters in this study included both clusters attested in Greek (e.g., (/pt/, /kt/, /ft/, /st/, /fθ/, /sθ/), and clusters that are not found in Greek, such as /tk/ and /θf/. Tserdanelis's results show that Greeks, who are more familiar with these types of unusual clusters, respond more quickly than English listeners and their responses are more likely to be correct. Nevertheless, both groups of listeners responded most slowly to fricative+fricative clusters and fastest to fricative+stop clusters. Tserdanelis (2001, 2002) argues that this perceptual result explains why fricative+fricative clusters are not productive in Greek and why stop+stop clusters were regularly replaced by more easily perceptible fricative+stop sequences, a preference that Tserdanelis attributes to acoustic factors: fricatives have internal cues that help with their identification independently of context, while stop bursts, which are crucial for the identification of stop place of articulation, are acoustically salient only before vowels (for phonological accounts of the preference for fricative+stop clusters see Drachman & Malikouti-Drachman 1997and Kappa 2001; for a review see Malikouti-Drachman 2001).[5]

2.3 The sonorants

Greek has only two nasal phonemes, bilabial /m/ and alveolar /n/, and two alveolar liquids, /l/ and /r/. The nasals are briefly examined in Arvaniti (1999b; 2001c), who presents durational data in intervocalic position showing that both [m] and [n] are shortened at fast speaking rate. These data are presented in Table 3, together with durational data for [l] and [r].

Beyond that, only the articulation of [n] has been examined in some detail, and it has been shown to be that of an alveolar consonant, which is, however, susceptible to coarticulatory influences particularly from following vowels, so that its articulation can range from apical when followed by /i/ to retracted alveolar before /a/ and /u/ (Nicolaidis 2001, 2004). In addition, Nicolaidis (2001) notes that [n] is frequently lenited in spontaneous speech: 23% of [n]s from one of her speakers and 13% of [n]s from the other showed incomplete closure and significantly reduced duration (lenited [n]s had 56% of the duration of [n]s with complete closure for the speaker who showed more lenition, and 26% for the speaker who showed less lenition). According to Nicolaidis, a similar pattern of lenition and also variability in its exact place of articulation may be present for the palatal [ɲ] as well, though her tokens for [ɲ] were not sufficiently numerous to allow for firm conclusions (see also 2.4 below).

Table 3. Durations of Greek intervocalic [m], [n], [l] and [r] in normal and fast speaking rate; the data of Arvaniti (1999b) are for consonants in stressed syllables (e.g., [ðaˈni] "Danish, pl."); the data of Arvaniti (2001c) are pooled across stress conditions (e.g., [n] in both [ˈkani] "it does" and [kaˈni] "shin")

	Rate	[m]	[n]	[l]	[r]
Arvaniti (1999b)	normal	94	87	88	27
	fast	81	70	75	25
Arvaniti (2001c)	normal	74	55	67	29
	fast	58	48	53	24

In addition, it has often observed that [n] assimilates for place of articulation to following obstruents (e.g., Nespor & Vogel 1986, Joseph & Philippaki-Warburton 1987), though scholars tend not to mention more than three places of articulation for this type of assimilation (roughly labial, alveolar and velar; see e.g., Thumb 1964). However, the EPG data of Nicolaidis (2001)

suggest that phonetically Greek may have a whole series of nasals that appear before obstruents. Although Nicolaidis herself points out that her data are limited to two speakers and that additional evidence is needed to confirm the generality of the patterns she discovered, I would venture to suggest that nasals do assimilate for place to following obstruents, yielding a series of allophonic nasal articulations in Greek, viz. labiodental, as in [aɱfivoˈlia] "doubt", dental, as in [ˈan̪θos] "flower", retracted alveolar, as in [ˈpen̻sa] "pliers", alveolo-palatal, as in [siɲ̟ˈçizo] "to annoy" and velar as in [ˈaŋxos] "stress".

Phonologically Greek has one rhotic sound, which I transcribe here as /r/ for the sake of convenience, though phonetically it is typically described as an alveolar tap [ɾ]. Arvaniti (1999b, 2001c), who examined the effects of speaking rate on intervocalic [r], reports an average duration of 27 ms that was not affected by speaking rate. Both the short duration and the lack of speaking rate effects are consistent with [r] being a tap, that is a short ballistic movement during which the tip of the tongue briefly hits the palate. This description is also in line with the articulatory data presented in Nicolaidis (2001). According to Nicolaidis, the tap is often a retracted alveolar ([ɾ̺]), though it also shows substantial variation in place of articulation. Further, both Nicolaidis (2001) and Baltazani (2005) note that the tap is frequently produced with incomplete closure; in the data of Baltazani (2005) in particular, taps with incomplete closure amount to 48% of the corpus.

Other realizations of the Greek rhotic are also possible. Baltazani (2005) reports three realizations in intervocalic position: tap [ɾ] (64% of her data), approximant [ɹ] (34% of her data), and trill [r] (2% of her data). Trills are also reported in Arvaniti (1987) who studied /r/ word initially as a single consonant and in clusters with stops ([pr], [tr], [kr]). According to Arvaniti (1987), although /r/ is pronounced mostly as a tap when on its own, in clusters it is pronounced mostly as a short trill with two or three cycles. In addition, /r/ is probably a short trill when in coda position as well, as in [ˈartos] "bread" or [arˈluba] "nonsense". Spectrograms and waveforms of the possible realizations of Greek /r/, tap, trill and approximant, are shown in Figure 1.

The above description of the realizations of /r/ in clusters is consistent with the data of Baltazani (2005, 2007c) who examines the acoustics of /r/ is C_V and V_C contexts, where *C* is

a stop or fricative (e.g., [aˈkrata] “name of town”, [ˈmarka] “brand” respectively). Baltazani herself assumes that /r/ is realized as a tap in these contexts, and interprets her data as showing a short vowel that intrudes between the tap and the consonant that precedes or follows it. Although it is possible that such intrusive vowels are present in the speech of some speakers of Greek, the vocalic stretches that are present when /r/ is found before or after an obstruent are on average just 33 ms long (according to Baltazani 2007c; see also Figure 1a) and not experienced by either the speakers or the researchers as distinct vowels. For this reason they have never been reported in descriptions of Greek before, unlike intrusive vowels in other languages, such as Armenian, Scots Gaelic and various Latin American varieties of Spanish (see Hall 2006 and references therein). Because of their acoustic characteristics (discussed in some detail below), short duration and aural undetectability, I believe that, given our present knowledge, it is best to interpret these vocalic stretches as nothing more than the typical vocalic portions of trills. Specifically, trills are produced when a flexible articulator such as the tongue tip is made to “flap in the wind”: in our case, the tongue tip is set in motion by the pulmonic egressive airstream so as to intermittently create a short but complete constriction with the alveolar ridge (for a more technical analysis of the aerodynamics of trills, see McGowan 1992). Thus a trill consists of short closures alternating with stretches during which voicing continues and the airstream is unimpeded; inevitably, these stretches look vowel-like (see e.g. the discussion and spectrograms of trills in Lindau 1985, Ladefoged & Maddieson 1996:217ff.; Ladefoged 2003:150ff). Crucially, when trills have only two cycles (that is, two closures), only one vocalic element appears between them, as in [meˈtro] “subway” in Figure 1(a) in which the two closures are marked by arrows. The presence of two closures is in itself an indication that we are dealing with a trill; if we were dealing with a tap, then only one closure would be detectable. The interpretation of such data as showing evidence for a trill rather than an intrusive vowel is further supported by two types of evidence. First, with emphatic pronunciation, it is possible to produce longer trills in Greek as in [ˈprizo] “to swell” shown in Figure 1(a), in which two short vocalic segments alternate with three short closures (marked by arrows). Second, both in the examples used here and in the extensive quantitative data of Baltazani (2007c), the combined duration of a tap and a vocalic stretch averages 57 ms, giving a frequency of closure repetition of 18 Hz. This timing pattern fits squarely within the duration and frequency range reported by Lindau (1985) for trills (also discussed in Ladefoged &

Maddieson 1996:218). Thus although vocalic stretches are present in trills and are the most likely origin of intrusive vowels when trills cluster with obstruents, it appears doubtful that such vowels are widespread in Greek for all the reasons outlined above (for similar conclusions about similar acoustic patterns as manifested in waveforms and spectrograms from several languages see Lindau 1985; Ladefoged & Maddieson 1996:217ff.; Ladefoged 2003:150ff).

Regarding [l], Nicolaidis (2001, 2003a) shows that it is also produced with some degree of variability in its place of articulation, ranging from alveolar to retracted alveolar, and can also be produced with incomplete median closure. Arvaniti (1999b) and Arvaniti (2001c) report average durations for [l] in normal and fast speaking rate that show regular shortening of [l] as speaking rate increases (see Table 3).

Beyond Greek, the articulatory study of laterals by Gick et al. (2006) shows that in many languages laterals involve not only an anterior lingual gesture, but also a dorsal gesture, that is some degree of velarization, which gives rise to so-called "dark" [l]s. For languages with "brighter" [l]s, such as Canadian French and Beijing Mandarin, the presence of this dorsal gesture is determined by syllabic position, with [l] in codas showing greater velarization than [l] in onsets. Although [l]s can appear in coda position in Greek, we have no knowledge of how syllable structure affects the articulation of Greek [l] in words like [almiˈros] "salty" vs. [aliˈci] "salt-pit". We know, however, but again without instrumental studies, that [l] is velarized before the back vowels [a], [o] and [u] in northern varieties of Greek, and that it is palatalized before [i] and [e] in many southern varieties, including varieties spoken in Crete and the Peloponnese (for a review of the possible articulations of /l/ in the Peloponnese variety of Patras in particular, see Papazachariou 2005, 2006; for a review of dialectal variation regarding the palatalization of alveolars on the basis of auditory data alone, see Newton 1972:137 ff.). It is clear that further articulatory studies are needed in order to discover the whole gamut of possible [l] realizations in Greek.

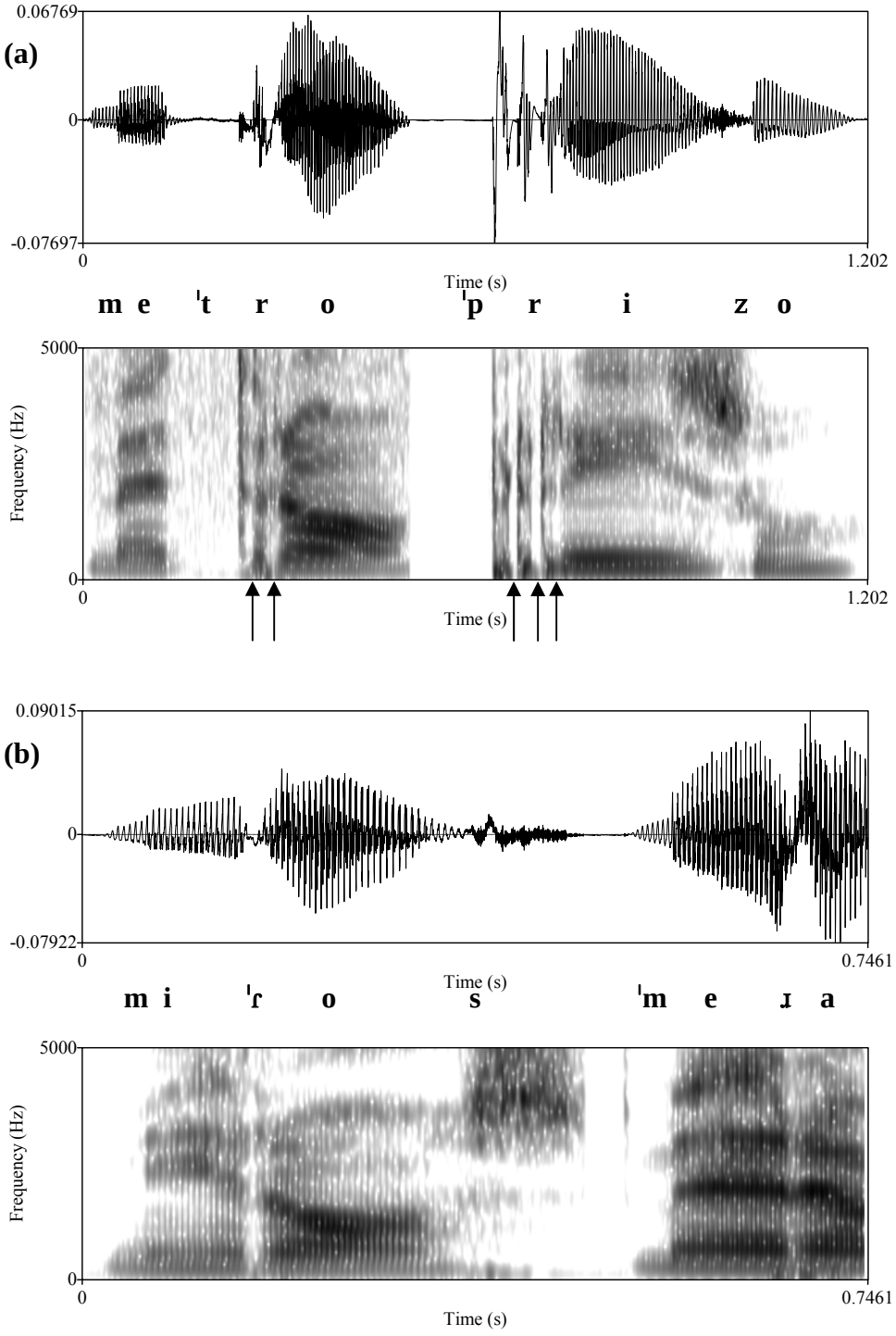


Figure 1. Examples of four variants of the Greek rhotic; in panel (a), short trill [r] in [meˈtro] "subway" (left) and trill with three cycles in [ˈprizo] "to swell" (right); in panel (b), the "canonical" tap variant [ɾ] in [miˈɾos] "thigh" (left), and approximant [ɹ] in [ˈmeɹa] "day" (right).

2.4 The Greek palatals

The palatal consonants have been very little investigated phonetically. Phonologically, in all descriptions so far palatal consonants are seen as allophones of the velar obstruents and the alveolar sonorants. Specifically, palatal stops and fricatives, [c ɟ] and [ç ʝ], are said to be surface realizations of /k g/ and /x ɣ/ respectively before the front vowels /i/ and /e/ (e.g., Holton et al. 1997). In addition, however, palatal stops and fricatives appear before sequences of /i/ and a back vowel *in the same syllable*, in which case what surfaces is a palatal consonant followed by a single back vowel; e.g., *κυάλι* [ˈcali] "field glass", *γκιαούρης* [ɟaˈuris] "infidel", *χιόνι* [ˈçoni] "snow", *γυάλα* [ˈʝala] "fish tank". Similarly, [n] and [l] surface as their palatal allophones, [ɲ] and [ʎ] respectively, if followed by /i/ and a back vowel *in the same syllable*, as in *νιάτα* [ˈɲata] "youth" and *παλιός* [paˈʎos] "old, masc.". This distribution of the palatals means that at the surface minimal pairs involving the palatals and their velar or alveolar counterparts are possible, and that the presence of the palatals is not transparent as it does not always involve morphophonemic alternations; e.g., *γυάλα* [ˈʝala] "fish tank": *γάλα* [ˈɣala] "milk", *Κιάτο* [ˈcato] "name of town": *κάτω* [ˈkato] "down", *χιόνι* [ˈçoni] "snow": *χώνει* [ˈxoni] "s/he stuffs. Thus, in examples like the above, spelling is the *only* indication that a vowel [i] is involved; at the surface such sequences are opaque at least until literacy is achieved. Possibly because of their distributional characteristics, palatals appear rather late in the acquisition of Greek (Thomadaki & Magoula 1998; for a review of relevant data, see Mennen and Okalidou 2007).

Nicolaidis (2003a) is the first study of the Greek palatals from a phonetic perspective (they are also examined in passing in Nicolaidis 2001). Specifically, Nicolaidis (2003a) examines all the palatal consonants of Greek, using EPG data from two female speakers. The consonants examined are [c] [ɟ], [ç], [ʝ], [ɲ] and [ʎ] and they are compared to their velar and alveolar counterparts and to palatal consonants of Italian, Catalan and Czech. The results of Nicolaidis (2003a) show that although these segments are often described as *palatals* in the Greek literature they do not all share the same place of articulation: [ʎ] is produced with extensive contact of the tip and blade of the tongue with the alveolar and post-alveolar region;

[ɲ] shows a similar pattern of contact but also contact in the front/mid palatal region. In contrast, the stops and fricatives are articulated much further back in the oral cavity, with the posterior part of the tongue dorsum making contact with the posterior part of the palate, but with side contact extending all the way to the alveolar region. In short, [ʎ] is probably best described as post-alveolar, [ɲ] as alveolopalatal, and [c], [ɟ], [ç] and [ʝ] as retracted palatals. On the basis of these results Nicolaidis (2003a) argues that these consonants of Greek are better described as *palatalized*, rather than palatals, since their place of articulation is obviously influenced by the place of articulation of their basic allophones, alveolar for /l/ and /n/ and velar for /k/, /g/, /x/ and /ɣ/.

The results of Nicolaidis (2003a) also resolve the issue of the phonetic identity of the voiced palatal continuant. Specifically, many descriptions of Greek postulate the existence of a palatal approximant [j] also referred to as *yod* (e.g., Mirambel 1959, Householder 1964, Newton 1972, Joseph & Philippaki-Warburton 1987). Arvaniti (1999a), on the other hand, argues that independently of its phonemic status, this segment is a voiced fricative, not an approximant and thus best transcribed as [ʝ]. Nicolaidis (2003a) also uses the symbol [ʝ] to transcribe her "yod" data, which clearly show that this segment is a fricative, since it has the same type of narrow constriction as its voiceless counterpart [ç]. Obviously, due to the voicing of [ʝ], the same articulation does not result in as much frication as for the voiceless fricative, since volume velocity is reduced (Johnson 2003:124), but nevertheless the constriction is clearly too narrow to be that of an approximant. Acoustic results showing frication and therefore support for transcribing "yod" as a voiced palatal fricative rather than an approximant are also presented in Malavakis (1984).

2.5 On [ts] and [dz]

A perennial issue with respect to the Greek consonantal system is the status of [ts], and by extension that of [dz] (for a discussion, see Householder 1964). Some researchers have argued that [ts] is a phoneme of Greek (e.g., Mirambel 1959, Householder 1964, Householder et al. 1964), others have preferred to treat it as a cluster (among many, Thumb 1964, Setatos 1974,

Newton 1972, Holton et al. 2004), and yet others remain agnostic (e.g., Joseph & Philippaki-Warburton 1987, Holton et al. 1997). The arguments used for or against a particular analysis are based on the distribution and patterning of [ts] and, to a lesser extent, of [dz]. Thus, the fact that [ts] does not participate in clusters like the other Greek obstruents has been used as an argument against a single-segment analysis, while the fact that /t/+/s/ sequences across a morpheme boundary do not behave in an analogous manner to /p/+/s/ or /k/+/s/ (cf. /ˈθet+s+ame/ > /ˈθesame/ "we put", but /ˈplek+s+ame/ > /ˈpleksame/ "we knitted") has been used as an argument against the cluster analysis (Joseph & Lee 1988, Pagoni 1995). A full discussion of the phonological arguments on the status of [ts] is beyond the scope of this paper (but see Malikouti-Drachman 2001:212ff.). However, it is worth noting that Joseph (1984a, 1984b, 1985) suggests that [ts] (and [dz]) have "allolinguistic" status in Greek, on the grounds that they are not a regular development from the Classical phonological system, have different distribution from the other obstruents and participate in a large number of affective morphemes, such as the diminutive suffix /–ˈitsa/, and in reduplications (e.g., [tsaˈtsara] "comb", [tsiˈtsidi] "naked", [tsouˈtsouna] "willy"].

Given the plurality of views on the phonological status of [ts], it is worth reviewing the phonetic literature for evidence that may favor one phonological analysis over the other. So far, we have three studies of the phonetics of [ts], Arvaniti (1987), Joseph & Lee (1988)—who also examined [dz]—and Fourakis, Botinis & Nigrianaki (2002). All three studies show that [ts] is phonetically different from [ps] and [ks] in that it is much shorter in duration, with both the stop closure and the fricated portion showing shortening, compared both to [p], [t] and [s] in [ps] and [ks] and to [t] and [s] in isolation. Joseph & Lee (1988) provide similar results for [dz]. The results of Arvaniti (1987) and Joseph & Lee (1988) are given in Table 4 (Fourakis et al. 2002 do not provide mean segment durations in their paper). On the basis of this phonetic evidence, Joseph & Lee (1988) and Fourakis et al. (2002) argue that [ts] and [dz] must be treated as affricates, not clusters; Joseph & Lee in particular argue that [ts] and [dz] should be phonologically treated as complex segments.

One problem with using these phonetic data to argue for an affricate analysis of [ts] is that results from Fourakis (1986a), Arvaniti (1987) and Fourakis et al. (2002) show that the shortening observed in [ts] also affects [st] when compared to [sp] and [sk]. If we treat [ts] as a

phoneme, on the basis of its short duration, we cannot explain why [st], which cannot under any framework be considered anything but a cluster, is similar to [ts] in timing. As Arvaniti (1987) argues, there are no adequate articulatory explanations for the shortening of either [st] or [ts] in Greek. Their homorganicity could offer an explanation if it were not for the fact that results for the same sequences in English—in some studies at least—show less shortening for [ts] and [st] than [ps], [ks] and [sp], [sk] respectively (e.g., Haggard 1973, Hawkins 1976). On the basis of these differences, Arvaniti (1987)—who implicitly treats [ts] as a cluster—argues that the timing of [ts] (and [st]) may simply reflect a language specific realization of these sequences.

Table 4. Durations (in ms) of [t] and [s] as single consonants and as part of [ts].

	[t]	[s]	[t] in [ts]	[s] in [ts]
Arvaniti (1987)	89	121	52	67
Joseph & Lee (1988)	100	119	72	64
MEAN	95	120	62	66

On the other hand, the short duration of [ts] may indeed be an indication of its articulation as an affricate, since articulatory results for the English affricate [tʃ] show that the release of the [t] closure in the affricate starts just after maximum contact for [t] is reached, while the release of the closure for single [t] is delayed by on average 50 ms after maximum contact (Mair et al. 1996; I am grateful to Katerina Nicolaidis for bringing this reference to my attention). Although it would be interesting to confirm whether this difference in timing found in English applies to Greek [ts] as well, the articulatory data cannot address the issue of the timing similarity between Greek [ts] and [st].

Perceptual evidence which confirms the affinity of [ts] and [st] comes from recent experimental data of Tzakosta and Vis (2007). Tzakosta & Vis asked 21 native speakers of Greek to break up consonantal sequences in 150 Greek words by inserting any vowel wherever they thought fit. They found that their subjects were less likely to break up [ts] and [dz] than [sp] and [sk]. However, the subjects were equally reluctant to break up the other C+s clusters, [ps] and [ks], and even [st] and [tr]. Overall, these data could be showing two effects: an effect of consonant "distance"—with COR+COR clusters being felt to be less easy to separate than clusters containing consonants with different places of articulation—and an effect of spelling, since [ps] and [ks] (spelled <ψ> and <ξ>) behave similarly to [ts]. Because of the spelling

complications it seems unlikely that experiments like that of Tzakosta & Vis can provide a definite answer as to the status of [ts] in the grammars of native speakers, though they can certainly shed light onto the issue.

Phonetically, however, the evidence so far suggests that [ts] is produced as an affricate. Additional indirect support for this view comes from the results of Tserdanelis (2005). Tserdanelis examined instances of [t] and [s] belonging to a noun and possessive enclitic respectively as in (1) below (henceforth NP [t#s]), and compared them to instances of [t] and [s] separated by a (possible) phrasal boundary, as in 2 below (henceforth VP [t#s])

(1) [to ˈɟot su ˈkovi ti ˈθea stus perastiˈkus] "your yacht blocks the view of the passersby"

(2) [to ˈɟot | su ˈkovi ti ˈθea] "the yacht blocks your view"

His assumption was that in (1), [t] would resyllabify and that the resulting [ts] sequence would be indistinguishable from lexical instances of [ts]. His results show some evidence in favor of this analysis, in that [t] was affected more by the rounding of the following [u] in NP [t#s], where resyllabification was expected, than in VP [t#s]. On the other hand, however, the timing of both [t#s] sequences was different from that of lexical [ts]: in NP [t#s], [t] was very short (42 ms on average), as in lexical [ts], but [s] was very long (117 ms on average), longer than the average unclustered [s] previously reported for Greek (see 2.2). In contrast, in VP [t#s], [t] was relatively long (60 ms on average) and [s] was of average duration for an unclustered phrase initial [s] in an unstressed syllable (90 ms on average).

Tserdanelis interprets these data as showing evidence for the resyllabification of [t] in NP [t#s] (and by extension for resyllabification of word-final consonants in Greek, a point discussed in more detail in 6.1). Independently of whether [t] resyllabifies, however, the timing of the NP [t#s] sequence remains different from that of lexical [ts]. In my view, this is because the speakers try to keep this sequence distinct from lexical [ts] by substantially lengthening [s] in the NP [t#s] context in which the two are likely to be confused. If my interpretation of the data is correct then there is a possible difference between NP [t#s] and lexical [ts] in terms of *rise-time*, the amount of time it takes for the fricative to reach full amplitude. Rise-time has been used as a diagnostic for true affricates, which are said to have shorter rise-time than stop+fricative clusters (see

Howell & Rosen 1983 and references therein, and Johnson 2003:144ff.). In the data under consideration here, one would expect that rise-time would be longer in NP [t#s] than in lexical [ts]. Articulatory data on this point regarding the coordination of the [t] and [s] gestures would be extremely illuminating as discussed above.

In sum, the existing timing data in combination with the data of Tserdanelis (2005) strongly suggest that [ts] is *phonetically* produced as an affricate. This conclusion could be further strengthened by articulatory data and measurements of rise-time, neither of which is available at this point. However, strong phonetic evidence that Greek [ts] is an affricate does not necessarily mean that it should be treated phonologically as a phoneme (on this point, see Ladefoged & Maddieson 1996:90). The phonemic status of [ts] should primarily rest on phonological arguments; those available so far do not provide absolute support for one or the other analysis. Experimental evidence that taps into speaker intuitions and their phonological categories should in principle help resolve the issue; unfortunately, the results of Tzakosta & Vis (2007) suggest that tapping into these intuitions is very difficult and in Greek it may be an enterprise additionally complicated by the existing spelling conventions which clearly influence the speakers' judgment and responses.

2.6 Consonants: Summary

Greek has a relatively small consonant inventory which, however, has presented phonologists with some challenging (and so far unresolved) problems, namely the phonological status of voiced stops, affricates and palatals (the "three dreams" of Householder 1964). Possibly because the types of alternations found in Greek are rather puzzling and were difficult to account for in a satisfactory manner in traditional frameworks, the phonological analysis of the system has attracted much more attention that the phonetic realization of the consonants themselves. However, recent studies show that Greek also has a rich and interesting phonetic inventory. This inventory is not at this point fully understood. A great deal of work is still needed on the realization of Greek consonants in different contexts and speaking styles, their realization in clusters, their overall timing patterns and their perceptual properties. Studies like Tzakosta & Vis (2007) suggest that various type of experimental data could help us understand how native speakers categorize the types of sequences and segments that linguists have found difficult to

analyze (though they may not always provide a solution). To sum up, this review of the phonetics of Greek consonants suggests *at least* the matrix of phonetic consonantal segments shown in Table 5 below. In this table, the symbols should be interpreted as short-hand representations of broad categories that are expected to show further subtle variation depending on speaker, style, context, speaking rate and so on.

Table 5. The phonetic inventory of Greek consonants. Note that since there is no clear consensus at this point as to the default place of articulation of several coronal consonants, which can vary from dento-alveolars to retracted alveolars, I treat them all here as basically alveolar, unless there is clear evidence to the contrary (as is the case with sibilants and rhotics).

	Bilabial	Labio-dental	Dental	Alveolar	Retracted Alveolar	Post-alveolar	Alveolo-palatal	Retracted Palatal	Velar
Plosive	p b			t d ts dz				c ɟ	k g
Fricative		f v	θ ð		s z			ç ʝ	x ɣ
Nasal	m	ɱ	n̪	n			ɲ̟		ŋ
Tap					ɾ				
Trill					r				
Approximant					ɹ				
Lateral approx.				l		ʎ			

3. Vowels

3.1 The acoustics of Greek vowels

Phonologically, the vowel system of Greek is a typical five vowel system, /i e a o u/.[6] Auditorily, /i/ and /u/ are high front unrounded and high back rounded vowels respectively. The low vowel /a/, on the other hand, is best described as central; according to Nicolaidis (1991) its height is intermediate between low and low-mid (e.g., it is higher than British English [ɑ]); thus the most appropriate symbol for its phonetic transcription is [ɐ]. (For convenience, however, I use here the

symbol [a] in all transcriptions on the understanding that it represents a low *central* vowel.) These descriptions for [i], [u] and [a] are largely supported by the acoustic studies of Samaras (1974), Botinis (1981), Tseva (1989), Fourakis, Botinis & Katsaiti (1999), Sfakianaki (2002), Nicolaidis (2003b), Nicolaidis & Rispoli (2005), and Baltazani (2007a). Average values for the first two formants of all five vowels as presented in Fourakis et al. (1999) are reproduced in Table 6 below; Table 7 presents, for comparison, the values given by Sfakianaki (2002) and Nicolaidis (2003b) for the same vowels.

Table 6. F1 and F2 values (in Hz) for the five vowels of Greek in slow/normal speaking rate after Fourakis et al. (1999). On the left, values are presented separately for stressed and unstressed vowels; on the right, F1 and F2 values are pooled over stress conditions. All data for male speakers only.

	Stressed and Accented Vowels		Unstressed Vowels		Pooled Data	
	F1 (Hz)	F2 (Hz)	F1 (Hz)	F2 (Hz)	F1 (Hz)	F2 (Hz)
[i]	340	2046	322	2088	331	2067
[e]	491	1788	463	1745	477	1767
[a]	738	1350	692	1280	715	1315
[o]	508	1020	475	1002	492	1011
[u]	349	996	338	926	344	961

Table 7. On the left, F1 and F2 values (in Hz) for the five vowels of Greek separately for male and female speakers (after Sfakianaki 2002); the data are averaged over stress and position in the word. On the right, F1 and F2 values in Hz for the five vowels of Greek in spontaneous speech averaged over stress and position in the word (after Nicolaidis 2003b).

	Sfakianaki 2002				Nicolaidis (2003b)	
	Male speakers		Female speakers		Male speakers	
	F1 (Hz)	F2 (Hz)	F1 (Hz)	F2 (Hz)	F1 (Hz)	F2 (Hz)
[i]	423	2073	469	2571	360	1892
[e]	601	1811	687	2231	475	1672
[a]	736	1466	873	1699	575	1453
[o]	583	1137	657	1219	462	1202
[u]	434	921	451	955	377	1163

A comparison of the acoustic data for male speakers presented in Tables 6 and 7, and illustrated for clarity in Figure 2, reveals general differences some of which are not easy to explain. In particular, a comparison of Sfakianaki's (2002) male data with those Fourakis's et al. (1999), shows that all vowels in Sfakianaki's study are substantially lower, while at the same time the back vowels are more peripheral than those of Fourakis et al. (1999). It is not clear why such a difference would be present. On the other hand, the reduced and centralized vowel space in Nicolaidis (2003b) can be plausibly attributed to the fact that her data came from spontaneous speech rather than isolated sentences or words (for such differences between isolated sentences and running speech, see Nicolaidis 1991, 1994, 1997a).

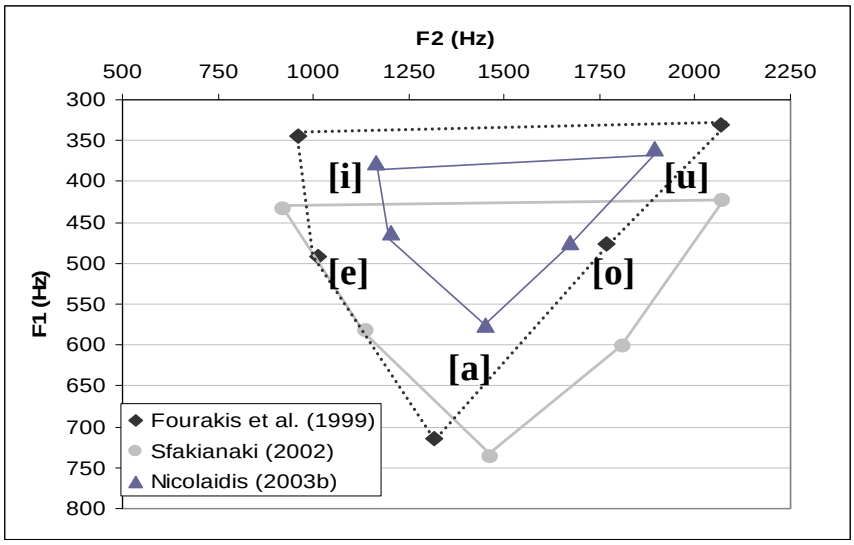


Figure 2. F1 × F2 plots of the five Greek vowels [i e a o u] as produced by male speakers; values are averaged across stress conditions.

Such differences proliferate as the number of studies increases and make it difficult to reach a conclusion particularly about the acoustic quality of the mid vowels of Greek /e/ and /o/ which seem to be the ones showing the greatest degree of variability. The results of Fourakis et al. (1999) suggest that /e/ and /o/ are phonetically between high-mid and low-mid vowels, and that [o] is somewhat lower in quality than [e]. On the other hand, Botinis (1981) presents F1 average values for [o] and [e] at 460 Hz and 465 Hz respectively; these values are very similar to those reported in Fourakis et al. (1999), but suggest that there is no height difference between [e]

and [o]. In contrast, the results of Sfakianaki (2002) show substantially higher F1 values for both vowels suggesting that [e] and [o] are "true" low-mid vowels, with [o] showing a somewhat more open quality than [e]. On the other hand, the perceptual study of Hawks and Fourakis (1995), discussed in more detail in 3.3, places [o] higher than [e]. This is also the line taken in Arvaniti (1999a) on the basis of auditory data,[7] and it is also supported by the data of Nicolaidis & Rispoli (2005) and Baltazani (2007a). It is not clear why these differences would exist from study to study, though I offer some *possible* reasons in 3.4 below. Tentatively, the gross position of the five vowels on the vowel quadrilateral can be illustrated as shown in Figure 3.

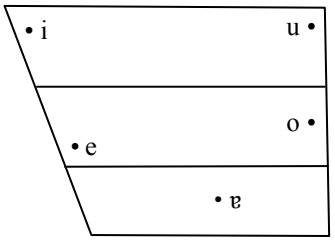


Figure 3. The position of the Greek vowels on the vowel quadrilateral.

Several studies examine the effects of stress, speaking rate and context on the quality of Greek vowels, but in some cases again their results are not in agreement with one another. Regarding the effects of stress on vowel quality a number of early studies (Samaras 1974, Dauer 1980a, Tseva 1989, Arvaniti 1991a, 1991b, 1994, 2000) suggest that any differences in vowel quality due to stress are minimal in Greek. On the other hand, Fourakis et al. (1999), Nicolaidis & Rispoli (2005), Baltazani (2007a) and Nicolaidis & Sfakianaki (2007) report that stress significantly affects vowel quality, though studies do not always agree on what the effects are. According to Fourakis et al. (1999) unstressed vowels have overall lower F1, which would suggest that they are all higher in quality than their stressed counterparts. On the other hand, Nicolaidis & Rispoli (2005) report a lowering of F1 in unstressed position for [a], [o] and [e], but not for [i] and [u]; they also report a lowering of F2 for all vowels except [u]; overall, their results suggest a smaller more centralized vowel space for unstressed vowels. Similarly, Baltazani (2007a) reports that lack of stress results in an overall reduction of the vowel space, suggesting more centralization for all vowels (and therefore lower quality for the high vowels [i] and [u] and higher quality for at least the low vowel [a]). Indeed her data show that unstressed Greek vowels overlap to a great extent and that this overlap can exhibit different patterns across

speakers: e.g., in unstressed syllables immediately following the stressed one, one speaker shows extensive overlap between [i] and [o], while the other speaker shows overlap between [o] and [u] and, to a certain extent, between [e] and [a]. The results of Nicolaidis (2003b), on the other hand, show extensive overlap especially among [e] [o] and [a], since [a] is raised and [e] and [o] become more centralized, further supporting the view that individual variability may be quite substantial among Greek speakers, particularly regarding the quality of unstressed vowels. Overall, these results largely agree with data from Dutch (Sluijter and van Heuven 1996), and English (Campbell & Beckman 1997) regarding the higher F1 of stressed vowels, though it should be noted that the differences reported in most studies of Greek are not as great as those found in other languages (cf. Hillenbrand et al. 1995 for American English), and they are certainly not phonologized as in English.

Other effects on vowel quality, particularly coarticulatory effects, are less well-studied. Nicolaidis (1999a, 2003b) shows that consonants can affect the quality of vowels, but her results are based on two speakers and since the effects can be quite speaker-specific it is difficult to draw firm conclusions on the effects of consonant place and manner of articulation on vowel production. On the other hand, Nicolaidis (1999b) shows that vowel quality is influenced not only by consonants but also by other vowels, in a way that interacts with stress and the quality of the intervening consonant: in two syllable words of the form CVCV in which the stressed vowel could be either in the first or the second syllable, Nicolaidis (1999b) found that the stressed vowel exerted both anticipatory and carry-over coarticulatory effects on the unstressed vowel but not vice versa. Further, the effects of the stressed vowel on the unstressed vowel depended on the intervening consonant: in most cases, the influence of the stressed vowel on the unstressed one was greater when the intervening consonant was [p]—the production of which does not require the use of the tongue—and reduced when the consonant was [t]—which requires relatively precise placement of the tongue tip and blade. Finally, Diakoumakou (2004) shows that vowels abutting nasal consonants show extensive carry-over nasalization in Greek, but little anticipatory nasalization whether the vowel and nasal are hetero- or tautosyllabic. Similarly Nicolaidis (2001:74) mentions that nasalization is evident on vowels "neighboring" nasal consonants but without specifying the position of the vowels relative to the consonants. Overall these studies do not yet present a complete picture of what coarticulation is like in Greek: more studies, with more speakers and a variety of contexts, are necessary before firm conclusions can be reached.[8]

In addition to effects on quality, many studies report on the effects of speaking rate, stress, word length and prosodic context on the duration of Greek vowels. Generally, vowels shorten as speaking rate increases (Fourakis et al. 1999), and appear to be more affected by speaking rate than consonants (Arvaniti 2001c). The duration of vowels is also affected by word length, with vowels in longer words being shorter than vowels in shorter words (Baltazani 2007a). Similar effects of word length on segmental durations have been observed in other languages, such as English (Nakatani, O'Connor & Aston 1981) and Japanese (Beckman 1982).

Table 8. Durations of Greek vowels in stressed and unstressed position after Arvaniti (1991a, 2000), Fourakis et al. (1999), Nicolaidis (2003b). In Nicolaidis (2003b) duration values are pooled over stressed and unstressed vowels.

Vowel	Stress	Arvaniti (1991a, 2000)	Fourakis et al. (1999)	Nicolaidis (2003b)
[i]	stressed	106	76	69
	unstressed	77	44	
[e]	stressed	113	94	81
	unstressed	85	57	
[a]	stressed	126	105	85
	unstressed	89	78	
[o]	stressed	123	94	78
	unstressed	96	67	
[u]	stressed	120	88	60
	unstressed	89	54	

In addition, it is generally agreed that stressed vowels are longer than unstressed vowels, as shown in Table 8 (Dauer 1980a, Botinis 1989, Arvaniti 1991a, 1991b, 2000, Fourakis et al. 1999, Nicolaidis & Rispoli 2005, Nicolaidis & Sfakianaki 2007, Baltazani 2007a). According to Dauer (1980a) this difference results in a 30% reduction in duration between stressed and unstressed vowels, while Fourakis et al. (1999) report a 40% reduction in duration. In addition, the duration of both stressed and unstressed vowels is affected by context. Stressed vowels lengthen in stress clash conditions, that is, when in a syllable immediately followed by another stressed syllable (Arvaniti 1991a, 1994, 2000). Stressed vowels are also longer when they are found in word-initial syllables compared to stressed vowels that appear later in a word (Fourakis 1986a). The duration of unstressed vowels, on the other hand, is affected primarily by their position relative to the stressed syllable: unstressed vowels immediately preceding a stressed

syllable are consistently longer than unstressed vowels immediately following a stressed syllable (Dauer 1980a, Arvaniti 1994, Baltazani 2007a). The latter show a more reduced vowel space and extensive overlap and can be so reduced that they are altogether elided (Baltazani 2007a).

Dauer (1980b) reports extensively on a specific type of vowel reduction, the reduction observed in the high vowels [i] and [u] in unstressed position. She suggests that the reduction of those vowels can take one of four forms depending largely on context and speaking style: (a) [i] and [u] can appear as very short full vowels (less than 30 ms long); (b) between obstruents, but also between an obstruent and a sonorant, [i] and [u] can be voiced but so reduced in amplitude that only the first formant can be seen in spectrograms; (c) [i] and [u] can appear as whispered vowels between voiceless obstruents (a realization noted for [u] in particular by Nicolaidis & Rispoli 2005 as well); (d) [i] and [u] can be completely elided but leaving behind coarticulatory cues of their existence so that they are "heard" by the native speakers. Reduction is more widespread if [i] and [u] are placed in syllables immediately following the stressed one (Dauer 1980b, Baltazani 2007a). Dauer found no correlation between speaking rate and vowel reduction scores, though this observation is based on comparing speaking rates across her three speakers, not within speaker, so her conclusion may be due to a confound between speaking rate and speech clarity (for a distinction between clear speech and slow speech see Bradlow 2002). Indeed Dauer mentions that speaking style is more important than rate: a more careful style resulted in more whispered vowels, while less careful speech resulted in more elisions.

More recent results by Tserdanelis (2003) indicate that high vowel reduction—and possibly the reduction of the other vowels as well—may be also related to prosodic phrasing. Specifically, Tserdanelis (2003) examined the patterns of reduction of the vowel [u] in the clitic [su] which can be either a possessive enclitic ("your") or a proclitic personal pronoun ("to you").

(3) [o ðiciˈɣoros su paˈreðose …]

Tserdanelis constructed similar sentences in which the clitic could be construed as either enclitic to the noun immediately preceding it or as proclitic to the verb following it, so that (3) could mean "your lawyer delivered (something)" or "the lawyer delivered to you (something)". Tserdanelis provided his subjects with contexts that would favor one or the other interpretation, but instructed them not to try to disambiguate the two readings by inserting a pause before or

after [su]. He found that the speakers disambiguated the two readings intonationally (by aligning a continuation pitch rise either before or with [su]), but also by producing [u] in two distinct ways: when [su] was a proclitic, and therefore phrase-initial, the speakers significantly reduced the duration of [u] (by about 50% relative to the duration of a canonical unstressed [u]) and devoiced the vowel at least partially; when [su] was an enclitic, and therefore phrase-final, [u] was fully voiced and of regular length. The results of Tserdanelis show that taking prosodic position into account when examining vowel devoicing in Greek is going to be crucial for fully understanding this phenomenon.

Finally, in addition to other types of changes, the high front vowel /i/ is noted for two realizations that are dependent on its position in a syllable. Specifically, /i/ is realized as a vowel when it is the nucleus of a syllable, but as a palatal fricative if found between a labial or coronal obstruent and another vowel. The voicing of this fricative depends on the voicing of the preceding consonant (an indication that in such cases non-vocalic /i/ becomes part of the syllable onset); thus /i/ is realized as a voiced palatal fricative [ʝ] (and not as a glide, as shown in 2.4 above) when the preceding obstruent is voiced—e.g., [ˈlaðʝa] "oils"—and as a voiceless palatal fricative [ç] if the preceding obstruent is voiceless, e.g., [niˈsça] "islands".

It should be noted that in classic phonological descriptions of Greek, a "yod" ([j]) phoneme is posited instead (e.g., Newton 1972, Joseph & Philippaki-Warburton 1987). A discussion of the phonemic status of yod is beyond the scope of this paper. Keeping with surface facts, my position here is that the palatal fricatives [ʝ] and [ç] are allophones of two different phonemes: (a) of the velar fricatives [x] and [ɣ] respectively when there are found before the high vowels [i] and [e], as in [ˈçeri] "hand", [ʝeˈri] "strong, fem."; (b) of the vowel /i/ when it is not a syllable nucleus. Not everyone agrees with this analysis, even if they reject the "yod" analysis. For example, according to Holton et al. (1997) the realization of /i/ as a vowel or as a non-vocalic segment depends on stress. However, their own data show that the facts are more complex than that and depend on syllabification rather than stress. Thus, although it is correct that if /i/ is followed by a stressed vowel it is pronounced as a fricative (e.g., [peˈðʝa] "children"), this only happens if /i/ can syllabify as part of the syllable onset; if it cannot, it remains vocalic, as in [a.ɣri.ˈa.ða] "savagery" in which the two possible onset slots of the second syllable are

already occupied. Similarly, /i/ can surface as a fricative when followed by another vowel even if that vowel is not stressed, as in the first and last syllable of [ðja'kosçi] "two hundred, masc.". (For an up-to-date discussion of the sociolinguistic value of the [i]~[j] alternations, see Rytting (005; for alternative phonological analyses, see Deligiorgis, 1987, and Malikouti-Drachman & Drachman,1990; Malikouti-Drachman, 2001, presents a review of this topic.)

3.2 F0, amplitude, and the Greek vowels

In addition to typical measurements of duration and formant frequencies, several studies (e.g., Dauer 1980a, Botinis, Fourakis & Katsaiti 1995, Fourakis et al. 1999, Nicolaidis & Rispoli 2005, Papazachariou & Politis in press) report on other phonetic measures relating to vowels, specifically peak amplitude, Root Mean Square amplitude (henceforth RMS, roughly, the "average" amplitude of a sound), and average fundamental frequency (henceforth F0). I will not discuss these measurements in great detail here, but it is worth explaining why.

First, some of these measurements, such as peak amplitude have been repeatedly shown not to be accurate measurements of the loudness of a sound and thus they are best avoided (for reviews, see Beckman 1986:Chap.5, Johnson 2003:31). RMS measurements, on the other hand, do have the advantage of more accurately representing loudness, although they do not take into account the interaction of amplitude and duration which results in a sound being perceived as louder than another sound with the same RMS, if the former is longer than the latter (Lieberman 1960, Beckman 1986, Arvaniti 1991a, 2000, Gordon 2002). In addition, as far as I know, Greek does not manipulate amplitude linguistically, that is, it does not contrast more and less loud vowels of the same quality and duration, so measurements of RMS *on their own* are not likely to provide us with much insight (though they are necessary for some experimental protocols, such as the investigation of noise in speech production undertaken by Nicolaidis & Rispoli 2005).

Similarly problematic, except in some circumstances, seem to be measurements of average F0. Greek is an intonation language, in which the F0 of each syllable depends on the melody that is used for the utterance and is not a property of the syllable itself (for extensive argumentation on this point, see Arvaniti et al. 2006a, Arvaniti 2007a, Arvaniti & Ladd, subm.). Figure 4 illustrates this point: in Figure 4(a), F0 is high on the stressed vowel of [pa'raθira] in the

question [sto ˈspiti me ta ˈble paˈraθira] “the house with the blue windows?” (which asks about the color of the windows of the house I am referring to), but low and falling in the question [sto ˈspiti me ta ˈble paˈraθira] (which asks about whether it is the windows of the house that are blue, or some other structure). Although such a difference is meaningful and systematic (see e.g., Arvaniti 1998a, 2002, Arvaniti et al. 2006a), it does not constitute a characteristic of the vowel [a], as the same vowel will be found in a host of contexts the F0 of which can vary a great deal. Most importantly perhaps, at least some of this variation is not linguistically meaningful but simply the result of the context in which a given vowel is found intonationally. For instance, the F0 of the vowel [a] in the first syllable of [paˈraθira] “windows” is low in Figure 4(a), but high falling in Figure 4(b) and thus in the former case [a] will have lower average F0 than in the latter. This difference, however, is neither meaningful nor significant, but simply the result of the unspecified F0 of that particular syllable and the fact that in Figure 4(a) it is found between [ble] “blue”, which is specified to have low F0, and [ra], which is specified to show a rise from a low point. On the other hand, in Figure 4(b), the same syllables, [ble] and [ra], have different intonational specifications: [ble] has low and rising F0, while [ra] is specified to be low; as a result the intervening [pa] is produced with a high fall. Therefore, such average F0 measures do not provide helpful information regarding the Greek vowel system; at best average F0 can be considered as a characteristic of each vowel only in the sense that in most languages high vowels tend to have somewhat higher F0 than low vowels when produced in isolation, or when *all aspects of prosody are the same*, a phenomenon known as *intrinsic F0* (Reinholt Petersen 1978, Thorsen 1985, Whalen & Levitt 1995).[9] In this respect, such F0 measures for Greek vowels at best can tell us that, under constant prosodic conditions Greek vowels follow universal trends in intrinsic F0.

3.3 The perception of Greek vowels

Our knowledge of how Greek vowels are perceived is based on three studies, Jongman et al. (1989), Hawks & Fourakis (1995), and Botinis, Fourakis & Hawks (1997). Jongman et al. (1989) compared Greek and German vowels by placing vowels produced by native speakers of these languages onto a three dimensional auditory-perceptual space. The resulting vowel space for

Greek shows well separated [i], [e] and [a], with [a] being a central vowel and [o] and [u] being distinct but quite close together (a configuration that leads credence to the idea of [o] being a higher vowel than [e] and is consistent with the results of some production studies, such as Nicolaidis 2003b and Baltazani 2007a). On the other hand, the vowel space of German, which has a much larger vowel inventory, showed that vowels are more variable and closer to each other.

(a)

(b)

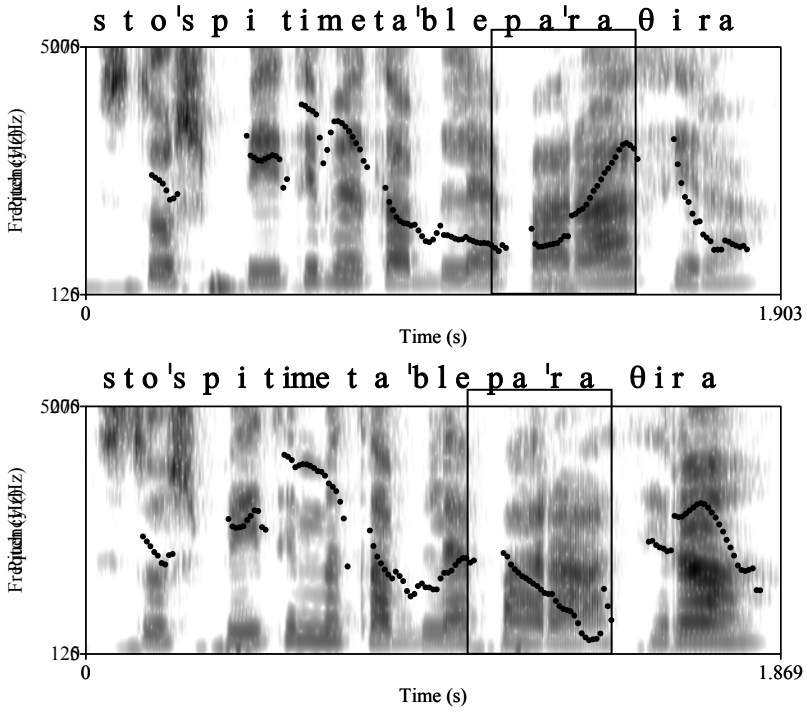


Figure 4. Spectrograms and F0 contours of the phrase [sto ˈspiti me ta ˈble paˈraθira] "in the house with the blue windows" with focus on [ble] "blue" (top) and on [paˈraθira] "windows" (bottom). The first two syllables of [paˈraθira] "windows" are boxed for ease of reference.

Results consistent with those of Jongman et al. (1989) were obtained by Hawks & Fourakis (1995) who compared the perceptual vowel space of American English and Greek by asking ten American and ten Greek speakers to listen to synthetic vowels and classify them as either examples of a vowel of their language or as vowels that are not part of their inventory. The results showed that the Greek vowel space includes clearly separated areas for each vowel, while the American vowel space—which includes approximately three times as many vowels—is more

"crammed" so that vowels although still separated often abut each other in the perceptual space. It is particularly interesting to note that in Hawks & Fourakis (1995), the Greek and American listeners behaved similarly in many respects except one: the American speakers accepted a large number of stimuli as possible vowels of their language, consistent with the idea of a crowded perceptual space in which the boundaries between vowels are very close, while the Greek listeners had distinct and peripheral vowels, and rejected a large number of stimuli as not belonging to their language. These results were largely replicated with four female listeners in Botinis et al. (1997). Most interestingly, the vowels that showed the most spread among listener responses were [e] and [a], two vowels that seem quite variable in production as well (Nicolaidis 2003b, Baltazani 2007a).

The above results have been used by the authors to argue against Lindblom's theory of dispersion (Lindblom 1986), according to which a language with a large vowel inventory would circumscribe small acoustic spaces for each vowel in order to keep them distinct in production and perception, while a language with a smaller inventory can allow its vowels more leeway as they are less likely to be confused. The Greek data reviewed here cast doubt on this theory by showing comparatively little variation in production and rather tightly organized perceptual categories for Greek, which has a small vowel inventory. This has important repercussions for our understanding of the development and structure of sound systems; in particular, it shows that functional explanations, such as inventory size, do not necessarily drive either production or perception.

A question that arises, however, when one compares these perceptual results with those of the production studies reviewed in section 3.1., is why the former show such a concentrated vowel space for Greek, while the production studies reveal a fair degree of variability. The reason appears to be that the production and perception studies tap into distinct levels of processing. On the one hand, production studies aim at uncovering variability: they provide the speakers with a variety of contexts (speaking rate, stress, intonation) in which they are to produce the vowels and then examine the phonetic details of the vowels produced. On the other hand, in perceptual studies such as those of Hawks & Fourakis (1995) and Botinis et al. (1997), the listeners' task is removed from this level of phonetic detail in that the listeners are asked to match each stimulus to some standard version of each vowel of their language; in other words, this type of study probably taps into prototypical representations that are associated with distinct

phonological categories, rather than accessing the initial level of processing during which listeners make use of the phonetic detail in the incoming signal (on the use of such prototypical representations in perception, see Blumstein, Myers and Rissman 2005). This view is supported by the fact that the same effect is observed in the English data as well: the perceptual vowel space for English in Hawks & Fourakis (1995) shows spaces for individual vowels that are close but separate, while the acoustic vowel space maps of Hillenbrand et al. (1995) show quite a lot of overlap between categories.

3.4 Greek vowels: summary

To summarize, although we now know a fair amount about the acoustics of Greek vowels, several questions still remain unanswered. First, we need to account for the variability in formant values reported in the existing studies. Quite possibly the differences have to do with a host of factors, some of which at least are not fully understood. For instance, the results so far show that vowel duration and reduction are influenced by stress, position in the word, word length, prosodic position, speaking rate and speaking style. Furthermore, it is clear that when these factors conspire to make vowels shorter, the shortening results in more centralized vowels that can show a substantial degree of overlap in the vowel space (Nicolaidis 2003b, Baltazani 2007a). This variability in quality is also related to coarticulatory influences from other vowels and from consonants. Despite this long list of factors that can influence the quality and duration of vowels, few are controlled in the existing studies; e.g., Fourakis et al. (1999) do not have data for normal speaking rate, while in one of the experiments reported in Arvaniti (2000) word-final stressed syllables are in a stress clash context (i.e., immediately followed by another stressed syllable). In addition, results may be presented in ways that make direct comparisons across studies difficult if not downright impossible, as when formant values are not given separately for stressed and unstressed vowels, as in Sfakianaki (2002) or Nicolaidis (2003b).

Further many of the studies either do not take into account or do not control for certain factors that can have a large effect on vowels, namely speaker gender and dialect. Most of the studies rely on male data only, while in others no systematic distinction is made between data elicited from males and females (e.g., Papazachariou & Politis in press present formant values for male and female speakers together making the comparison with other studies impossible). A

related factor that is now understood to affect vowel quality in English is sexual orientation (Pierrehumbert et al. 2004, Munson 2007). Although it is not to be expected that sexual orientation is manifested in speech in the same way across languages, the issue is worth investigating further, or at least taking into account when the Greek vowel system is examined.

Equally importantly, the effect of the dialect spoken by the subjects is often underestimated. Thus many studies report that the data were elicited from speakers with no local accent (e.g., Hawks & Fourakis 1995, Nicolaidis 2002b, Sfakianaki 2002), yet in many cases the authors mention that their speakers come from various parts of Greece. Although various works claim that the differences between many Greek dialects are negligible at this point (e.g., Contossopoulos 2001), we know from a variety of recent studies (e.g., Hagiwara 1997, Clopper et al. 2005, Atterer & Ladd 2004, Arvaniti & Garding 2007) that accent can affect minute details of production which may not be easily detectable aurally and thus not sufficiently strong to become sociolinguistic markers. A case in point is the discrepancy among studies regarding the quality of the mid vowels, [e] and [o]. If the data of some studies were elicited from Athenian speakers, while those of others were elicited from speakers from Thessaloniki or other parts of Northern Greece, it is possible that acoustic differences would be present, although the two groups of speakers may sound almost identical to the ear. In particular, given what we know about mid-vowel raising in northern varieties of Greek, it is possible that speakers from Northern Greece have mid vowels of a closer quality than the Athenian speakers.

In addition, changes in the system itself may be a reason for some discrepancies among studies, such as the disagreement regarding the degree of unstressed vowel centralization. In particular, it is somewhat surprising that Dauer (1980b) found less reduction, both in quantity and in quality, in natural speech than Fourakis et al. (1999) and Baltazani (2007a) found in lab speech; more careful and elaborate styles of speaking are expected to show less reduction overall (a result that is supported for Greek by the data of Papazachariou & Politis in press who compared the speech of newscasters and lay speakers). One possible reason for this difference on vowel reduction between earlier and more recent studies, for which I am only based on my own impressionistic observations at this point, is that vowel reduction is becoming more prevalent, especially among younger male speakers. If this is the case, then the discrepancies between studies from the early 1980s and studies conducted almost a quarter of a century later could be

due to changes in the system itself. Such possible stylistic changes would certainly be worth investigating further.

More generally, we need to study in more detail the parameters that affect vowel quality and reduction in particular, both in quality and in quantity. So far, most studies examine vowels in words that carry the nucleus in short sentences (i.e., they are the words in focus), a position that has been shown to result in hyperarticulation (e.g., Beckman & Edwards 1994, de Jong 1995, Sluijter & van Heuven 1996). Given such findings, it is important, if we want to understand the full range of vowel reduction in Greek, to examine vowels in other prosodic positions in a systematic way, taking various sociolinguistic factors into account as well. In addition, as far as I know, the role of reduced and elided vowels in perception and in language acquisition has not been investigated to any extent in Greek, yet reduced vowels pose interesting problems for acquisition and recoverability which are certainly worth investigating. Thus, studying vowel reduction in Greek from a sociophonetic, acquisitional and perceptual perspective would be a fruitful enterprise, not only for Greek linguistics but more generally as well.

Finally, as already mentioned, the perceptual results on the Greek vowels pose an interesting problem for our current understanding of how linguistic systems are constructed and for our understanding of the relationship between production and perception. It would be worth studying in more detail the perception of Greek vowels using different experimental protocols that can tap into different levels of processing. The results of such experiments would not only contribute to our knowledge of Greek phonetics, but could well shed light onto the issue of how phonetic categories are created, organized and used during speech processing.

4. Stress

4.1 The phonetics of Greek stress

It is generally agreed that Greek words carry only one stress, on one of their last three syllables (among many, Setatos 1974, Householder et al. 1964, Warburton 1970a, Joseph & Warburton 1987, Holton et al. 1997). The position of stress is largely determined by morphology and is phonologically unpredictable, though some patterns are more frequent than others (Revithiadou 1998, 1999). Compared to languages like English, stress in Greek bears a significant amount of

functional load, in that there are several pairs and even triplets of words distinguished solely by stress location, as in [xaˈmoʝela] “smiles, n.”, [xamoˈʝela] “smile, imper.”, [xamoʝeˈla] “s/he smiles”.

Stress should not be confused with orthographic accent (as is sometimes done, e.g., by Nespor & Vogel 1989). As Arvaniti & Baltazani (2005) discuss, all content words in Greek have a stressed syllable, but most multisyllabic function words are stressless in running speech (independently of whether they are orthographically accented or not), although there are exceptions: thus, *από*, which bears orthographic accent, is rarely stressed in speech and is typically cliticized to its complement NP; the stresslessness of [o] is also indicated by the fact that in running speech it is often elided before articles; e.g., /apo tin eˈlaða/ > [aptineˈlaða] “from Greece”. On the other hand, the monosyllabic negative particles [ðen] and [min], which are not accented in writing, are stressed in speech, and in many cases carry the most prominent stress of the utterance (Arvaniti & Baltazani 2005, Baltazani 2003a, 2006a). It is also possible to find homonyms, one of which is stressed while the other is always cliticized; e.g., in (4)-(6) below the underlined function words have stress on the syllable that bears orthographic accent, while the functions words in (7)-(9) are cliticized (see also Setatos 1974 and Arvaniti & Baltazani 2005 for similar remarks).

(4) [paˈdreftikan <u>paˈra</u> tis adiˈrisis toŋ ɣoˈɲon tus] “They got married <u>despite</u> their parents objections”

(5) [ˈime <u>kaˈta</u> tis θanatiˈcis piˈnis] “I am <u>against</u> the death penalty”

(6) [θa ˈftaso <u>meˈta</u> tis ˈteseris] “I’ll arrive <u>after</u> four”

(7) [ˈine ˈtris <u>para</u> ˈpede] “It is five to three”

(8) [θa ˈime eˈci <u>kata</u> tis eˈftamisi] “I will be there around seven thirty”

(9) [tin ipoˈðextikan <u>meta</u> vaˈion ce ˈklaðon] “they welcomed her with a lot of fanfare” *lit*. “<u>with</u> laurels and branches”

Traditionally Greek stress is said to be "dynamic" (e.g., Setatos 1974), although it is not always absolutely clear what this might entail from the point of view of acoustics or articulation. According to Mirambel (1959) stress in Greek results in higher, longer and louder vowels. Householder et al. (1964:3) say that "Greek […] has distinctive accent (loud stress combined with high pitch)", while according to Thumb (1964:29) "[t]he Modern Greek accent may generally be termed expiratory or stress, though the musical element is not quite absent". According to Joseph & Philippaki-Warburton (1987:242) stressed syllables in Greek are louder, somewhat longer and have "some degree of high pitch". On the other hand, Mackridge (1987) claims that vowels do not change quality when stressed and are not longer, except minimally, so stress is primarily manifested as loudness. Finally, Holton et al. (1997:16) say that "stress is manifested by extra loudness on the stressed syllable, clearer quality of the vowels and some slight lengthening."

The acoustic study of stress in Greek has been the focus of Dauer (1980a), Botinis (1982a, 1989) and Arvaniti (1989, 1991a, 1991b, 1992, 1994, 2000), while results relating to stress are also reported in Botinis, Fourakis & Prinou (1999), Botinis et al. (1995), Fourakis et al. (1999), Botinis, Fourakis & Bannert (2001), Kastrinaki (2003), Nicolaidis & Rispoli (2005), Baltazani (2007a), and Papazachariou & Politis (in press). Although these studies vary in the number of stress correlates they examine and the results they yield, they generally show that Greek stressed vowels are 30-40% longer than unstressed vowels, and this difference is usually reflected in the overall duration of syllables. In addition, stressed vowels have higher amplitude than unstressed vowels, a direct result of the higher subglottal pressure used for stressed syllables, according to Botinis (1982b, 1989). However, as neither duration nor amplitude appears to be consistently greater in stressed than in unstressed vowels—at least in the studies of Dauer (1980a) and Arvaniti (1991a, 2000), though not in that of Botinis (1989)—Arvaniti (1991a, 2000) argues that it is best to see *amplitude integral*—a measure that sums up amplitude and duration and gives a good indication of the loudness or "prominence" of a sound—as the most representative correlate of stress in Greek (for a similar treatment of English stress, see Lieberman 1960 and Beckman 1986). To put it simply, this would mean that Greek stressed syllables must be more prominent than unstressed syllables; speakers have the option of achieving this greater prominence either by making the stressed syllables louder, or by making them longer, or by a combination of the two.

In addition, as mentioned earlier, Greek vowels have been reported to be not only shorter but also centralized in unstressed syllables (Fourakis et al. 1999, Nicolaidis 2003b, Nicolaidis & Rispoli 2005, Baltazani 2007a). As yet, it is not clear why there is a discrepancy between these studies and several other studies that report minimal quality differences (Samaras 1974, Dauer 1980a, Tseva 1989, Arvaniti 1991a, 2000). Nevertheless, the results generally suggest that stressed vowels must be produced with *localized hyperarticulation* (de Jong 1995) as in other languages. Hyperarticulation results in more extreme quality (e.g., Beckman & Edwards 1994) and could lead to different spectral characteristics for the stressed vowels, particularly changes in spectral tilt—that is a boosting of higher frequencies that are typically low in amplitude (Sluijter & van Heuven 1996 for Dutch, Campbell & Beckman 1997 for English). This interpretation is in line with the results of Fourakis et al. (1999) and Nicolaidis & Rispoli (2005) who found that most Greek vowels exhibit higher F1 when stressed than when unstressed; this acoustic result is consistent with a more open jaw for stressed vowels that could result in spectral tilt. On the other hand, the more centralized quality reported by many studies for unstressed vowels is most probably the result of their short duration which does not allow articulators to achieve extreme positions; e.g., a short unstressed [a] may not show as great jaw lowering as a stressed [a]. However, we still lack articulatory measures and even acoustic measures such as spectral tilt that would allow us to determine with greater accuracy the differences between stressed and unstressed vowels in Greek. On the other hand, it should be noted that our overall understanding of the Greek vowel system and the effects of stress (or lack thereof) on vowel duration and quality, strongly suggest that quality plays at best a small role in signaling stress in Greek, especially when compared to a language like English in which vowels enter in regular alternations with the reduced vowel schwa [ə] and, to a lesser extent, [ɪ] (for a discussion, see Beckman & Edwards 1994). This conclusion is supported by the results of Botinis (1989) on the perception of stress: Botinis did not manipulate vowel quality differences but this did not seem to affect responses, in that listeners easily identified the location of stress on the basis of amplitude, duration and F0 alone (for details see section 4.2).

Effects of stress on consonants are less well understood than those on vowels. Many studies have measured consonant durations in stressed and unstressed syllables and show that consonants are longer when in stressed syllables, though the effects are not as consistent as on the vowels (Fourakis 1986a, Botinis 1989, Arvaniti 1991a, 2000, Botinis et al. 2001). This may

partly be due to the consonants used. For instance, Fourakis (1986a) and Arvaniti (1991a, 2000) examined stressed syllables with voiceless stops in onset position. As mentioned earlier, Greek voiceless stops have short-lag VOT which has been shown to be resistant to durational changes; this is reported for Greek by Fourakis (1986a), who found neither stress nor speaking rate effects on VOT duration for [p] and [t], and strongly supported by the results of Kessinger & Blumstein (1997) who show that short-lag VOT in French and Thai is not affected by changes of speaking rate, but long-lag VOT in Thai is; similar results for Greek VOT (and a difference in speaking rate effects on short- and long-lag VOT in Cypriot Greek) are also reported in Arvaniti (2001c). This resistance to change seems to be related to the fact that changes in VOT length would place a stop in a different category: lengthening VOT could turn a stop from unaspirated to aspirated, while shortening short-lag VOT could result in *negative* VOT, that is, stop voicing. If the VOT of Greek stops is not affected by changes of speaking rate, it is also likely that it remains unaffected by stress for the same reasons and not because stress *per se* does not affect consonant duration. Supporting evidence comes from the results of Fourakis (1986a) that the VOT of [k]—which is substantially longer than that of [p] and [t]—does show stress-related durational changes. However, since we do not yet have published data on the durations of all consonants in prosodically comparable stressed and unstressed position it is not clear to what extent we can generalize from these findings to the effect of stress on all Greek consonants. Given previous results on the effects of speaking rate on consonant duration (Fourakis 1986a, Arvaniti 1999b, 2001c), I venture to suggest that consonants the articulation of which can be easily shortened or lengthened without affecting quality (fricatives, nasals and [l]) should also show consistent lengthening when in stressed syllables, while consonants with articulations that impose durational limits (stop VOT and the tap [ɾ]) would not be significantly affected by stress in terms of their duration (though they may be affected in other ways; cf. the approximant articulation of the tap in unstressed syllables discussed in 2.3).

4.2 The role of pitch in stress production and perception

It has often been suggested that stress is cued by "rises in pitch," "high pitch" and the like (Fry 1958 for English; for Greek, Householder et al. 1964, Joseph & Warburton 1987, Nespor & Vogel 1989, Papazachariou & Politis, in press). Although this is often seen as an uncontroversial

position, it has been known for some time that stress in Greek—as in many other languages—is not cued by pitch, except indirectly. This is clearly shown in Botinis (1989, 1998) who examined the production and perception of stress in declaratives. Specifically, Botinis tested the production of stress in the minimal pair [ˈnomo]~[noˈmo] "law"~ "county" in the sentence [i maˈria ˈiksere to *nomo* kaˈla] "Maria knew the law/county well", in which manipulations in the position of focus placed the test words in *focal*, *prefocal* and *postfocal* position (e.g., in [i maˈria ˈiksere to ˈnomo kaˈla] "MARIA knew the law well", [ˈnomo] is in postfocal position). Botinis showed that in focal and prefocal position stressed syllables are produced with a pitch rise (a point discussed in more detail in section 7 below), while in postfocal position F0 is flat and low. Now, if F0 is the main cue to stress, we should find minimal acoustic differences between [ˈnomo] "law" and [noˈmo] "county" postfocally. The results of Botinis, however, show that in this position the distinctions in amplitude and duration between stressed and unstressed syllables are the same as in focal and prefocal position, clearly demonstrating that pitch changes and stress are independent of each other (for a more detailed analysis of this point, see Arvaniti 2000).

In addition, if F0 is a cue to stress, listeners should experience at least some difficulty in distinguishing minimal pairs postfocally, even if some acoustic cues to stress are present. This is not the case, however, as results on the perception of stress postfocally clearly demonstrate (Botinis 1989). Specifically, in Botinis (1989) amplitude and duration values both separately and together were switched from those of [ˈnomo] "law" to those of [noˈmo] "county" and vice versa, in the utterance [i maˈria ˈiksere to *nomo* kaˈla] "MARIA knew the law/county well", and Greek listeners were asked to identify the word they heard as [ˈnomo] "law" or [noˈmo] "county". Listeners were typically at guessing level when only duration or amplitude was manipulated, but clearly switched from one word to the other when both parameters were manipulated together. This result plainly supports the view that, as argued in Arvaniti (1991a, 2000), amplitude integral is a more robust correlate of stress in Greek than either duration or amplitude alone. Regarding the role of F0 in stress perception, it is obvious from this experiment that if high or rising pitch were necessary for a syllable to be perceived as stressed, it would be impossible, or at least very difficult, for the listeners to correctly identify the stressed syllable in these stimuli; as shown,

however, this was not the case. The interested reader can put these results to the test by producing Botinis's test sentence as a question with focus on [nomo]; in this case, [nomo] will have low F0 but the stress placement difference between [ˈnomo] "law" and [noˈmo] "county" will be easy to hear.

It should be noted that Botinis (1989) also tested the perception of stress in prefocal position and there he found that listeners switched from [ˈnomo] "law" to [noˈmo] "county" as the pitch contour changed from that appropriate for the former to that appropriate for the latter. In addition, in prefocal position, switching intensity, duration or both did not affect the listeners' responses unless F0 was changed as well: e.g., listeners reported they heard [ˈnomo] "law" when there was a pitch rise on [no], even if [mo] had higher amplitude and was longer than [no]. Botinis (1989) obtained similar results in an experiment in which the *timing* of the F0 rise was manipulated in prefocal position in such a way that the peak of the contour moved from the first to the second vowel of [nomo] and vice versa: in this case, there was a categorical switch from one to the other word as soon as the alignment of the F0 peak moved from one to the other syllable.

At first blush, these results appear to provide strong evidence for the widespread view that high pitch is a stress correlate, since F0 cues clearly override duration and amplitude. However, the relationship between F0 and stress in such cases is indirect: as Beckman (1986) has successfully argued, in languages in which stress is lexically determined but intonation is computed postlexically, such as English and Greek, listeners expect certain pitch movements to co-occur with stressed syllables. Thus, when they hear such a pitch movement (a *pitch accent*), they assume that the syllable it co-occurs with was meant to be stressed, even if it lacks the appropriate duration, amplitude or vowel quality. In other words, Greek speakers who hear a pitch accent on [mo] in the sequence [nomo] assume that the speaker meant to stress that syllable, and hear it as stressed even if in all other respects it does not fit the acoustic profile of a stressed syllable. It is only in this sense that we can say that F0 cues override duration, amplitude and quality information in the perception of stress.

4.3 Degrees and types of stress in Greek

An issue that has occupied both the phonetic and phonological literature on Greek stress is the number of degrees of stress that Greek exhibits. Phonological studies such as Malikouti-Drachman & Drachman (1981), Nespor & Vogel (1986, 1989), Nespor (1988), Revithiadou (1998, 1999) suggest that Greek has several degrees of stress.[10]

In particular, in phonological analyses, lexically stressed syllables are said to have primary stress; in addition, two types of postlexical stresses are posited, *secondary stress* and *rhythmic stress*. The appearance of secondary stress is associated with "enclitic" stress (a term that denotes the origin of this stress, rather than its prominence level). As is well known, enclitic stress appears on the penult of a host+enclitic group if the host is stressed on the antepenult (or the penult) and is followed by one (or two) enclitic(s); e.g., [afto'cinito] "car" but [afto'cini'to mu] "my car"; ['fere mu] "bring me" but ['fere'muto] "bring me it".

There is not complete agreement in the phonological literature regarding the degree of prominence associated with enclitic stress. According to most sources, when enclitic stress is added to a sequence, it becomes the most prominent stress, while the stress of the host is demoted to secondary stress (e.g., Malikouti-Drachman & Drachman 1981, Joseph & Philippaki-Warburton 1987). On the other hand, Nespor & Vogel (1986) analyze enclitic stress as secondary, with the stress of the host remaining the primary stress of the group; in their description, they follow Setatos (who, however, points out that the enclitic stress *can* be stronger than the lexical stress; Setatos 1974:55).

The two competing analyses regarding the relative prominence of lexical and enclitic stress were tested in Arvaniti (1992). Arvaniti compared sequences with two lexical stresses, as in (10), with segmentally identical sequences with one lexical and one enclitic stress (as in 11).

(10) ['ari 'stasu] "Ari stop"

(11) [to 'ari'sta su] "your A grade"

Since Greek has a rule similar to the "Nuclear Stress Rule" of English (Chomsky & Halle 1968) according to which the rightmost constituent in a phrase receives primary stress, in (10) the stress

of [ˈstasu] “stop” is expected to be the most prominent (Nespor & Vogel 1986, Botinis 1989). Regarding (11), if the added stress on [sta] is the most prominent, as most analyses suggest, then the two sequences should be acoustically and perceptually indistinguishable. On the other hand, if the lexical stress of [a] remains the most prominent of the two, as Nespor & Vogel (1986) maintain, then the two sequences—now [ˈari ˈstasu] “Ari stop” and [to ˈariˌsta su] “your A grade”—should be acoustically and perceptually distinct. Paradigmatic comparisons showed that the stressed syllables in these types of sequences have the same F0 pattern and are not statistically distinct in amplitude, duration or amplitude integral; further, they cannot be disambiguated by native speakers. These results clearly show that the most widely held analysis of enclitic stress—that when added to a sequence, it becomes its primary stress, while the lexical stress becomes a secondary stress—is actually correct. Similar results are presented for the Patras dialect in particular by Papazachariou (in press); supporting results for Standard Greek can also be found in Malavakis (1985).

An alternative analysis of enclitic stress is given in Botinis (1989) in which enclitic stress is analyzed as “phrase stress”, an analysis based on Bruce’s (1977) analysis of the Swedish “phrase accent”.[11] The problem with this analysis is that as it provides no explanation why a prosodic feature that is the property of the phrase would appear only in host+enclitic sequences and not in all phrases (as it does, e.g., in Swedish from where the notion was borrowed). A detailed review and reinterpretation of some results of Botinis (1989) that appear puzzling if his analysis is adopted is provided in Arvaniti (1990). Despite disagreements on the analysis of enclitic stress, it is important to note that the experimental results of Botinis (1989) support the generally accepted view that enclitic stress is the most prominent in host+clitic groups.

Specifically, the production results of Botinis (1989) are based on comparisons between the sequence [to ˌmaθiˈma tis] “her lesson” in which [tis] is an enclitic to the noun and [to ˈmaθima | tis …] “the lesson, her…” in which [tis] is a proclitic to a following verb. These comparisons demonstrate that enclitic stress is the primary stress in host+clitic groups and does not substantially differ from lexically specified primary stresses in the same position in terms of amplitude and duration. Further, when the word [ˈmaθima] was produced with narrow focus, it exhibited two distinct F0 patterns, depending on whether its last syllable carried enclitic stress:

when there was no enclitic stress (i.e., when [tis] was a proclitic to the following verb), [ˈmaθima] was produced with a pitch rise on its first syllable; but when enclitic stress was present (i.e., when [tis] was cliticized to [ˈmaθima]), [ˈmaθima] was produced with an accentual pitch rise on its final syllable, the one with enclitic stress. Since pitch accents, as mentioned, associate with the most prominent syllable in a constituent, the co-occurrence of the pitch rise with the enclitically stressed syllable plainly demonstrates that in host+clitic groups, enclitic stress is stronger than the lexical stress of the host.

As mentioned, the phonological analyses of Malikouti-Drachman & Drachman (1981) and Nespor & Vogel (1989) also make use of another stress category, rhythmic stress. Like enclitic stress, the term *rhythmic stress* refers to a source or type of stress that is lower in prominence than primary stress, since it is formally represented as similar to the weaker stress in host+clitic groups with enclitic stress. Malikouti-Drachman & Drachman (1981) and Nespor & Vogel (1989) suggest that rhythmic stresses are postlexical stresses that appear at regular intervals in stretches of unstressed syllables so as to resolve stress lapses, a common occurrence in Greek in which only one syllable per word bears lexical stress and words tend to be polysyllabic. Thus a word like [taçiðaktilurˈɣos] "magician" is said to have lexical stress on its last syllable, but in an utterance such as [ˈine taçiðaktilurˈɣos] "S/he's a magician" it could appear with rhythmic stresses on [ta] and [ða] or [ta] and [kti] or even perhaps on [çi] and [kti] (the accounts do not agree with one another, nor do they provide criteria for preferring one pattern over another, except that obviously these extra stresses should not appear immediately before or after a lexically stressed syllable; for some exceptions to this tendency, see Malikouti-Drachman & Drachman 1981).

The existence of rhythmic stresses in Greek was tested by means of production and perception experiments in Arvaniti (1992) and Arvaniti (1994). Arvaniti (1992), in particular, compared syllables said to carry rhythmic stress to syllables with demoted lexical stress in host+clitic groups. This comparison was based on Malikouti-Drachman & Drachman (1981) in which these two types of stress are formally represented in the same way (as strong syllables heading weak feet) and are both said to be the result of the application of the Greek rhythm rule, which applies optionally to create rhyhthmic stresses, but is obligatory "when two or more

syllables follow the lexical trochee" (p. 285). In order to compare these two types of stress, Arvaniti (1992) examined sequences such as [i ˌsimvuˈli tu] "his counselors" where the lexical stress of the host becomes subordinate to the *enclitic* stress (Arvaniti 1992), and [i *sim*vuˈli tu] "his advice" which is said to have rhythmic stress on [sim]. If this phonological description is correct, then such sequences should be identical in production and difficult for native speakers to disambiguate. However, the results of Arvaniti (1992) clearly show that lexically stressed syllables are acoustically more prominent than syllables with rhythmic stress, and sequences like [i ˌsimvuˈli tu] "his councilors" and [i *sim*vuˈli tu] "his advice" are perceptually distinct. Overall, the results of Arvaniti (1992) show that demoted lexical stresses in host+clitic groups are indistinguishable from other non-phrase-final lexical stresses, while syllables with so-called rhythmic stress do not share the acoustic features of stressed syllables of any type. On the basis of these results, Arvaniti (1992) argues against equating rhythmic stresses with subordinate lexical stresses, and questions the presence of rhythmic stress in Greek altogether.

Arvaniti (1994) further tests the claim that Greek has rhythmic stress by comparing syllables said to have rhythmic stress to syllables with lexical stress, and to unstressed syllables found in metrical positions that do not allow them to bear rhythmic stress: e.g., the stressed [ku] of [aˈkustikan] "they were heard" is compared to the [ku] of [akuˈstikan] (a variant pronunciation of [aˈkustikan]) which cannot bear stress of any sort, and the [ku] of [akustiˈka] "headphones", which can have rhythmic stress. The results show that syllables said to have rhythmic stress are acoustically indistinguishable from unstressed syllables, but clearly less prominent than stressed syllables, casting further doubt on the existence of rhythmic stress, and generally to the idea of multiple degrees of stress in Greek.[12]

Durational results supporting the view that Greek does not exhibit rhythmic stress were more recently reported in Kastrinaki (2003). Kastrinaki compared syllables purported to have rhythmic stress with lexically stressed syllables and found no durational differences between the two, unless the syllable said to have rhythmic stress was word-initial (e.g., [ði] in [ðiciˈɣoro] "lawyer, acc.". In this case, however, Kastrinaki found that the lengthening affected the *onset*, not the vowel of the syllable. She thus concludes that this effect is best analyzed as word-initial strengthening (Keating et al. 2003) rather than as evidence for rhythmic stress. One could,

perhaps, interpret the strengthening found by Kastrinaki as evidence for rhythmic stress. In my view, there are several reasons why this is not a desirable interpretation, however. First, seeing consonant strengthening as evidence for rhythmic stress would force us to conclude that stress can have an arbitrary set of manifestations within the same language, an interpretation that—to my knowledge—does not seem to be universally applicable. Further, this interpretation cannot answer the question of why rhythmic stresses that are not in word-initial position do not exhibit the same strengthening. Even if we assume that rhythmic stress is qualitatively different from other types of stress in Greek, we should, at the very least, expect it to be realized in similar fashion in various structural positions.[13] In addition, Kastrinaki's own interpretation of her results as word-initial strengthening is in line with the way similar phenomena are interpreted in languages with prosodic systems that are quite different from that of Greek. Specifically, this type of initial strengthening has been found in English, in which (i) the presence of at least two degrees of stress with specific cumulative properties has been amply demonstrated (e.g., Beckman & Edwards 1994) and (ii) stress is clearly a phenomenon distinct from articulatory strengthening *per se*. Strengthening has also been reported for Korean, French and Taiwanese which, by most descriptions, do not have stress at all (Keating et al. 2003 for all four languages). Thus, Kastrinaki's interpretation of her results as word-initial strengthening seems the most plausible given the cross-linguistic evidence available so far.

Finally, Arvaniti (1997) provides a preliminary analysis of another type of stress in Greek, which she dubs "emphatic stress" (similar observations are made in Malikouti-Drachman & Drachman 1981, and in Kabak & Revithiadou in press, who analyze this type of emphasis as rhythmic stress). Arvaniti (1997) examines data from journalistic speech (news-reading and documentary voice-overs) and shows that in this style of speech, particular emphasis is given to word-initial syllables that are not lexically stressed. This "emphatic stress" can even apply to words that are inherently unstressed and typically cliticized, such as articles and prepositions. Arvaniti shows that the type of prominence that these syllables acquire is not dependent so much of their duration and amplitude but rather on their pitch pattern which is not what would be expected of unstressed syllables in the context in which they appear, and yet it is not like any of the Greek *pitch accents* (pitch movements associated with stressed syllables). Arvaniti suggests that "emphatic stress" is akin to the French *accent didactique* which is used as a group marker by public speakers (Lucci 1979). It is not however clear that "emphatic stress" functions in a similar

manner in Greek. It is possible that "emphatic stress" is frequent in media speech because of the presenters' need to speak slowly and clearly (Papazachariou & Politis in press) leading them to cut up their utterances into relatively small chunks which, in turn, "emphatic stresses" helps them demarcate. On the other hand, it is also possible that "emphatic stress" is used for the benefit of listeners, that is in order to flag for them important information without using contrastive accent (of the type "I said *x*, not y") which may be pragmatically odd in some contexts. Whatever its function, an issue that awaits further research, Arvaniti (1997:23) concludes that this phenomenon is "neither a type of stress [as in the analyses of Malikouti-Drachman & Drachman 1981, and Kabak & Revithiadou in press], nor is it emphatic".

4.4 Focus, pitch and degrees of stress in Greek

Recent research indicates that it may be necessary to make a further distinction in the degrees of prominence used in Greek. So far we have examined stress on the assumption that it is a property of words and results suggest that Greek makes a strong phonetic distinction between stressed and unstressed syllables but does not further distinguish degrees of stress at the level of the word (with the notable exception of enclitic stress).

A traditional view of stress, however, that goes back to Chomsky & Halle (1968) requires the use of another level, that of *sentence, phrase* or *nuclear stress*. Nuclear stress is seen as the strongest stress in a phrase and appears, by default, on the last word (for English, Chomsky & Halle 1968; for Greek, Nespor & Vogel 1986). For example, if (12) were uttered out of the blue, [mixaˈni] "motorbike" would be expected to carry default sentence stress.

(12) [i ˈlena oðiˈji mixaˈni] "Lena drives a motorbike"

However, a non-final word may also carry phrase stress, if it is in narrow focus or spoken contrastively. For example, if one wants to clarify that it is Lena and not her brother who drives a motorbike, (12) would be uttered with (contrastive) sentence stress on Lena as in (13); the following words would then have low and flat pitch, as illustrated in Figure 5. In some cases it is possible to have early narrow focus, and therefore sentence stress, on an item that is not

contrasted with something else, but is simply new information. This, for example, applies to (14) if uttered without preceding context, as a piece of news; in this case, [paˈpus] has narrow focus and the following word [tiˈlefono] "telephone" has flat F0.

(13) [i ˈlena oðiˈʝi mixaˈni] "LENA drives a motorbike (not her brother)"

(14) [ˈpire co paˈpus tiˈlefono] "grandpa (also) called"

Several studies have investigated differences between regular lexical stress and phrase stress in Greek, but the results are far from conclusive. Baltazani & Jun (1999) report that under narrow focus stressed syllables show extra lengthening, and that the duration of the entire word in focus is increased, compared to the same word in non-focal position. On the other hand, Botinis, Bannert & Tzimokas (2002), Botinis & Bannert (2003) and Kastrinaki (2003) report that focus lengthens only the stressed syllable of the focused word (compared to the same syllable in accented but non-focal position). In contrast, Botinis et al. (1995) and Botinis et al. (2001) report that focus does not affect the duration of either the segments of the stressed syllable or of the focused word at large (compared to the same word in accented but non-focal position).

One of the reasons for these mixed results is that these studies do not all look at the exact same phenomena, and that in some cases different types of narrow focus are treated as being similar although it is not clear that this is so: in particular, we do not have strong evidence yet that the type of narrow focus that relates to information structure, as in (14), and contrastive or corrective focus, as in (13), are manifested in the same way in Greek. Yet, some of the results discussed above relate to the latter category (Baltazani & Jun 1999, Botinis et al. 2001, 2002, Botinis & Bannert 2003), while others do not make a principled distinction between the two (Kastrinaki 2003). Auditorily, I would suggest that there are clear differences between the two types, with contrastive focus showing extra lengthening of the stressed syllable (see also Arvaniti et al. 2006b) and possibly a different pitch movement than non-contrastive narrow focus, but this impression requires empirical confirmation. Further, none of the studies examines whether focus has any durational effect on the stressed syllable of a word that is utterance-final and is focused by default, such as [mixaˈni] "motorbike" in (12). Thus, at this point, it is not clear whether we

need an extra type of stress that could be called nuclear or phrase stress, and if so, which cases it would cover.

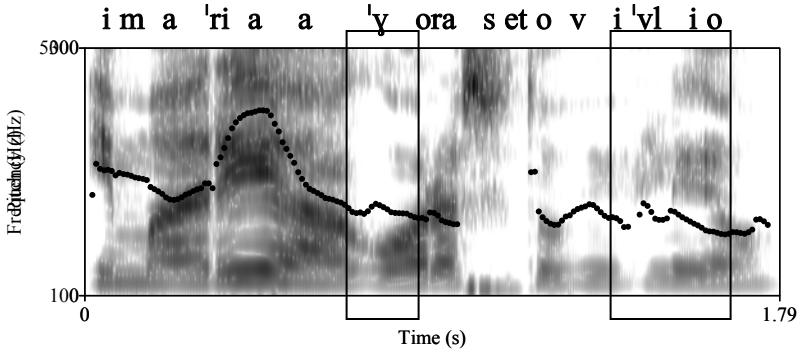


Figure 5. Spectrogram and F0 contour of the phrase [i maˈria aˈɣorase to viˈvlio] "MARIA bought the book" with narrow (contrastive) focus on [maˈria]. The stressed syllables of [aˈɣorase] "s/he bought" and [viˈvlio] "book" are boxed for ease of reference. It should be noted that the small "bumps" on these stressed syllables are the result of microprosodic variation expected during the production of voiced consonants in particular.

4.5 Greek stress: summary

To sum up, the phonetic evidence so far suggests that Greek distinguishes two types of syllables: (a) unstressed syllables, which are the least prominent and show some reduction in duration and/or amplitude and, to an extent, in vowel quality; (b) stressed syllables, which are characterized by some degree of hyperarticulation resulting in longer duration and/or higher amplitude and more peripheral quality for their vowels and, less consistently, for their consonants. Stressed syllables can be further distinguished into stressed and accented and stressed and unaccented syllables. Accented syllables are the most common type of stressed syllable in Greek (since in most melodies all content words are accented until the focused item is reached): they are stressed syllables which in addition to showing greater acoustic prominence than unstressed syllables are accompanied by a pitch accent which cues their prominence (since pitch accents co-occur only with stressed syllables); this pitch movement is not necessarily rising but could well be low or falling; see e.g., the F0 of [ble] "blue" in Figure 4(a) and of the stressed

syllable [ra] of [paˈraθira] in Figure 4(b). Stressed and unaccented syllables exhibit the typical prominence of accented syllables in terms of amplitude, duration and vowel quality, but are not accompanied by a specific pitch movement and may have flat F0, as is the case with the stressed syllables of the last two content words in the utterance [i maˈria aˈɣorase to viˈvlio] "MARIA bought the book" shown in Figure 5. It is not clear at this point if a further distinction is necessary between focused accented syllables and accented syllables that are not in focus, in other words whether an additional and distinct category of phrase stress should be posited. On the other hand, there is no evidence so far that rhythmic and enclitic stress are distinct types or levels of stress; thus terms such as enclitic stress are best seen as referring to the origin of a particular stress, and not to relative strength, while rhythmic stress is not a stress category supported by empirical evidence. Finally, the term "emphatic stress" used by Arvaniti (1997) does not appear to refer to a type of stress at all.

5. Rhythm and timing

Reviewing research on rhythm is a challenge, as there is no consensus among linguists as to what constitutes linguistic rhythm, though there is general consensus that speech is a rhythmic activity (but see Nolan 2008). The studies of Greek rhythm are no exception to this general trend: researchers who have examined rhythm in Greek have adopted different concepts of this phenomenon. Because of these differences, I present separately the studies within each of the two main frameworks, with a brief introduction to the basics of each.

5.1 Stress-timing, syllable-timing and the rhythm of Greek

A very popular view—despite the lack of supporting empirical evidence—is that languages fall into two rhythmic types, syllable-timing and stress-timing (with a third type, mora-timing, specifically for Japanese sometimes also being postulated). The names of these categories, which date from Pike (1945), derive from the organizing unit said to be used in each rhythmic type. In stressed-timed languages, the prototypical example of which is English, rhythm is said to be based on the equal duration of interstress intervals or *feet*, the temporal intervals that stretch from

the onset of one stressed syllable to the next. In contrast, in syllable-timed languages, the prototypical example of which is French, rhythm is said to be created by the repetition of successive syllables of equal duration. This notion of *isochrony*, that is of either syllables or feet being of equal duration, has been put to the test on numerous occasions, using various experimental protocols: e.g., Nakatani et al. (1981) measured English feet of varying syllable lengths expecting to find no differences in duration despite the differences in the number of syllables in the feet; Lehiste (1990) measured feet in read poetry, hypothesizing that isochrony would be easier to observe in poetry than in regular speech; Wenk & Wioland (1982) studied syllable duration in French, while Scott, Isard & Boysson-Bardies (1985) asked French and English speakers to tap to the beat while listening to both French and English sentences. None of these studies found evidence for isochrony in either stress- or syllable-timed languages or differences between the two types (similarly weak appears to be the evidence for mora-timing in Japanese, according to Warner & Arai 2001 who review the relevant literature).

This failure to find empirical evidence for isochrony led Roach (1982) to suggest that the distinction between rhythmic categories simply reflects the *auditory impression* that languages like French give to native speakers of English: given the features of their own language, English speakers expect the stressed syllables to stand out by virtue of being longer, louder and having vowels of peripheral quality; they equally expect unstressed syllables to be significantly less prominent, since in English they contain short centralized vowels. When speakers with such expectations encounter a language like French in which vowel reduction is limited and syllables do not vary significantly in structure, they tend to perceive all syllables are equally prominent. But this impression is not necessarily shared by the speakers of French, as shown by Scott et al. (1985).

Other researchers, however, have used the same arguments as Roach (1982) to argue that it is indeed these differences in phonological patterns that give rise to distinct rhythmic types (Dasher & Bolinger 1982, Dauer 1983, 1987). Dauer (1987) in particular provides a list of parameters that in her opinion affect the rhythmic classification of a language. In her view physical measurements are not likely to provide much insight into rhythmic types; instead she proposes that languages be placed on a continuum from least to most stress-timed depending on their settings in her list of parameters.

More recent research (among others, Ramus, Nespor & Mehler 1999, and Grabe & Low 2002) has tried to quantify some of Dauer's parameters (which are re-interpreted as defining a continuum from syllable- to stress-timing, rather than the continuum envisioned by Dauer from less to more stress-based rhythm). Thus, Ramus et al. (1999) propose that %V (the percentage of vocalic elements in speech) and Δ*C* (the standard deviation of consonantal intervals) are together good measures of rhythmic type: stress-timed languages have small %V and large Δ*C*, while syllable-timed languages have large %V and small Δ*C*. These differences are said to reflect the fact that in stress-timed languages unstressed vowels are reduced and consonant clusters are frequent, while in syllable-timed languages there is little vowel reduction while syllable structure is typically CV. Grabe and Low (2002), on the other hand, measure the differences between successive intervocalic (essentially consonantal) and vocalic intervals and calculate metrics for both (Intervocalic rPVI and Vocalic nPVI respectively). Unfortunately, as Grabe & Low (2002) amply show, the metrics proposed by them and Ramus et al. (1999) result in different classification for several languages, including Polish, Tamil and Greek. Taken together these studies suggest that although it is relatively easy to find metrics that will classify English separately from Spanish, classifying other languages on some stress- vs. syllable-timing continuum is not an easy enterprise.

Greek is a case in point. The rhythm of Greek was first examined within the rhythmic categories framework by Dauer herself (Dauer 1983, 1987). As mentioned, Dauer proposes a continuum from least to most stress-based timing, and classifies Greek as slightly leaning towards more stress-based (Dauer 1987:60) as illustrated in the continuum in Figure 6 (adapted from Dauer 1987).

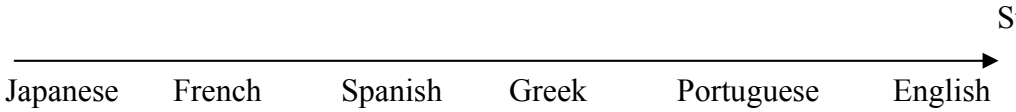


Figure 6. The continuum from least stress-based to most stressed-based rhythm, after Dauer (1987). Dauer's continuum is most often (erroneously) interpreted as a continuum between syllable-timing (left) and stress-timing (right).

However, as Arvaniti (1994) points out, if we assign a score to Greek following Dauer's own parameters (explicitly presented in Dauer 1987), Greek should be classed closer to the least stressed-based end of the continuum, and thus it should be a language in which stress plays little or no role. Yet, we know that stress in Greek has a high functional load (much higher than stress in English, a stress-timed language), and that one of the least tolerated mistakes a non-native speaker can make in Greek is to stress a word on the wrong syllable.[14] Dauer herself concurs with this assessment:

> "Most stress-timed languages have lexical or word level stress […] realized by a complex set of changes in length, pitch contour, loudness and quality, which clearly make stressed syllables more prominent than unstressed syllables. There is a clearly discernible "beat", *though not all languages with this feature have been labeled stress-timed* (e.g., Italian, Spanish, Greek). [Dauer 1983:58; emphasis added].

Greek has been proven equally difficult to classify following the various recently proposed metrics as well. Grabe and Low (2002), ignoring Dauer's classification, treat Greek as "unclassified" and conclude on the basis of their metrics that it is essentially unclassifiable (p. 531) since it falls right on the boundary between stress- and syllable-timed languages. Baltazani (2007a), on the other hand, uses the Grabe & Low metrics for Greek and reports results that would make Greek very similar to Catalan, a language said to have "mixed" rhythm (Ramus et al. 1999, Grabe & Low 2002) because it combines significant vowel reduction with relatively simple syllable structure. More disturbingly, Greek appears to belong to a different rhythmic category depending on the metric or corpus used. Thus, Grabe & Low (2002) calculated %V and ΔC–the metrics of Ramus et al. (1999)—for their data and found that if those metrics are used, Greek must be more stress-timed than German. Similarly mixed results are presented in Ross, Ferjan & Arvaniti (2008): according to these authors, Greek has low scores for both vocalic and consonantal variability but these scores are not similar to those presented in Grabe & Low (2002) or Baltazani (2007a). All the metric scores for Greek are given in Table 9 for comparison. All together they amply demonstrate how problematic rhythm metrics are. Even when the experimental design is such that it allows for the statistical treatment of the scores, as in White & Mattys (2007), there is no principled way of deciding whether two scores show a difference in rhythmic type or not, except in a circular fashion: scores are said to be different if they classify

two languages according to their predetermined rhythmic types (or, occasionally, according to what the investigator would like a language's classification to be).

Other studies also provide contradictory data regarding the rhythmic classification of Greek. According to Johnson and Sinsabaugh (1985), the vocalic system of Greek changed dramatically since Classical times because the underlying rhythm of Greek changed from syllable- to stress-timing, with which features such as contrastive vowel length are incompatible. Their classification of Modern Greek as stress-timed rests on the change of the pitch-accent based system of Classical Greek to the stress-based system of Modern Greek. Finally, Barry & Andreeva (2001) compared the reduction patterns of languages classified as syllable-timed (Greek and Italian) to those of languages classified as stress-timed (Russian and Bulgarian) and to mixed-rhythm languages (Polish and Czech). Specifically, they compared these six languages in terms of reduction of consonant clusters, weakening of consonant articulation, residual properties from elided consonants on context segments, phonetic "schwa-isation" and syllable elision. Barry & Andreeva advance the plausible hypothesis, based on the literature reviewed above, that syllable-timed languages would exhibit lower rates of certain types of reduction, such as schwa-isation, than stress-timed languages. Their results, based on quasi-natural speech, show no evidence that any type of reduction is less widespread or less extreme in syllable-timed languages than in those classified as mixed or stress-timed, a result that echoes previous results of Roach (1982).

Table 9: Metric scores for Greek as reported in various studies; the Ramus et al. (1999) scores for Japanese (which is said to belong to a different rhythmic class, mora-timing, showing less vocalic and consonantal variability) are presented here for comparison.

	%V	ΔC	nPVI	rPVI
Grabe & Low (2002)	44.1	52.7	48.7	59.6
Baltazani (2007a)			45	68
Ross et al. (2008)	48	37	58	46
Ramus et al. (1999) *Japanese*	53.1	35.6		

The great variability in the results of the above studies points to a fundamental weakness in the conception of rhythm as isochrony (which, however liberally interpreted, is still part of the

notion of rhythmic categories). In my opinion there are several reasons why this is so. First, the notion of rhythmic types is based on the dubious premise that different languages create rhythm using totally distinct principles: while stressed-timed languages (at least implicitly) rely on the alternation of more and less prominent syllables (in that each foot normally includes both types), syllable-timed languages are expected to create rhythm out of utter monotony. As Dauer (1987) rightly points out, it is difficult to see what rhythm would be based on in this case, since psychologically rhythm is defined as the perception of series of stimuli as series of groups of similar and repetitive pattern (Woodraw 1951). Thus Dauer argues that rhythm in all languages is based on prominence, and for this reason in her continuum the term "syllable-timed" does not appear at all. It could of course be argued that both rhythmic types involve a kind of periodicity, of stress feet and syllables, but as shown by experiments in which listeners are asked to tap to the beat, syllables are not as basic in French rhythm as syllable-timing would predict, while the responses of both English and French subjects to both English and French stimuli were very similar (Scott et al. 1985). Furthermore, psychological research on rhythm clearly shows that if humans are presented with series of identical stimuli they tend to impose rhythmic structure on them, by "hearing" alternate stimuli as more prominent (Woodrow 1951, Fraisse 1963, 1982). It is difficult to reconcile these results with the claim that in syllable-timed languages all syllables sound equal: even if this were shown to be the case for a syllable-timed language, the listeners would still not perceive all syllables as equal because their perceptual system would impose prominence alternations on them. Thus, the notion of syllable-timing in particular is problematic as it suggests that speakers strive to produce an acoustic effect that their listeners promptly discard (for a more extensive discussion, see Arvaniti 2008).

5.2 Rhythm, timing, and Greek

Despite the lack of empirical evidence discussed above, in recent years, the classification of languages into rhythmic categories has acquired new appeal thanks to experimental evidence that infants, and to a certain extent adults, can distinguish between languages said to belong to different rhythmic categories (e.g., Nazzi & Ramus 2003). These results have been interpreted as evidence for the existence of rhythmic types, even though, as shown above, we have no good method of reliably quantifying this view of rhythm. One possible reason for the success of these

studies could be that most of this line of research has relied on languages that are easy to classify as belonging to the same or different categories (possibly because of similarities or differences in speaking rate respectively; Dellwo 2008). For instance, Nazzi, Jusczyk & Johnson (2000) compared infant reactions to English and Dutch (genetically related and both considered stress-timed), and English and Japanese (unrelated and prototypical examples of stress- and mora-timing respectively). In addition, the language materials on which such studies are based on are often very limited in some respect; e.g., Ramus et al. (1999) relied on a small set of short sentences for each language, while Grabe & Low (2002) had their speakers read the story of *The North Wind and the Sun* but elicited data from only one speaker per language.

Most importantly, the relative success of the metrics could well be due to the fact that they confound two distinct elements of speech, speech timing and rhythm. *Timing* or *temporal coordination* refers to the temporal relations and interactions of segments, and larger prosodic constituents, such as syllables, feet, words and phrases, while *rhythm* refers specifically to the grouping and prominence relations of such constituents. It follows that while timing can be quantified by means of durational measures of various sorts, it is not as easy to quantify rhythm along the same lines.

The pervasive role of temporal coordination and its direct relation to metrics of consonantal and vocalic variability employed to quantify rhythm can easily be demonstrated by reviewing what we know about timing in Greek. First, Greek is spoken at a fast rate (a characteristic most probably related to its relatively simple syllable structure and the lack of phonological quantity distinctions in vowels). For instance, Baltazani (2007a) reports an average of 9.8 syllables/s for her two speakers together; in her data, the rate increased to 10.3 syllables/s when the test words were five instead of three syllables long (though the difference is not significant according to t-tests ran on Baltazani's data by the present author). Papazachariou & Politis (in press) report a slightly slower rate of 7.5 syllables/s for "every day narratives" and 8.3 syllables/s for news reading (though they say that average syllable duration was not significantly different between the two styles). Although there are clearly differences in rate between these studies, presumably due to the style of the elicited data, they both show speaking rates that are quite fast and certainly much faster than those reported for English; e.g., Ryan (2000) reports a rate of 6.4 syllables/s for spontaneous speech elicited from American adults, and White & Mattys (2007) report a rate of 5.2 syllables/s for laboratory data elicited from British English speakers.

Further, changes of speaking rate, like those investigated by Arvaniti (2001c) and Botinis et al. (2001) show that speaking rate does not affect Greek consonants and vowels equally: as tempo increases, vowels are temporally reduced more than consonants. Since Arvaniti (2001c) also found that the opposite obtains in Cypriot Greek, it is clear than this greater reduction of vowels in Standard Greek is a language specific strategy. I would further speculate that it has to do with the elision of high vowels in Greek. This is supported by the results of Baltazani (2007a) who found that [i] and [u] were significantly reduced in post-stress syllables in test words that were three syllables long, and were completely elided (acoustically at least) in the same position in five syllable long words. Similar results are reported by Kastrinaki (2003) for three- and four-syllable words.

Segmental durations are also affected by context. For example consonants are reduced when they appear in clusters, and this reduction affects homorganic sequences, such as [ts] and [st] more than heterorganic sequences (Fourakis 1986a, Arvaniti 1987, Botinis et al. 1999). Vowels, on the other hand, are affected primarily by following consonants and less by preceding ones (Botinis et al. 1999, Nicolaidis 2002b). Position in the word also affects segment duration: stressed syllables are longer in word-initial position than if placed later in a word (Fourakis 1986a, Kastrinaki 2003). Unstressed syllables, on the other hand, are affected both by their position in the word and their position relative to the stressed syllable: generally word-initial unstressed syllables are longer than later unstressed syllables (Kastrinaki 2003), but it is also the case that unstressed syllables immediately preceding stressed-syllables are longer than those that immediately follow them (Dauer 1980a, Arvaniti 1994, Kastrinaki 2003, Baltazani 2007a). Finally, as discussed earlier, there is at least some evidence that not only stress and accent but also focus lengthens segmental durations (Baltazani & Jun 1999, Botinis et al. 2002, Botinis & Bannert 2003, Kastrinaki 2003) and that phrase-final syllables may also show some lengthening (Tserdanelis 2005, Kainada 2007).

In short, the studies on Greek timing so far provide evidence that a multitude of factors affects the timing of segments: stress, accent, focus, position in the word, position relative to the stressed syllable, position in the phrase, clustering of consonants, identity of the following consonant and tempo effects all conspire to create a particular language-specific timing profile. Greek has a relatively simple syllable structure in which consonants appear typically in the onset, the position in which they are least likely to affect vowel duration (Botinis et al. 1999). On the

other hand, vowels can be seriously reduced in duration when not stressed, depending on their position in the word and relatively to the stressed syllable. These characteristics coupled with a fast speaking rate that reduces vowels more than consonants results in substantial vocalic variability but not as much consonantal variability. It is thus not surprising that the various metrics fail to place Greek into a rhythmic category, but as I argue here this is because the metrics do not reflect rhythm at all.

Overall, the problems that research on rhythmic categories has encountered suggest that simple durational measurements, however sophisticated their mathematical manipulation might be, do not provide us with much insight into the nature of linguistic rhythm. Further they do not seem to reliably classify languages beyond the most prototypical ones, which present a "coherent conspiracy of factors" favoring one or the other rhythmic type (Bertinetto 1989:108). Most importantly perhaps, none of these measures tell us anything about how the native speakers acquire, produce and perceive the rhythm of their language. Thus, it seems imperative to revisit this entire literature taking into account not only simple durational measures but also the prosodic and metrical system of each language. This is the view of rhythm to which I now turn.

5.3 Rhythm as alternation: the relationship between stress and rhythm

In addition to the studies above, Greek rhythm has been investigated from a different perspective, which views rhythm as the result of alternation between more and less prominent prosodic constituents, such as syllables and feet. Thus, Mirambel (1959) states that the rhythm of Greek is ternary, i.e., that stressed syllables are separated by two unstressed syllables. Dauer (1980a) modifies this somewhat by noting that stressed syllables in Greek tend to be preceded by a slightly reduced syllable and followed by a more significantly reduced syllable. In contrast, as mentioned in 4.3., Malikouti-Drachman & Drachman (1981), Nespor (1988), and Nespor & Vogel (1989) suggest that Greek is essentially parsed into trochaic feet and exhibits repair mechanisms the aim of which is to correct for stress clashes (stresses too close together) and lapses (stresses too far apart): lapses are rectified by adding rhythmic stresses, and clashes are rectified by what Malikouti-Drachman & Drachman (1981:288) call "covert trochee-making", namely pausing or lengthening of the first syllable in the clash (or only of its coda, according to Malikouti-Drachman & Drachman 1981). Nespor & Vogel (1989) suggest an additional strategy

for clash repair, a change in pitch such that the first syllable in the clash is pronounced with low pitch and the second one is pronounced with high pitch (a vestige, according to them, of the pitch accent system of Classical Greek).

Arvaniti (1994) examined experimentally these claims by testing for the presence of rhythmic stresses in cases of lapses, and for mechanisms of clash resolution. As discussed in section 4.3, the results do not show evidence that lapses are repaired in any way (though Arvaniti does mention that the extensive durational reduction of vowels that Greek exhibits must bring stressed syllables in closer temporal proximity than phonological representations might suggest, a proposal discussed in more detail below). Regarding stress clash resolution, Arvaniti (1994) shows that clashes are occasionally resolved by lengthening the first syllable in the clash, and may also be remedied by a pause, *but only if a phrasal boundary can be inserted between the clashing syllables*. Further, Arvaniti (1994) shows that the claim of Nespor & Vogel (1989) that Greek uses a change in pitch between clashing syllables to resolve a clash can be more plausibly reanalyzed as the byproduct of tonal crowding of two consecutive pitch accents (for details see section 7). This re-analysis of the role of pitch in clashes is confirmed by the stress clash data of Arvaniti et al. (1998, 2000, 2006a).

On the basis of these results and the review of Italian data, Arvaniti (1994) proposes viewing rhythm as resulting in all languages from the same principle, the alternation of strong and weak constituents. This has the advantage of not requiring that different languages rely on distinct principles for the creation of rhythm, but rather on the same psychologically plausible principles of grouping and relative prominence (Woodrow 1951, Fraisse 1963, 1982). In this model, it is hypothesized that the difference between stress- and syllable-timed languages is related to differences in metrical structure: syllable-timed languages have metrical structures that do not allow them much flexibility and thus they cannot easily remedy clashes and lapses (as shown in more detail below for Greek). Stress-timed languages, on the other hand, have metrical structures that allow them to change prominence relations between constituents in order to avoid clashes and lapses and keep alternation regular. This difference is partly due to the full metrification of segmental material in stress-timed languages, which allows them to alternate prominence among feet both within and across words. Thus stress-timed languages can remedy non-eurhythmic sequences due to clashes using rules similar to the *Rhythm Rule* of English, which allows the relative prominence of multiple stresses in a word to change depending on

context: e.g., the English word *phonetician* is produced with main stress on its penultimate syllable in non-clash contexts, as in the phrase *I'm a phònetícian*; however, when another stress follows in the same phrase, it is the first syllable of the word *phonetician* that takes primary stress, as in the phrase *Greek is a phónetìcian's dream!* In addition, in languages like English it is possible to remedy lapses by making some stressed syllables more prominent (a strategy that has been formalized as the addition of beats in a metrical grid column); e.g., in the phrase *three red shirts*, in which *three* and *red* have equal prominence originally, stress is "added" to *three* in order to create an alternating pattern of prominences: *thrèe red shírts* (Liberman & Prince 1977:325ff.).

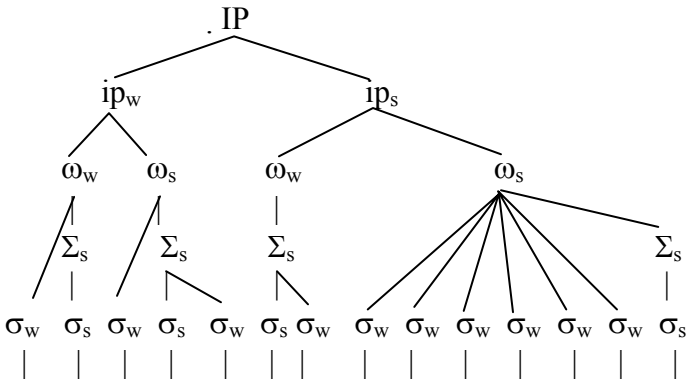
Syllable-timed languages on the other hand, tend to be more tolerant of non-eurhythmic sequences, a feature that suggests they lack the metrical structure required for the resolution of clashes and lapses. Since clash and lapse repair mechanisms rely primarily on the metrification of all segmental material into binary feet, it is plausible to assume that such metrification does not take place in syllable-timed languages. This is indirectly reflected in several measurements reported in Dauer (1983). Dauer measured interstress interval durations and showed that these are very similar among the languages she examined; e.g., the average interstress interval in English was 505 ms long, while in Greek it was 528 ms, a difference that is not statistically significant (statistical results are based on two-tailed t-tests ran by the author on the data presented in Dauer 1983). What is different, however, is the number of syllables that these intervals contain: Dauer reports interstress intervals in English with a maximum of five syllables, while in Greek (and in Spanish and Italian) she reports intervals of up to seven syllables in length; this difference in number of syllables between English and the other languages is statistically significant. These results show that stresses appear equally frequently in all the languages in question, but Greek, Italian and Spanish cram more unstressed syllables between stresses. This can only be achieved if interstress intervals (and therefore feet) can contain more than one unstressed syllable each.

A possible way to formalize the above observation is presented in Arvaniti (1998b) who examined nonsensical Greek blends used as jokes—such as [ˈvarka] "boat" + [arˈkuða] "bear" > [varˈkuða]—to argue that Greek parses into feet only the lexically stressed syllable of each word

and any following unstressed syllables; syllables preceding the lexically stressed syllable remain unmetrified and simply attach to the prosodic word node, as shown in (15).[15]

This prosodic structure, in which words contain only one foot that is defined by the lexically stressed syllable, can explain several aspects of the rhythmic behavior of Greek, such as why it is not possible to remedy lapses and clashes using strategies similar to the English Rhythm Rule and beat addition discussed above. On the one hand, Greek words do not have multiple feet that can exhibit alternation in prominence and thus strategies such as the Rhythm Rule have no structure on which to apply. On the other hand, all heads of feet in Greek are (and must be) accented and thus it is not possible to add prominence to a foot or to leave one unaccented.[16] Finally, the parsing into feet only of syllables to the right of the lexical stress explains the presence of enclitic stress: this sequence is parsed into trochees if the position of the lexical stress allows it. The same characteristic explains the fact that typically both the lexical stress and the enclitic stress in host+clitic groups are accented: as mentioned, all heads of feet in Greek are accented.

(15)



"this law is unconstitutional"

An alternative way of interpreting structures like that in (15) would be to say that in syllable-timed languages feet are not a salient prosodic constituent, while in stress-timed languages they are (for similar views about the prominence of different prosodic constituents, see Beckman 1995). This view finds some support in the psychological literature: Cutler et al. (1986, 1992) have shown that English speakers rely on feet to segment speech, while French speakers rely on syllables. Similarly, in a series of experiments reviewed in Cummins (2002) it was found that English speakers could produce alternating stressed and unstressed syllables in time with a

metronome-governed cycle in such a way that a sequence normally containing two stresses (e.g., ***big*** *for a* ***duck***) could be produced with three beats by turning *for a* into an extra foot. In contrast, Spanish and Italian speakers could not produce similar phrases (e.g., Italian: ***mun****go la* ***muc****ca*; Spanish: ***bus****ca la* ***mo****to*) following the rhythmic pattern with three beats, presumably because their languages do not allow them the same flexibility in the formation of feet.

The relative salience of syllables and feet is manifested in various ways in Greek. As shown, Greek blends are not based on foot structure in a straightforward fashion. According to Tzakosta (2004a, 2004b), children acquiring Greek produce truncated forms that are not based on feet and do not always follow the adult prosodic pattern; in addition, the acquisition of Greek stress data does not support the idea of a trochaic bias. L2 also provides supportive evidence if we examine the way Greek speakers respond to English rhythm and vice versa. Native speakers of Greek do not expect an elaborate metrical structure and thus are often oblivious to all stresses in English words except the last one, happily producing forms such as *exercíse* or *syllabificátion*, essentially adapting them to their own metrical template, which requires that there be only one stress per word, and therefore no more than one foot. Equally, native speakers of English have difficulties with Greek words with more than one initial unstressed syllable, that is words that are not clearly parsed into binary feet: my own first name is a prime example, becoming [əmˈliə] [ˌæməˈliə], [ˌʌməˈleɪə], [əˈmɑliə] or even [m̩ˈliə], all forms that conform to English metrical templates that prefer to parse words into trochees and allow for at most one unstressed syllable word-initially and two word-finally (for a recent account of this type of perceptual adaptation of the L2 signal into L1 categories, illustrated here in the linguistic behavior of both English and Greek speakers, see Halle & Best 2007 and references therein).

5.4 Rhythm and timing: Summary

In conclusion, the research on the rhythm of Greek does not yet provide us with a clear picture. Studies on Greek from the perspective of rhythmic categories have classified Greek as syllable-timed, stress-timed, or mixed, while in others Greek is presented as unclassifiable. Although no conclusion is reached, the research on Greek has certainly shown that classifying languages into some stress- to syllable-timing continuum is harder than was previously assumed: several

languages, among them Greek, have defied classification by means of simple metrics and have shown that these metrics are unreliable as they classify non-prototypical languages like Greek in different ways.

One of the reasons for the failure to classify Greek is, as I argued above, that the metrics used to rhythmically classify languages do not reflect rhythm but general timing properties and these clearly place Greek in a half-way position between prototypical stress-timed languages and prototypical syllable-timed ones. However, as argued, it is not these timing features that create rhythm in Greek. Following Dauer's original conception of a more or less stress-based continuum, I argue here (and elsewhere; e.g., Arvaniti 1994, Arvaniti in prep.) that the rhythm of Greek and of languages in general is based on prominence patterns. Prominent syllables in Greek appear to be irregularly placed and far apart, yet the fast speaking rate and vowel reduction result in them appearing at regular intervals that are similar in duration to those found in English (approximately every half second). This pattern is best formalized by means of a rhythmic structure in which feet play only a small part. This type of metrical structure allows us to explain also certain characteristics of Greek, such as the fact that stresses cannot be moved and non-eurhythmic sequences cannot be remedied. In turn, as I have argued elsewhere these characteristics quite possibly underlie the differences between stress- and syllable-timed languages (Arvaniti 1994), a hypothesis supported by the results of Cummins (2002).

From a formal perspective, the research on Greek rhythmic structure has also wider repercussions, as it shows that not all languages rely on strict alternation of strong and weak metrical constituents (as is sometimes advocated e.g., Hayes 1995), and therefore proposed metrical structures must be flexible enough to accommodate such languages. Finally, the conception of rhythm as patterns of grouping and prominence provides a possible method of assessing a language's rhythmic type that relies on both phonetic criteria and phonological structure, rather on simple timing measures alone.

6. Sandhi and prosodic phrasing

A well-known observation dating back to the Indian grammarians is that segments within or at the edges of words may undergo changes when words are strung together to produce an utterance. This phenomenon has been known as *sandhi*.

The study of sandhi has been instrumental in the development of prosodic phonology (Selkirk 1981, Nespor and Vogel 1986[17]), a main aim of which was precisely to provide a principled account of the application of sandhi rules. Briefly, prosodic phonology suggests that once a sentence is syntactically assembled and its component words have been selected, the result becomes the input to the postlexical component of the grammar where prosodic structure, a hierarchical structure akin to syntactic trees, is created. Sandhi rules are said to apply within specific prosodic constituents (*domain span* rules), across domains nested within a larger constituent (*domain juncture* rules), or at the edge of a domain (*domain limit* rules).

As mentioned, prosodic and syntactic trees are similar, but they also differ in principled ways. Prosodic trees are built algorithmically from syntactic trees (and thus they are contingent upon the syntactic framework one assumes). Crucially, prosodic trees do not show recursion; rather, they have a limited number of levels onto which all constituents of the preceding level are exhaustively parsed, a principle known as the *Strict Layer Hypothesis*. However, the number of prosodic levels is not the same in all models. Selkirk (1981) proposes five levels (syllable, foot, prosodic word, phonological phrase and intonational phrase), while Selkirk (1986) posits that only the syllable and intonational phrase are necessary. On the other hand, Nespor & Vogel (1986) expand Selkirk's original inventory to seven levels (syllable, foot, prosodic word, clitic group, phonological phrase, intonational phrase, phonological utterance), and make the strong prediction that all languages are prosodically organized using all seven levels of their hierarchy. Finally, Pierrehumbert & Beckman (1988) posit a smaller inventory of prosodic constituents (prosodic word, accentual phrase, intermediate phrase, intonational phrase), and add that particular levels may be absent from a language's prosodic structure (e.g., the accentual phrase is not part of the set of English prosodic categories and the intermediate phrase is not part of the Japanese prosodic hierarchy). Pierrehumbert and Beckman (1988) also allow limited extrametricality: e.g., syllables may be directly attached to a prosodic word node without being parsed into feet.

A great deal of influential work within prosodic phonology is based on Greek which has an abundance of sandhi rules. These phenomena are described as *fast speech rul*es in Theophanopoulou-Kontou (1973) and are analyzed largely in terms of morphosyntactic constituency in Kaisse (1985). A *selective* subset of these sandhi phenomena are reanalyzed from a prosodic phonology perspective in Nespor & Vogel (1986) and Nespor (1986, 1987).

Unfortunately, the discussion of at least some Greek sandhi in these publications appears not to be descriptively adequate, casting doubt on the viability of seeing sandhi as dependent on prosodic constituency. In what follows I discuss some of the most controversial rules and present, where available, empirical data that shed light on the reasons why phonological descriptions of sandhi may be inadequate.

Nespor & Vogel (1986) rely on the clitic group, a constituent that includes content words and their clitics as separate prosodic words, to account for several phenomena in Greek, including enclitic stress, nasal deletion before continuants (16), nasal assimilation before stops and stop voicing before nasals (17), and the deletion of vowels in hiatus (18).

(16) /tin ˈlimni/ > [tiˈlimni] “the lake, acc.”

(17) /tin periˈmeno/ > [timberiˈmeno] “I am waiting for her”

(18) /to aˈɣori/ > [taˈɣori] “the boy”

Enclitic stress is discussed in section 4.3, and, as shown there, alternative and more economical explanations to positing a clitic group are possible (see also Malikouti-Drachman & Drachman 1992b on the accentuation of clitics). Regarding the rules involving nasals, Malikouti-Drachman & Drachman (1992a) point out that they do not apply whenever their structural description is met, a problem for prosodic phonology according to which the application of rules is exceptionless. In particular, Malikouti-Drachman & Drachman point out that deletion does not apply with all clitics, as shown in (19)-(21), while, as shown in (22), nasal assimilation and stop voicing apply only between hosts and proclitics but not between hosts and their enclitics (with the exception of certain sequences of imperatives followed by pronouns, such as /ˈpline to/ > [ˈplindo] “wash it” or /ˈkane to/ [ˈkando] “do it”).

(19) /ton ˈfilisa/ > *[toˈfilisa] “I kissed him”

(20) /ton ˈfilon/ > *[toˈfilon] “the friends, gen.”

(21) /ton akustiˈkon su/ *[ton akustiˈko su/ “the headphones, gen.”,

(22) /ton ˈparkon tus/ > [tomˈbarkontus] – *[tomˈbarkondus] “their parks, gen.”

Similarly problematic is the description of vowel elision due to hiatus provided by Nespor & Vogel (1986). Nespor & Vogel use the part of Kaisse’s (1985) *mirror-loss rule* that applies to clitics to advance the proposal that vowel elision in hiatus is a domain juncture rule that applies across the prosodic words of a clitic group following the strength hierarchy in (23), which was first proposed by Hatzidakis (1905) and was later adopted by Kaisse (1985).

(23) strongest weakest
o a u i e

As Arvaniti (1991a) points out, however, this description cannot account for differences in /e/ elision between morphological markers and vowels that belong to a stem, i.e., for the fact that /e/ can be deleted in (24) or (25) but not in (26) or (27). Similar arguments are also presented in Malikouti-Drachman & Drachman (1992a) and Baltazani (2006b).

(24) /ta ˈexo/ > [ˈtaxo] “I have them”

(25) /to ˈemaθa/ > /ˈtomaθa/ “I learnt it”

(26) /ta eˈðafia/ > *[taˈðafia] “the passages”

(27) /to eryaˈlio/ > *[toryaˈlio] “the tool”

To complicate things further, other analysis, such as Malikouti-Drachman and Drachman (1992a) disagree with Nespor & Vogel (1986) on the outcome of the vowel elision rules, a difference that leads Malikouti-Drachman and Drachman to revise the vowel hierarchy as shown in (28).[18]

(28) strongest weakest
a o u i e

Still different outputs for hiatus are posited in Condoravdi (1990) who relies on vowel elision to motivate one more prosodic constituent, the minimal phrase *z*. According to

Condoravdi, some rules of vowel elision apply within *z*, a constituent larger than the prosodic word but smaller than the phonological phrase (in Condovardi's model the clitic group is not part of the prosodic hierarchy). Unfortunately, her analysis sometimes results in sequences that are impossible for Greek speakers to pronounce: e.g., according to Condoravdi (1990:68), Unrounded First Vowel Deletion applies within *z*, as in /ˈʝipsina eˈlafʝa/ > [ˈʝipsineˈlafʝa] "plaster deer, pl." (p.81). Although this example appears acceptable (at least to some speakers), if we replace it with /aˈnaɣoɣa eˈgoɲa/ "rude grandchildren", then Unrounded First Vowel Deletion should result in the sequence [aˈnaɣoɣeˈgoɲa], in which /ɣ/ remains a velar, according to Condoravdi. However, a sequence of a velar fricative followed by a high front vowel *in this context* is impossible for all Greek speakers I have consulted, while [aˈnaɣoʝeˈgoɲa] is unacceptable.

6.1 Empirical studies of sandhi

Recent research suggests that the main reason for this type of disagreement in the phonological literature may well be related to the fact that in production sandhi is much more variable than the phonological analyses suggest. This variability is related to a host of factors, as shown below: results show inter- and intra-speaker variability, as well as effects of style, with more casual speech exhibiting more instances of sandhi. Most importantly, empirical studies show that not all sandhi phenomena have categorical outcomes, as their formalization as phonological rules implies. Rather, in many cases, sandhi applies in a gradient manner.

At present we have no phonetic studies of nasal deletion before continuants in Greek, but the gradient nature of sandhi is clearly demonstrated in several studies that examine vowel hiatus, nasal assimilation and stop voicing, and /s/-voicing (a domain span rule that applies within intonational phrases according to Nespor & Vogel 1986).

Vowel hiatus has been documented using both naturally occurring data (Fallon 1994, Arvaniti & Pelekanou 2002), and controlled laboratory experiments (Baltazani 2003c, presented in more detail in 2006b, and Kainada 2007). The results of these studies show that vowel deletion applies to only a fraction of the instances of hiatus and is more likely when the vowels

are identical: Fallon (1994) found that hiatus resulted in deletion in only 30% of his data, but this rate was substantially higher for identical vowels (59%) than non-identical vowels (22%). Similarly, Baltazani (2006b) reports that almost half of her tokens showed some degree of assimilation rather than deletion of one vowel, in other words coalescence was at least as common as deletion. Coalescence as the output of vowel hiatus was first discussed in Malikouti-Drachman and Drachman (1992a) who suggest that in [a o] sequences coalescence rather than deletion occurs. Arvaniti & Pelekanou (2002), Baltazani (2006b) and Kainada (2007) all show that coalescence is possible between other vowels as well, while it is not the only outcome for [a o]. Interestingly, coalescence does not seem to be directly linked to gestural overlap, as the duration of the coalesced segment produced in hiatus is close to that of two vowels rather than one (Baltazani 2006b); in other words, speakers do not produce a vowel of intermediate quality, but rather a long vocalic stretch the quality of which is closer to the first vowel in the beginning and to the second vowel in the end.

In addition, studies show that the outcome of hiatus depends also on the vowels involved. Fallon (1994) found that the likelihood of deletion in identical vowel hiatus was higher for [a] (deletion applied in 73% of cases), lowest for [o] (38% deletion), and intermediate for [e] and [i] (58% and 44% deletion respectively). (There were no instances of [u u] sequences in Fallon's data.) Similar results are reported in Baltazani (2006b) for non-identical vowels, for which she notes that overall V1 was the vowel likely to be deleted: e.g., for the sequence [i a], there were no tokens with deletion; for [u a] deletion was rare, while [a o] and [o u] showed the biggest percentages of deletion (39%).

Finally, empirical studies show that although stress and prosodic phrasing affect hiatus resolution, their effects are not exactly as described in Nespor (1986) and Nespor & Vogel (1986). According to Nespor (1986) identical vowels do not degeminate if the second one is stressed; yet Fallon (1994) found several instances in which stressed vowels were deleted, including cases in which both vowels in hiatus were stressed. Further, all studies show that vowel deletion does not take place only within the clitic group but can apply across phrasal constituents as well; e.g., Baltazani (2006b) reports that hiatus across words within the same phrase was resolved by deletion in 31% of her data. At the same time, vowel deletion may fail to apply within smaller prosodic constituents (Fallon 1994, Arvaniti & Pelekanou 2002, Baltazani 2006b), although application does get rarer across stronger boundaries (Baltazani 2006b). In

addition, focus—a factor that had not been noted before—appears to play a significant role in the outcome of hiatus: according to Baltazani (2006b), lack of vowel assimilation was most common if one of the words involved was in focus.

The role of prosodic phrasing in vowel deletion was expressly tested in Tserdanelis (2005), who hypothesized that deletion could be used to disambiguate sentences such as [ˈiðame ˈomorfa aˈmaksça ce mixaˈnaca stin ˈekθesi] "we saw beautiful cars and mopeds at the exposition", i.e., that speakers would apply deletion if there was a phrase break after [aˈmaksça] "cars", but would not do so if the phrase break separated [ˈomorfa] "beautiful" from [aˈmaksça] "cars". This difference, however, was not realized by the speakers, leading Tserdanelis to conclude that vowel degemination is not categorical in Greek. However, his results may be due to the type of ambiguity (adjective-scope ambiguity) that the speakers were called upon to clarify prosodically. As Tserdanelis himself notes, many failed to do so, that is, failed to place a phrasal boundary after either the adjective or the first noun; in addition, when the sequence involved was [i i], Tserdanelis found that the vowels were either devoiced or elided making measurements difficult.

Taken all together, these studies clearly show that vowel deletion in hiatus is not a categorical rule that deletes one of the vowels in the sequence found within a particular prosodic domain. The resolution of hiatus can be deletion, but this outcome depends on the vowels involved, the position of focus, and prosodic constituency (and possibly other factors that have not yet been investigated). At least half of the time, the outcome of hiatus is gradient, and can vary both within and across speakers, with different outputs being possible even across the repetitions of the same sentence by the same speaker (Baltazani 2006b).

The other two rules that according to Nespor & Vogel (1986) are said to apply *optionally* within the clitic group are nasal assimilation and stop voicing, as in [ton kaˈpno] > [toŋgaˈpno] "the smoke, acc.". These rules were the subject of empirical investigation in Arvaniti & Joseph (2000) the results of which do not entirely agree with the phonological description. Specifically, they show that in casual conversational Greek, post-lexical nasal+stop sequences (e.g., /tin paˈlami/ "the palm") are overwhelmingly produced as oral voiced stops ([tibaˈlami]), that is in the same way they are produced within lexical items (cf. /amˈpeli/ > [aˈbeli] "vineyard"). Unlike

word-internal sequences, however, in formal speech, postlexical nasal+stop sequences may remain completely unassimilated ([tin paˈlami]) or show only nasal assimilation for place ([timpaˈlami]). On the other hand, if the stop assimilates for voice, the actual production of a nasal is extremely rare, especially among the younger speakers, i.e., the output expected by the rules of Nespor & Vogel (1986), [timbaˈlami], is rarely attested. Arvaniti & Joseph (2000) speculate that this difference between lexical and postlexical nasal+stop sequences has a sociolinguistic rather than phonological explanation. Specifically, Arvaniti & Joseph suggest that nasalized voiced stops are no longer part of the inventory of many young Greek speakers; therefore the use of oral stops within words is no longer stigmatized. When these speakers, however, need to use a more careful style of speech, they may deem oral voiced stops unacceptable postlexically; since they no longer have the option of nasalizing the stop, their only way to show formality is to block assimilation altogether. Although these data of Arvaniti & Joseph (2000) provide some insight into this particular phenomenon of Greek, and clearly indicate that sociolinguistic factors may play a part in the realization of sandhi, it should be noted that as yet we do not have empirical data that involve all proclitics, and no data on enclitics with respect to nasal assimilation, stop voicing and nasal deletion (as shown earlier, according to Malikouti-Drachman & Drachman 1992a and Arvaniti 1991a, enclitics do not participate in these rules).

Gradient outcomes are possible for another rule that has often been reported for Greek, /s/-voicing, a domain span rule said to apply whenever a word-final /s/ is followed by a voiced consonant within an intonational phrase (Nespor & Vogel 1986). Arvaniti & Pelekanou (2002) and Baltazani (2006c) report clearly gradient outcomes for /s/-voicing, with some instances of /s/ showing no voicing at all, others showing partial voicing, and yet others being fully voiced; similarly gradient outputs are mentioned in passing in Nicolaidis (2001). A breakdown of the three outcomes, based on Baltazani (2006c), is presented in Figure 7, which shows that categorical /s/-voicing applies only to 50% of the data overall. As can also be seen in Figure 7, one of Baltazani's most interesting results is that /s/-voicing is least likely to occur when /s/ is followed by a sonorant and most likely to occur when /s/ is followed by a voiced stop, possibly a result related to the well known tendency of clusters of obstruents to agree in voicing in Greek. It is equally worth noting that both Arvaniti & Pelekanou (2002) and Baltazani (2006c) found that

when partial voicing occurs, it is the early part of /s/ that is voiced. This suggests that /s/-voicing may be the result of carry-over coarticulation (residual voicing due to the preceding vowel) rather than anticipatory coarticulation (voicing due to the following voiced consonant), though the results of Nicolaidis (2002b) cast doubt on this interpretation.

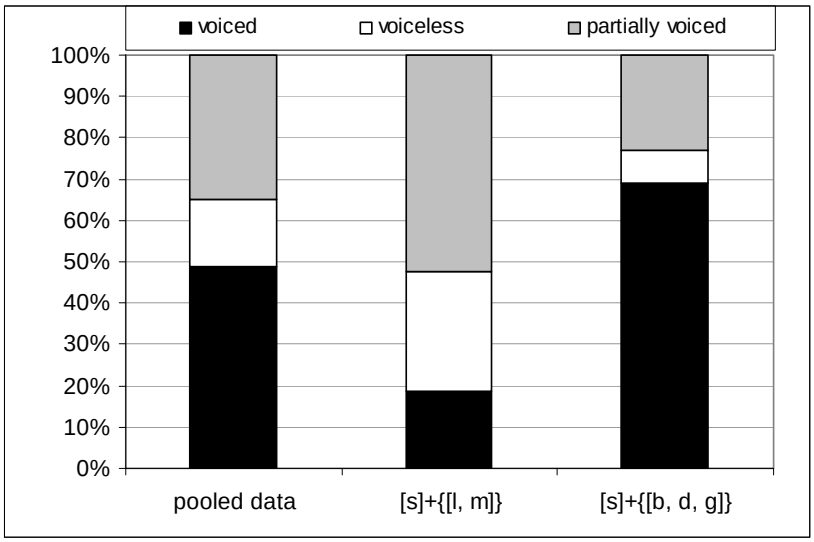


Figure 7. Percentage of /s/ outcomes after Baltazani (2006c); on the left, data pooled across consonants following /s/; on the right, percentages are separately presented for sonorants and voiced stops.

In contrast to Arvaniti & Pelekanou (2002) and Baltazani (2006c), Tserdanelis (2005) presents data in which /s/ is fully voiced in all cases, both in laboratory speech and in child-directed speech (elicited from three mothers from Thessaloniki addressing their toddler daughters). Although these differences in results could appear to cast doubt on the validity of experimental evidence, it should be borne in mind that the overall picture of sandhi is one of great individual variation, which may or may not surface in a small corpus. For instance, Baltazani (2006c) reports that two of her five speakers rarely produced /s/ tokens that were not fully voiced, so most of her voiceless and partially voiced instances of /s/ come from three of her speakers. Such inter-speaker differences suggest that in order to fully understand sandhi we need studies with large numbers of speakers so that we can capture the variability present in the population. Note, for instance, that /s/-voicing does not normally apply to /sl/ sequences within words (e.g., /ˈslavos/ > [ˈslavos] “Slav”, /sliˈpaki/ > [sliˈpaki] “underwear”), but some speakers do

produce forms such as [ˈzlavos] or [zliˈpaki], obviously overgeneralizing the /s/-voicing rule.[19] Such speakers would be less likely to produce partially voiced or voiceless /s/ before voiced consonants, than speakers who do not produce such forms.

Another factor that may well have contributed to the variable results in the studies of /s/-voicing is accentuation and phrasing. Arvaniti & Pelekanou (2002) did not do a systematic comparison of accentuation, though they do note that /s/-voicing applies across several types of prosodic boundaries. Baltazani (2006c), on the other hand, examined the final /s/ of a word that was accented but placed immediately before an item meant to be in focus: Baltazani examined the /s/ of the word /ˈoros/ "term" in the phrase /o ˈoros ___ silaˈvizete ˈefkola/ "the term ___ is easily syllabified". In this context, the word following /ˈoros/ was most probably produced with hyperarticulation and some degree of "separation" from adjacent words (note, e.g., that Baltazani 2006b found less deletion in hiatus if one of the words involved was in focus). Thus in her experiment, the word /ˈoros/ may not have been in optimal position for coarticulation with the following word; hence /s/ was less likely to be fully voiced. In contrast, Tserdanelis (2005), who was interested in using sandhi to disambiguate ambiguous sentences, by necessity placed /s/ in two different prosodic positions: in half of his materials, /s/ was meant to be followed by an intonational phrase boundary (Nespor & Vogel 1986:213 ff.), while in the other half, there was no phrasal boundary after /s/. This difference could well have affected the realization of /s/.

Two more sandhi phenomena of Greek that have been subjected to empirical investigation are consonant degemination, a type of sandhi first discussed in Arvaniti & Baltazani (2000, 2005), and resyllabification, mentioned in passing in Nespor & Vogel (1986). Consonant degemination is shown to apply categorically within intermediate phrases, so that when identical consonants are found across a word boundary only one consonant is produced (Arvaniti & Pelekanou 2002, Tserdanelis 2003, 2005). In addition, Tserdanelis (2005:94) shows that listeners can successfully use degemination as a clue to disambiguate ambiguous sentences.

Resyllabification also appears to apply categorically at least within prosodic words that include hosts and their clitics. As discussed earlier (see 2.5), Tserdanelis (2005) found some evidence that word final consonants, such as the [t] of [jot] "yacht", resyllabify to the onset of the following syllable, at least when this syllable is part of the same prosodic word, as in [to jot su] "your yacht". Evidence for the resyllabification of word-final consonants is also presented in

Katsika (2007) who examined proclitic and host sequences such as [ton ˈevro] "the (river) Evros, acc." and [to ˈnevro] "the nerve". Katsika expected that the duration of the [n] in [ton] would be longer than the duration of the [n] in [ˈnevro] due to word-final lengthening. Katsika found no durational differences for the nasal, but does report some differences for the preceding vowel (which, however, being only 4-9ms on average, may not be perceptible). Crucially, she also found that the dip in F0 associated with the presence of a rising pitch accent always co-occurred with [n], suggesting that the coda [n] of [ton] resyllabifies as onset of the following syllable (on the phonetics of accent alignment see section 7.2).

6.2 The Greek prosodic hierarchy

On the basis of the above, it is difficult to reach a firm conclusion regarding the sandhi phenomena of Greek. It is still not certain that we have even rudimentary descriptions of all the phenomena that apply, and we clearly do not yet know for all of those that have been described whether they are categorical or gradient. Most importantly, the existing results cast serious doubt on the claim that sandhi rules can be used as a heuristic for determining prosodic structure. For these reasons, a conservative approach would be to adopt a relatively flat prosodic hierarchy, such as that proposed by Pierrehumbert and Beckman (1988) which includes only three levels above the foot, and to use not only sandhi but also intonation, timing and stress patterns as evidence for constituent structure.

This is the view adopted in Arvaniti & Baltazani (2000, 2005) which I present here in brief together with some additional evidence in its favor. The Greek prosodic hierarchy proposed by Arvaniti & Baltazani includes three levels above the foot (on the foot, see section 5.3): the phonological word, the intermediate phrase and the intonational phrase.

The prosodic word includes lexical items and any clitics attached to them. Evidence that the prosodic word in Greek is larger than the terminal element of the syntactic tree comes from several sources, including sandhi and the behavior of stress and intonation when enclitics are present. The sandhi phenomena in question include resyllabification (Tserdanelis 2005, Katsika 2007), and—to an extent—nasal assimilation and stop voicing (Arvaniti & Joseph 2000), as well as nasal deletion before continuants (as analyzed in Malikouti-Drachman & Drachman 1992a).

Additional evidence that hosts and enclitics form one prosodic word comes from enclitic stress and its interaction with intonational structure and focus, a topic examined in some detail in Botinis (1989).

As discussed in 4.3, Botinis elicited data in which sequences with enclitic stress were compared to similar sequences with lexical stress. Botinis (1989) based his comparisons on the sequences in (29) and (30). Both sequences were produced with narrow focus on [ˈmaθima] "lesson" which entails a pitch accent on this word.

(29) [to ˈmaθima | tis …] "the lesson, her…"

(30) [to ˌmaθiˈma tis] "her lesson"

Crucially, Botinis's F0 results show two distinct patterns of accentuation depending on whether [tis] is an enclitic, as in (30), or a proclitic, as in (29). In (29) the pitch accent co-occurs with the first lexically-stressed [ma]. In (30) however, it co-occurs with the second [ma], that is the syllable with enclitic stress, while there is no accent on the lexically-stressed [ma]. This accentual pattern can only be interpreted as evidence that the noun and its enclitic behave as one word, since [to ˌmaθiˈma tis] is in narrow focus.

Further evidence in support of this conclusion comes from another experiment of Botinis (1989) in which he attempted to elicit the sequences in (31) and (32) with narrow focus either on their noun ([ˈɣrama] "letter" and [ˈproɣrama] "program" respectively), or on the adjective [ˈproto] "first" in the case of (31) or the possessive [tis] "hers" in the case of (32). Although Botinis's speakers had no difficulty switching the focus from [ˈproto] to [ˈɣrama] in (31), they were unable to do the same with [to ˌproɣraˈma tis], which was invariably produced with a pitch accent on the enclitically-stressed [ma]. The fact that in (32) it is impossible to selectively focus on the noun or the enclitic is further evidence that the two form one prosodic word.

(31) [to ˈproto ˈɣrama] "the first letter"

(32) [to ˌproɣraˈma tis] "her program"

Finally, evidence for the intermediate and intonational phrase comes from both intonational and durational results. As Arvaniti & Baltazani (2005) show, intermediate phrases are demarcated by simple pitch movements, such as plain rises and falls that are scaled lower than similar movements associated with intonational phrases. Further, these rises and falls clearly co-occur with phrase-final vowels, whether these are stressed or not (Tserdanelis 2003, Baltazani 2006f). On the other hand, intonational phrases often end with very complex pitch movements, such as the rise-fall of yes-no questions (Arvaniti et al. 2006a). These complex movements are attested only utterance-finally, that is only at the end of intonational phrases (Botinis 1993, 1995, 1998, Baltazani 2006f). These complex pitch movements can only be analyzed as the product of several independent tones (Arvaniti et al. 2006a; for additional arguments on this point, see section 7). From a durational perspective, Kainada (2007) provides evidence that segmental durations increase as words are found at the edges of increasingly strong boundaries; her durational results suggest a three level distinction between prosodic words, intermediate phrases and intonational phrases. Evidence for lengthening of segments adjacent to an intermediate phrase boundary is also presented in Tserdanelis (2003) as discussed in detail in 3.1.

6.3 Sandhi and prosodic phrasing: summary

In conclusion, the results of the studies discussed above cannot provide definite answers regarding the types of sandhi examined, while there are still several types of sandhi that have not been empirically investigated, and others that may yet be discovered. Despite their limitations, these studies show clearly that we cannot simply rely on impressionistic data for the description of sandhi (or any other speech phenomenon, for that matter), let alone develop phonological analyses that disregard the existing empirical evidence (as happens, e.g., in Kabak & Revithiadou in press, who discuss /s/-voicing, resyllabification, vowel deletion and rhythmic stress without taking into account the host of recent empirical studies on these phenomena). The empirical data clearly demonstrate that impressionistic descriptions are at best incomplete and at worst inaccurate or inconsistent with the tenets of prosodic phonology itself. Thus it is crucial that every pattern uncovered be subject to acoustic and articulatory investigation before we can say with any degree of certainty whether we are dealing with a categorical rule or gradient variation. Examining the speech of a large number of speakers, while taking into account the

effects of intonation, stress, focus and accentuation is crucial for obtaining a clear view of how spoken Greek is truly structured. In addition, it is vital to investigate different styles of speech; a study that highlights the importance of style in the realization of sandhi is Tserdanelis (2005) who found that the occurrence of several sandhi phenomena showed an overall reduction from 92% to 62% between adult directed and child directed speech.

Studies that rely on large numbers of speakers and elicit data in a variety of styles will shed light on the application of sandhi in Greek, but it is equally important to recognize that sandhi should not be the only criterion for positing prosodic phrasing, for which independent evidence should also be sought. At present we have only one study, Kainada (2007) that looks for independent evidence for phrasing, such as duration differences at the edges of putative prosodic constituents.

Despite their limitations, the results of the empirical studies presented here have important repercussions for our understanding of sandhi and phrasing. A widespread assumption based on the tenets of prosodic phonology has been that the application of sandhi is regulated by prosodic boundaries; in practice this has meant that the application of sandhi rules has been seen as evidence for the presence of specific prosodic constituents and in some cases has even motivated the positing of new constituents in the prosodic hierarchy (e.g., Condoravdi 1990). The studies of Greek sandhi show clearly that the view that sandhi can be a reliable predictor of prosodic phrasing, and conversely that prosodic phrasing determines the application of sandhi is too simplistic (not to mention circular). More extensive empirical work of Greek, a language rich in sandhi phenomena, should shed new light onto the question of prosodic phrasing and the nature of connected speech phenomena at large.

7. Intonation

The intonation of Greek has been studied from many different perspectives, including those of phonetics, phonology, semantics, pragmatics, sociolinguistics, discourse analysis. Unfortunately, most of this body of work is couched within a variety of analytical frameworks some of which are quite idiosyncratic. For example, Mennen & Den Os (1993, 1994) use the stylized contours of the IPO tradition (’t Hart, Collier & Cohen 1990), divide the melody into a head and a nucleus as in the British school (e.g., O’Connor & Arnold 1973), and represent it

using autosegmental representations following the conventions of Hayes & Lahiri (1991). Papazachariou & Politis (in press), on the other hand, divide syllables into accented and unaccented, but consider accented only syllables with focal accent (or "sentence stress"). Botinis, Ganetsou and Griva (2005) examine not actual F0 contours but rather average F0 values for each syllable (derived by taking a measurement of F0 at the onset, middle and end of each syllable), arguing that this "normalizes tonal measurements with reference to temporal and tonal alignments of produced utterances" (p. 95). Yet, in other models, the exact temporal alignment of F0 with the segmental string is considered crucial (see 7.1) and has been shown to be important for perception as well as production in Greek (e.g., Botinis 1989, Chorianopoulou 2002).

The overall picture of these very diverging views on how intonation should be examined and represented is the reverse of what we observe in all other areas of phonetic inquiry in Greek: while in other areas, as shown earlier, there is quite a lot of disagreement regarding the data (see e.g., the discussion on Greek vowel quality in 3.1), in intonation, all studies present remarkably similar data but analyze them in widely different ways. For example, the F0 pattern on [ˈfiɣane] in Figure 8 is analyzed as the suppression of accent in Botinis et al. (2005), but as sequence of a low accent on the stressed syllable of [ˈfiɣane] followed by a phrasal rise in Arvaniti & Baltazani (2000, 2005), Baltazani (2006f), and Tserdanelis (2003).

In order to provide a cohesive picture, in what follows I review and interpret the existing work using the most widely adopted framework in intonational research, the autosegmental-metrical framework of intonational phonology (henceforth AM; Pierrehumbert 1980, Beckman & Pierrehumbert 1986, Pierrehumbert & Beckman 1988, Ladd 1996). Further, my focus here is the review of research on the phonological structure and phonetic realization of intonation (see also 7.1). I note, however, the breadth and significance of interdisciplinary research involving Greek intonation (e.g., Botinis 1991, 1992, 1993, 1995, 1998, Botinis, Gawronska & Haida 2003, Botinis et al. 2003, Bannert et al. 2003, Jun 2003, Georgiafentis & Sfakianaki 2004, Papazachariou 1998, 2000, Papazachariou & Archakis 2001, Baltazani 2003a, 2004, 2006a).

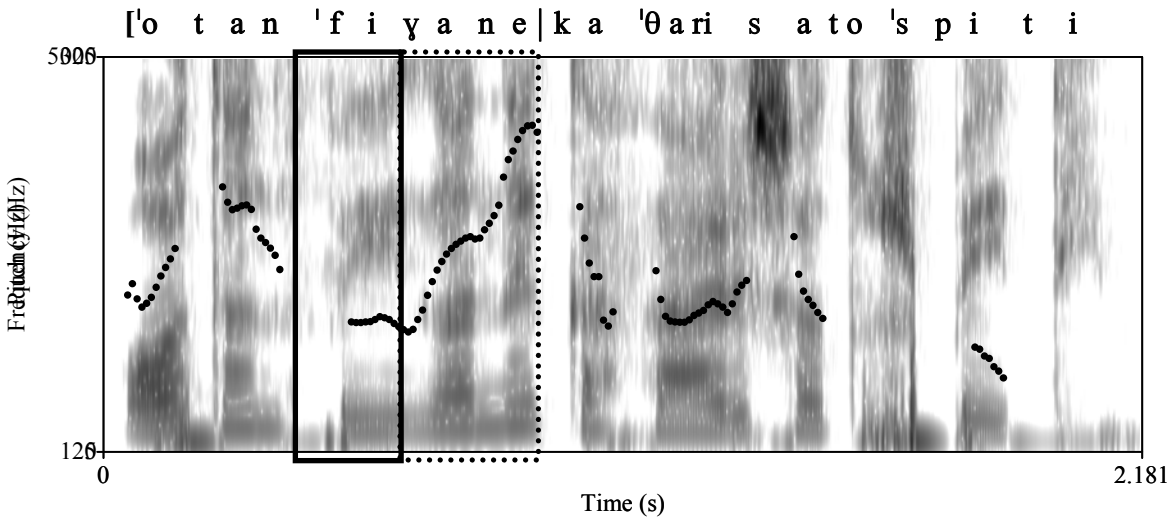


Figure 8: Spectrogram and F0 contour of [ˈotan ˈfiɣane | kaˈθarisa to ˈspiti] "When they left, I cleaned the house"; the stressed syllable of [ˈfiɣane] "they left", which is interpreted as unaccented by Botinis et al. (2005) but as carrying a L* accent by Arvaniti & Baltazani (2000, 2005), Baltazani (2006f) and Tserdanelis (2003) is boxed in solid lines for ease of reference; the broken lines demarcate the unstressed syllables of [ˈfiɣane], which show a continuation (phrasal) F0 rise.

7.1 The autosegmental-metrical framework of intonational phonology

In the AM framework of intonational phonology, the melody (intonation) of an utterance is phonologically represented as a series of *high* (henceforth H) and *low* (henceforth L) tones and combinations thereof; these tones are considered to be autosegments and are represented in linear order in an intonational tier. As with all phonological elements, tones are associated to elements in other tiers by means of association lines. Tones associate with structural positions, such as the boundaries of prosodic constituents, or with prosodic heads (which, in the case of Greek, are the stressed syllables).

There are two types of tones that associate with phrasal boundaries: *boundary tones* (e.g., H%) associate with intonational phrase boundaries, while *phase accents* (e.g., L-) associate with intermediate phrase boundaries. The function of both types of phrasal tones is largely delimitative, i.e., their aim is to mark the edges of phrasal constituents. On the other hand, tones

that associate with heads of constituents are called *pitch accents* (e.g., H*). In this model is it assumed that syllables are independently prominent (because of their metrical strength) and thus pitch accents are seen as *prominence cueing* rather than prominence lending (Ladd 1996 following a suggestion by Francis Nolan). It follows, as shown earlier, that metrically the syllables of Greek are divided into stressed and unstressed syllables: the former may be associated with a pitch accent, in which case they are stressed and accented, or not, in which case they are stressed but unaccented. By definition, pitch accents do not associate with unstressed syllables, though unstressed syllables may show pitch movement associated with a phrasal tone; this is illustrated in Figure 8 in which the unstressed syllables of the word [ˈfiɣane] "they left" have rising F0 that indicates to listeners the presence of a phrasal boundary at the end of this word, but does not render these syllables metrically prominent.

As mentioned above, tones constitute an *abstract phonological representation* (in other words, they are not, as it is often assumed, a type of transcription system for intonation). The tones of an intonational representation are phonetically realized as *tonal targets*, that is as specific points in the F0 contour, defined along two dimensions: their *scaling*—their value in Hz or any other unit of measuring F0 or pitch—and their *alignment*—their temporal occurrence relative to specific segmental landmarks; e.g., boundary tones are typically aligned with the last vowel before the boundary they are associated with. It is this alignment of a H% boundary tone that produces the rise on the last (unstressed) vowel of [meˈseona] "Middle Ages" and [siˈnaðelfi] "colleagues" in Figure 9.

Both the scaling and alignment of targets are considered to be stable. However, stability is to be interpreted somewhat liberally, as with all other phonetic realizations. First, the exact scaling of tones depends partly on non-linguistic factors, such as the physical characteristics of the speaker, and paralinguistic factors such as her state of excitement or surprise at the moment an utterance take places. Tonal alignment on the other hand, is less affected by such external factors; rather it is linguistic context that affects it the most, such as the position of the tone in the utterance, the number and position of other tones, the phonological weight of the syllable the tone is associated with, speaking rate and so on (among many, Arvaniti et al. 1998, 2000; Fougeron & Jun 1998, Ladd et al. 1999; Ladd, Mennen & Schepman 2000). When all these variables are kept constant, both scaling and alignment are remarkably stable.

Since in the AM framework only some syllables are associated with tones that are realized as tonal targets, it follows that syllables not tonally specified in phonology are realized with variable F0 depending on their position relative to syllables with tonal specification. In other words, F0 between tonal targets is derived by interpolation (on recent evidence on the validity of this point, see Arvaniti et al. 2006a, Arvaniti & Ladd, subm.; for a brief discussion see below and also section 3.2).

This brief description of AM largely explains the theoretical reasons for which many of the studies mentioned earlier—studies that examine the phonetics of intonation with respect to discourse or focus structure—are not discussed here in detail. First, although many of these studies clearly shed light on the relationship between intonation and other aspects of the grammar, they are not directly concerned with either formal or realizational properties of intonation. Yet intonation is best understood if we assume that its phonetic manifestation is the result of independent units that are strung together to create a melody (for a discussion of this point, see Arvaniti 2007a). These units are finite and their meaning is related to the context in which they are found. It follows that there is no one-to-one relationship between meaning and melody: various pragmatic functions are often expressed by the same intonational means, while intonational meaning is derived by the combination of intonational units in a melody, the sentence with which they are used and the context in which the entire utterance is produced. For example in Figure 9, two very different utterances with identical F0 are presented: [ðe ˈzume sto meˈseona] "We don't live in the middle ages" (a phrase borrowed from Baltazani 2003a) and [ˈpu ˈpiɣan i siˈnaðelfi] "where did (our) colleagues go?". The reason for the similarity is obviously not that the melody has the same meaning or function in these two utterances. Rather, in both cases, the same phonological string of pitch accents and boundary tones (in autosegmental terms L*+H L- !H%) is used and its meaning is derived in conjunction with the sentence meaning. The strings are phonetically identical because they are applied to utterances with the same number of words and syllables and with stresses in the same location (for an illustration of the effect that the number of syllables in an utterance can have on a pitch contour, see Figure 12).

The above follows from the AM view that the phonological structure of intonation mediates between the actual realization of intonation as F0 modulation and particular uses of intonation, such as its use in the expression of focus. Because the link between pragmatic

function and phonetic form is not direct, we cannot assume a direct link between intonation and, say, focus expression, syntax, or discourse topic, as in Botinis (1998), Botinis et al. (2003a), Botinis et al. (2003b), Botinis et al. (2004) (for related arguments see Arvaniti 2007a, Ladd 1996, chap. 1).

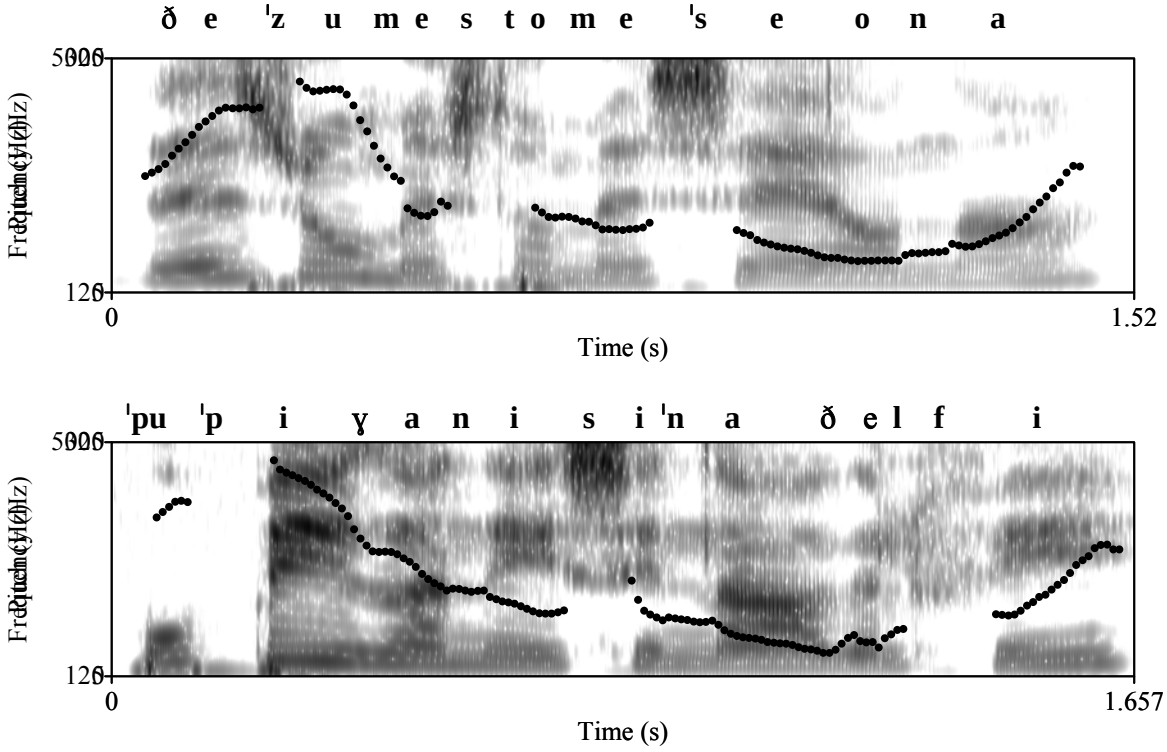


Figure 9: Spectrograms and F0 contours of (a) [ðe ˈzume sto meˈseona] "We don't live in the middle ages" and (b) [ˈpu ˈpiɣan i siˈnaðelfi] "where did (our) colleagues go?"

7.2 Prenuclear accents in Greek

Within the AM framework, a series of findings about Greek intonation have been reported in the past decade or so. Thus, Arvaniti & Ladd (1995) and Arvaniti et al. (1998) in a series of experiments examined the phonetics of the "prenuclear" accent of Greek. This accent appears on practically all the content words of an utterance that come before the word that carries the *nuclear accent* (which, by definition, is the last accent of an utterance; in broad focus utterances, this accent appears on the last content word; Nespor & Vogel 1986, Botinis 1989, Arvaniti &

Baltazani 2005). The results of Arvaniti & Ladd (1995) and Arvaniti et al. (1998) clearly show that these accents are bitonal, consisting of a L and a H tone; the L tone consistently aligns just before or at the very onset of the stressed syllable, while the H tone appears a few milliseconds (on average 10-20 ms) after the onset of the *postaccentual* vowel. Data that agree with this interpretation are presented in Arvaniti & Baltazani (2000, 2005), and Baltazani (2006f). Baltazani (2006f) in particular presents quantitative data showing that the position of the stressed syllable relative to the word boundary does not affect the alignment of the accentual peak. These results support the conclusion of Arvaniti et al. (1998) on this point and refute a related hypothesis advanced in Arvaniti & Ladd (1995). This LH accent, although analyzed in a variety of frameworks, can be clearly observed in the data of Botinis (1989)—where it is referred to as "prefocal accent", Tramboulis (1997) and Baltazani & Jun (1999). In addition, the alignment of this accent's peak has been shown to affect listeners' perception of the location of stress within a word (Botinis 1989, Chorianopoulou 2002).

Arvaniti et al. (1998) and Arvaniti et al. (2000) discuss the patterns of variation in the scaling and alignment of the LH prenuclear accent. Their results show that the alignment of the L and H tones is dependent on the location of preceding and following accents. Prenuclear accents show the canonical alignment described above if there are separated by at least two unstressed syllables. When accents appear closer together the result is "tonal crowding" a phenomenon that has variable repercussions on the realization of the pitch accents involved. Under tonal crowding, the L tone of the second of two adjacent prenuclear accents may be undershot or elided; alternatively, the second accent may be displaced to the right, that is, show later alignment than what is expected by default; it is also possible for the peak of the first accent to be displaced to the left, showing earlier than canonical alignment (for a discussion see Arvaniti et al. 1998, 2000).

One issue that has attracted some attention in the intonational literature is the phonological representation of the prenuclear LH accent of Greek. Within the autosegmental-metrical framework it is assumed that in bitonal accents like this one, one tone is "starred" (e.g., L+H*). The star indicates the primacy (or headedness) of the starred tone and in fact Pierrehumbert (1980) assumes that only this tone is phonologically associated with the segmental string, while the unstarred tone depends on the starred tone, which it precedes or trails by a constant amount of time. However, the results of Arvaniti et al. (1998) clearly show that neither

the L nor the H of the LH pitch accent of Greek is aligned with respect to the other tone and neither co-occurs with the stressed syllable, questioning a simple relationship between phonological association and phonetic alignment, and the exact meaning of starredness (Arvaniti et al. 2000). These findings have led to a critical examination of tonal alignment in a host of languages (among many, Asu 2005 on Estonian, Frota 2002 on Portuguese, Dalton & Ni Chasaide 2005 on varieties of Irish, Schepman, Lickley & Ladd 2006 on Dutch, Welby 2006 on French, Prieto & Torreira 2007 on Spanish). The rather unexpected phonetic realization of the Greek LH accent has also been responsible for the variability of its representation in the relevant literature: Arvaniti (1994) represents it as L*+H; Arvaniti et al. (2000) lean towards L+H*, while Arvaniti & Baltazani (2005) suggest L*+H on the basis of evidence for the existence of an accent which shows clear alignment of its peak with the stressed syllable and thus can be more straightforwardly described as L+H*; this is also the analysis adopted by Arvaniti et al. (2006b).

7.3 Nuclear accents and phrasal tones in declaratives

The pitch accent described as L+H* is examined in more detail in Arvaniti et al. (2006b). This accent is used in Greek to indicate narrow or contrastive focus in an utterance (e.g., [ˈpire ci ˈstela tiˈlefono] “STELLA also called” or [o baˈbas ˈitan sto tiˈlefono] “It was DAD on the phone (not mom)”. Arvaniti et al. (2006b) compare this accent to the prenuclear accent and to data from a similar rising tonal movement found in Greek polar questions (see section 7.4). They show clearly that the narrow focus accent shows a dip close to the onset of the stressed syllable of the focused word and a peak that co-occurs with the stressed vowel of that word, and thus appears much earlier than the peak of the prenuclear accent, even when there is no tonal-crowding that could “push” the peak to the left. Thus, Arvaniti et al. (2006b) conclude that the accent used in narrow focus is best analyzed as L+H* and that therefore the prenuclear accent is best represented as L*+H, since it contrasts with L+H* within the system of Greek intonation. These results are in line with similar observations in Arvaniti & Baltazani (2000, 2005), and the data of Botinis (1989) who elicited sentences with narrow focus.

The phonetics and phonology of the nuclear accent in broad focus declaratives are less well understood. Arvaniti & Baltazani (2005) propose that there are two possible nuclear accents

in broad focus declaratives, which they represent as H* and H*+L (H*+L was analyzed as !H* in Arvaniti & Baltazani 2000; this description was not satisfactory as it implied that the difference between the two accents was one of scaling rather than tonal composition; data suggest that the latter is a more likely reason for the difference between the accents, though quantitative research is still lacking on this point).

Arvaniti & Baltazani (2005) mention that H* is used in broad focus declaratives in which the last word carries, by default, the nuclear accent and the utterance presents new information. The use of H*+L on the other hand implies that the answer is obvious and therefore it should be known to or inferred by the addressee (e.g., in an old Greek comedy an actor uses this accent when responding with [ˈaspro] "white" to the question *What color shirt did you buy for your wedding?*.

In one-word utterances, H* is realized as a (small) rise to a peak which co-occurs with the stressed vowel; in longer utterances, it can be realized as a gradual fall that starts after the onset of the stressed vowel; between H* and the preceding L*+H there is a declining F0 plateau. H*+L, on the other hand, is realized as a steep fall throughout the stressed syllable, so that the peak appears before that syllable.[20] In terms of scaling, the peak of H* is typically scaled lower than the peaks of preceding prenuclear accents (when such accents are present), but H*+L shows higher scaling compared both to H* and to prenuclear accents (if such accents precede H*+L in the same utterance). The realization of the two accents in illustrated in Figure 10.

Greek declaratives normally end in a fall that may include a final stretch of low F0 represented as L- L% (Arvaniti & Baltazani 2000, 2005), though so far we do not have any empirical studies that examine the exact realization of this sequence of low tones. In particular, a point of contention within the intonational literature is the alignment of the L- phrases accents in declaratives (for a discussion see Ladd 1996, ch. 3). As far as I could ascertain, there are no data from Greek on this point.

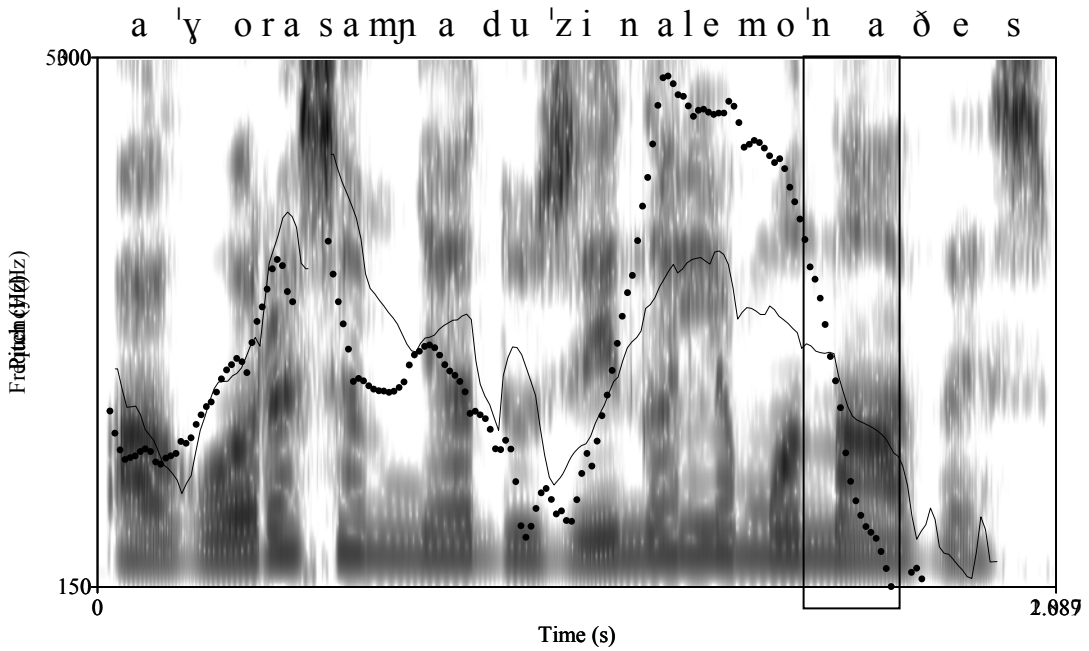


Figure 10: Spectrogram and F0 contours of [aˈɣorasa mɲa duˈzina lemoˈnaðes] "I bought a dozen lemonades"; the final accent in the solid line contour is a H* accent, realized as a gradual fall that coincides with the stressed vowel of [lemoˈnaðes] "lemonades" (this syllable is boxed for ease of reference); the final accent in the dotted line contour is a H*+L accent, which is realized as a steep F0 drop throughout the stressed syllable of [lemoˈnaðes]. Note that in both melodies the final pitch accent is followed by L- L% phrasal tones.

Given the above, we can phonologically represent the default intonation of Greek declaratives as (L*+H) {H*, H*+L} L- L%. Prenuclear L*+H accents are optional only in the sense that an utterance may contain only one word, which by default will be accented with a nuclear accent, either H* or H*+L; if other content words are present, however, these will all carry L*+H accents.

The only exception to the accenting of all content words in Greek declaratives involves early or contrastive focus. In this case the overall melody is (L*+H) L+H* L- L%. The presence of early focus means that F0 remains low and flat after it, so that any content words that follow the focused item remain unaccented (Botinis 1989, Baltazani & Jun 1999, Botinis, Bannert & Tatham 2000). For listeners, the lack of pitch accents after the nucleus is the most important cue for the detection of early narrow focus in Greek; in contrast, increasing the pitch range on the

focused word is not as effective (Botinis & Bannert 1997). This result clearly demonstrates the need to take intonational structure—and by extension intonational phonological representations—into account when examining the relationship between focus and intonation, rather than assuming some direct link between focus and pitch range as Botinis & Bannert (1997) do (for a discussion of this point, see Arvaniti et al. 2006a, Arvaniti 2007a).

The above melody descriptions apply to cases in which IPs contain only one ip. Baltazani & Jun (1999) also examined longer utterances, such as [tis ˈliðas ti ðuˈʎa | tin anaɣnoˈrizun oli i vioˈloʝi] "as for Leda's work, all biologists recognize it" which are usually broken down into more than one ip. As the data of Baltazani & Jun (1999) show, the right edge of IP-medial ips is demarcated by H- phrase accents. These H- phrase accents are realized as rises in pitch that co-occur with the last syllable of the ip (for an example, see Figure 8). These H- phrase accents do not appear to be used for the IP-final ip, the right edge of which is demarcated by L- instead. Similar results for ip rises are reported in Tserdanelis (2003) and Baltazani (2006f).

As mentioned earlier, the dip and subsequent rise of F0 in words that are final in IP-medial ips is observed in Botinis et al. (2005). However, Botinis and his colleagues assume that stressed syllables should always have high F0 and since this is not the case here they conclude that the accent in these words is suppressed. This is in line with the assumptions of Fujisaki's model of intonation (e.g., Fujisaki 1983, Fujisaki, Ohno & Yagi 1997) which assumes a declining phrasal component of F0 onto which local rises called "accent commands" are superimposed.

Yet, Baltazani (2006f) shows clearly that the stressed syllable of words in ip-final position is consistently low in F0 and that the exact realization of this low F0 stretch is determined by the position of the stressed syllable in the word. When stress is on the ultima, the low F0 stretch starts up to 15 ms before the onset of the stressed syllable (this happens in 40% of the tokens); at the same time, the duration of the final syllable is 1.5 times that of the same syllable in ip-medial position. This lengthening is an indication that this stressed syllable must be in turn low and then rising in F0; in autosegmental terms, this syllable carries both a L and a H tone, and the realization of both tones is achieved by lengthening the segmental material with which the tones are to co-occur. This explanation is further supported by the pattern observed when the ip-final word is stressed on the penult or the antepenult: in this case, the low level F0

stretch largely co-occurs with the stressed syllable, and the rise starts after it. The consistent association of low F0 with the stressed syllable suggests that the connection between the two is intended on the part of the speakers: if the aim was simply to have rising F0 at the very end of the word, we should not observe a relationship between the stressed syllable and the beginning of the rise (that is, the end of the low-level F0 stretch). Thus, it is best to analyze this pattern as the presence of a L* accent, as Baltazani (2006f) does, rather than as the suppression of accent, as in Botinis et al. (2005), since in the absence of accent one would expect low F0 to be less strictly aligned with the stressed syllable. Generally, the alignment of F0 falls and rises with particular segments is a point that is easy to account for within AM, but can only be accounted for in an *ad-hoc* fashion in models such as Fujisaki's; the difficulties of this model with respect to Greek are discussed in some detail in Arvaniti & Ladd (subm.).

7.4 The intonation of Greek polar questions

In addition to statements, a significant amount of work has been devoted to the investigation of the polar questions of Greek and their possible melodies (Waring 1976, Contossopoulos 1991, Georgountzou 1991, 1995, Mennen & Den Os 1994, Baltazani & Jun 1999, Papazachariou 1994, 2000, 2004a, 2004b, Grice, Ladd & Arvaniti 2000, Arvaniti 1998a, 2002, Arvaniti et al. 2006a, 2006b, Baltazani 2006d, 2006e, 2007b). In brief, the data of all studies show that the default melody of Greek polar questions consists of low pitch on the word that is the focus of the question and a rise-fall at the end of the utterance. As illustrated in Figure 4, if the word in focus is utterance-final, then its stressed syllable is low and its last syllable shows an abrupt rise and fall. Most interestingly, if the focused item appears earlier in the utterance, then the melody is realized as a low level stretch that extends from the stressed syllable of the word in focus to the onset of the *last stressed syllable* in the utterance, at which point a rise begins that reaches a peak towards the end of this stressed syllable and is followed by a fall. In both melodies, the final fall, reached at the end of the question, extends to the bottom of the speaker's range (contra the impressionistic description of polar question intonation presented in Waring 1976 and adopted by Holton et al. 1997, according to which Greek questions fall to mid-pitch).[21]

The above description of the Greek polar question intonation is generally accepted among those working within the AM framework (at least), though researchers do not entirely agree on its exact phonological representation. The melody is autosegmentally represented as L* L+H-L% in Arvaniti et al. (2006a) who present extensive quantitative data on Greek polar questions. On the other hand, Mennen & Den Os (1994), Grice et al. (2000) and Arvaniti (1998a, 2002) analyze the phrase accent as H-, not L+H-. In turn, Baltazani & Jun (1999) suggest that the melody is best analyzed as L* H+L%; in this analysis, there is no phrase accent, but a complex boundary tone instead. I briefly discuss here the problems I see with these alternative analyses.

The problem with representing the phrase accent as H- is that it cannot account for the fact that F0 remains low after the focal L* pitch accent instead of rising steadily, as one would expect if no L tone intervened between L* and H-. The analysis of Baltazani & Jun (1999) suffers from the same problem, but there are additional issues with it. First, their analysis assumes no phrase accent. Yet, as mentioned earlier, Arvaniti & Baltazani (2005) and Kainada (2007) present evidence that Greek has two levels of phrasing above the word, each associated with different types of tonal configurations and durational effects. Second, their analysis assumes that the H and following L form a unit. If so, then we should expect these two tones to be realized in proximity to each other or to have a common reference point, such as the last syllable, neither of which applies. As shown in detail in Arvaniti et al. (2006a), the L tone is always realized at the very end of the question, while the H is realized either immediately before it (if the last word is in focus), or several syllables earlier (if the focused word is not final). Thus, if we adopt this analysis, we need a language-specific mechanism to control the bimodal alignment of the first half (and only the first half) of the bitonal H+L% boundary tone of polar questions.

In more recent work, Baltazani (2006e) found that in long polar questions which contain several ips, the right edges of IP-medial ips are demarcated by L- phrase accents. Baltazani uses this finding to argue against the L+H- analysis of Arvaniti et al. (2006a). She proposes instead that the melody of polar questions is L* L- H+L%, because this provides a uniform representation of phrase accents across ips within a polar question: their right edge is always demarcated by a L- phrase accent. In my view, this analysis presents the same problems as the analysis of Baltazani & Jun (1999) regarding the complex boundary tone. Furthermore, there is no particular reason why IP-medial and IP-final ips should be demarcated by the same type of phrase accent. Indeed, as mentioned earlier, according to Baltazani & Jun (1999), in declarative

sentences, IP-medial ips are always demarcated with the opposite phrase accent than the IP-final ip: the former are demarcated by H- (the continuation rise illustrated in Figure 8), while the latter is demarcated by L- (as illustrated in Figure 10). Baltazani (2006e) also argues against the L+H- phrase accent proposed by Arvaniti et al. (2006a) on the grounds that this bitonal phrase accent is unique to polar questions in Greek. This appears so far to be true, in that no other bitonal phrase accents have yet been reported for Greek. However, this is also a problem for the H+L% analysis of Baltazani (2006e), since there are no other bitonal boundary tones in the Greek inventory either. At the very least, the analysis of Arvaniti et al. (2006a), which involves a phrase accent with secondary association, fits the larger typological pattern discussed in Grice et al. (2000).

Specifically, Grice et al. (2000) use the pattern of Greek polar (and wh-) questions as well as data from several other varieties and melodies (Cypriot Greek, Standard and Transylvanian Hungarian, Standard and Transylvanian Romanian, English, German and Dutch) to argue in favor of phrase accents as a distinct tonal category that, in addition to its primary association to a boundary, can have a secondary association to a particular (and language specific) tone-bearing unit. For Greek polar questions in particular, Grice et al. propose that the rise to the peak is a phrase accent that has secondary association to the last stressed syllable: the secondary association takes over if the last stressed syllable is not already associated with another tone; if it is, as happens when focus is on the last word of the question—in which case this syllable is associated with the L* nuclear accent—the phrase accent is realized according to its primary association, that is as close to the right edge of the question as possible. Arvaniti et al. (2006a) provide quantitative data that support this analysis.

More generally, the melody of Greek polar questions has interesting repercussions for our understanding of intonation beyond those that deal with theory-internal topics, such as the status of the phrase accent in the inventory of intonational categories. First, the melody of Greek polar questions shows that the relationship between focus and its realization is neither universal, not straightforward as some have argued (e.g., Xu 2005). According to this widespread view, it is often expected that focus is realized by an increase in absolute pitch or in pitch range; this is, for instance, the rational behind the experimental manipulations of Botinis & Bannert (1997) with respect to focus, discussed in section 7.3. Yet, the Greek polar questions show clearly that the word in focus has low not high F0, while a word that is not pragmatically as important shows a large pitch rise. Second, the data clearly show that under conditions of tonal crowding, different

parts of the melody are affected in different ways, so that troughs and peaks are adjusted in alignment in ways that reflect pressure from either preceding or upcoming tones. This in turn indicates that melodies are not gestalts that shrink and stretch to fit the segments on which they "ride"; the patterns of accommodation observed in the data of Arvaniti et al. (2006a) clearly show that contours are composed of smaller elements, while the interpolation in between is not meaningful (for a discussion see Arvaniti et al. 2006a, Arvaniti 2007a).

7.5 An alternative view of Greek polar question intonation

Papazachariou in his thesis and a series of papers (Papazachariou 1994, 1998, 2000, 2004a, 2004b, Papazachariou & Archakis 2001) suggests a very different analysis for Greek polar questions. According to Papazachariou this melody consists of a rising and a falling element and the pitch range (low, mid or high) of the starting point of each of these two elements directly expresses a possible question meaning so that each combination of rising and falling elements has a discrete interpretation, and each pragmatic nuance that can be expressed in Greek using a polar question has a distinct melodic reflex. On the basis of this analysis, Papazachariou argues that the autosegmental analyses are inaccurate (e.g., Papazachariou 2004b) or at least that they do not take into account the whole gamut of possible realizations of polar questions and concomitant pragmatic interpretations. There are several points worth discussing here.

As mentioned earlier, the AM analysis of polar question intonation discussed above pertains only to the default melody, that is, the melody that speakers will spontaneously use and recognize as a question in the absence of context. This of course does not mean that this melody is the only one that can be used with polar questions in Greek; e.g., echo questions, which are treated together with information-seeking polar questions in the work of Papazachariou, could well have a different melody (see Figure 11 for an example). Similarly, it is to be expected that permutations of speech range are *significant* (in the sense of Arvaniti 2007a, i.e., elements that the listeners treat as important for interpreting the overall interaction but which do not have linguistic meaning); e.g., a higher pitch range is clearly significant and may indicate anger on the part of the speaker, yet it is doubtful that anger should be analyzed as a grammatical distinction and not seen as *paralinguistic* (on this term, see Ladd 1996, chap. 1).

Second, most autosegmental studies are based on data elicited from speakers of standard Greek as spoken in Athens. It is quite possible that other melodies are used for polar questions in other varieties of Greek, as the comparison of Standard Greek and Cypriot polar questions already indicates (Arvaniti 1998a, Grice et al. 2000). Papazachariou's production studies deal with a particular Northern Greek dialect as spoken by adolescent male speakers. This variety could well be employing different melodies for questions from those available to standard speakers from the south like those used in the studies of Arvaniti and Baltazani; Papazachariou himself contends that this is so (e.g., Papazachariou 2004b:191). Such differences are well known to be present in the segmental system of the language, and have more recently been also documented for intonation patterns as well (Atterer & Ladd 2004, Arvaniti & Garding 2007), and thus there is no reason why they might not affect the intonation of Greek polar questions. For instance, I have repeatedly tried to reproduce the contours shown in Papazachariou's work, using the contexts he provides as a guide, but cannot produce the melodies he shows, most probably because they are not part of my grammar. Having said that, there are several questions in his corpus that fit squarely within the descriptions of Baltazani & Jun (1999), Arvaniti (2002), Arvaniti et al. (2006), and Baltazani (2006e). This suggests that a default polar question has a particular contour, but other options are also possible.

In addition, Papazachariou (2004b) presents perceptual results in support of his analysis. Although these results do not contradict his analysis, it is also the case that they do not contradict other analyses either. As mentioned, Papazachariou's analysis rests on the assumption that the rise and fall of the final rise-fall of polar questions are discrete units and that their range affects the interpretation of the question. The autosegmental analyses do not disagree: their representation for the default contour is L* L+H- L%, and if presented in terms of pitch movements this melody can be described as a rise-fall. What is crucial is that a rise-fall can also be obtained from a different autosegmental configuration, such as L+H* !H- !H%; in this melody, the rise is not expected to start from as low an F0 level as in L* L+H- L% (since now the only L tone is the weak tone of a bitonal accent), and the phrasal tones are *downstepped* (as indicated by *!*) and are thus expected to be realized as mid-pitch (cf. Arvaniti & Baltazani 2005:95 on "incredulous questions"). Thus, while according to Papazachariou the difference between the two rise-falls is one of pitch range, according to any AM analysis the difference lies in the fact that the two rise-falls are composed of different tonal elements.

The distinction between the two is sometimes subtle. This is illustrated in Figure 11(a) which shows two contours for the same question, [ˈklei to moˈro] "is the baby crying?". The solid line represents the pitch contour of a default question with focus on [moˈro] "baby", while the dotted line represents the contour of a question with the same focus, but one that expresses surprise or is an echo question. The contours look quite similar, the main difference being the exact alignment of the final peak within the last vowel [o], and the scaling around the entire syllable [ˈro]. Thus, at first blush both contours could be compatible with either the AM or Papazachariou's analysis. However, whether we adopt one or the other is not a matter of preference: crucially, the AM analysis makes testable predictions about the alignment (and scaling) of the rise-fall. Specifically, it predicts that the rise-fall derived from L* L+H- L% and that derived from L+H* !H- !H% are (i) scaled differently and (ii) aligned differently with the segmental string, depending on the place of focus, the length of the utterance and the position of stresses. Both differences are shown clearly in Figure 11(b), in which the final stress is on the antepenult of the last word (rather than the ultima, as in Figure 11(a), a position that confounds accentual and phrasal aspects of intonation). In Figure 11(b) it can be clearly seen that the peaks align very differently: the later peak of the default question contour (solid line) still aligns with the last vowel of the last word, as predicted by AM, in which this rise is analyzed as a L+H- phrase accent with primary association to the last syllable. In contrast, the peak of the echo question now aligns with the stressed syllable of the final word, an outcome also predicted by AM, in which this rise is analyzed as a L+H* pitch accent and is thus expected to align with a stressed syllable. In addition, in Figure 11(b), in which tones are not crammed onto one syllable, as in Figure 11(a), it is easier to see the difference in the scaling of the two questions. These differences, especially those of alignment, cannot be explained in a framework in which both melodies are composed of a rise and a fall and the differences are predicted to relate only to pragmatic meaning of the question. Specifically, if we analyze both contours as rising-falling, we have no principled way of explaining why the rise-fall is *not* aligned in the same way in the two contours in either Figure 11(a) or in Figure 11(b).

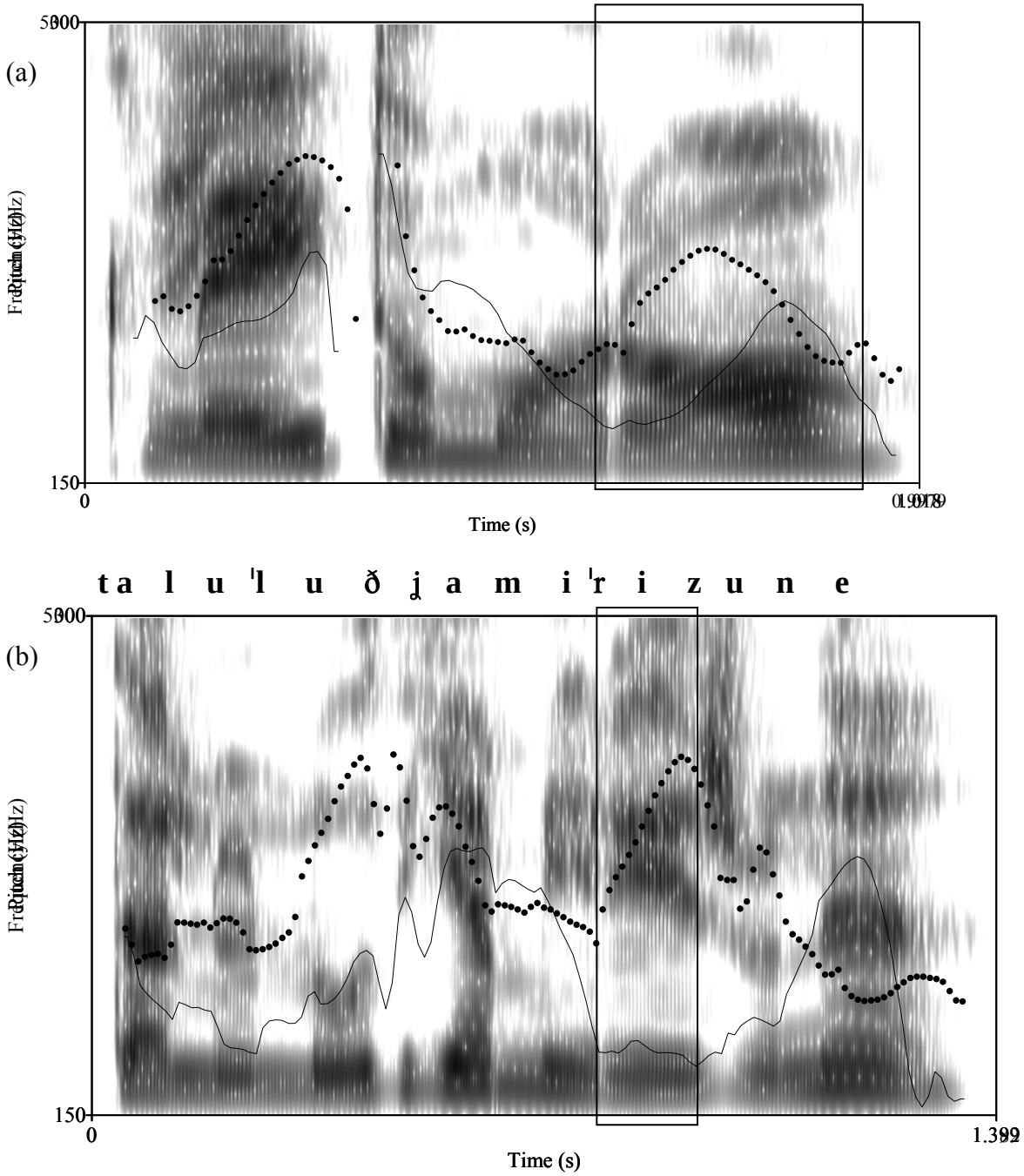


Figure 11. Spectrograms and F0 contours of the utterances [ˈklei to moˈro] "is the baby crying?" (panel a), and [ta luˈluðʝa miˈrizane] "did the flowers smell?" (panel b) produced as default polar questions (solid lines) and as echo questions or questions showing surprise (dotted lines); in all melodies the focus is on the last word of the question. The final stressed syllable is boxed for ease of reference.

It is also important to note that Papazachariou's corpus is based on one-word utterances, many of which are even monosyllables. It is well known that in such cases, melodies tend to be squeezed because of tonal crowding, so that it is often difficult to extrapolate from one-word utterances to longer ones. If nothing else, one-word utterances can only have focus on their (first and) last word, and thus constitute a subset of the realizations that the yes-no question melody can show (see Arvaniti et al. 2006a). It is of course the case that Papazachariou does not adopt the autosegmental-metrical assumptions about the structure of tunes, and thus considers it an advantage to use one-word utterances to investigate polar questions. This is in the spirit of the British school of intonation in which the nucleus is the most important, and only required, part of a tune (this remains so in Papazachariou's work despite the fact that he breaks down the nucleus into two parts instead of seeing it as a whole, as would be the case in a traditional British school analysis). However, more recent research has clearly shown that using one-word utterances is a serious limitation that can lead to misanalyses of a prosodic system. This is precisely what Bruce (1977) and Remijsen & van Heuven (2005) have shown for Swedish and Papiamentu respectively. Similarly, it was the use of one-word utterances to test the perception of stress that lead Fry (1958)—and many others following him—to erroneously conclude that the main correlate of stress is pitch because effects of stress and intonation are confounded in one-word utterances (for a discussion see Arvaniti 2000).

The reason why using one-word utterances is undesirable is that, as mentioned, tunes are not gestalts but rather they are composed on discrete tonal elements with specific associations to particular elements in the segmental string (Arvaniti et al. 2006a; Arvaniti 2007a). Although this has sometimes been seen as a matter of framework choice, there is irrefutable evidence that melodies cannot be seen as atoms that can shrink and stretch uniformly to fit particular utterances. This point is further illustrated in Figure 12, which shows wh-questions of two different lengths. If we focus on the one-word question, we might say that the melody of wh-questions in Greek is a rise-fall-rise; but if we compare this question to the longer question, it is clear that the contour although similar in its gross shape is not simply a stretched out version of the shorter contour. This is illustrated by the thicker "F0" line superimposed on the longer question, which is indeed a stretched out version of the F0 contour of [ˈti] "what". As will be shown in 7.6, the reason is that there are particular segments that must be associated with the first peak and final fall of wh-questions, while the exact extent of the low-level stretch in

between them is regulated partly by the location of the stressed syllables (Arvaniti, 2001a; Arvaniti & Ladd, subm.). For all the above reasons, it is best overall to use utterances of varying lengths and with different prosodic characteristics before one can describe a melody with any certainty.

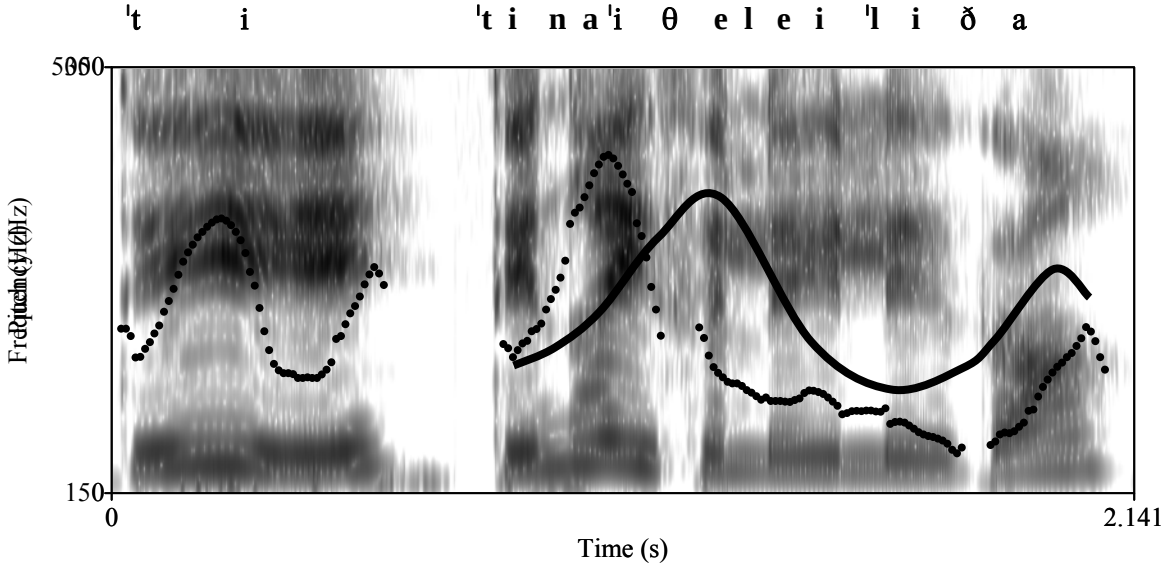


Figure 12. Spectrograms and F0 contours of [ˈti] "what?" and [ˈti na ˈiθele i ˈliða] "what could have Lida wanted?" The thick solid line represents the contour of [ˈti] stretched out to fit the duration of the longer question; as is evident, this contour is not the same as the original contour of the longer question which is represented by the dotted line.

Such research is currently being undertaken regarding polar questions in Greek (Baltazani 2006d, Arvaniti 2007c). For instance, on the basis of such longer questions, Baltazani suggests that the prenuclear accents in questions may be phonetically distinct from the prenuclear L*+H found in statements (discussed in 7.2): in polar questions there are relatively long stretches of F0 between rises, which are absent in statements. According to Baltazani (2006d) this is largely due to the fact that L tones appear earlier (36 ms on average) in the accents of questions than in the accents of statements, while peaks are reached earlier in statements than in questions. Unfortunately, no absolute durational data are provided, so it is difficult to tell what the differences between statement and question prenuclear accents could be due to. In particular, if the syllables with which the L and H tones align are of similar length, the

differences in alignment could reflect a difference in phonological structure; on the other hand, if the differences in alignment are due to the stressed syllables being longer (or drawn out) in questions, a phenomenon that impressionistically seems possible, the differences may be simply an epiphenomenon of the durational effect. Although the data of Baltazani (2006d) are tentative at this point, further investigation of this topic is certainly worth undertaking.

Finally, Arvaniti (2007c) examines the issue of post-nuclear accents in relation to polar questions in Greek. Specifically, Ladd (1996) has argued that phrase accents are in fact *postnuclear* pitch accents. This analysis obviates the need for an extra tonal category (the phrase accent), but runs foul of orthodoxy, since it is erroneously believed that in Pierrehumbert (1980) post-nuclear pitch accents are by definition impossible. Grice et al. (2000) show that phrase accents are necessary but their data cannot provide an answer to whether phrase accents with dual association can replace the notion of postnuclear pitch accent altogether. Greek polar questions of increasing length but with nuclear accent on the first content word in all cases address this point: results show that many speakers have pitch excursions on post-nuclear stressed syllables. These tonal events are very reduced in scale (6-15 Hz or roughly ~10% of the final rise) and take a variety of shapes, but are most frequently realized as falls from a peak or as delayed rises (similar to those reported in Baltazani 2006d). Their forms suggest that they are not copies of the phrase accent or the nuclear accent, since the former is an early rise and the latter is a low level stretch. Therefore these pitch excursions are best analyzed as postnuclear accents. These accents are optional on several levels: they are not present on all words, they are not found in all the repetitions of a question produced by the same speaker, and they are not equally frequent in the data of all speakers. Further, their presence is affected by speaking rate (slower talkers are more likely to use postnuclear accents) and question length (postnuclear accents are more frequent in longer questions).

7.6 The intonation of Greek wh-questions

As mentioned, research has also been done of the wh-questions of Greek (Arvaniti 2001a; Arvaniti & Ladd subm.). Wh-questions show a different melody from polar questions. Their melody is analyzed as consisting of a L*+H accent on the wh-word, followed by a L- phrase accent and either a L% boundary tone or a downstepped !H%, a boundary tone that is high in

pitch, yet does not exceed the middle of the speaker's range. Figure 12 presents two wh-questions that exemplify this contour. As can be seen there, when the melody of wh-questions must be realized on one syllable, the low level stretch that is the reflex of the L- phrase accent is significantly reduced in duration. On the other hand, the vowel of the wh-word is dramatically lengthened to accommodate all the tones: e.g., in Figure 12, the vowel of [ti] "what?" in the one-word wh-question is 539 ms long, while that in the longer question is 74 ms long.

In addition, the realization of the low level stretch that is associated with the L- phrase accent is governed by the position of the postnuclear stressed syllables, though the connection is less strict than that observed in polar questions: specifically, Arvaniti (2001a) and Arvaniti & Ladd (subm.) show that this low level stretch is timed so as the first stressed syllable after the wh-word has low F0 (unless it immediately follows the stressed syllable of the wh-word). Further, the low level stretch extends roughly to the last syllable of the question: if this syllable is stressed, the final rise starts during the vowel of that syllable; if it is unstressed the rise starts earlier. The overall effect appears to be driven by the need to keep the post-nuclear stressed syllables of the wh-question low in pitch, to the extent that this is possible. As mentioned, these data have been used by Grice et al. (2000) as additional evidence for the predilection of phrase accents to seek metrically prominent syllables whenever possible.

The final rise of the wh-question melody also poses a theoretical problem: as mentioned wh-questions can end with a pitch rise which, however, is distinctly small in size and ends roughly in the middle of the speaker's range (see Figure 12). Within the AM framework, which operates on the assumption that tones can be either high or low, a mid-level pitch is hard to account for except as a contextual variant; e.g., Grice, Baumann & Benzmüller (2005) analyze an utterance-final mid-level tone in German as a H% that is downstepped by a preceding L- phrase accent, while Beckman & Ayers-Elam (1997) analyze a similarly scaled tone in English as a L% boundary tone that is upstepped by a preceding H- phrase accent. Neither analysis is possible in Greek, however. Arvaniti & Baltazani (2005) and Baltazani (2006f) present evidence from several melodies of Greek, in which the utterance final pitch movement is plausibly analyzed as a combination of L and H tones, namely L- H% and H- L%. These configurations do not show any scaling interactions that would result in mid-level pitch: L- H% represents a high rise from a low point, while H- L% represents a fall to the bottom of the speaker's range. Given these data, it is not clear how we can represent the mid-level of Greek wh-questions. One possible solution is

to analyze the final rise in wh-questions as the absence of tone, i.e., as a return to a "default" mid-level pitch (Esther Grabe and Carlos Gussenhoven, pers.com). However, this mid-level pitch is stable in its scaling and alignment and, more to the point, its presence is meaningful: it is very clear that the final rise in wh-questions gives them a more polite, concerned reading or what Arvaniti & Baltazani (2005) call "involved" interpretation; e.g., [ˈpu ˈxtipises] "where did you get hurt?" delivered without the rise to mid pitch would sound rather callous addressed by a mother to a crying child. It is, thus, somewhat difficult to reconcile this additional and meaningful nuance with a lack of a tonal specification. In conclusion, although the data on the wh-questions of Greek show a clear phonetic picture, their phonological interpretation is not entirely straightforward. It remains also to be seen if additional melodies are possible with wh-questions, as with polar questions.

7.7 Greek intonation and tonal scaling

Less attention has been paid so far to issues of tonal scaling in Greek. Although several studies report results on scaling, presenting an overview of them is difficult for several reasons. First, since not all studies adopt the same method for measuring scaling, direct comparisons between some studies are not possible; e.g., the results of Botinis et al. (2005), which are based on average F0 values per syllable, cannot be compared to the results of any research based on AM principles, since the latter present values of peaks and troughs rather than syllable averages. Second, many analyses show null results, that is, little effect of various factors on tonal scaling (e.g., Arvaniti et al. 1998, 2006a, 2006b; Arvaniti & Ladd subm.). Although such null results may testify to the stability of tonal scaling, they do not provide us with significant insights. Finally, some scaling differences, such as those reported in the work of Papazachariou on polar questions, can be analyzed—more plausibly in my view—as the reflex of different tones.

At present we have only two studies on Greek that explicitly address the scaling of tones and the role of declination, that is, the lowering of pitch as an utterance progresses (Arvaniti 2003a, Arvaniti & Godjevac 2003). In addition, the effect of declination on tonal target scaling is briefly addressed in Arvaniti et al. (2006a) and Arvaniti & Ladd (subm.).

Arvaniti (2003a) compares the scaling of accents in declarative utterances that include two to five words in which the stressed syllables are separated by either two or four unstressed

syllables, as illustrated in (33) and (34) respectively. In this work, Arvaniti tests certain hypotheses that follow from models that include a declination component (e.g., Fujisaki 1983, Fujisaki et al. 1997). In these models, it is expected that accents separated by more segmental material would be scaled lower than accents with the same order in the utterance but separated by less segmental material; e.g., the accent on /poˈlina/ in (34) is expected to show lower scaling than the accent on /ˈlina/ in (33), since declination is directly related to utterance duration and not to the number of accents. In addition, since declination stretches throughout the utterance but F0 cannot go below a speaker-specific minimum, the scaling of accents is expected to be affected by utterance length: early accents in longer utterances are expected to be scaled higher than those in shorter utterances, so that the bottom of the speaker's range is not reached prematurely (Cooper & Sorensen 1981).

(33) [i meˈlina θarˈθi me ti ˈlina sti ˈlimno] "Melina will come to Limnos with Lina"

(34) [i meˈlina mas θaɟiˈrisi me ti boˈlina sti saloˈniki] "Our Melina will return to Salonica with Paulina"

These hypotheses were weakly supported by the data of Arvaniti (2003a). First, the accents of sentences with more segmental material, such as (34), were scaled lower overall than the accents of sentences with less material, such as (33). The effect, however, was very small: the difference was on average 4 Hz which may or may not be perceptible in running speech. In addition, the first accent in scaled increasingly higher as the number of words in the utterance increased (though not in the data of all speakers). Although the data show some evidence for declination, Arvaniti (2003a) suggests that it is possible to account for them without assuming a declination component, by modeling the scaling of each peak as a fraction of the scaling of the preceding peak (with the exception of the final peak, discussed below). Thus, these Greek data provide some support for the modelling of accent scaling as exponential decay to a non-zero asymptote, previously used for English (Liberman & Pierrehumbert 1984) and Spanish (Prieto, Shih & Nibert 1996).

Some weak evidence for declination is also presented in Arvaniti et al. (2006a) for the L* in polar questions: specifically, these authors report that the L* pitch accent—for which the F0

minimum within the nuclear vowel was measured—is scaled lower in questions in which the nucleus was on the last word, than when it was on the first one (their questions included two content words). Arvaniti et al. suggest that this difference in the scaling of L* is due to declination. However, Colavin (2007), who examined the low-level F0 stretch of polar questions with more than two content words, found no evidence for a downward trend in this stretch, a result that suggests a lack of declination effects. Similarly, Arvaniti & Ladd (subm.) did not find declination effects in the low-level F0 stretch of wh-question contours.

The scaling of final accents in declaratives is examined in Arvaniti & Godjevac (2003) using the data of Arvaniti (2003a). Specifically, Arvaniti & Godjevac tested these data for evidence of *final lowering*, the lower than expected scaling of final accents in a series. In their data, final lowering effects were documented in two ways. First, final accents were lower in scaling than penultimate accents with the same order; e.g., accents on the third word of a three-word utterance were scaled lower than accents on the third word of a four-word utterance. In addition, if accent scaling is modeled as exponential decay to a non-zero asymptote (as discussed above), then it is shown that final peaks are scaled lower than the model predicts, as happens in other languages as well (e.g., Liberman & Pierrehumbert 1984, and Arvaniti 2007b for English; Prieto et al. 1996) for Spanish).

The above results are very limited and do not provide us with a clear picture of declination effects and general scaling trends in Greek. Evidently a more thorough examination of the effects uncovered so far is needed. Such effects can be challenging for AM intonational phonology in which scaling is not adequately analyzed. In this respect, research on Greek may have a great deal to offer to our understanding of intonational scaling at large.

8. Conclusion

Overall, this overview of the research in Greek phonetics demonstrates that this is a very fruitful field of study. Research in all aspects of Greek phonetics has provided interesting results which have not only altered our understanding of spoken Greek but have also significantly contributed to our understanding of the organization of sound systems more generally, whether this has to do with the organization of vowel systems, the structure of intonation, the nature of rhythm or the relationship between phrasing and sandhi phenomena.

Nevertheless it is clear that much more needs to be done. As yet we have very few perceptual studies of Greek speech. In addition little phonetic work has been done on dialectal variation, while we know virtually nothing regarding the role of sociolinguistic variables in Greek speech, such as the role of gender and sexual orientation, and of social and stylistic distinctions, even though the existing data hint that such differences are present and research in other languages clearly shows that the study of variation can shed light on the structure of linguistic categories and the architecture of grammar (e.g., Hay, Warren & Drager 2006). With the notable exception of Nicolaidis' research, we have no articulatory data from Greek, while articulatory research in other languages has greatly contributed to our understanding of coarticulation (e.g., Zsiga 1995, Holst & Nolan 1995), language acquisition and pathological speech patterns (e.g., Scobbie et al. 2000). Even in areas that have been investigated to greater extent, such as stress and rhythm or the acoustics of vowels, questions still remained unanswered. Finally, more research is necessary that examines not only laboratory speech but also running speech in more naturalistic contexts. I do hope that the present review will provide the impetus for more extensive and more varied work on Greek phonetics.

Acknowledgments

I would like to thank the Editors for giving me the opportunity to write this paper, and Brian Joseph for frequently reminding me that I needed to finish it! My absence from Greece since 2002 has inevitably meant that I had no access to several local publications, yet needed them in order to provide a fair and comprehensive review of the field. I am grateful to Katerina Nicolaidis, Mary Baltazani and Dimitris Papazachariou for so promptly responding to my requests for copies of their work published in Greek venues. Many thanks are also due to all those who maintain websites from which hard-to-find papers can be downloaded! I warmly thank Angeliki Malikouti-Drachman, Gaberell Drachman, Katerina Nicolaidis and Brian Joseph who reviewed the submitted manuscript, alerted me to various inaccuracies, omissions and discrepancies, and provided me with comments that helped me clarify and sharpen various parts of this review. Finally, I acknowledge the useful contribution of an anonymous reviewer whose suggestion that I cite Kabak & Revithiadou (in press), Tzakosta (2004a) and (2004b) provided me with important references that helped me further strengthen or illustrate some crucial points. Any remaining omissions and misunderstandings are of course my responsibility.

Notes

1. As an indication, Linguistics Departments that counted phoneticians among their faculty were few and far between in the U.S. Notable exceptions in the second half of the 20th c. included Berkeley, The Ohio State University, Northwestern, and the University of California, Los Angeles (UCLA).

2. Efthymiou & Baltazani (2007) suggest than in Epirus [t] can be aspirated in clusters. However, as their study is based on one speaker it is not clear whether this is a general or idiosyncratic feature. Further, since the clusters that show aspiration resulted from vowel deletion, as in /tu ˡkosta/ > [ˡtʰkosta] "Kostas, gen." it is not clear whether the longer aspiration of these [t]s is independent of the extensive vowel deletion patterns of this Northern variety of Greek.

3. The term *prenasalization* has often lead to the assumption that Greek voiced stops may be complex segments with nasal closure and oral release (see Malikouti-Drachman 2001 for a review). However, the phonological distribution of nasality in relation to voiced stops suggests that the nasal and oral parts are not phonologically treated as a unit, in that the nasal element is not pronounced unless it can be syllabified, presumably as a coda. Thus, producing the nasal element is possible intervocalically, but not word-initially or word-finally or if another sonorant precedes it: *[ˡmbira] "beer", *[ˡalmburo] "mast", *[armbaˡroriza] "lemon verbena", *[klumb] "club", *[klombs] "club/cudgel". This distribution favors a phonological analysis involving a nasal+stop sequence, as argued in Arvaniti (1999c). For a full discussion of the phonological implications of the variability in the production of Greek voiced stops see Malikouti-Drachman (2001).

4. In contrast to the results of the studies discussed in the main text, the speaker with normal hearing used as a control in Nicolaidis (2007) had a mean duration of 148 ms for intervocalic [s] in unstressed position. This duration is longer than any reported for Greek [s] and most likely reflects a slow speaking rate. This interpretation is supported by this speaker's mean durations for [x] (132 ms), [l] (106 ms) and [n] (102 ms), all of which are substantially longer than those reported in other studies; cf. 118 ms for [x] in word-initial stressed position (Fourakis 1986b), and 87 ms for [l] and 88 ms for [n] in word-medial stressed position (Arvaniti 1999b).

5. The fricative+fricative clusters present in the current form of Greek are not the natural outcome of Ancient Greek clusters such as <φθ> and <χθ>, which were clusters of voiceless aspirated stops, i.e., /pʰtʰ/ and /kʰtʰ/ respectively. These clusters were regularly replaced by fricative+unaspirated stop clusters, i.e., the natural outcome of /pʰtʰ/ and /kʰtʰ/ is /ft/ and /xt/ respectively. The unusual fricative+fricative clusters were introduced in Greek with the advent of Katharevousa, in which Ancient Greek orthographic forms were adopted but pronounced with Modern Greek values for the letters involved (Browning 1983:76).

6. Thumb (1964) also mentions that Greek creates diphthongs out of all vowels followed by [i], as in [ajˡðoni] "nightingale" or [aˡkuj] "she/he/it listens". Holton et al. (1997) posit also diphthongs with [w] as their second element; e.g., /ˡfra.u.la/ "strawberry" is said to be produced as [ˡfraw.la]. Arvaniti (1999a) mentions that if we accept the marginal presence of an [aj] diphthong, then [ˡɣaj.ða.ros] "donkey" ceases to be the only exception to the "trisyllabic" accentuation rule of Greek, according to which all words are stressed on one of their last three syllables. I do not discuss diphthongs here in detail, since there are no phonetic data on diphthongization in Greek. However, the results of Baltazani (2006b) and Kainada (2007) on the phonetics of hiatus across word boundaries do not support the proposal that diphthongization takes place in Greek: when both vowel qualities are present in the vocalic segment created by hiatus, its duration is almost as long as that of two vowels, while under diphthongization we would expect the duration of roughly a single vowel together with a change in quality.

7. In the actual figure in Arvaniti (1999a) [o] is mistakenly transcribed as [ɔ].

8. Two more studies, Okalidou & Koening (1997) and Koening & Okalidou (2003) examine coarticulatory effects on Greek vowels. Unfortunately, it is not possible to tell from the published abstracts what their results show.

9. It should also be noted, that this intrinsic F0 effect is not observed in tone languages, as Connell (2002) shows, and is impossible to detect when F0 is generally low, as it typically is towards the end of utterances (Ladd & Silverman 1984; Shadle 1985; Steele 1986).

10. Setatos (1995) also argues for several degrees of stress, but his analysis confuses linguistic uses of prominence, such as the difference in meaning between [keˈrasça] "cherries" and [keraˈsça] "cherry tree", and paralinguistic uses, such as speaking louder in anger or in order to contradict an interlocutor.

11. Briefly, the phonetics of the two types of Swedish lexical accent appeared elusive because words seemed to change pitch contour depending on context. Bruce's (1977) thesis provides a breakthrough to this deadlock by analyzing the two lexical accents as an early and a late fall (Accent 1 and Accent 2 respectively), and showing that when pronounced in isolation, words have a melody that consists of their own accent plus a high phrase tone and a low boundary tone: when these phrasal tones are added to the early falling melody of lexical Accent 1 they result in one peak; when they are added to the late falling melody of Accent 2 they result in two peaks; for a discussion see Bruce (1977); Ladd (1996).

12. It is true, of course, that one cannot prove a point on the basis of null results, as the lack of statistical significance could be due to a host of reasons and not necessarily to the absence of an effect; in other words, it is conceivable that rhythmic stress is present in Greek, but the studies so far have failed to find evidence for it. Although this possibility cannot be dismissed off hand, it seems rather unlikely that a robust phenomenon would be impossible to detect in an entire series of production and perception experiments, and would have evaded the attention of astute analysts of the *Standard* Greek sound patterns, such as Mirambel (1959), Newton (1972) and Setatos (1974) to mention but a few. In turn, of course, the absence of solid evidence for rhythmic stress in Standard Greek does not preclude its presence in other varieties of the language, such as the dialect of Chios (Pernot 1907) or that of Siatista (Margariti-Roga 1985).

13. The same comment applies to phenomena such as vowel elision, strengthening, and gemination discussed in Malikouti-Drachman & Drachman (1981), Anttila & Revithiadou (2000), Revithiadou (2004), Malikouti-Drachman (2007) *to the extent that they are presented as evidence for rhythmic stress*. Although it is undeniable that some of these phenomena are used to enhance the prominence of *lexically* stressed syllables, it is doubtful that they can be used *on their own* as correlates of stress; to make a segmental analogy, although lip rounding enhances the quality of back vowels, lip rounding on its own cannot turn a front vowel into a back vowel. Furthermore, as shown in Arvaniti (1991, 1994), at least some of the phenomena that are said to provide evidence for rhythmic stress, such as vowel elision, apply too irregularly to be able to remedy non-eurhythmic sequences. Finally, it should be noted that even if it can be shown that morphology makes use of full metrification in Greek, the issue at hand is whether stresses additional to the lexically specified stress are present in Greek speech. The evidence so far does not suggest that they are.

14. Personal experience suggests that native speakers as well may occasionally make similar mistakes, e.g., when reading unfamiliar words with ambiguous morphology written in capitals (as in cartoon dialogues and street signs).

15. An anonymous reviewer suggests that blends have primary stress on the same syllable as their right element and are isosyllabic to it; this is achieved by using the stressed foot of the right element and filling any remaining structural positions to the left with material from the left element in the blend. Although this analysis can account for some blends (e.g. [karxaˈrias] "shark" + [kanaˈrini] "canary" > [karxaˈrini]), it does not account for all of them; e.g., [nixterˈɟiða] (from [nixteˈriða] "bat" + [ˈɟida] "goat") has four syllables, not two, and includes segmental material from both elements on its stressed syllable). Examples that do not follow the template suggested by the reviewer include those provided by her/him: e.g., in [ˈsfixterman] (from [sfiˈxtiras] "clamp" + [ˈsuperman] "Superman" according to the reviewer) the material of the right element spans a foot boundary and includes the two unstressed syllables of that word. But even for the blends it can account for, the reviewer's analysis does not provide any evidence in favor of metrifying the material to the left of the lexical stress of Greek words.

16. This analysis rests on the idea, generally accepted within intonational phonology, that the prominence of stressed syllables does not rely only on "stress" but also on whether they are accented or not, as discussed in some detail in sections 4.2 and 4.4. To put it simply, this means that in a sequence such as *three red shirts*, English has the option to leave the word *red* unaccented, a phenomenon interpreted as "beat addition" on *three* in the metrical literature. In Greek, words cannot be left unaccented for similar reasons. Thus, [ˈtria ˈkocina puˈkamisa] "three red shirts" cannot be delivered without a pitch accent on [ˈkocina] "red". (Content words can only be unaccented in utterances with early focus, as discussed in some detail in section 7.3.)

17. Although a second edition of Nespor & Vogel (1986) is now available (Nespor & Vogel 2007), I refer here to the original edition, since this is the one addressed in all the studies reviewed here.

18. A final problem with the analysis of Nespor & Vogel (1986) is that the rules of nasal deletion and vowel deletion in hiatus do not apply within prosodic words (cf. [ˈanθos] "flower", [aeroˈporos] "air pilot"). This necessitates the positing of the Clitic Group as a constituent of the prosodic hierarchy, so that these rules can be expressed as domain juncture rules, rather than domain span rules (since domain span rules cannot apply to the span of a larger domain without applying to the constituents under it). This is cumbersome for two reasons. First, it requires that nasal assimilation and stop voicing are expressed as both domain span rules (so they can apply within the prosodic word) and domain juncture rules (so they can apply within the Clitic Group). Most importantly, it requires that clitics are seen as independent prosodic words, even though they cannot be utterances on their own, as other prosodic words can. Analyzing clitics as prosodic words also contradicts a basic feature of the prosodic word in Greek (as defined by Nespor & Vogel themselves), namely that it is the domain of stress placement, since clitics are inherently stressless (except in some positions; e.g. [ˌfere ˈmu to] "bring it to me").

19. Note also that this observation runs counter to Nespor & Vogel's formulation of the /s/ voicing rule which, being a domain span rule, should apply whenever its structural description is met provided that /s/ and the following voiced consonant are within the same intonational phrase.

20. Angeliki Malikouti-Drachman and Gaberell Drachman point out that the early alignment of the peak in H*+L is at odds with its phonological description, a point with which I agree. Here I follow Arvaniti & Baltazani (2005) in analyzing this accent as H*+L, but note that the full gamut of this accent's realization is not yet known, so this phonological representation is tentative. In my experience H*+L is an accent that is easy to spot in natural conversation but hard to elicit in laboratory conditions, making its controlled examination, and hence a more accurate representation, very difficult.

21. It is quite possible that Waring (1976), who was working in London, observed the intonation of Greek speakers of Cypriot descent. Polar questions in Cypriot Greek have a similar pattern to those in Standard Greek but often end without a fall or with a curtailed fall (Arvaniti 1998a).

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