Acoustic features of Greek rhythmic structure

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This study deals with the resolution of stress lapses and clashes in Greek. It has been suggested that in Greek, lapses are remedied by the addition of rhythmic stresses which create alternating rhythm, and clashes by the insertion of "phonological distance" (usually lengthening) between the clashing stresses. Two experiments examine these suggestions: Experiment 1 compares syllables which are claimed to curry rhythmic stress to syllables with primary stress and to unstressed syllables; Experiment 2 investigates the resolution of clashes by comparing sentences containing a clash to sentences without one. Experiment 1 shows that syllables which are purported to have rhythmic stress are rarely more prominent than unstressed ones and almost never as prominent as those with primary stress. Experiment 2 shows that clashes are resolved by lengthening the first vowel in the clash or the following consonant. A similar tolerance of lapses, but not of clashes, has been reported for Italian which, like Greek, is said to be syllable-timed. The Greek and Italian results suggest that the stress-timing/syllable-timing distinction may not be related to different isochronous units (inter-stress intervals and syllables, respectively), but to certain rhythmic tendencies of the languages in each rhythmic category, such as the resolution or tolerance of rhythmic anomalies.

1. Introduction

The purpose of the present paper is to investigate the resolution of clashes and lapses in Greek and to compare the rhythmic tendencies of Greek, as manifested in the resolution of clashes and lapses, to those reported for Italian which, like Greek, is considered syllable-timed.

To date, many phonetic studies of rhythm have focused on the search for acoustic evidence for isochrropy in order to support the traditional division of languages into those that are stress-timed and those that are syllable-timed (among others, Pointon, 1980; Nakatani, O'Connor & Aston, 1981; Wenk & Wiooland, 1982; Hoequist, 1983; for a comprehensive review, see Bertinetto, 1989). Most of these studies have shown that there is no reliable acoustic basis for isochrropy either in the inter-stress intervals of stress-timed languages or in the syllable duration of syllable-timed ones. Although these findings have sometimes resulted in the questioning of the stress-timed/syllable-timed distinction (see, e.g., Roach, 1982), most researchers have tried instead to find other types of evidence for the two rhythmic categories.
Among the most notable efforts in this direction is that of Lehiste (1977) who suggested that rhythm is based on perceptual rather than acoustic isochrony. Similar ideas were expressed by Allen (1975), who based his proposals on Woodrow’s (1951) and Fraise’s (1963) findings that listeners overestimate the duration of short stimuli and underestimate the duration of long ones. The resulting perceptual isochrony is said to explain why inter-stress intervals (or syllables in the case of syllable-timed languages) of unequal durations are perceived as more isochronous than they are. Lehiste’s suggestion was supported by the results of the perceptual studies of Donovan & Darwin (1979). Scott, Isard & de Boysson-Bardies (1985), on the other hand, found no evidence that the rhythm of (stress-timed) English is perceived differently from that of (syllable-timed) French either by French or English speakers.

A different argument in support of the stress-timing/syllable-timing distinction was put forward by Dauer (1987) who suggested that the rhythm of a language sounds stress-based or syllable-based because of certain features which relate to the language’s phonological organization, such as phonemic vowel length and syllable structure, and the acoustic correlates of accent—the phonological feature which when realized promotes the perception of one particular syllable [or mora] in relation to others” (Dauer, 1987: 448). Thus, a language with predominantly CV syllables and no distinctive vowel length will sound more syllable-timed, while a language with more varied syllable structure and distinctive vowel length will sound more stress-timed. Dauer’s classificatory system does not always accurately predict a language’s rhythmic characteristics, however. Greek, for instance, has all the characteristics of a syllable-timed language according to Dauer’s system: predominantly CV syllables [69% of all syllables in her corpus (Dauer, 1980a: 335)], no phonological vowel length distinctions, and relatively small durational differences between stressed and unstressed vowels. Thus, according to Dauer, “naive native speakers would have difficulty identifying the place of accent consistently in continuous speech, and linguists would have difficulty finding its acoustic correlates, even in words said in isolation” (Dauer, 1987: 449). On the contrary, Greek native speakers are very sensitive to misaccentuations, while stressed syllables are clearly differentiated acoustically from unstressed ones by being longer, having higher amplitude and being the carriers of pitch accents (Dauer, 1980a; Bottinis, 1989; Arvaniti, 1991).

While no satisfactory evidence in favor of the two rhythmic categories has been found either in acoustic or perceptual terms, their existence is often taken as proven. One possible explanation of the persistent popularity of the two rhythmic categories could be that the languages of each category have in common certain rhythmic tendencies which have given rise to the impressionistic terms “stress-timing” and “syllable-timing”. A similar line has sometimes been adopted by phonological studies of rhythm which, while taking the stress-/syllable-timing distinction for granted, examine the extent to which stress clashes (adjacent stresses) and lapses (sequences of more than two unstressed syllables) are remedied in a language, and the means by which this is achieved (e.g., Nespoulous & Vogel, 1989).

The interest in clashes and lapses arises from the fact that in both stress-timed and syllable-timed languages these two phenomena affect rhythm by disrupting the periodic occurrence of prominences on which rhythm is based, i.e., by creating rhythmically anomalous (non-eurhythmical) sequences. Both the structures that are considered clashes and lapses, and the means by which they are remedied vary among languages and provide insight into their rhythmic structure. As an illustration, language differences in what constitutes a clash are shown in examples (1) and (2): according to Nespoulous & Vogel (1989: 73, 99), the grid in example (1) is well-formed in Italian, while the grid in example (2), though of similar structure, constitutes a stress clash in English (underlined). Thus, while in Italian the stressed syllables of *quattro* and *grandi* are considered sufficiently separated by the unstressed last syllable of *quattro*, the stress on the penult of *achromatic* and that on *lens* are considered too close for eurhythm in English, hence they constitute a clash.

![Image](https://via.placeholder.com/150)

**quattro grandi libri** “four big books”

Furthermore, the two languages have different ways of resolving clashes. A characteristic of English rhythm is said to be the regular resolution of clashes by means of the Rhythm Rule (otherwise referred to as Tactic Reversal, Beat Movement, stress shift, etc.), i.e., the displacement of a stress to a more eurhythmic position. For example, the clash in example (2) is remedied by shifting the main stress of *achromatic* to the first syllable, as shown in example (3).

![Image](https://via.placeholder.com/150)

**achromatic lens → achromatic lens**

The use of stress shifts suggests that one of the main requirements of English rhythm is (as far as possible) an even alternation of stressed and unstressed syllables, although acoustic evidence for the application of the Rhythm Rule has not always been easy to find (see, e.g., Cooper & Eady, 1986; Horne, 1988). In contrast, this tendency to shift stress is not found in Italian, which is traditionally classified as syllable-timed. Farnetani & Kori (1983) show that Italian does not use the Rhythm Rule, but destresses one of the syllables involved in the clash by decreasing its duration [see, however, Nespoulous & Vogel (1989) for an alternative interpretation of clash resolution in Italian]. In addition, Italian does not seem to remedy lapses. Farnetani & Kori (1990) compared the durations of the initial vowels (in the following examples the vowel [a] in two-word noun phrases with two primary stresses (e.g., *mani 'korte*, “short hands”), compound words with secondary stress (e.g., *manìkure*, “manicures”), polysyllabic simplex words which are said to have a rhythm on a syllable
preceding the primary stress (e.g., [maniko'mo], “madhouse”), and words whose first syllable was unstressed (e.g., [ma'ni'polo], “platoon”). Farnetani & Kori (1990) found that only one of their three speakers had a durational difference between unstressed vowels and vowels with rhythmic stress, and even then only for some words in the corpus. The evidence for secondary stress in compounds was equally weak. These results are again different from those reported for stress-timed languages; for instance, Bruce (1983, 1987) found that in Swedish, lapses are regularly resolved by the addition of rhythmic stresses, whose acoustic correlate is longer duration.

Finally, Farnetani & Kori (1990) found that in the few instances in which there were durational differences between rhythmically stressed and unstressed vowels, these were on a smaller scale than those reported by Bruce (1983) for Swedish. In other words, all syllables, except those with primary stress, tended to have very similar durations. This characteristic of Italian is supported by a perceptual experiment reported in Bertinetto & Fowler (1989), which shows that Italian subjects are more sensitive than English subjects to the manipulation of unstressed syllable duration, in that the former found shortened versions of unstressed vowels unnatural more often than the latter.

The comparison of Italian to English and Swedish data suggests that there are some fundamental differences in rhythmic organization between stress-timed and syllable-timed languages which are not necessarily related to isochrony or to the factors mentioned by Dauer (1987). Therefore, it would be interesting to see whether the rhythmic tendencies of Italian are also manifested in the rhythmic organization of other syllable-timed languages, like Greek.

Stress lapses abound in Greek, because words tend to be polysyllabic and are assigned only one stress in the lexicon. This stress can be placed on any of the last two syllables of a word but no further to the left, a restriction which has been called the Stress Well Formedness Condition (henceforth SWFC) by Nespor & Vogel (1986).

The SWFC applies not only within words but also within sequences of a word and its enclitics (henceforth host-and-clitic groups), so that when a word stressed on the antepenult is followed by an enclitic, a stress is added two syllables to the right of the host’s original stress; e.g.,

\[\text{[to afo'kinito] “the car”}\]

but

\[\text{[to afo, kini’to mu1 “my car (lit. the car my)”}\].

Note that the lexical stress of the host becomes a secondary stress, while the added stress becomes the primary one of the host-and-clitic group. Although some phonologists claim that the stress of the host remains the primary one after the addition of the enclitic (Setatos, 1974; Nespor & Vogel, 1986), the interpretation of the value of the two stresses in examples like example (5) as being secondary followed by primary stress is supported by acoustic and perceptual evidence (see Arvaniti, 1992, for details).

Recently, it has also been suggested that Greek has an additional type of stress, rhythmic stress: Malikouti-Drachman & Drachman (1980) and Nespor & Vogel (1989) claim that Greek rhythm is based on the even alternation of stressed and unstressed syllables which they say is achieved by the insertion of rhythmic stresses on alternating lexically unstressed syllables. Thus, Malikouti-Drachman & Drachman and Nespor & Vogel claim that a phrase like,

\[\text{[mu a’resi na xo’revo] “I like dancing”}\]

is pronounced with two rhythmic stresses in addition to its primary ones:

\[\text{[mu a’resi na xo’revo] “I like dancing”}\].

Although these rhythmic stresses are said to be added at the surface, they are often assumed to be an integral part of the phonological representation of Greek rhythm, as they are always included in metrical trees (Malikouti-Drachman & Drachman, 1980) and grids (Nespor & Vogel, 1989). Moreover rhythmic stresses are assigned the same phonological representation as secondary stresses (Malikouti-Drachman & Drachman, 1980), although their origin is different: the former are said to appear because of rhythmic requirements, while the latter result from the application of the SWFC within host-and-clitic groups.

Stress clashes in Greek are briefly mentioned in Mirambel (1959), Dauer (1980a), Malikouti-Drachman & Drachman (1980) and Botinis (1992), and in more detail in Nespor & Vogel (1989). Although there is no consensus on the strategies available to Greek speakers for clash resolution, all authors agree that Greek does not use the Rhythm Rule, i.e., stress shifts are not permissible. They suggest two different strategies for stress clash resolution in Greek: first, the deletion of one of the stresses in the clash (Mirambel, 1959; Dauer, 1980a; Malikouti-Drachman & Drachman, 1980); and second, the insertion of “phonological distance” between the clashing syllables, a strategy which is said to be achieved by (i) lengthening either the vowel of the first of the clashing syllables or the consonant following it (Malikouti-Drachman & Drachman, 1980; Nespor & Vogel, 1989), (ii) inserting a pause between the syllables (Malikouti-Drachman & Drachman, 1980; Nespor & Vogel, 1989), or (iii) pronouncing either the first or the second of the stressed syllables with high pitch and the other one with very low pitch (Nespor & Vogel, 1989) (According to Nespor & Vogel, pitch change makes the two clashing syllables perceptually sufficiently distinct for the clash to be resolved.)

This paper describes two experiments intended to test these various claims about the resolution of stress clashes and lapses in Greek. The first experiment is an extension of part of Arvaniti (1992), and addresses the question of rhythmic stress as a mechanism to resolve lapses. Because the phonologists represent the purported rhythmic stresses as extra secondary stresses inserted at regularly alternating intervals, the existence of rhythmic stress can be tested by comparing syllables to which these accounts would assign rhythmic stress with segmentally identical sequences which indisputably bear secondary stress by the SWFC. This comparison was undertaken in Arvaniti (1992). The results showed that rhythmic and secondary stress in Greek are acoustically distinct and easily differentiated perceptually by native speakers. While syllables with secondary stress are acoustically very similar to syllables with primary stress, purportedly rhythmically stressed syllables are close to unstressed ones in terms of duration and amplitude. However, due to the structure of the material used in Arvaniti (1992), a direct comparison between rhythmically stressed and unstressed syllables of the same segmental makeup was not possible. It is therefore conceivable that rhythmic stress is present, albeit acoustically different
from secondary stress, and that the material used in Arvaniti (1992) simply failed to provide evidence for it. In order to confirm whether syllables with rhythmic stress and unstressed syllables are acoustically the same or not a direct comparison between the two is necessary. This comparison is undertaken in Experiment 1. The purpose of Experiment 2 is to investigate whether the means suggested by phonologists are used for stress clash resolution and if so to what extent.

2. Experiment 1

2.1. Experimental method

2.1.1. Material and speakers

The corpus consisted of two sets of tetrasyllabic words, (1) and (2) in Table 1, embedded in carrier phrases. Each set comprises three test words with different stress patterns: test words (1a) and (2a) have primary lexical stress on the antepenultimate syllable, test words (1b) and (2b) on the penultimate syllable, and test words (1c) and (2c) on the final syllable. All words within each set were identical around the target syllables, which were the first two of each test word; thus, although test word (2c) does not contain a final [n] like (2a) and (2b), this minor difference should not have any effect on the acoustic manifestation of rhythmic stress. As the glosses indicate, the test words in each set were semantically related; indeed test words (2a) and (2b), [akustikan] and [aku'stikan], are just two different forms for "they were heard", and are both equally common in standard Greek.

The two sets of words allowed the observation of potential differences with respect to rhythmic stress between vowels that can be reduced, the [u] of the [akustikan] set, and vowels that cannot, the first [a] and the [o] of the [kamojela] set and the first [a] of the [akustikan] set. (The conditions under which vowel reduction takes place and the differences between the two sets in relation to it are discussed in Section 2.3.)

Different carrier phrases were chosen for each test word stress pattern, and care was taken for the carrier phrases to be phonetically similar at their boundaries with the test words. [The carrier phrases differed slightly between sets (1) and (2) to facilitate the segmentation of the initial [a] of the test words in set (2).] The aim was to create sentences which would have the same overall stress pattern. Each sentence contained three primary lexical stresses, one before, one after, and one on the test word; in all cases there were three unstressed syllables between the stress of the test word and each of the stresses of the carrier phrase.

This pattern resulted in different possibilities for rhythmic stress on the test word, depending on the position of its lexical stress. In (1a) and (2a), where the test words were stressed on the antepenultimate, there could be no rhythmic stress on the test words, since a rhythmic stress on their initial syllable would result in a stress clash.1 In (1b) and (2b), where the test words were stressed on the penultimate, the first syllable of the test words could carry rhythmic stress, as it was the middle one of the three unstressed syllables between the first two stresses of the sentence. Finally, in (1c) and (2c), where the test words were stressed on the last, a rhythmic stress could fall on the antepenultimate of the test word, which was the middle one of three unstressed syllables. Thus, within each test word set it was possible to compare the initial syllables of the three words, to see whether the initial syllable of (b), which could carry rhythmic stress according to phonological accounts, was acoustically more prominent than the initial syllables of (a) and (c), which were unequivocally unstressed. It was also possible to compare the antepenultimate syllables, to see whether the antepenultimate of (c), which was said to have rhythmic stress, was acoustically closer to the antepenultimate of (a), which carried primary stress, or to the antepenultimate of (b), which was unequivocally unstressed.

Table 1 schematically presents the possibilities for the first two syllables of each word to carry rhythmic stress according to the position of the test word’s lexical stress. For clarity in subsequent discussions, initial and antepenultimate syllables which by Nesper & Vogel’s and Malikouti-Drachman & Drachman’s accounts should carry rhythmic stress are preceded by [ ] (e.g., [mo]), syllables carrying

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1 According to Nesper & Vogel (1989) and Malikouti-Drachman & Drachman (1980), it is possible for these words to have rhythmic stress on their final syllable, but this was not investigated here.
lexical stress are preceded by [ ] (e.g., [ˈmoj]), and unequivocally unstressed syllables are written without a diacritic.

In addition to the test sentences, the recording material included three pairs of distracter sentences (i, ii and iii in Table I), which were added to the reading list to avoid a very rhythmic and monotonous reading. The distracter sentences included phonemically identical words with primary lexical stress on different syllables.

The material was recorded by four native speakers of Greek, three females (DT, VK, and AA) and one male (SC). All the speakers were in their twenties and at the time of the recording they were all, except AA, first-year graduate students at the University of Edinburgh; AA is the author. All speakers were brought up in Athens and spoke Greek with a standard Athenian accent; in addition, they all spoke English. None of the speakers reported any speech or hearing problems. All speakers, apart from the author, were naïve as to the purposes of the experiment.

2.1.2. Procedure and measurements

The recording took place in the studio of the Department of Linguistics at the University of Edinburgh. The speakers read each test sentence six times from a randomized list typed in Greek; the test words are clearly distinguished in Greek by orthographic accent. Prior to the recording the speakers were instructed to read the sentences as naturally as possible and were given some time to practice. The recording was monitored, and the speakers were asked to repeat any misread sentence.

The material was low-pass filtered at 8 kHz and digitized at 16 kHz. Duration, amplitude, and F0 measurements of the first two syllables of each test word (i.e., of those that could have rhythmic stress according to phonological accounts) and of the whole word were obtained. Durational measurements were obtained from digital spectograms using the Audlab signal-processing program, and following standard criteria of segmentation (see, e.g., Peterson & Lehiste, 1960). The error range was one pitch period (approximately 4–5 ms for the female speakers, and 8–9 ms for the male speaker).

Fundamental frequency contours were plotted and measured using the F0 tracker facility of a signal-processing package (ILS), which performed measurements of F0 every 10 ms over a 32 ms Hamming window. The F0 contours, which were originally presented as series of dots (one for each measurement), have been smoothed to a continuous line by hand.

Two types of amplitude measurements were obtained using a specially written program which read the Audlab digitized speech files used for the duration measurements: root mean square (RMS) and amplitude integral (AI). Both measurements were calculated automatically between points specified in the waveform (those obtained when measuring the duration of the syllable nucleus), using the amplitude values that were stored for every sampled point in the Audlab files. To calculate the RMS, the amplitude of each sampled point within the range representing the syllable nucleus was squared and the sum of squared amplitudes was divided by the number of points; the square root of this measurement represents the average amplitude of the sound and is independent of the sound’s duration. AI measurements were obtained by simply calculating the square root of the sum of square amplitudes of all points within the syllable nucleus without dividing the sum by the number of points, thus taking the duration of the nucleus into account.

The original amplitude measurements were in arbitrary units given by the signal processing package. To minimize statistical artifacts due to both accidental changes, such as a speaker’s leaning towards the microphone or uttering some sentences louder than others, and to the fact that some speakers talk louder than others, the RMS and AI values for each syllable were divided by the word’s RMS and total AI, respectively; thus, the RMS and AI of each syllable are presented as percentages of the word’s RMS and AI, respectively. Furthermore, the natural logarithms of these normalized data were used for the statistical analysis, in order to ensure that the data were normally distributed (though tables and figures show the original normalized values).

2.1.3. Statistical analysis

Syllable and vowel durations, and AI and RMS measurements were statistically analysed by means of analyses of variance (stress type × speaker) with repeated measures on the variable stress type. The factor speaker had four levels and was treated as a random effects factor. The factor stress type had three levels (primary, rhythmic and no stress) and was treated as a fixed effects one. Separate ANOVAs were performed on the data from each test word set, because the segmental makeup of the syllables under investigation was quite dissimilar. ANOVAs that showed a significant effect of stress type and no interaction between the two factors were followed by planned comparisons between the different stress levels. Specifically, for the ANOVAs on initial syllables in both sets, planned comparisons were made between the purportedly rhythmically stressed syllable of test word (b) and each of the unequivocally unstressed initial syllables of test words (a) and (c). Similarly, the ANOVAs on antepenultimate were followed by planned comparisons between the purportedly rhythmically stressed antepenultimate of test word (c) and first, the antepenultimate with primary stress of test word (a), and second, the antepenultimate of (b). In order to minimize the risk of type I error due to multiple comparisons, it was decided that the acceptable p-level would be 0.025, which is derived by dividing the overall acceptable p-level (0.05) for each ANOVA by the number of comparisons (two) (for a similar procedure see Weismer, 1980). It should be noted that in order to do the planned comparisons the factor speaker had to be treated as a fixed effects one. This resulted in differences in the denominator degrees of freedom between the omnibus F-test and the F-scores for the planned comparisons, as in the latter each repetition was treated as a separate entry within each level of the factor speaker.

Finally, if the ANOVA showed interaction between stress type and speaker, post hoc Scheffé tests were performed to establish the differences among speakers, and the relevant p-levels are reported. Thus the results are presented for all speakers together, unless there was interaction between factors, in which case individual differences are reported.

I would like to thank Marios Foursakis for bringing this reference to my attention.
2.2.1. Duration
Table II shows mean consonant, vowel and syllable durations and standard deviations for all speakers together; syllable means for each speaker separately are shown in Fig. 1. (As the vowel data agreed entirely with the syllable data, they are not presented in detail.) The results are presented separately for each test word set.

The purportedly rhythmically stressed initial syllable [xa] of [xa'umo'jela] was compared with the unequivocally unstressed initial syllable [xa] of [xa'mojela] and [xa,moje'la]. There was a significant effect of stress type \(F(2, 6) = 27.002, \ p < 0.001\) but not in support of rhythm stress. Planned comparisons showed that [xa] had the same duration as the [xa] of [xa,moje'la] \(F(1, 20) = 0.2, \ ns\), but was shorter rather than longer than the [xa] of [xa'mojela] \(F(1, 20) = 11.28, \ p < 0.003\). Stress type was also significant in the [mo] data \(F(2, 6) = 169.35, \ p < 0.00005\). The purportedly rhythmically stressed antepenult of [xa,moje'la], [mo], was shorter than [mo] \(F(1, 20) = 199.04, \ p < 0.00001\), and also shorter than the unequivocally unstressed [mo] \(F(1, 20) = 34.02, \ p < 0.0001\). In short, the [xamojela] data did not show any evidence for rhythm stress.

The comparison of [a] to the [a]s of [a'kustikan] and [a,kusti'ka] did not show any differences between the three syllables \(F(2, 6) = 0.355, \ ns\). The results for [ku] showed a significant effect of stress type \(F(2, 6) = 35.05, \ p < 0.0004\), but also interaction between speakers and type of stress \(F(6, 40) = 4.02, \ p < 0.003\). Scheffé tests showed that this interaction was due to DT, in whose data there was no difference between the durations of [ku] and [k'u], nor between those of [ku] and [ku]. For the rest of the speakers, [ku] was of the same duration as [ku], but shorter than [k'u] (for VK, \(p < 0.01\); for SC, \(p < 0.00001\); for AA, \(p < 0.0004\). Thus, DT's [ku] data were the only ones to show a pattern that might be interpreted as evidence for rhythm stress, albeit rather weakly since the purportedly rhythmically stressed

![Figure 1](image)

Table II. Means (in ms) and standard deviations of the consonant, vowel and syllable durations for all speakers; (top) [xa] (left) and [mo] (right) of the [xamojela] set; and (bottom) [a] (left) and [ku] (right) of the [kustikan] set

<table>
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<th>[xa]</th>
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<td>Mean</td>
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<td>85</td>
<td>97</td>
<td>182</td>
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<td>12</td>
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<td>Mean</td>
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<td>66</td>
<td>71</td>
<td>137</td>
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<tr>
<td>SD</td>
<td>11</td>
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<tr>
<td>Mean</td>
<td>135</td>
<td>59</td>
<td>60</td>
<td>120</td>
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<td>SD</td>
<td>9</td>
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- [a] [k] [u] [ku]

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<th>[a]</th>
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<tr>
<td>Mean</td>
<td>62</td>
<td>77</td>
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<td>SD</td>
<td>8</td>
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The initial syllable of [kustikan] was shorter than the initial syllable of [kustikan] and [ku] of [kustikan] \(F(1, 20) = 0.94, \ ns\). Finally, stress type was significant in the [ku] data \(F(2, 6) = 47.18, \ p < 0.0002\), but there was also interaction between stress type and speaker \(F(6, 40) = 2.56, \ p < 0.03\). Scheffé tests showed that in the data of VK, SC and AA, [ku] occupied

[ku] was also shown to be no longer than the unstressed [ku].

Two more types of analysis, similar to the normalization of the AI and RMS data, were performed on the duration data. First, the durations of the first two syllables of each test word were divided by the duration of the word, in order to see what percentage of the whole word's duration each of these syllables occupied (as with the amplitude data, the ANOVAs were performed on the natural logarithms of the ratios). The results showed that, in most cases, syllables claimed to have rhythm stress and unstressed syllables had similar relative durations (see Table III). Specifically, there was a significant effect of stress type in the [xa] data \(F(2, 6) = 8.58, \ p < 0.01\). Planned comparisons showed that [xa] occupied a smaller proportion of the word's duration than [xa] of [xa'mojela] \(F(1, 20) = 61.22, \ p < 0.0001\), and the same proportion as [xa] of [xa,moje'la] \(F(1, 20) = 1.46, \ ns\). Stress type was also significant in the [mo] data \(F(2, 6) = 47.47, \ p < 0.0002\); [mo] was proportionally shorter than [mo] \(F(1, 20) = 171.1, \ p < 0.00001\), and also shorter than the unequivocally unstressed [mo] \(F(1, 20) = 13.22, \ p < 0.0016\). The initial syllable of [kustikan] occupied the same proportion of the word's duration as the unstressed [a] of [kustikan] and [kusti'ka] \(F(2, 6) = 0.94, \ ns\).
the same proportion of the word's duration as [ku], but was proportionally shorter than [ku] (for VK, p < 0.002; for SC, p < 0.00007; for AA, p < 0.002); as syllable durations, the three ratios showed no differences in DT's data. In short, the results of the ratios agreed entirely with those of the syllable durations, and showed weak evidence for rhythmic stress only in DT's [ku] data.

In the second type of analysis, the ratio of the initial to the antepenultimate syllable was obtained for test words with penultimate and final stress. Since in the former the initial syllable could carry rhythmic stress and the antepenultimate was unstressed, while in the latter the stress pattern was reversed, rhythmic stress could have been shown by a change in the relative duration of these two syllables. The results, however, did not show any differences between the two ratios. The [xa]-to-[mo] ratio turned out to be smaller than the [xa]-to-[mo] one \( F(1, 3) = 12.18, p < 0.039 \), while there was no difference between the ratios of [a]-to-[ku] and [a]-to-[ku] \( F(1, 3) = 0.85, \) ns.

In conclusion, both the absolute and relative durations of purportedly rhythmically stressed syllables were much smaller than those of syllables with primary stress, but very similar to those of unequivocally unstressed syllables; only DT's [ku] data showed some evidence for rhythmic stress.

### 2.2.2. Amplitude

Means and standard deviations of AI and RMS for all speakers are presented in Table IV; Fig. 2 shows AI means for each speaker separately.

The [xa] of [xamo'jela] had the same AI as the two [xa]s \( F(2, 6) = 0.63, \) ns. The [mo] data showed a significant effect of stress type \( F(2, 6) = 27.48, p < 0.001 \), but also interaction between speakers and type of stress \( F(6, 40) = 3.95, p < 0.0003 \). Scheffé tests showed that in DT's speech, [mo] had the same AI as [mo], and greater AI than [mo] \( p < 0.03 \); in AA's data there was no difference between the AI of these three syllables, while in VK's and SC's speech, [mo] had the same AI as [mo], but lower AI than [mo] (for VK, p < 0.007; for SC, p < 0.0005). Thus, DT's data clearly showed evidence for rhythmic stress, while those of AA showed only weak evidence, since the AI of the purportedly rhythmically stressed [mo] was not higher than that of its unstressed counterpart (a result similar to that of DT's durational data for [ku]).

In the data from the initial [akustikan] syllables there was no effect of stress type \( F(2, 6) = 1.47, \) ns, but there was interaction between speakers and type of stress \( F(6, 40) = 8.14, p < 0.00009 \); this was due to SC, in whose data the [a] of

### Table IV. Means and standard deviations of the normalized AI and RMS for all speakers: (top) [xa] (left) and [mo] (right) of the [xamo'jela] set; and (bottom) [a] (left) and [ku] (right) of the [akustikan] set

<table>
<thead>
<tr>
<th></th>
<th>[xa]</th>
<th>[mo]</th>
<th>[a]</th>
<th>[ku]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[xamo'jela]</td>
<td>23.95</td>
<td>24.16</td>
<td>11.62</td>
<td>22.83</td>
</tr>
<tr>
<td>SD</td>
<td>0.41</td>
<td>0.51</td>
<td>0.36</td>
<td>0.43</td>
</tr>
<tr>
<td>Mean</td>
<td>24.70</td>
<td>21.79</td>
<td>11.45</td>
<td>23.62</td>
</tr>
<tr>
<td>SD</td>
<td>0.66</td>
<td>0.47</td>
<td>0.40</td>
<td>0.44</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[xamo'jela]</td>
<td>33</td>
<td>33.35</td>
<td>11.51</td>
<td>21.24</td>
</tr>
<tr>
<td>SD</td>
<td>5</td>
<td>7</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>33</td>
<td>33</td>
<td>11.51</td>
<td>21.24</td>
</tr>
<tr>
<td>SD</td>
<td>6</td>
<td>16</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[a]</td>
<td>42</td>
<td>42</td>
<td>11.51</td>
<td>21.24</td>
</tr>
<tr>
<td>SD</td>
<td>7</td>
<td>7</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>46</td>
<td>46</td>
<td>11.51</td>
<td>21.24</td>
</tr>
<tr>
<td>SD</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Mean</td>
<td>49</td>
<td>49</td>
<td>11.51</td>
<td>21.24</td>
</tr>
<tr>
<td>SD</td>
<td>8</td>
<td>8</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>
[a:kusti'ka] had higher AI than the purportedly rhythmically stressed [a] (p < 0.03). The [ku] data showed a significant effect of stress type \( F(2, 6) = 25.73, p < 0.001 \): [ku] had smaller AI than [k'u] \( F(1, 20) = 61.39, p < 0.0001 \), and the same as [ku] \( F(1, 20) = 1.5, ns \). Thus, neither syllable in this set showed evidence for rhythmic stress.

In summary, the AI data showed that in the [xamojela] set there was no evidence for rhythmic stress on [x] of [xamojела], but DT, and possibly AA, showed evidence for rhythmic stress on [mo] of [xa,mojela]. In the [akustikan] set, none of the speakers showed evidence for rhythmic stress. As there were virtually no differences in the durations of rhythmically stressed and unstressed syllables, the few AI differences between them could only reflect differences in RMS. This was confirmed by the RMS data which agreed almost entirely with the AI ones. The only discrepancy between the AI and RMS data concerned the antepenult of the [xamojela] set: while the factor stress type had a significant effect on RMS \( F(2, 6) = 11.91, p < 0.008 \), there was also interaction between speakers and type of stress \( F(6, 40) = 5.52, p < 0.0003 \). In DT's data, the RMS results agreed with her AI ones in showing no difference between [mo] and [m,o]. and [m,o] as having higher RMS than the unstressed [mo] (p < 0.001); no differences between the RMS of the three syllables were found in the data of SC, VK and AA. DT's RMS data clearly support the rhythmic stress hypothesis, as do her AI data for the same syllable. In the author's opinion, though, the results for the other speakers cannot be interpreted as showing weak evidence for rhythmic stress, as in their case the effect of high RMS is not reflected in their AI data, and earlier work has shown that high RMS does not correlate strongly with stress as AI does (Arvaniti, 1991).

2.2.3. Fundamental frequency

Typical fundamental frequency contours of the [xamojela] set are shown in Fig. 3. Each contour was composed of three pitch accents which fell on the syllables with primary lexical stress. The last one of these, a simple H* accent falling on the last syllable of the whole sentence and followed by an L% boundary tone, will not concern us here. The first two pitch accents were bitonal, of the form L* + H, a particularly prevalent type of pitch accent in Greek "neutral declarative" intonation [see, for instance, Dauer (1980a: 182 ff.) for similar patterns]. In this type of "scooped" accent the F0 minimum coincides with the very beginning of the stressed syllable, and the subsequent rise stretches to the following unstressed syllables. If another L* + H accent follows, F0 after reaching a peak value falls in such a way that its minimum coincides with the beginning of the stressed syllable carrying the second "scooped" accent. The rise associated with the first accent and the subsequent fall between two accented seem to be timed in this way regardless of the number of intervening unstressed syllables; for instance, this pattern is found in Botinis’s data, in which there are four unstressed syllables between the two L* + H accents (Botinis, 1989: 43).

The [akustikan] contours were not as easy to interpret as they were not continuous, and included two very short vowels [u] and [i] for which F0 values were shown only rarely. In many cases, the pitch accent of the stressed syllables of [akustikan] and [aku'stikan] was a simple H*, while the more typical L* + H was more frequent in [a,kusti'ka], possibly because the bitonal accent was
easier to realize on a long vowel like [a]. Despite this difference between the two test word sets, the [akustukan] contours resembled the [xamojela] ones in showing no $F_0$ excursions which could be related to rhythmic stress.

However, it could be argued that in these data the [mo] of [xa,moje'la] was more prominent than the [mo] of [xamojela] because, although they both had falling $F_0$ in [mo], had higher maximum and minimum $F_0$ values than [mo]. By this argument, though, the [xa] of [xa,moje'la] (which follows the carrier phrase's stressed syllable) must also be considered more prominent than the [xa] of [xamojela], since the former had higher minimum and maximum $F_0$ values than the latter. Clearly, however, one would not wish to postulate that in Greek rhythmic stresses immediately follow primary ones; such a claim would defeat the purpose of rhythmic stress.

Consequently, the relative $F_0$ values of the unstressed and purportedly rhythmically stressed syllables can be interpreted only as being by-product of the "scooped" accents and not as lending prominence to the purportedly rhythmically stressed syllables. In other words, the $F_0$ of [mo] was higher than that of [mo] because [mo] was closer to the previous accentuated syllable than [mo]: compare [ba po xa,moje'la] with [ilpe, xamojela]; similarly, the $F_0$ of [xa] of [xa,moje'la] was higher than that of [xa] of [xamojela] because [xa] was closer to the carrier phrase's accentuated syllable.

In conclusion, only syllables with primary lexical stress can carry pitch accent, while the $F_0$ value of a syllable which does not have lexical stress depends on its position in relation to the sentence's accentuated syllables. Purported rhythmic stress has no effect on a sentence's $F_0$ contour.

2.3. Discussion

The present data provided very little evidence that stress lapses in Greek are remedied by the addition of rhythmic stresses. First, syllables which have been claimed to have rhythmic stress were acoustically much less prominent than syllables with primary stress, which had longer duration and higher AI than all other syllables, and carried pitch accents. Second, syllables with purported rhythmic stress were acoustically very similar to unstressed syllables. These results corroborate those of Arvaniti (1992), which show acoustic similarities between purportedly rhythmically stressed and unequivocally unstressed syllables, and considerable acoustic and perceptual differences between the former and syllables with secondary stress.

There were, however, cases in which syllables claimed to have rhythmic stress differed from the unstressed ones. First, there were two instances (in the [xa] and [mo] data) in which the purportedly rhythmically stressed syllables were shorter than their unstressed counterparts. It could be argued that this shortening constitutes evidence for rhythmic stress, since the purpose of this stress, namely to make some unstressed syllables stand out in relation to the rest, could be achieved equally well by shortening as by lengthening. We cannot dismiss such a possibility out of hand, since according to Williams (1988), stress in Welsh is indicated by shortening rather than lengthening the stressed syllable. In Greek, however, unequivocally stressed syllables are regularly lengthened (Dauer, 1980a; Botinis, 1989; Arvaniti, 1991), so it seems unlikely that shortening would be used to indicate rhythmic stress.

Moreover, it is not possible to accept both shortening and lengthening as a prominence lending device, or the listeners would have no principled way of knowing whether a syllable is meant to be prominent or not. It is thus assumed here that rhythmic stress would involve at least one of the acoustic correlates associated with primary and secondary stress in Greek, namely longer duration and higher AI.

The two cases ([klu duration for DT] and [mo] AI for AA) in which there was negative evidence (the purported rhythmically stressed syllables were not different either from the stressed or from the unstressed ones), and the one case where there was positive evidence (DT's "rhythmically stressed" [mo] has higher AI than the unstressed [mo]) do not provide sufficient evidence for rhythmic stress to justify including it in the representation of Greek rhythm. First rhythmic stress appears to be a very rare phenomenon. Its rarity becomes more evident if one considers the fact that under the present experimental conditions, which were likely to encourage rhythmic reading, and thus maximize the occurrence of rhythmic stresses, such stresses were used only sporadically and not by all speakers.

Second, the native speakers of Greek are not aware of rhythmic stress. The fact that rhythmic stress is not perceived by listeners casts doubt on the relevance of representing rhythmic stresses in Greek, since metrical structure is taken to reflect mental representations. For instance, Hayes (1981: 16) states: "[i]f the reader wonders, then, just what PHONETIC reality the trees in this thesis represent, the answer is essentially none: the trees depict the mental representation of the relative prominence of syllables and words in an utterance".

The fact that Greek speakers are unaware of stresses other than primary (and secondary) ones has been observed by other researchers as well. Dauer (1980a: 5), for instance, says: "Drachman and Malikoudi-Drachman . . . in their phonological analysis assign 'secondary stress' to every other syllable before the main stress in a word . . . . this word would then have to be [prɔparaljusa] [anteplenniti]. Nevertheless, none of my informants ever felt that a syllable to the left of the accented one in a word is stressed".

And later on (Dauer 1980a: 340) "... Drachman and Malikoudi-Drachman . . . have a phonological rule which assigns secondary stress to alternate syllables to the left of the main stress . . . . None of my informants assigned stress in continuous texts according to this principle, and there is no acoustic evidence for it".

Dauer (1980a: 5), accepting her informants' judgment, states:

Thus, although a compound word like [xartspetneta] . . . [paper eapkin] . . . may have phonetic prominence on the first syllable (because of the inherent sonority and length of [a]) as well as the fourth, this syllable is not considered to be stressed by a native speaker of Greek . . . . and will not be considered stressed here. As a native speaker of English, I sometimes felt that the initial syllable was prominent in long words such as [zinavoyctyfidos] . . . [notary public] . . . or [krevatokdimata] . . . [bedroom] . . . in English we need another stress in a word of that many syllables, and we generally prefer one towards the beginning of the word. These syllables are not considered to be stressed in Greek [emphasis added].

Despite the strength of native intuitions, which are corroborated by acoustic data, it is worth considering whether there are any reasons why the acoustic evidence for rhythmic stress is so slim in the present data. One conceivable reason could be that there are not enough unstressed syllables between stresses in the present data for the speakers to add a rhythmic stress. In other words, it could be argued that the
minimal lapse in Greek must contain more than three unstressed syllables. Obviously, the present data cannot provide evidence against this argument. Yet, it must be borne in mind that both Mallikouti-Drachman & Drachman (1980) and Nespor & Vogel (1989) argue that a minimal lapse in Greek, as in English, contains three unstressed syllables and is eliminated by the addition of a rhythmic stress. In this respect Mallikouti-Drachman & Drachman (1980) and Nespor & Vogel (1989) share the opinion of other phonologists who maintain that rhythmic patterns are ideally binary and that the maximum number of consecutive unstressed syllables that can be tolerated is two (e.g., Liberman & Prince, 1977; Selkirk, 1984). Therefore, even if in Greek rhythmic stresses appear in sequences of more than three unstressed syllables, the fact remains that the data disagree with phonological descriptions of rhythm in general, and of Greek rhythm in particular, since they show that Greek rhythm does not follow a strictly alternating pattern.

However, it could still be argued that there may be other means by which the alternating rhythm postulated by phonologists could be achieved in Greek. In English, for example, alternating patterns are partly achieved by the qualitative difference between full and reduced vowels. In Greek this is not an option: the language has a five vowel system and no phonological weight distinctions due to either differences in vowel quality or syllable structure (for details see Arvaniti, 1992). Moreover, although spectral differences in relation to stress have not been investigated in great detail, it is fairly certain that unstressed vowels are not centralized in Greek; for instance, Dauer (1980b) reports that even whispered unstressed vowels have the same basic formant structure as their stressed counterparts (similar results are reported in Dauer, 1980a).

On the other hand, in Greek the high vowels [i] and [u] can be considerably reduced in duration or altogether elided when they are in unstressed syllables. The phonological studies were both phonologically (Theophanopoulou-Kontou, 1973) and phonetically (Dauer, 1980b). Dauer observes that phonetic context and, to a lesser extent, stress pattern play a major part in regulating high vowel reduction. A high vowel is more susceptible to reduction when it is preceded and/or followed by voiceless consonants, in particular [s], and when it is in a syllable immediately following a stressed one. In contrast, a vowel surrounded by voiced consonants or immediately preceding a stressed syllable is least likely to be reduced. In addition, Dauer observes that there are various stages of high vowel reduction in Greek, ranging from very short vowels (up to 30 ms) with full formant structure following nasals and laterals, to voiceless and usually fricative periods “with energy in the region of the second and third formants which clearly identifies the vowel as [i] or [u]” (Dauer, 1980b: 18).

There are two ways in which reduced vowels could contribute to rhythm. First, they could do so by making the unstressed but reduced vowels surrounding them more prominent, and thus rhythmically strong. If this hypothesis is correct, then high vowels should be reduced when their reduction helps create alternating rhythm, but not when they are in a syllable which can carry rhythmic stress. Thus, high vowels should be reduced more often immediately before and after stressed syllables, and when they are an odd number of syllables away from the primary stress. This hypothesis is not confirmed by the general characteristics of vowel reduction in Greek, as described by Dauer (1980b). For example, the fact that the most unlikely position for reduction is the syllable preceding the stressed one is the reverse of what a hypothesis of vowel reduction for rhythmic purposes predicts.

The present findings support Dauer’s observations on vowel reduction. As mentioned, the reason for using the [akustikan] set of test words was to see what the effect of rhythmic stress would be on [u]. If one of the purposes of reduction is to help create an alternating rhythm, then [ku] should be reduced more often in [akustikan], where its reduction would make the initial [a] more prominent, than in [akusti’ka] where it is the only syllable that can carry rhythmic stress. As unstressed [u] was very short in the present data, to test this hypothesis this author considered reduced only vowels that appeared as friction in the waveform or were whispered (there were no elided vowels). The data do not support the above hypothesis: in the 24 tokens from all subjects, there are a total of eight reductions of [u] in an environment in which reduction could create an alternating pattern, i.e., in [akustikan], and a total of six reductions in an environment in which [u] can carry rhythmic stress, i.e., in [akusti’ka].

Dauer’s observation that vowels are reduced more often in post-stress syllables is borne out by the [i] of [a’kustikan] which is shown to be reduced in 15 tokens out of 24, if the same criteria for reduction as for [u] are applied. In contrast, in [a’kusti’ka], where [i] precedes the stressed syllable, and where by being reduced it would make [ku] more prominent, [i] is reduced in only seven out of 24 tokens. It is not clear why there should be this difference in the reduction patterns of pre- and post-stress high vowels, although it certainly does not point towards an alternating rhythm. Thus, the present data confirm Dauer’s observation that high vowel reduction is regulated by phonetic parameters, such as the lack of voicing in the surrounding consonants, rather than by rhythm.

The second way in which vowel reduction could contribute to rhythm would be by reducing the temporal interval between successive stresses, shortening the duration of the intervening unstressed syllables. This type of contribution seems somewhat unlikely however, as first, the duration of the syllables with reduced (or even elided) vowels remains virtually intact (Dauer, 1980b); and second, the elided vowels are always perceived by the listeners as being present, probably because of residual coarticulatory information.

In short, there does not appear to be any convincing evidence that stress lapses in Greek are consistently remedied either by the addition of rhythmic stresses or by vowel reduction. It is possible that acoustic prominence (by means of increased duration or AI) and vowel reduction are used to a greater extent in longer words, as Joseph & Philippaki-Warburton (1987) predict. However, everything points to the fact that Greek does not require alternation of strong and weak syllables, i.e., in Greek there does not seem to exist the same strict requirement for the elimination of stress lapses observed in English and other so-called stress-timed languages, such as Swedish (Bruce, 1983, 1987). Instead, the data on rhythmic stress and vowel reduction suggest a predilection for sparse stresses and rather stable syllable duration (with the exception of syllables with primary stress) manifested in the reluctance to use duration as a correlate for the rarely occurring rhythmic stress.

3. Experiment 2

3.1. Experimental method

3.1.1. Material and speakers

In order to examine how clashes are resolved in Greek, the author compared sentences which contained stress clashes with sentences which did not using 10 pairs
TABLE V. The test sentence pairs; in test pairs (9) and (10) the questions which triggered change of focus in the answers are in brackets. The stress clashes are in bold.

<table>
<thead>
<tr>
<th>Test Sentence</th>
<th>Translation</th>
</tr>
</thead>
<tbody>
<tr>
<td>[i ma'ma 'mafise 'monomo 'cefi'e]</td>
<td>My mum left me alone and went.</td>
</tr>
<tr>
<td>[i ma'ma mu 'mafise 'monomo 'cefi'e]</td>
<td>My mum left me alone and went.</td>
</tr>
<tr>
<td>[i pe'fia 'mazuan sto ba'teratus]</td>
<td>The children take after their father.</td>
</tr>
<tr>
<td>[i pe'fia mu 'mazuan sto ba'teratus]</td>
<td>The children take after their father.</td>
</tr>
<tr>
<td>[mas 'kerasan 'ena va'ri 'nostimo yl'ko]</td>
<td>They treated us to a heavy tasty pudding.</td>
</tr>
<tr>
<td>[mas 'kerasan 'ena va'ri ma 'nostimo yl'ko]</td>
<td>They treated us to a heavy but tasty pudding.</td>
</tr>
<tr>
<td>[tu 'e'osa tus c'ja 'mavrus marka'dorus mu]</td>
<td>I gave him my nine black markers.</td>
</tr>
<tr>
<td>[tu 'e'osa tus c'ja mu 'mavrus marka'dorus]</td>
<td>I gave him my nine black markers.</td>
</tr>
<tr>
<td>[i kane'fa yata mu 'jenise 'tira yata]</td>
<td>My brown cat had three kittens.</td>
</tr>
<tr>
<td>[i kane'fa yata yata 'jenise 'tira yata]</td>
<td>My brown cat had three kittens.</td>
</tr>
<tr>
<td>[to 'ifazma 'ine po'il yano ja 'ena 'forena]</td>
<td>The fabric is too little for a dress.</td>
</tr>
<tr>
<td>[to 'ifazma 'ine po'il poilo into a'poto 'nomiza]</td>
<td>The fabric is much less than I thought.</td>
</tr>
<tr>
<td>[sto a'ti'ci'ma 'exaa to ariste 'ro 'mati mu]</td>
<td>In the accident I lost my left eye.</td>
</tr>
<tr>
<td>[sto a'ti'ci'ma 'exaa to ariste ra mu]</td>
<td>In the accident I lost my left eye.</td>
</tr>
<tr>
<td>[koppos mu 'eklepse tin akri'vi mu yana mu]</td>
<td>Somebody stole my expensive fur coat.</td>
</tr>
<tr>
<td>[koppos mu 'eklepse tin akri'vi mu yana]</td>
<td>Somebody stole my expensive fur coat.</td>
</tr>
<tr>
<td>[De do 'fanis to vi'viloj]</td>
<td>(Can't you reach the book?)</td>
</tr>
<tr>
<td>[o'ci ja'tine sto pe'l 'to 'rafi]</td>
<td>No, because it is on the high shelf.</td>
</tr>
<tr>
<td>[De do 'fanis to vi'viloj]</td>
<td>(Can't you reach the book?)</td>
</tr>
<tr>
<td>[o'ci ja'tine sto pe'l'lo to 'rafi]</td>
<td>No, because it is on the high shelf.</td>
</tr>
<tr>
<td>[l'ipes o'ti 'tha 'minun o'xi'o meres]</td>
<td>(Did you say they will stay five days?)</td>
</tr>
<tr>
<td>[l'ipes o'ti 'tha 'minun o'xi'o meres]</td>
<td>No, they will stay eight days.</td>
</tr>
<tr>
<td>[l'ipes o'ti 'tha 'minun o'xi'o meres]</td>
<td>(Did you say they will stay five days?)</td>
</tr>
<tr>
<td>[l'ipes o'ti 'tha 'minun o'xi'o meres]</td>
<td>No, they will stay eight days.</td>
</tr>
</tbody>
</table>

of test sentences (see Table V). In each pair, one of the sentences contained a stressed clash; e.g.,

[i ma'ma 'mafise 'monomo 'cefi'e] "Mum left me alone and went". (8)

These sentences will be referred to as SC (for Stress Clash). The other test sentence in each pair (henceforth NSC for No Stress Clash) was identical with the SC sentence around the target syllables except that in the NSC one the clash was avoided by inserting a syllable between those clashing; e.g.,

[i ma'ma mu 'mafise 'monomo 'cefi'e] "My mum left me alone and went". (9)

In six of the NSC sentences the inserted syllable was the possessive enclitic [mu] "my", which in four of these sentences had been moved from after the noun it qualifies to a position after the adjectival adjunct of the same noun; these two positions of the possessive enclitic are equally possible and common in Greek. In addition to the possessive enclitic, the definite article [to] "the" was used in NSC test sentence (9), the word [mu] "but" in NSC (3), and the word [poo] "more" in NSC (7). Finally, in test pair (10) two different forms of the word "day", [mera] and [i'mera], were used. Although [mera] is a more common form in conversation, [i'mera], a somewhat more formal word, is by no means uncommon.

In order to achieve smooth and continuous F0 contours, the author tried, as far as possible, to use words which did not contain voiceless segments or stops. This is the reason why the possessive enclitic [mu] "my" was preferred to the exclusion of others, like [su] "yours" or [ta] "hers".

The clashing syllables appeared in different positions in the test sentences. In test pairs (1) and (2), the first of the clashing stresses was on the final syllable of the subject NP, while the second stress was on the first syllable of the following verb; thus, there was a syntactic and a possible intonational phrase boundary between the two stresses. In test pairs (3)–(6) the two clashing stresses belonged to the same intonational phrase (they were either adjectives or adverbs qualifying the same noun, or an adjective followed by the noun it qualified). In test pairs (7) and (8), the clashing stresses were also part of the same intonational phrase, except that the second stress carried the sentence's nuclear pitch accent (since in declarative sentences with "neutral" focus this is associated with the last stressed syllable of the final phrase in the sentence). In test pairs (9) and (10) focus was shifted so that instead of the second stress carrying the nuclear pitch accent, it was the first stress that did so, while the second syllable was a post-nuclear deaccented syllable with primary lexical stress [according to Botinis (1989) these have increased duration and amplitude relative to unstressed syllables, i.e., they are still stressed albeit deaccented]. To achieve the desired effect, i.e., the shift of focus, test sentences (9) and (10) were presented with a question preceding them (see Table V). The inclusion of questions made it easier for the speakers to pronounce the correct shifted focus.

These various structures offered the possibility of examining the use of the suggested clash resolution strategies in different cases, and of finding evidence for interaction between rhythm and intonational structure. This interaction is well established in English: for instance, Beckman, Swora, Rauschenberg and de Jong (1990) found that the presence of an intonational boundary resolves a clash, and they have also shown that stress shift does not occur if one of the stresses carries the nuclear pitch accent of the phrase (as suggested first by Liberman & Prince, 1977; Shattuck-Hufnagel (1991), on the other hand, has shown that the preception of a stress shift may be closely related to intonational organization in English. The investigation of the interaction of rhythm and intonational structure in Greek becomes particularly important in the light of Nespor & Vogel's (1989) suggestion that pitch change can be used to alleviate a clash, a strategy that could result in a radical reorganization of the F0 contour. Thus, test pairs (7)–(10) could help examine the interaction between intonation and rhythm under specific constraints due to the presence of the nuclear pitch accent on one of the syllables in the clash, while test pairs (1) and (2) could help establish whether the insertion of an

Footnote 3: The fact that in these test pairs the two stresses belonged to the same intonational phrase could only be assumed on the basis of the syntactic relationship between the words they belonged to, and what is known of Greek intonational phrasing (e.g., Nespor & Vogel, 1986; Botinis, 1992). A speaker could, of course, choose a different phrasing from the one assumed here, but it is rather unlikely that he would choose, for example, to end an intonational phrase after "brown" in test pair (5) (l'ikane'fa yata mu 'jenise 'tira yata). "My brown cat had three kittens".
intonational phrase boundary between the clashing stresses could be used in Greek to resolve a clash.

The data were elicited from two native speakers of Greek, CN and AA. AA was brought up in Athens and spoke Greek with a standard Athenian accent; CN comes from the north of Greece but does not have the distinctive accent of many speakers of that area. At the time of the recording both speakers were in their twenties and had no known speech or hearing problems. CN, a first-year graduate student at Oxford, was naive as to the purpose of the experiment; AA is the author.

3.1.2. Procedure and measurements

The recordings took place in the recording booth of the Oxford University Phonetics Laboratory, following the same procedure as for Experiment 1. Each speaker read the sentences from sheets which were typed in Greek and contained six repetitions of each sentence in random order. Both an audio and a laryngeal signal (by means of a laryngograph) were recorded. The laryngeal signal was used to obtain more reliable F0 curves.

The material was low-pass filtered at 8 kHz and digitized at 16 kHz. Durational measurements were made from digital spectrograms (obtained from a Kay Sonograph 5500) following standard criteria of segmentation. For each test sentence two durational measurements were obtained: the duration of the vowel of the first syllable involved in the clash (and of the equivalent syllable in the NSC condition), and the duration of the consonant of the second syllable in the clash (and of its NSC counterpart). The author decided to measure the duration of the first vowel rather than that of the whole syllable because previous stress clash data (Arvaniti, 1991) show that the duration of vowels is much more consistently affected by the stress clash than the duration of syllables.4 In addition to durational measurements, F0 tracks were obtained using the pitch extraction routine of the Sonograph.

3.2. Results

Mean durations and standard deviations of first vowels in the clash of the following consonants are shown in Table VI. The durations of SC and NC vowels and consonants were compared by means of analyses of variance (stress clash condition × speaker) with repeated measures on the variable stress clash condition. The statistical analysis followed the same procedure as for Experiment 1.

First vowel lengthening was observed in test pairs (5) and (10) [for test pair (5): F(1, 1) = 296.6, p < 0.036; for test pair (10): F(1, 1) = 624.98, p < 0.025]. In test pair (9) there was no effect of stress clash [F(1, 10) = 20.95, ns], but there was interaction between the two variables [F(1, 10) = 10.53, p < 0.008]. Scheffé tests showed that the SC vowel was longer than the NSC one for both speakers (for CN, p < 0.007; for AA, p < 0.0002). Finally, in test pairs (1)–(4) and (6)–(8), no durational differences were observed between NSC and SC first vowels, and there was no speaker and stress clash condition interaction.

As mentioned, it has been suggested that instead of lengthening the first vowel in the clash it is possible to lengthen the consonant(s) intervening between the stressed

4 In the data of Arvaniti (1991), although vowels were lengthened when in a stress clash, syllable durations remained unaffected by it in more than half of the relevant data, possibly because of consonant shortening.

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<table>
<thead>
<tr>
<th>Test pair</th>
<th>First syllable vowel SC</th>
<th>NSC</th>
<th>Second syllable consonant SC</th>
<th>NSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mean 125</td>
<td>122</td>
<td>89</td>
<td>82</td>
</tr>
<tr>
<td>2</td>
<td>Mean 131</td>
<td>128</td>
<td>123</td>
<td>114</td>
</tr>
<tr>
<td>3</td>
<td>Mean 128</td>
<td>137</td>
<td>84*</td>
<td>66*</td>
</tr>
<tr>
<td>4</td>
<td>Mean 111</td>
<td>134</td>
<td>88*</td>
<td>80*</td>
</tr>
<tr>
<td>5</td>
<td>Mean 135*</td>
<td>109*</td>
<td>79</td>
<td>78</td>
</tr>
<tr>
<td>6</td>
<td>Mean 127</td>
<td>7</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>Mean 72</td>
<td>48</td>
<td>77</td>
<td>79</td>
</tr>
<tr>
<td>8</td>
<td>Mean 107</td>
<td>88</td>
<td>101</td>
<td>112</td>
</tr>
<tr>
<td>9</td>
<td>Mean 140*</td>
<td>93*</td>
<td>34</td>
<td>31</td>
</tr>
<tr>
<td>10</td>
<td>Mean 112*</td>
<td>108</td>
<td>80*</td>
<td>88</td>
</tr>
</tbody>
</table>

vowels. It was expected that this strategy would be used in the seven test pairs which did not show first vowel lengthening. The results offer some support to this hypothesis; the second consonant was lengthened by both speakers in test pairs (3) and (4) [F(1, 1) = 1248.41, p < 0.018]; F(1, 1) = 162.56, p < 0.049, respectively], which were among those that showed no durational difference between the first vowels. In short, of the three strategies said to be used to create phonological distance in case of a stress clash, in the present data lengthening was used in five of the 10 test pairs.

The second way in which it has been suggested that phonological distance can be achieved, namely the insertion of a pause, was not observed in AA’s speech. There were seven occurrences of pause insertion in CN’s data, four in the SC and three in the NSC sentences of test pairs (1)–(3), all of which contained a position in which an intonational phrase boundary could be inserted: in test pairs (1) and (2) after the subject NP [ma`ma] “mum” and [ma`ma mu] “my mum” in (1), and [pe`o]a] “children” and [pe`o]a mu] “my children” in (2), and in test pair (3) between the two consecutive adjectives [`va`ri] “heavy” and [`nosto] “tasty”), where an intonational phrase boundary is possible, though rare. Since pauses seemed to have been inserted only at intonational phrase boundaries, the stress clash was not resolved by the pause but rather by the presence of the boundary, which was signalled by the pause. As mentioned, the fact that a stress clash can be resolved by the presence of an intonational phrase boundary is also reported for English by Beckman et al. (1990).

The third way in which phonological distance is said to be achieved is the pitch
change strategy suggested by Nespore & Vogel (1989). At first glance it would appear that the pitch change strategy was used quite often in the present data, which show similar F0 contours for the two speakers (though in CN’s data F0 was less prone to microprosodic effects, such as small drops in value during [j], [y] and nasal consonants, than in AA’s, in whose data such perturbations were more widespread). A typical example of the type of F0 contour observed in test pairs (1)–(6) is shown in the top graph of Fig. 4; as can be seen, the first syllable in the clash was pronounced with rising F0, which reached a high peak, while the second syllable in the clash was pronounced with low F0 which rose only towards the end of this syllable. However, the same pattern was also observed in the NSC member of these test pairs, as the bottom graph of Fig. 4 shows. Two other types of contours around the clash sequences were observed, one in test pairs (7) and (8), and the other in test pairs (9) and (10). In the former there was virtually no difference between the F0 of the first and second syllable in the clash, both of which were high (see Fig. 5); in the latter there was a sharp fall from a high F0 value in the first syllable to a very low one in the second (see Fig. 6).

Although superficially the patterns observed in all test pairs except (7) and (8) could be seen as supporting Nespore & Vogel’s pitch change strategy, they can easily be accounted for by what has already been said of pitch accents in Greek. Specifically, as mentioned in Section 2.2.3, in sentences with declarative intonation stressed syllables which carry bitalonal pitch accents, of the form L* + H, show a distinct F0 rise which begins on the stressed syllable and reaches its peak on the following unstressed syllable. This is the type of F0 contour observed also in test

Figure 4. Speaker CN, waveforms and F0 contours for test pair (5): (a) [i kane’]a ‘yata mu jesnise ’tria ya’taca]; (b) [i kane’]a mu ‘yata ‘jesnise ‘tria ya’taca].

Figure 5. Speaker AA, waveforms and F0 contours for test pair (7): (a) [sto a’tica]’ma exasa to ariste’ro mu ’mati mu]; (b) [sto a’tica]’ma exasa to ariste’ro mu ’mati].

Figure 6. Speaker CN, waveforms and F0 contours for test pair (10): (a) [’opi ja’tine sto p’i’lo ‘rafi]; (b) [’opi ja’tine sto p’i’lo to ‘rafi].
pairs (1)–(6), with one predictable difference between SC and NSC sentences: as Fig. 4 shows, in the SC case the $F_0$ maximum was reached at the end of the first of the clashing syllables, since no unstressed syllable followed, while in the NSC case it was reached on the intervening unstressed syllable, [mu]. However, it is important to observe that while the second one of the stressed syllables started with low $F_0$ in both SC and NSC sentences, $F_0$ rose towards the end of this syllable’s vowel and the rise continued during the next unstressed syllable; in other words, in both SC and NSC sentences $F_0$ followed the usual pattern for Greek “scopped” pitch accents. As shown in Fig. 6, in test pairs (9) and (10) in which the nuclear pitch accent was associated with the first syllable in the clash, while the following one was a deaccented stressed syllable, the first syllable had high $F_0$ because it had a H$^*$ accent (similar to the one associated with the last accented syllable of the test sentences in Experiment 1) followed by a sharp fall, since there was no accent following but only an L$\%$ boundary tone. On the other hand, in test pairs (7) and (8) both syllables in the clash were accented, and carried H$^*$ accents followed by an L$\%$ tone (hence the flat contour of the two syllables in the clash and the fall at the end of the phrase, shown in Fig. 5).

In short, of the three means said to achieve phonological distance and thus resolve a clash, only lengthening was used fairly regularly in the present data, and pause was used occasionally. The second strategy that has been suggested by phonologists, namely destressing, was absent from the present data, probably because it is more likely to be used with function rather than content words, and in the material used here function words were deliberately avoided in the target sequences. Clearly, however, the issue of destressing is an important one and requires further investigation.

### 3.3. Discussion

The data from Experiment 2 show that stress clashes were not always resolved; in half of the test pairs used here, no differences were found between SC and NSC sentences, at least in the parameters that have been examined. Although this result could be interpreted as an indication that so-called syllable-timed languages like Greek are not only tolerant of lapses but also relatively tolerant of clashes, clearly further data are needed in order to strengthen this claim.

In the cases in which the clash was resolved, the strategy most commonly used was the insertion of distance between the two stresses; this was achieved either by lengthening the vowel of the first syllable involved in the clash, or by lengthening the consonant of the second syllable. The present results on lengthening as stress clash resolution strategy are supported by Arvaniti (1991), who, in an experiment on stress which inadvertently included a stress clash, found that the stressed final vowel of a disyllable, like [pa'pa] “priest”, which was involved in the clash, was significantly longer than the stressed initial vowel of a disyllable like ['papa] “pope". When the experiment was repeated with different carrier phrases, in order to avoid the stress clash, four of the five speakers did not show any length difference between initial and final stress. Lengthening as a means of stress clash resolution is also reported by Lehiste (1972), and Rakerd, Sennet & Fowler (1987) for English stress clashes which cannot be remedied by stress shift. In contrast, Beckman et al. (1990) found no evidence of lengthening in similar clashes [see, however, Edwards & Beckman (1988) for an articulatorily-based account of similar data, which suggests that acoustic duration may not constitute the most reliable evidence for stress clash resolution; instead Edwards & Beckman argue that reorganization of articulatory gestures takes place in such clashes].

The data show no evidence that pitch change is used in Greek to resolve a clash. The observed $F_0$ patterns could, however, explain why Nespor & Vogel (1989) report a pitch change between the clashing syllables. First, patterns which include “scopped” accents show high $F_0$ on the first syllable and low $F_0$ on the second. A native speaker, however, is likely to concentrate on the oncoming rise rather than the initial low of the second syllable's $F_0$ because she expects a time lag between the beginning of the stressed syllable and the peak of the associated pitch accent. Similarly, in test pairs (9) and (10) the second syllable in the clash was deaccented and showed a sharp $F_0$ fall. Again this was the result of the L$\%$ boundary tone at the end of the utterance, not of a reorganization of the pitch contour.

The above suggestion concerning Nespor & Vogel’s pitch change strategy still leaves unexplained their claim that it is equally possible for the second syllable in the clash to have high pitch and the first one to have low pitch. Although such patterns are also reported by Botinis (1992), they do not, in this author’s opinion, support Nespor & Vogel’s suggestion. In Botinis’s data, three of the examples involve stress deletion, since the first item in the clash is a function word which is not normally stressed in running speech [e.g., [a'po 'delta ar'cizı], lit. “from delta (it) starts”]. Thus, if as expected the word [a'po] “from” is destressed it will also be unaccented, while the following accented syllable [‘be] will have rising $F_0$, if it carries an L$^* + H$ or an H$^*$ accent. In such cases however the clash is resolved by destressing, and not by pitch change. Botinis’s fourth example, in which the second of two pitch accents is indeed higher than the first, is a question with an overall rising intonation pattern [‘poko ka'la 'kseris], “how well (do you) know”]; i.e., it is expected that the second accent will be higher than the first. Although neither the present nor Botinis’s data support Nespor & Vogel’s pitch change suggestion (unless pitch change is seen as a consequence of intonational organization in Greek, rather than a radical reorganization of intonational structure), the issue is by no means resolved; further research is needed on the question of pitch change as a stress clash resolution strategy, using material in which the intonational structure is carefully controlled.

Another strategy for which the data of Experiment 2 presented no strong evidence is the insertion of pauses. Although pauses did occur in CN’s speech, they seemed to be determined by intonational phrasing rather than the stress clash, as indicated by their insertion in entirely predictable positions (such as between the subject NP and the following VP), and in both SC and NSC sentences. This does not of course mean that inserting a pause does not remedy the clash, but rather that a pause would not be inserted in order to resolve a clash unless it could be placed at a suitable intonational phrase boundary. Moreover, as shown, pauses were rather rare.

The fact that an intonational phrase boundary between the clashing syllables resolves the clash is the only interaction between rhythmic and intonational structure observed in the present data. In all other respects, the two systems seem to remain fairly independent. For instance, the resolution of the clashes was not influenced by the presence of nuclear pitch accents: there was no difference between
the resolution of stress clashes which involved a nuclear pitch accent and those which did not, as there is in English, where the former cannot be remedied by stress shift (Liberman & Prince, 1977; Selkirk, 1984; Beckman et al., 1990). This (relative) lack of rhythm and intonation interaction in Greek may be due to the fact that the predominant phonetic means of clash resolution is duration, which can be manipulated separately from intonation.

4. Final discussion

In summary, the results of Experiments 1 and 2 indicate that Greek tolerates fairly long stretches of unstressed syllables, since no extra stress is added to achieve rhythmic alternation, but it is less tolerant of clashes and uses duration as a means of resolving them. In addition, the lack of rhythmic stresses suggests a tendency to keep the duration of unstressed syllables relatively stable.

These rhythmic characteristics of Greek are very similar to those reported for Italian by Parnetani & Kori (1983, 1990). Thus, Greek and Italian seem to share two main rhythmic features: sparsity and irregularity of stresses and relatively stable duration of syllables with the exception of those with primary stress. The fact that syllables with primary stress are longer (hence more prominent) than unstressed syllables suggests that the rhythm of syllable-timed languages is based on stress patterns like the rhythm of stress-timed ones. On the other hand, the tendency to keep the duration of all other syllables relatively constant indicates that syllable-timed languages, unlike stress-timed ones, can tolerate long stretches of unstressed syllables.

In contrast to lapses, stress clashes are less well tolerated, a tendency which implies some kind of incompressibility of the smallest acceptable inter-stress interval. This incompressibility follows naturally from the fact that stress is relational (Liberman & Prince 1977); in other words, a weak beat is needed between two strong ones for these two to be perceived as stressed. However, the means by which syllable-timed and stress-timed languages resolve clashes indicates again that absolute periodicity of stress recurrence may not be as important for syllable-timed languages as for stress-timed ones. Stress-timed languages resolve clashes by shifting stress, a strategy that results in more evenly alternating prominent syllables. In contrast, syllable-timed languages resolve clashes either by de-stressing or by inserting extra duration between clashing syllables. The former strategy clearly results in longer stretches of unstressed syllables, since one of the stresses is lost. The latter is considered by phonologists to result in the (notional) insertion of an unstressed syllable between two stress ones: in this respect the function of the extra duration is superficially similar to the function of stress shift in stress-timed languages, since both result in alternation of strong and weak syllables. The difference lies in the fact that this binary pattern is common in stress-timed languages, but rare in syllable-timed ones, since in the latter inter-stress intervals include usually more than one unstressed syllable, as the Greek and Italian data show. In other words, the pattern created after the insertion of extra duration between clashing stresses is still uneven.

Taken together these tendencies suggest that while the rhythm of both stress-timed and syllable-timed languages is organized around prominent syllables, its structure differs between categories. In particular, the rhythmic structure of syllable-timed languages is unlikely to be as regular as that of stress-timed ones due to lapse tolerance and the clash resolution strategies used.

If the above suggestion is correct, the difference between stress-timed and syllable-timed languages can be seen as reflecting different "settings" for the hierarchical structure of rhythm, rather than different isochrony tendencies, or differences in syllable structure or the acoustic correlates of accent [as Dauer (1987) would suggest]. The traditional view that the rhythm of syllable-timed languages is based on syllable isochrony, while that of stress-timed languages is based on inter-stress interval isochrony, could then be attributed to the impression a language's rhythm gives to non-native speakers who are not familiar with this language's rhythmic structure and prominence cues. Obviously the parameters proposed by Dauer (1987) play a large part in the creation of such impressions. For instance, Roach (1982) observed that the so-called syllable-timed languages have been described as such by native speakers of Germanic languages; it is likely that their impression stems at least partially from the fact that in languages like Greek, French or Italian, all syllables have qualitatively unreduced vowels. However, the Greek and Italian results indicate that there is probably a basis for the rhythmic categories independently of the impressionistic labels stress-timed and syllable-timed.

In conclusion, although the terms stress-timing and syllable-timing are likely to be purely impressionistic, the existence of two rhythmic categories appears to have a basis in the rhythmic organization of languages. The present results suggest that this basis could be related to default patterns of stress occurrence and the tolerance of the language to rhythmic anomalies, not to acoustic or perceptual isochrony.

The experiment on stress lapses is part of the author's doctoral dissertation, while the experiment on stress clashes has been carried out during part of a Research Fellowship at Wolfson College, Cambridge. The author would like to thank Sarah Hawkins and Francis Nolan for great assistance in the preparation of the thesis, and Bruce Connell for welcoming the author to the Oxford University Phonetics Laboratory. Special thanks go to Bob Ladd, Mary Beckman, John Coleman and Ian Watson for their valuable comments on earlier versions of this paper, and to Marios Fourakis and two anonymous reviewers for the Journal of Phonetics whose comments helped clarify the statistical procedure and the author's ideas on Greek prosody. Any mistakes and inaccuracies remain, of course, the author's.

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